GIS MAPPING
OF
CORRELATION BETWEEN
ARSENIC AND IRON CONCENTRATION
OF
GROUND WATER OF BANGLADESH

By

FAHIM NAWROZ TONMOY

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BOARD OF EXAMINERS

1. ------------------------------- Chairman (Supervisor)

Dr. Md. Mafizur Rahman
Professor
Department of Civil Engineering
BUET, Dhaka-1000

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Dr. Muhammad Zakaria
Professor and Head
Department of Civil Engineering
BUET, Dhaka-1000

3. -- Member

Dr. M. Habibur Rahman
Professor
Department of Civil Engineering
BUET, Dhaka-1000

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It is hereby declared that this project report or any part of it has not been submitted elsewhere (except for publication) for the award of any Degree or Diploma.

April, 2008 Fahim Nawroz Tonmoy

Dedicated

To

My

Father, Mother & Wife

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ABSTRACT

Arsenic, a toxic metal has become a major threat to a large number of populations of Bangladesh as this ground water has become contaminated. Excessive Iron concentration is also a problem for ground water of Bangladesh. Arsenic and Iron both are present in most of the wells. As Bangladesh is vulnerable for both the Arsenic and Iron, this made the correlation analysis more rational. GIS map of this correlation analysis will represent correlation status of each individual district of Bangladesh. Not only that, GIS maps produced in this research will give the graphical representation of correlation analysis for three different layer of wells. A 3-Dimentational water matrix was formed in this research considering different combination of arsenic and iron concentration in three different layers of wells. This 3-Dimentional matrix gave 12 sets of data which were used for analysis and GIS mapping. The same matrix was used for every district to categorize data more specifically.

It is evident from this study that a zone or belt of a region can be observed of similar correlation coefficient. From the analysis it was observed that 50.4% districts of Bangladesh showed correlation coefficient in excess of 0.4 and rest shows correlation coefficient less than 0.4. In the eastern part of Bangladesh a belt of very low correlation was observed. This analysis was performed considering only the geographic locations. The produced GIS maps and analysis results will enable some one to tentatively or statistically predict the arsenic concentration of a well by knowing the iron concentration of the same well.

Data were separated as per depth variation as well. It was observed that for most of the districts Correlation coefficient is higher for well depth bellow 50m. Correlation coefficient tends to decrease as the depth of aquifer increases. 3 separate sets of GIS maps were produced in this research for 3 different depth layers of wells for 61 districts of Bangladesh.

Data of each district were classified as per developed 3-Dimentional water matrix and analyzed for correlation. 12 different GIS maps were produced for 61 districts of Bangladesh.

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LIST OF ABBREVIATIONS

AIT	Asian Institute of Technology
APHA	American Public Health Association
AWWA	American Water Works Association
BBS	Bangladesh Bureau of Statistics
BGS	British Geological Survey
BDS	Bangladesh Standards
BOD	Biochemical Oxygen Demand
BUET	Bangladesh University of Engineering and Technology
COD	Chemical Oxygen Demand
CCA	Copper-Chrome-Arsenate
DIDA	Danish International Development Agency
DPHE	Department of Public Health Engineering
DWSSA	Dhaka Water Supply and Sewerage Authority
ECR	Environmental Conservation Rule
GIS	Geographic Information System
GWTF	Ground Water Task Force
IWM	Institute of Water Modeling
IARC	International Agency for Research on Cancer
ITN	International Training Network
JICA	Japan International Cooperation Agency
NGO	Non Governmental Organization
ppm	Parts per million
ppb	Parts per billion
SIW	Suitability of an Irrigation Water
TDS	Total Dissolved Solid
UNICEF	United Nations International Children's Emergency Fund
USPHS	United States Public Health Services
WHO	World Health Organization
WQS	Water Quality Standard

CHAPTER-1

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 Background of the problem:

Bangladesh faces multi-faceted problems in relation to groundwater. At present there is a new threat - arsenic contamination in groundwater. Arsenic is a shiny, grey, brittle element possessing both metallic and non-metallic properties. The degree of toxicity of arsenic depends on its chemical form and speciation. Humans are exposed to arsenic mainly through ingestion and inhalation. The World Health Organization (WHO) has set guideline value for arsenic in drinking water as 0.01 mg/L (WHO, 1993). Bangladesh standard set by Department of Environment (DoE, 1991) as 0.05 mg/l. Water with high level of arsenic leads to health problems such as melanosis,leuko-melanosis, hyperkeratosis, black foot disease, cardiovascular disease, hepatomegaly, neuropathy and cancer. Arsenic tends not to accumulate in the body but is excreted naturally. If ingested faster than it can be excreted, arsenic accumulates in the hair and fingernails. The toxicity of arsenic depends on the chemical and physical forms of the compound, the route by which it enters the body, the dose and the duration of exposure, dietary compositions of interacting elements and the age and sex of the exposed individuals.

British Geological survey (BGS) published a Technical report in 2001 on "Arsenic contamination of ground water in Bangladesh" (BGS and DPHE, 2001), based on the nation wide survey which has performed for determination of ground water quality of Bangladesh. A survey of well waters (n=4367) from throughout Bangladesh, excluding the Chittagong Hill Tracts, has shown that water from 20.1% of the 'shallow' tube wells, that is wells less than 150 m deep, exceeded the Bangladesh standard for arsenic in drinking water ($50\mu gL^{-1}$). 34.5% exceeded the WHO guideline value of $10\mu gL^{-1}$. Figures for 'deep' wells (greater than 150 m deep) were 0.1 % and 3.8%, respectively. Since it is believed that there are a total of some 6-11 million tube wells in Bangladesh, mostly exploiting the depth range 10-50 m, some 1.5-2.5 million wells are estimated to be contaminated with arsenic according to the Bangladesh standard. 35 million people are believed to be exposed to an arsenic concentration in drinking water exceeding 50 μgL^{-1} and 57 million people exposed to a concentration exceeding $10\mu gL^{-1}$.

1.2 Objectives of the study:

The overall objective of this research project is to analysis whether any correlation exits between arsenic and iron concentration of ground water and produce a correlation map of arsenic and iron concentration through GIS to present the phenomenon graphically. The specific objectives as following:

1. To determine different zones based on the combination of the concentration of Arsenic and Iron and to develop a 3-Dimentional water matrix.
2. To find the correlation among Arsenic and Iron concentration in these zones for three different depth range of aquifer and also analyzing correlation as per geographic locations of 61 different districts of Bangladesh.
3. To develop a correlation map in GIS between arsenic and iron concentration and to show the population vulnerable to arsenic and iron contamination.

1.3 Background study:

A research was performed by Sharif Mos. Ferdousy in 2005. (Ferdausy. Sharif.Mos, 2005),. In that research correlation among different water quality parameters was analyzed. Correlation between arsenic and iron concentration was also a part of that research. This research was performed using the data of some specific location of Bangladesh. Different combinations of arsenic and iron concentration were not considered for analyzing correlation. This research work has not provided any GIS map showing correlation of arsenic and iron concentration of ground water.

1.4 Scope of the study:

It is expected that the outcome of this research will be the development of an information system which can be used to describe the correlation of arsenic and iron concentration in ground water. Through correlation mapping it can be showed that correlation of arsenic and iron concentration is not a national phenomenon rather it may be a zonal phenomenon which varies even with the depth of aquifer. On the other hand, *As* is one of the most harmful pollutants of water and it is extremely important to determine the concentration of *As* in ground water in order to use it for irrigation or drinking purposes. High Iron concentration is also a major characteristic of ground water of Bangladesh. Arsenic Detection and measure in water is very expensive. It requires modern lab facility and expensive chemical. On the other hand determination of *Fe* concentration is relatively simpler and cheaper than that of concentration of *As* and also easily available in Bangladesh. Through some statistical correlation and regression model it can be analyzed to find some correlation between these two elements of ground water. GIS representation of this result will help to get the geographical feel of the issue. By using this correlation, regression analysis and produced GIS correlation map the presence of arsenic in a well can be tentatively verified by testing the presence of iron of the same well only. As the testing of arsenic is more expensive than the testing of Iron, this can save a lot of money if it is used in a large scale. This map will also show the population vulnerable to arsenic and iron contamination

1.5 Methodology:

Data collection

Data used for analysis have been collected from the following sources:

- British Geological Survey (BGS) technical report-Phase-II, Arsenic contamination of Ground water in Bangladesh (2001)
- Data set prepared by DPHE Bangladesh for the DPHE-JICA project in 2007 will also be used in this purpose.
- Result of chemical analysis data of the Deep Tube wells water samples in the Barind area performed by IWM (Institute of Water Modeling)

Formation of different combination zone for arsenic and iron

This stage of the research develops different zone of combination for arsenic and iron varying their concentration, depth of aquifer. Four sets of data will be separated for each depth class. Zone of combinations for shallow aquifers can be as follows:

1. *As* concentration is greater than BDS (Bangladesh Standards) and *Fe* concentration is greater than 5mg/L. (As>50μgm/L, Fe>5mg/L)
2. *As* concentration is greater than BDS, *Fe* concentration is less than 5mg/L. (As>50μgm/L, Fe<5mg/L)
3. *As* concentration is less than BDS, *Fe* concentration is greater than 5mg/L. (As<50μgm/L, Fe>5mg/L)

4. *As* concentration is less than BDS, *Fe* concentration is less than 5mg/L. (*As*<50μgm/L, *Fe*<5mg/L)

Same sets can be formed for three different sets of aquifers.

Analysis of collected data using computed generated software (SPSS) for different combination zone.

The analysis will be divided into different combination zones. This will determine if there is any correlation exists between arsenic and iron concentration of ground water in those combination zones. Another analysis was performed for 61 districts of Bangladesh without any grouping. All these analysis were performed for three depth layers of wells. Well depth less than 50m, well depth between 50m and 150m, well depth greater than 150m.

Development of correlation map using analyzed data through GIS.

This study area will develop a comprehensive correlation map of different area of Bangladesh using Geographic Information System (GIS) software. Data analyzed for different zone of combination will be used to produce this map.

1.6 Organization of the thesis:

This project report consists of five chapters. Chapter one is the introductory chapter includes Background, Objectives, Scope of the study and brief methodology. Chapter two presents a brief discussion on literature review for the study which includes mainly sources of drinking water, Different water quality parameters with their effects and specially the toxic characteristics of arsenic. Chapter three describes the methodology used in analysis and data collection. Chapter four discussed the findings of the study. Lastly chapter five that is the concluding chapter includes some recommendations for further study. In the Appendix-01 frequency distribution of 12 Groups for 61 districts are given and Appendix-02 contains Scatter plotting of Arsenic and Iron concentration for 61 districts of Bangladesh.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

Literature Review

2.1 Introduction

The name Arsenic is derived from the Greek word *arsenikon*, which means yellow orpiment. Arsenic compound have been mined and used since ancient times. The extraction of the element from arsenic compound was first reported by Albertus Magnus in 1250 A.D. Arsenic ranks 20_{th} in earth's crust, 14^{th} in sea water and 12^{th} in human body. Arsenic exhibits metallic as well as non-metallic characteristics and corresponding chemical properties. Hence, it is called metalloid. Arsenic is one of the oldest human poisons known to mankind. It has six specific characteristics

- It is a virulent poison on acute ingestion.
- It is extremely toxic on long term exposure to very low concentrations.
- It is not visible in water and food.
- It has no taste.
- It has no smell.
- It is difficult to analyze, even when occurring in concentration twice as high as WHO guidelines.

2.2 Environmental Chemistry of Arsenic

Arsenic in its various chemical forms and oxidation states is released into the aquatic environment by various process and industrial discharges. On release to aquatic environment, the arsenic species enter into methylation / demethylation cycle, while some are bound to the sediments or taken up by biota where, they could undergo metabolic conversion to other organo-arsenicals. Arsenic generally exists in the inorganic form in water samples. Under different redox conditions arsenic is stable in the +5, +3, -3, and 0 oxidation states. The pentavalent (+5) arsenic or arsenate species include $AsO_4{}^{3-}$, and H_2AsO^{4-}. The trivalent (+3) arsenic or arsenite species include $As(OH)^{4-}$, $AsO_2(OH)^{2-}$, and $AsO_3{}^{3-}$. The pentavalent arsenic species are predominant and stable in the oxygen-rich aerobic 6 environment, whereas the trivalent arsenic species are predominant in the moderately reducing anaerobic environment such as groundwater.

2.3 Properties of Arsenic

Arsenic is a chemical element in the Nitrogen family, existing in both yellow and grey crystalline forms. Although some forms of the Arsenic are metal-like, it is best classified as metalloid and non metal. Some of the significant properties of Arsenic are listed in Table 2.1.

Table 2.1 Properties of arsenic

Parameter	Value
Atomic Number	33
Atomic Weight	74.92158
Melting point	814^0 C at 36 atm
Boiling point	616 0 C
Oxidation number	-3, 0, +3, +5

2.4 Sources of Arsenic

There are mainly two sources of Arsenic, which are as follow:

a) Natural Sources

In nature, the Arsenic is distribute in variety of minerals, commonly as arsenide of iron, copper, lead, silver and gold or as sulfide minerals, for example arsenopyrite. The geochemical cycling of arsenic in the environment is through interaction of natural water with bedrock, sediments and soils, together with the local atmospheric deposition. The weathering of different geologic formation such as 8 volcanic rock, as well as mining waste consequently results in high level of arsenic in surface and ground water.

b) Anthropogenic Sources

Anthropogenic processes such as industrial activities are great sources of arsenic emissions. Arsenic based compounds have been used in pesticides, herbicides, insecticides, fungicides, rhodenticides, algaecides, dye-stuff, dipping agent for sheep, and vine killer. However, most developed countries have replaced such inorganic compounds by organic arsenicals in agriculture. Arsenic-based chemicals such as CCA (copper-chrome-arsenate) have been used in wood preservation industries and there by caused widespread contamination of soil and water. Other anthropogenic activities resulting high arsenic level in the environment are mining, smelting and ore benefaction.

2.5 Human Exposures to Arsenic

Arsenic is ubiquitous micro pollutant. It is naturally found in atmospheric air in concentration levels about 0.4 to 30 ng/m_3, in food at concentration level about 0.4 to 120 mg/kg and in water at concentration levels from undetectable to few mg/l. Approximate environmental concentration levels and human exposure through air, food and water to Arsenic is given in Table 2.2. The figures in the table are based on the estimation of WHO, 1993.

Table 2.2 Approximate environment concentration level of arsenic

Medium	Concentration	Daily Intake	Daily Exposure	Remarks
Air	0.4-30 ng/m_3	20 m_3	0.01-0.6 mg	may be higher in industrial area
Food	0.4 - 120mg/kg	1 kg	0.4-120 mg	75% inorganic and 25% organic
Water	1-2 mg/l	2 L	2-4 mg	Mainlyinorganic
Water	Up to 12000mg/l	2 L	24000 mg	Causing endemic diseases

Inorganic Arsenic, especially As III, is more toxic for human than organic arsenic. For the reason, the arsenic exposure of water is more serious than that of the food. As mentioned in table the arsenic ingested through food contains considerable portion of organic arsenic. The exposure of human to arsenic through water is now believed to be most hazardous to public health.

2.6 Effects of Arsenic on Health

Arsenic called the king of all poison. The fatal dose, the dose which is sufficient for the death of person, is 125 mg. The arsenic is 4 times stronger than mercury. Arsenic enters the human body either from respiration or from mouth. The effects of arsenic after it enters by breathing or meals and drinks depend on the amount and physico-chemical states. Arsenic has been identified as cause of cancer by the International Agency for Research on Cancer (IARC). Many people died due to the cancer caused by arsenic. (Saha J.C *et. Al* ,1999)

According to the consumption of arsenic in human body, its toxicity can be divided in three categories.

1. Acute toxicity
2. Sub acute toxicity
3. Chronic toxicity

Chronic arsenic poisoning, which occurs after long-term exposure through drinking- water is very different to acute poisoning. Immediate symptoms on an acute poisoning typically include vomiting, esophageal and abdominal pain, and bloody "rice water" diarrhoea. Chelation therapy may be effective in acute poisoning but should not be used against long-term poisoning. The symptoms and signs that arsenic causes appear to differ between individuals, population groups and geographic areas. There is no universal definition of the disease caused by arsenic. This complicates the assessment of the burden on health of arsenic. Similarly, there is no method to identify those cases of internal cancer that were caused by arsenic from cancers induced by other factors. Long-term exposure to arsenic via drinking water may causes cancer of the skin, lungs, urinary bladder, and kidney, as well as other skin changes such as pigmentation changes and thickening (hyperkeratosis). Increased risks of lung and bladder cancer and of arsenic associated skin lesions have been observed at drinking water arsenic concentrations of more than 0.05 mg/l. Absorption of arsenic through the skin is minimal and thus hand-washing, bathing, laundry, etc. with water containing arsenic do not pose human health risk. Following long-term exposure, the first changes are usually observed in the skin: pigmentation changes, and then hyperkeratosis. Cancer is a late phenomenon, and usually takes more than 10 years to develop. The relationship between arsenic exposure and other health effects is not clear-cut. For example, some studies have reported hypertensive and cardiovascular disease, diabetes and reproductive effects. (Saha J.C *et. Al* ,1999)

A large number of elements present in water may be toxic to plants or elements or human being. Special attention is needed to measure the parameters which relate to public health, environment and agriculture. The parameters are *As*, *Fe*, *TDS*, Chloride, Sulfate, Nitrate, Boron, pH and *SAR* values. Generally the ground water quality is suitable for irrigation. Outside coastal saline zone and brackish tidal zone the quality of water in Bangladesh is such that there is no adverse effect of surface water on irrigation. There are indications that locally high nitrate concentrations on ground water might be cause by infiltrating fertilizer residues.

2.7 Arsenic in Water

Arsenic may be found in water which has flowed through Arsenic rich rocks. Arsenic concentration in natural water varies widely depending upon the source of water, source of Arsenic and local conditions. Arsenic concentration in river water is normally low. But some polluted river water may have high concentration of Arsenic. Sea water normally shows relatively constant arsenic content of 1.5 mg/l. Arsenic content in atmospheric precipitation and snow is the lowest, typically less than 0.03 mg/l. The concentration and variation of Arsenic in ground water is the highest. It is because of its long and strong interaction with rocks and soils under physical and geochemical conditions favorable for the arsenic dissolution and accumulation. The concentration of As in ground water ranges from less than 0.5 to 5000 mg/l with a background concentration of less than 10 mg/l. Arsenic contamination of ground water all over the world is attributed geothermal sources, reductive desorption, oxidizing desorption at high pH and pyrite oxidation. Reductive desorption dissolution under anoxic condition are believed to be the main mechanism of Arsenic mobilization from soil to water phase in aquifers in Bangladesh, west Bengal, Romania, inner Mangolia, Taiwan, Veitnam, Hungery and Nepal. Shrestha Prem Krishna (December, 2004)

2.8 Sources of water

Absolute pure water is not always desired. Pure water is a relative term according to its use. As condensed water falls, it sweeps up other materials from the air and becomes still more contaminated on reaching the ground.

2.8.1 Surface Water:

During running over the surface silt, clay, other suspended materials and bacteria, viruses and other organisms mixed with water.

2.8.2 Ground Water:

Since water is an almost universal solvent, during percolation through the various strata of soil it dissolves various mineral compounds. However, most of the physical and living impurities are removed as a result of filtration and exchange and adsorption reactions during passage through the soil.

2.9 WATER QUALITY CRITERIA:

Generally water quality is judged considering the following criteria:

i) Total salt concentration, as measured by electric conductivity;

ii) Relative proportions of cations, expressed by sodium absorption ration and

iii) Bicarbonate and boron contents.

The suitability of an irrigation water (SIW) can be expressed as SIW = f(QSPCD) where, Q = Quality of Irrigation Water,

S = Soil Type,

P = Salt Tolerance Characteristics of the Plant,

C = Climate,

D = Drainage Characteristics of the Soil.

Some other facts like depth of ground water table, presence of hard pan of lime/clay, calcium carbonate content in the soils and potassium and nitrate ions in water also indirectly affect the suitability of irrigation water (Ferdausy. Sharif Mos. 2005),. The soil type, major crops of the area, climatic condition and drainage characteristics profoundly influence the suitability of particular water for irrigation. For example, highly saline water may be suitable for irrigation in a well drained light textured fertile soil, while much less saline water may be more harmful for the same crop grown on a heavy textured soil with impeded drainage. It is the actual soil concentration near the root zone, which determines the suitability of irrigation water rather than the chemical properties of irrigation water alone.

2.10 CHEMICAL CHARACTERISTICS OF WATER:

During the movement water comes in contact with minerals that make up the earth crust. Some of the minerals are soluble. The dissolved minerals in water affect its usefulness for various purposes. One or more of the minerals may be in excess of the amount that can be tolerated for a given use. Most ground water contains no suspended materials and practically no bacteria. It is usually clear, colorless, normally of superior quality and maintains relatively constant temperature whereas surface waters are usually turbid and contain considerable quantities of bacteria.

The constituents and properties of water are determined by well standardized methods of analysis both in field and laboratories. More than 50 properties are subjected to determination. But such complete analysis is not required to have an adequate picture of water quality considered for the usual domestic, municipal, industrial or irrigation use. The general properties of water that are especially useful in revealing the character of water are: TDS, pH, EC, Hardness etc.

2.11 WATER QUALITY STANDARD (WQS) OF BANGLADESH:

Water quality standards of Bangladesh of different parameters for both drinking and irrigation purposes described in Bangladesh Gazette (August 28, 1997) are given in the table 2.3:

Table 2.3: Water quality standard of Bangladesh for drinking and irrigation purposes

Chemical/Mineral	Drinking	Irrigation
Aluminium (Al)	0.2 ppm	1.0 ppm
Ammonia (NH_3)	0.5 ppm	3.0 ppm
Arsenic (As)	0.05 ppm	0.2 ppm
Bicarbonate		2.5 Me/L
Biochemical Oxygen Demand (BOD)	0.2 ppm	10 ppm or below
Boron (B)	1.0 ppm	2 ppm
Cadmium (Cd)	0.005 ppm	0.1 ppm
Calcium (Ca)	75 ppm	NYS
Chemical Oxygen Demand (COD)	4 ppm	NYS
Chloride (Cl)	150-600 ppm	600 ppm
Copper (Cu)	1 ppm	3 ppm

Dissolved Oxygen (DO)	6 ppm	4.5-8 ppm
Electrical Conductivity (EC)	600-1000 µs/cm	1200 µs/cm
Hydrogen Ion Concentration (pH)	6.5-8.5	6-9
Iron (Fe)	0.3-1 ppm	1-2 ppm
Lead (Pb)	0.05 ppm	0.1 ppm
Magnesium (Mg)	30-50 ppm	NYS
Manganese (Mn)	0.1 ppm	5 ppm
Mercury (Hg)	0.001 ppm	0.01 ppm
Nickel (Ni)	0.1 ppm	0.5 ppm
Nitrate (NO_3)	10 ppm	10 ppm
Nitrite (NO_2)	<1 ppm	-
Phosphate (PO_4)	6 ppm	10 ppm
Phosphorus (P)	0	15 ppm
Potassium (K)	12 ppm	-
Selenium (Se)	0.01 ppm	0.05 ppm
Silver (Ag)	0.02 ppm	-
Sodium (Na)	200 ppm	-
Sulfate (SO_4)	400 ppm	1000 ppm
Suspended Solid (SS)	10 ppm	-
Total Alkalinity	100 World Health Organization(WHO)/ 120 United States Public Health Services. (USPHS)	
Total Hardness	200-250 mg/l	
Temperature	20^0-30^0C (50^0F)	20^0-30^0C (50^0F)
Tin (Sn)	2 ppm	-
Total Dissolved Solids (TDS)	1000 ppm	2100 ppm
Zinc (Zn)	5 ppm	10 ppm

2.12 EXISTING WATER RELATED INSTITUTIONS:

The following departments are monitoring the water quality in Bangladesh:

a) Department of Environment (DOE);
b) Department of Public Health Engineering (DPHE);
c) Bangladesh Water Development Board (BWDB);
d) Bangladesh Agricultural Development Corporation (BADC).

2.12.1 DOE:

The department of environment was initially involved in river water monitoring and to extend in ground water quality investigation. Water quality is monitored at 38 stations in 17 rivers regularly once per month. DoE complied the water quality data of 5 rivers in 11 points under Dhaka Divisional Region for the period of 1980-1990 in August 1993.

2.12.2 DPHE:

DPHE is testing water quality in 4600 hand pump wells for drinking water supply in the rural areas since 1993. Iron and chloride are tested at the time of installation and once per year at the end of April/beginning of May. Bacteriological tests, analysis on iron, Mg, Cl, pH and Hardness of municipal wells are tested once in a year in DPHE laboratories.

2.12.3 BWDB:

BWDB deals with both surface and ground water in connection with irrigation, drainage and flood control. Ground water quality test was started in 1960 by EPWAPDA (now BWDB). Water samples are taken from 117 wells (Deep and Shallow) once in a year in the dry season. The following parameters are tested: pH, EC, TDS, SO_4, Ca, CO_2, Fe, Mn, Mg, Na, B, Cl, SiO_2, CO_3, HCO_3, NO_3 and SAR. BWDB has measured salinity in 1966 in Khulna and Barisal district. Also salinity was measured at 267 dynamic stations till 1980. In 1989 eighty monitoring stations were operating. Samples are collected; EC and Chlorides were measured at high and low flow in dry period from November to June.

2.12.4 BADC:

The present study is based on the multi-year program conducted by BADC. The detailed BADC program is summarized in the data collection section of the next chapter.

2.13 Depth Variation of aquifers:

Aquifer depth is a major factor for water quality. Water quality is found to be different in the different depth of wells. Sedimentation characteristic is the major reason behind this difference. The Bengal Basin is a tectonically active subsiding depression formed at the junction of the Asian, Burmese and Indian plates, and is in filled with more than 15 km of marine and alluvial sediments of Cretaceous to Recent age. Throughout the Quaternary, the combined Ganges, Brahmaputra and Meghna (GBM) river system of Bangladesh has deposited a thick sequence of mixed alluvial and deltaic deposits in response to changes in sea-level rise and fall brought about by glacial cycles. Within the Basin, there are areas of recent uplift (Madhupur and Barind Tracts) and subsidence (the Sylhet Basin) and major changes in the course of the Tista and Brahmaputra rivers can be seen in the sediments. Patterns of sediment deposition during the Upper Pleistocene were controlled by a fall in sea level to about 150 m below the present day sea level. This decline occurred between the last interglacial 120,000 years ago and the last glacial maximum some 21,000 years ago. Sea level recovered during the Holocene to the present-day level.

Depending on the depths, aquifers are classified in mainly two classes, Shallow wells and deep wells. This classification is general and old.

Shallow Aquifer:

A water bearing layer 50m below ground surface with an over laying thin layer of clay/silt blanket (thickness of clay/silt layer is also area depended). Water abstracted by hand tube well from this aquifer is known as shallow hand tube well. Most of the shallow tube well (STW) in the rural areas is contaminated by arsenic concentration exceeding Bangladesh standard of 50 ppb.

Deep Aquifer

A water bearing strata (below ground surface) situated under an impervious clay layer of 50 m to 150m thick which protect the deep ground water against inflow of possible contaminated water from upper aquifer. Thickness and depth below ground surface are area depended. Water abstracted by hand tube well from this aquifer is called as deep tube well.

Several new models for aquifer classification are provided by different researches. According to Groundwater Taskforce (GWTF, 2002) aquifer system of Bangladesh is classified according to the fig 2.1.

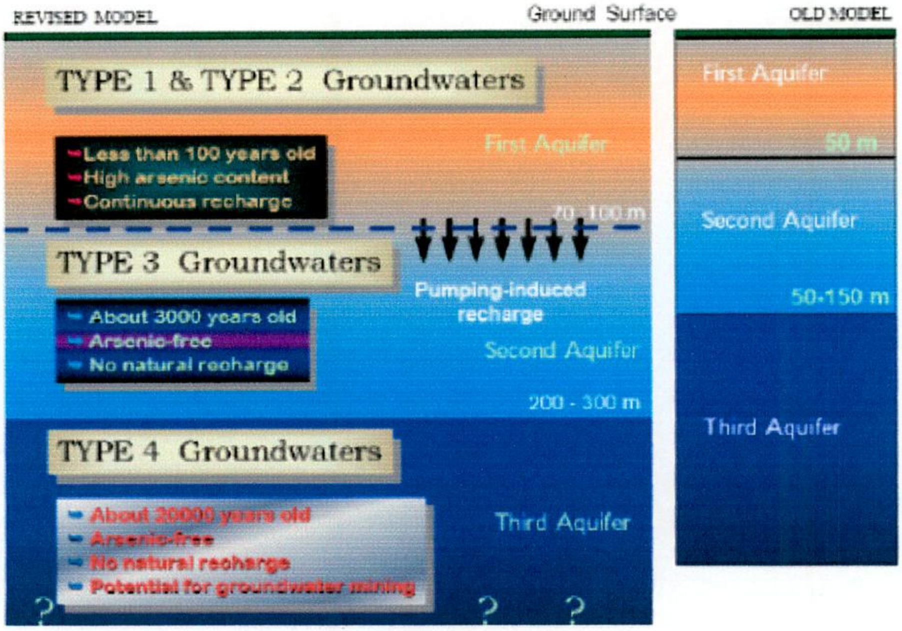

Fig 2.1 Proposed aquifer system for Bangladesh (Aggarwal et al., 2000)

The Ground Water Task Force (GWTF, 2002) in their report provided a classification from geological point of view. According to this classification, as shown in Figure 3.3, the major aquifers are: Upper Holocene Aquifer, Middle Holocene Aquifer, Late Pleistocene-Early Holocene Aquifer and Plio-Pleistocene Aquifer.

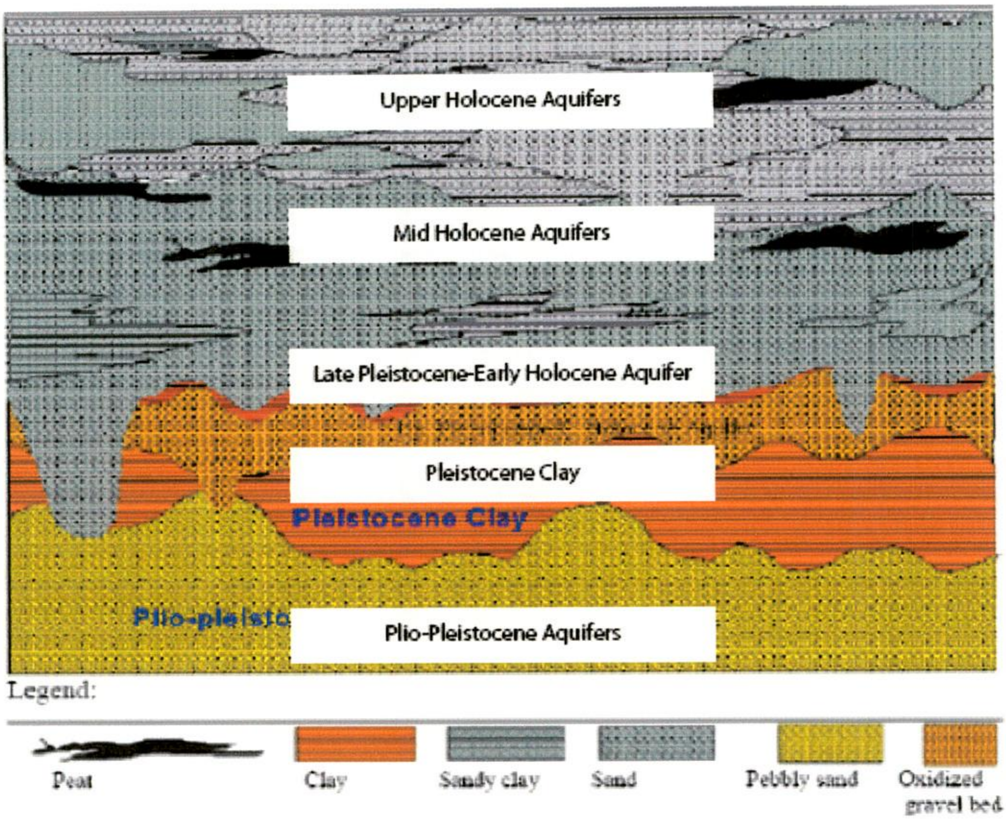

Fig 2.2 Schematic geological classification of aquifers of Bangladesh (GWT F, 2002)

The Upper Holocene aquifer is not exposed in all the deltaic and flood plain areas. The lower part of the aquifer is composed silt and clay at the bottom and fine sand at the top. The upper part is composed of silt and clay. The middle Holocene aquifer varies widely vertically and horizontally and is composed of fine sand becoming coarser in the upper part. The late Pleistocene- Early Holocene aquifer is characterized by coarse sands with widespread gravels. The Plio-Pleistocene aquifer consists of Dupi Tila sands overlain by a thick silty clay layer of Pleistocene age. The sands of this aquifer unit are medium to coarse with pebbles (JICA-APSU-DPHE, 2006)

Aquifer has been defined in number of different ways. For the practical purpose there should not be any depth assigned to the definition of aquifer system. The depth and type of deep and shallow aquifer would depend on the local geology and should be defined accordingly.

RockWorks 2004 software, specialized in visualization of subsurface data, has been used for aquifer mapping in the project of JICA. In the Final report on development of deep aquifer database and preliminary deep aquifer map (1st Phase) (DPHE-JICA-APSU, 2006) Hydrostratigraphic model of different region is developed through RockWorks 2004 software. It shows that aquifers are available in different depth in different locations depending on the geological condition of that place. Hydrostratigraphic model of Cumilla-Noakhali region shows that a shallow layer of aquifer is present with in 30m and depth of this aquifer varies in different portion of land.

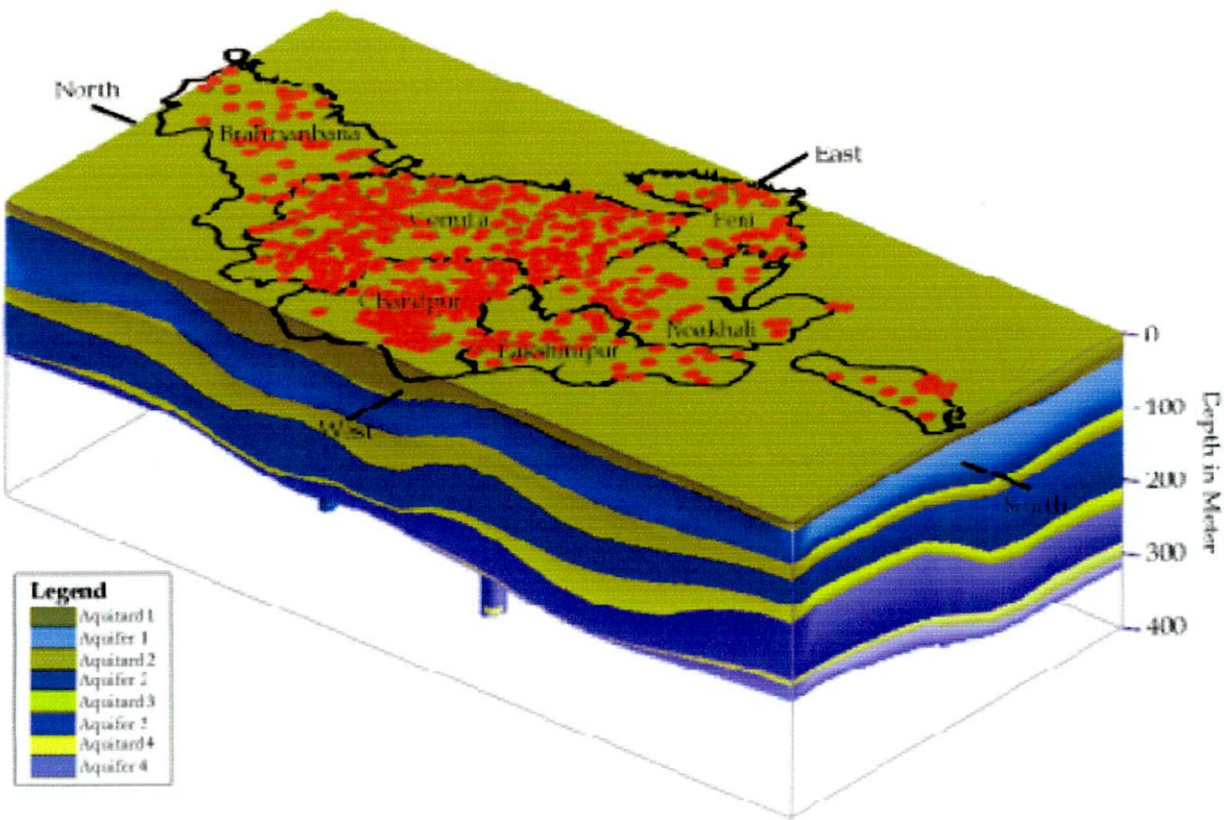

Fig 2.3 Hydrostratigraphic model of the Comilla-Noakhali region (DPHE-APSU-JICA, 2006)

On the other hand Hydrostratigraphic model of Kustia-Jessore-Khulna region shows a different pattern for aquifer layer. It has a thin layer of aquitard on top and a thick layer aquitard just beneath the shallow layer of aquifer. The depth also varies from north to south side of the region.

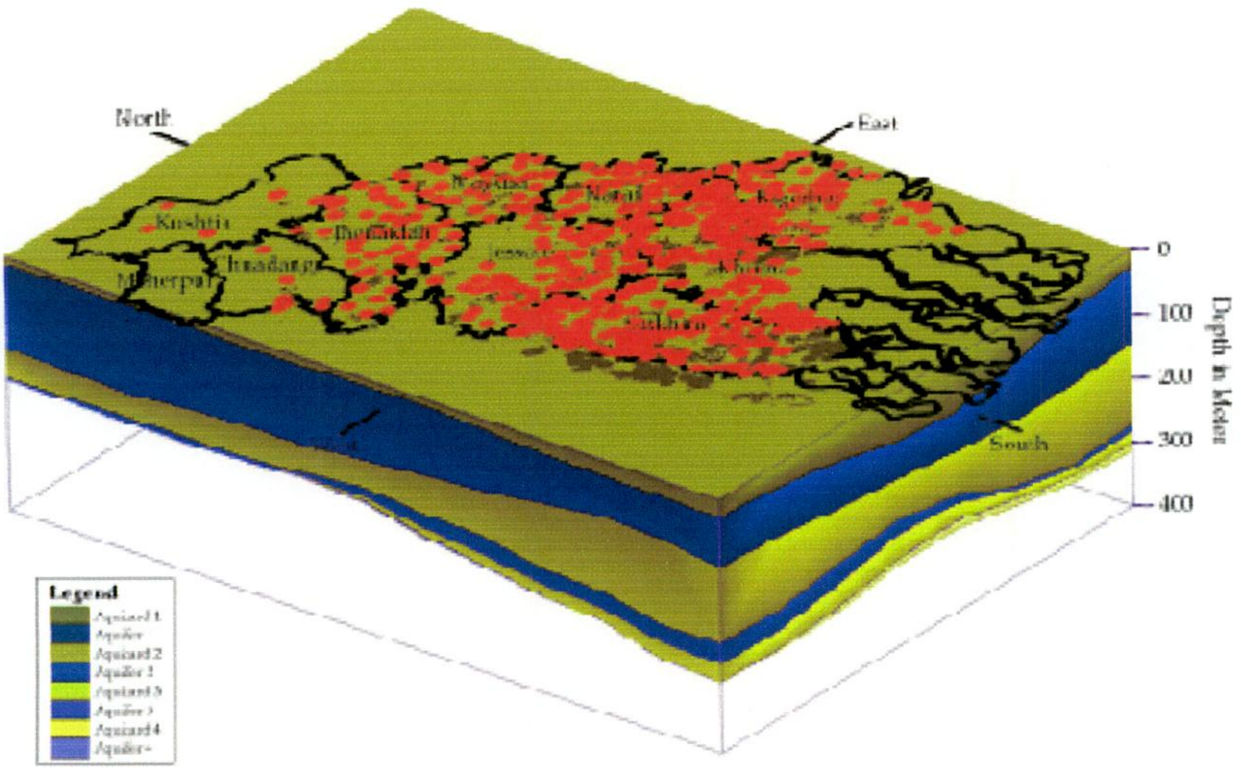

Fig: 2.4 Hydrostratigraphic model of Kustia-Jessore-Khulna region (DPHE-APSU-JICA, 2006)

Arsenic contamination also varies with the depth of aquifer. Arsenic contamination is more acute in the shallow aquifers than the deep ones. Not only arsenic, iron concentration also varies with the depth. If the data are plotted in a three dimensional scatter plotter, this issue becomes more visible.

2.14 Probable reason behind the Arsenic problem:

There is as yet no consensus amongst scientists' about the precise cause of the arsenic problem in Bangladesh but it can be indicated what was believed to be a plausible scenario that is consistent with most of the known facts. There is still a great deal of uncertainty about the timescale over which the events may have occurred. In order to understand the development of high-arsenic ground waters in Bangladesh, we have to rely on our scientific knowledge of the likely processes involved, the inferred past history of the aquifers and the present-day evolution of groundwater quality in comparable environment.

Everything points to the arsenic being of natural origin although it is not yet possible to exclude the possibility that modern agricultural practices (groundwater abstraction from shallow wells, irrigation and fertilization) will have no influence on the groundwater arsenic' concentrations whatsoever. It is believed that the arsenic has been in the groundwater for many years, certainty since before the' recent extensive abstraction of groundwater.

Both the arsenic content of Bangladesh sediments (0.4-10 mg kg-I) and their mineralogy are typical of young alluvial and deltaic sediments that contain a wide variety of minerals reflecting their diverse source rocks (BGS and DPHE, 2001). There is no need to speculate on a unique geological source of high arsenic rocks somewhere upstream of Bangladesh.

However, certain types of sedimentological processes have probably been more important in concentrating arsenic in some parts of the delta system than in others. In particular, colloidal-sized iron oxides with their strongly sorbed arsenic and platey, easily suspended, micaceous minerals appear to have been concentrated in the lower part of the delta.

Even 'ordinary' sediments such as these contain sufficient arsenic to give rise to the groundwater arsenic problem observed because of the very low drinking-water guideline value for arsenic and the high *solidi solution* ratios found in aquifers.

The development of strongly reducing conditions is believed to be the trigger that has been responsible for the release of naturally-occurring arsenic from the sediment into the groundwater. This arises from the rapid consumption of dissolved oxygen by the oxidation of fresh organic matter in the recently-buried sediments. Once strongly reducing conditions are achieved, arsenic is released from the sediments. The mechanism for this release is poorly understood quantitatively but is believed to involve the desorption from, and dissolution of, arsenic from various oxides, especially iron oxides (BGS and DPHE, 2001).

This reaction is probably rapid (on geological timescales) and is essentially a diagenetic response of the sediments to a change from an oxidising environment to a reducing environment following burial. Possible changes of significance are a reduction in surface area of the iron oxides following their partial recrystallisation (ageing) and a change in their surface chemistry as a result of the formation of a mixed-oxidation state Fe(II)-Fe(III)) surface. These changes, as well as the reduction of the strongly sorbed As(V) to the less strongly sorbed As(III), could lead to the release of arsenic from the sediments. Geochemical modeling has confirmed that much change could account for the high arsenic concentrations observed in Bangladesh ground waters. Phosphate is believed to be released by the same desorption and dissolution mechanisms (except that the oxidation state of phosphorus is not sensitive to redox conditions). (BGS and DPHE, 2001)

The release of arsenic (and phosphate) has also frequently been observed in recently-buried and reducing freshwater and marine sediments, and in flooded soils from many parts of the world. This release is magnified by a number of factors in Bangladesh, especially the large size of the delta and the unusually large depth of recently deposited sediments, i.e. sediments deposited over the last few thousand years.

The flow of water in the aquifer 'is also important since this is the normal natural mechanism for flushing away the arsenic so released. The large flat delta region of Bangladesh leads to extremely low hydraulic gradients and correspondingly low rates of flushing of the aquifer. This means that the arsenic released will accumulate, as observed.

Where groundwater flushing is more active, as in parts of northern Bangladesh, or has existed for longer periods as in the deep aquifer, then arsenic concentrations are lower. It is likely that the high concentrations of arsenic found in Bangladesh groundwater will eventually disappear as fresh groundwater flushes through the aquifer, albeit very slowly. The rate of groundwater flow is poorly understood at present but this flushing will probably take thousands or tens of thousands of years. Significant falls in sea level have occurred in the recent past which will have greatly accelerated the flushing of the deeper aquifer. Such changes could occur again if the earth goes through another ice age.

The concept that the present groundwater arsenic problem results from a relatively rapid change in response to recent burial, and that the desorption of arsenic from oxides is an important part of this process, is encouraging in the sense that once the initial release of arsenic has been flushed away, it should not continue to be released unless conditions once again change for the worse, e.g. become even more reducing. This is generally unlikely in the deep aquifer but could occur in those parts of the shallow aquifer that are not yet very strongly reducing. For example, certain changes at the land surface could lead to a reduced rate of diffusion of oxygen to the underlying aquifer. The establishment of more extensive flooding and the puddling of soils associated with paddy fields are the most obvious mechanisms for achieving this. However, the redox buffering by the large volume of sediments involved is large and so any such changes are likely to be slow.

Therefore we believe that the deep aquifers which are currently predominantly arsenic-free in Bangladesh are likely to remain so, at least under natural flow conditions. However, we stress that this is only an initial observation based on limited evidence and that the precautionary principle suggests that this should not be relied on until more solid evidence is established in its favor. In particular, more detailed studies are required on the influence of pumping in both the shallow and deep aquifer to see how this might change the situation. There is conflicring anecdotal evidence on this at present. The connectivity of the shallow and deep aquifers is an important factor.

The careful monitoring of water quality in the aquifers at different depths and over various timescales is essential. A better understanding of the ages of the sediments and groundwaters and of the regional distribution of aquifers and aquicludes would also be very useful.

2.15 Correlation and regression analysis:

Relation between two variables can be analyzed properly through correlation and regression analysis. By scatter plotting the variables it gives a graphical feel about relationship. Correlation analysis provides the degree of relationship. On the other hand regression analysis provides the numerical relationship between two variables. Given a value for one, it can predict the most likely value for other variable based on the available information.

The correlation is one of the most common and most useful statistics. A correlation is a single number that describes the degree of relationship between two variables. The measurement scales used should be at least interval scales, but other correlation coefficients are available to handle other types of data. Correlation coefficients can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation.

Positive Correlation:

The relationship between two variables is such that as one variable's values tend to increase, the other variable's values also tend to increase. This is represented by a positive correlation coefficient.

Negative Correlation:

The relationship between two variables is such that as one variable's values tend to increase. The other variable's values tend to decrease. This is represented by a negative correlation coefficient.

Pearson Correlation:

The most widely-used type of correlation coefficient is Pearson r. Also called linear or product-moment correlation. Using non technical language, one can say that the correlation coefficient determines the extent to which values of two variables are "proportional" to each other. The value of the correlation (i.e.. correlation coefficient) does not depend on the specific measurement units used; for example. the correlation between height and weight will be identical regardless of whether inches and pounds. Or centimeters and kilograms are used as measurement units. Proportional means linearly related; that is. The correlation is high if it can be approximated by a straight line (sloped upwards or downwards). This line is called the regression line or least squares line. Because it is determined such that the sum of the squared distances of all the data points from the line is the lowest possible. Pearson correlation assumes that the two variables are measured on at least interval scales. The Pearson product moment correlation coefficient is calculated as follows:

Regression and correlation measure the degree of *relationship* between two or more variables in two different but related ways. In regression analysis, a single dependent variable, Y, is considered to be a function of one or more independent variables, X1, X2, and so on. The values of both the dependent and independent variables are assumed as being ascertained in an error-free random manner. Further, parametric forms of regression analysis assume that for any given value of the independent variable, values of the dependent variable are normally distributed about some mean. Application of this statistical procedure to dependent and independent variables produces an equation that "best" approximates the functional relationship between the data observations.

Correlation analysis measures the degree of association between two or more variables. Parametric methods of correlation analysis assume that for any pair or set of values taken under a given set of conditions, variation in each of the variables is random and follows a normal distribution pattern. Utilization of correlation analysis on dependent and independent variables produces a statistic called the correlation coefficient (r). The square of this statistical parameter (the coefficient of determination or r^2) describes what proportion of the variation in the dependent variable is associated with the *regression* of an independent variable.

Simple Linear Regression

In a simple regression analysis, one dependent variable is examined in relation to only one independent variable. The analysis is designed to derive an equation for the line that best models the relationship between the dependent and independent variables. This equation has the mathematical form:

$Y = a + bX$

Where, Y is the value of the dependent variable, X is the value of the independent variable, a is the intercept of the regression line on the Y axis when X = 0, and b is the slope of the regression line.

2.16. GIS Mapping for Correlation of Arsenic and Iron of ground water:

A GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources. Mapping of correlation by GIS will give geographical view of the issue in a large scale. GIS maps will provide the graphical representation of the correlation issue. This map will indicate the correlation status in each district. After analyzing this GIS map of correlation between *As and Fe* it can give an idea whether any geographical pattern exists in this correlation or not. GIS map will be produced for 3 depth layer of wells. It will enable us to know the correlation status for each layer of wells all over the country.

CHAPTER-3

DATA COLLECTION

AND

ANALYSIS

CHAPTER 3:

DATA COLLECTION AND ANALYSIS

3.1 Data Collection:

Data used for analysis were collected from different sources. Technical report of British geological survey (BGS and DPHE, 2001) is one of the major sources of data. British geological survey (BGS) has published a technical report on Ground water quality of Bangladesh in 2001. This project was financed by DFID (Department For International Development) UK. A survey of well waters (n=3534) from throughout Bangladesh, excluding the Chittagong Hill Tracts, has shown that water from 27% of the 'shallow' tube wells, that is wells less than 150 m deep, exceeded the Bangladesh standard for arsenic in drinking water ($50\mu gL^{-1}$). 46% exceeded the WHO guideline value of $10\mu gL^{-1}$. Figures for 'deep' wells (greater than 150 m deep) were 1 % and 5%, respectively. On the Other hand 23% sample exceeded the iron content of $5mg/L^{-1}$.

Another major source of data was Second phase of DPHE-JICA Project-2006/2007. JICA (Japan International Cooperation Agency) in association with DPHE (Department of Public Health and Engineering) and has performed a water quality survey in the coastal area of Bangladesh between 2006 and 2007. These data sets were collected from DPHE in Hard copy and converted into soft copy.

3.2 Formation of different combinations of *As* and *Fe*:

If all these data are taken into consideration, it shows a very little correlation between arsenic and iron concentration of ground water. If the data are classified as per geographical locations then it shows different result in different geographical locations. It gives an idea that this correlation of arsenic and iron concentration of ground water may not be a national phenomenon. If the data are classified according to the six administrative division of Bangladesh, correlation scenario is different in every division. When the data are classified according to districts of Bangladesh, which are smaller in area than the divisions shows some improvement in correlation in some districts. This scenario leads to an idea that correlation between arsenic and iron concentration of ground water is not a national phenomenon in Bangladesh, rather it's a zonal phenomenon.

Water quality result of different wells shows that different amount of arsenic and iron is present in different wells. Some sample has higher *As* along with higher *Fe* while other may have Higher *As* along with lower *Fe.* In some samples the cases may be vice versa. Bangladesh standard for arsenic concentration of ground water is 0.05mg/L. For iron this value is between 0.3 to 1 mg/L. But a major part of the sample exceeds this range of iron. About 23% data exceeds iron content of 5mg/L. All the data can be categorized in different combination of arsenic and iron depending on their availability in different places. If 0.05mg/L is taken as the boundary value of arsenic and 5mg/L as the boundary value of iron, then the following water matrix in fig 3.1 can be achieved.

Arsenic Concentration is **Greater** than Bangladesh Standard 0.05mg/L and Iron concentration is **Greater** than 5mg/L	Arsenic Concentration is **Less** than Bangladesh Standard 0.05mg/L and Iron concentration is **Greater** than 5mg/L
Arsenic Concentration is **Greater** than Bangladesh Standard 0.05mg/L and Iron concentration is **Less** than 5mg/L	Arsenic Concentration is **Less** than Bangladesh Standard 0.05mg/L and Iron concentration is **Less** than 5mg/L

Fig: 3.1 Different possible combinations in matrix form

matrix shown in fig 3.1 can be simplified by using some mathematical notations rather than describing in words.

As>0.05mg/L and Fe >5mg/L	As<0.05mg/L and Fe >5mg/L
As>0.05mg/L and Fe <5mg/L	As<0.05mg/L and Fe <5mg/L

Fig: 3.2 Different possible combinations in matrix form using mathematical notations

3.3 Depth Variation of aquifers

In this analysis data are classified in three depth layers. One group is less than 50m depth. Another one is between 50m to 150m depth. The last one is greater than 150m depth. Which means each combination class now have three set of data classified according to the depth of aquifer. 1st depth range is chosen as depth bellow 50m. Most of hand tube well which are most common source of palatable water in our village areas lies in this depth range.

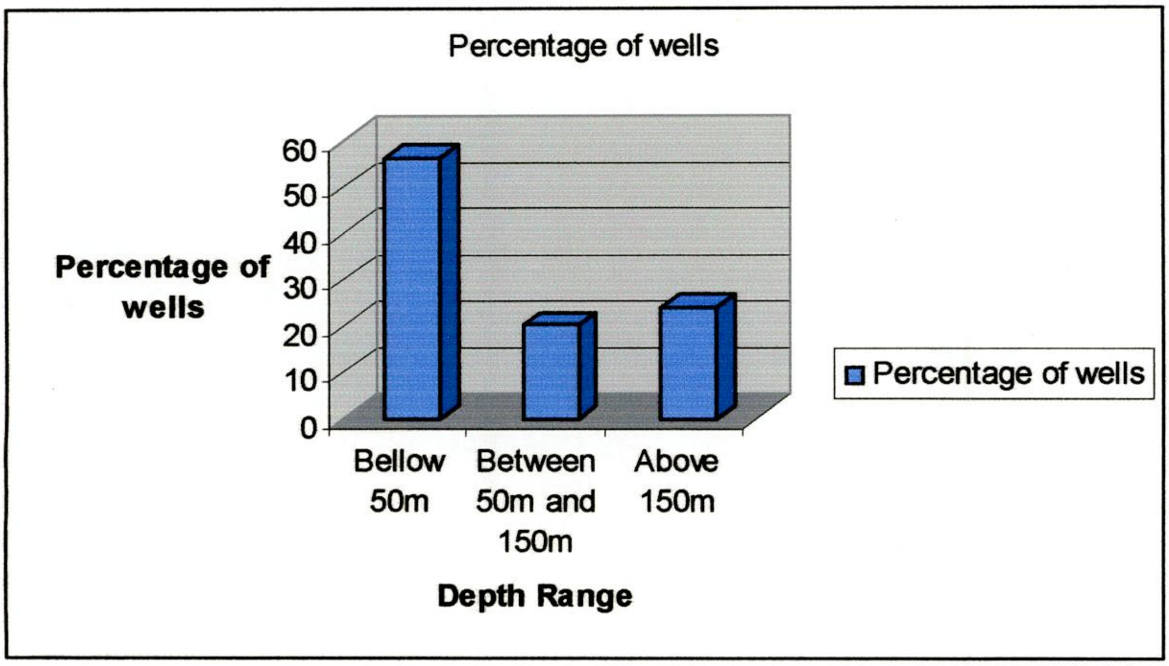

Fig 3.3 Percentage of wells in each depth group

More over 56.23% sample depth of this analysis is less than 50m where arsenic problem is acute. The 2nd range chosen between 50m to 100m in which well depth of 20% sample lies. In this layer arsenic concentration is less acute than the 1st layer. The least contaminated layer is depth greater than 150m in which 23.67% sample lies.

If the depth range of wells bellow 50m, wells between 50m to 150m and wells above 150m are termed as 1,2 and 3 respectively the scatterplotting of data are shown in the fig 3.4

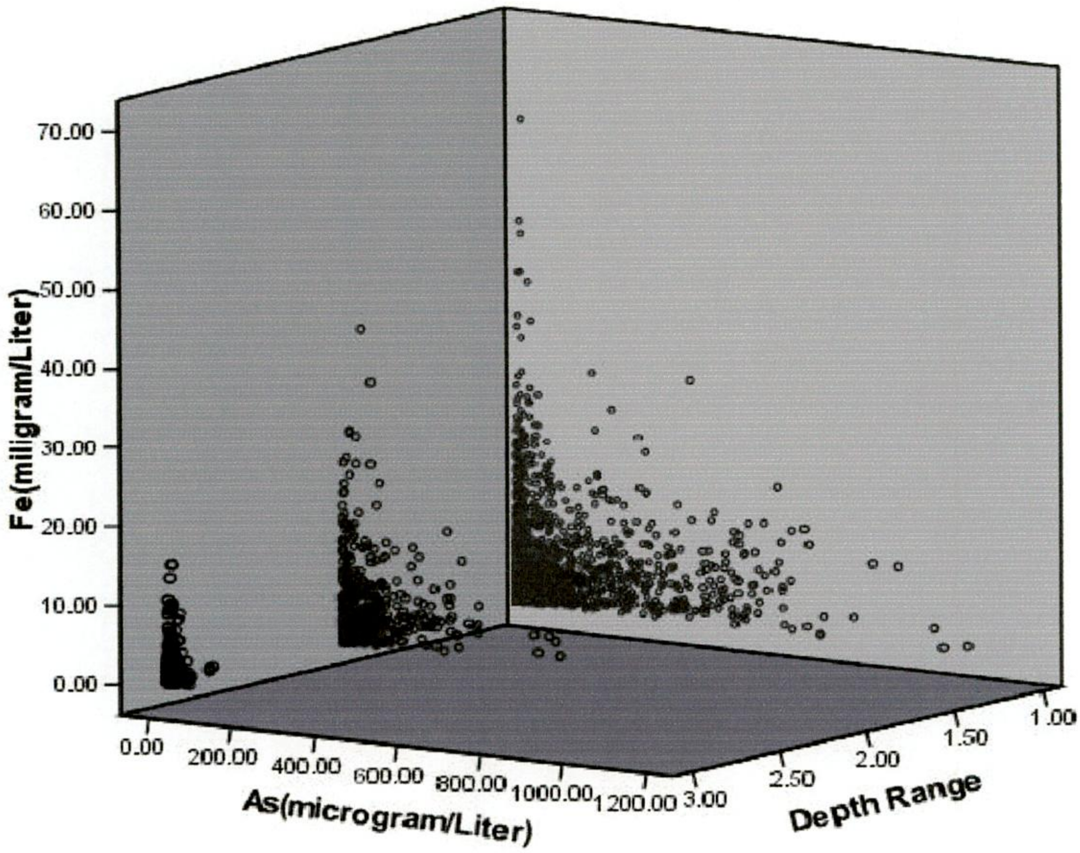

Fig 3.4 Depth variation for Arsenic and Iron

Scatterplotting of data shown in the fig 3.4 portrays the arsenic and iron concentration in those three depth range. In 1st depth range both arsenic and iron concentration is higher than the other two depth range. While the 3rd depth range which is greater than 150m shows lesser concentration of both arsenic and iron.

3.4 Conceptual development of 3-Dimensional water matrix:

The previous matrix is regrouped according to three depth levels which are Depth less than 50m, Depth between 50m to 150 m, Depth greater than 150m. The matrix now turns into the following matrix as in fig 3.5 . It's a 3 Dimensional water matrix.

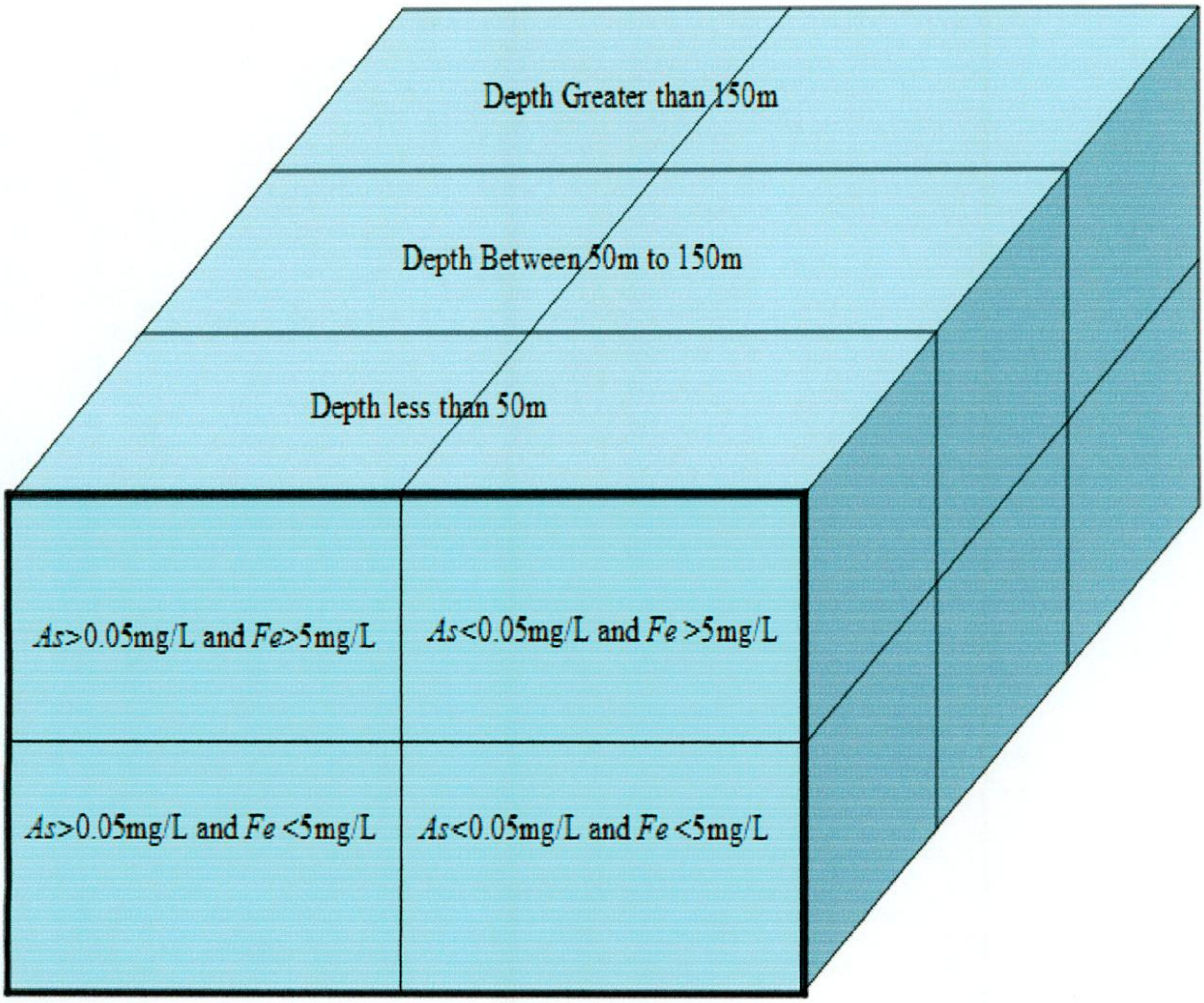

Fig. 3.5 Water matrix showing all possible combinations in different depth level

This is a conceptual model of all possible combination of Arsenic concentration, iron concentration and depth of well. All available data was categorized as per this developed model. This will provide twelve different data sets for analysis. This will allow analyzing the correlation issue more precisely.

3.5 Nomenclature of different combination groups:

To make the analysis easier twelve groups of data were given separate names. The names are shown in the table 3.1.

Table 3.1 Nomenclature of different combination groups

Combinations	Name
As>50μg/L, Fe>5mg/L, well depth<50m	Group-01
As>50μg/L, Fe>5mg/L, well depth between 50m to 150m	Group-02
As>50μg/L, Fe>5mg/L, well depth> 150m	Group-03
As<50μg/L, Fe>5mg/L, well depth<50m	Group-04
As<50μg/L, Fe>5mg/L well depth between 50m to 150m	Group-05
As<50μg/L, Fe>5mg/L well depth>150m	Group-06
As>50μg/L, Fe<5mg/L, well depth<50m	Group-07
As>50μg/L, Fe<5mg/L, well depth between 50m to 150m	Group-08
As>50μg/L, Fe<5mg/L, well depth>150m	Group-09
As<50μg/L, Fe<5mg/L well depth<50m	Group-10
As<50μg/L, Fe<5mg/L well depth between 50m to 150m	Group-11
As<50μg/L, Fe<5mg/L well depth>150m	Group-12

3.6 Data Analysis:

Initially all available data irrespective of combination and depth range were analyzed to find the correlation between arsenic and iron concentration it gave a very small correlation coefficient of 0.195. Analysis result is shown in the table 3.2.

Table: 3.2 Correlation between arsenic and Iron using all available data

Correlation coefficient	0.195
Number of Data	4367
Significance	0.0001

After scatterplotting all the data, the graph looks like the figure no 3.6.

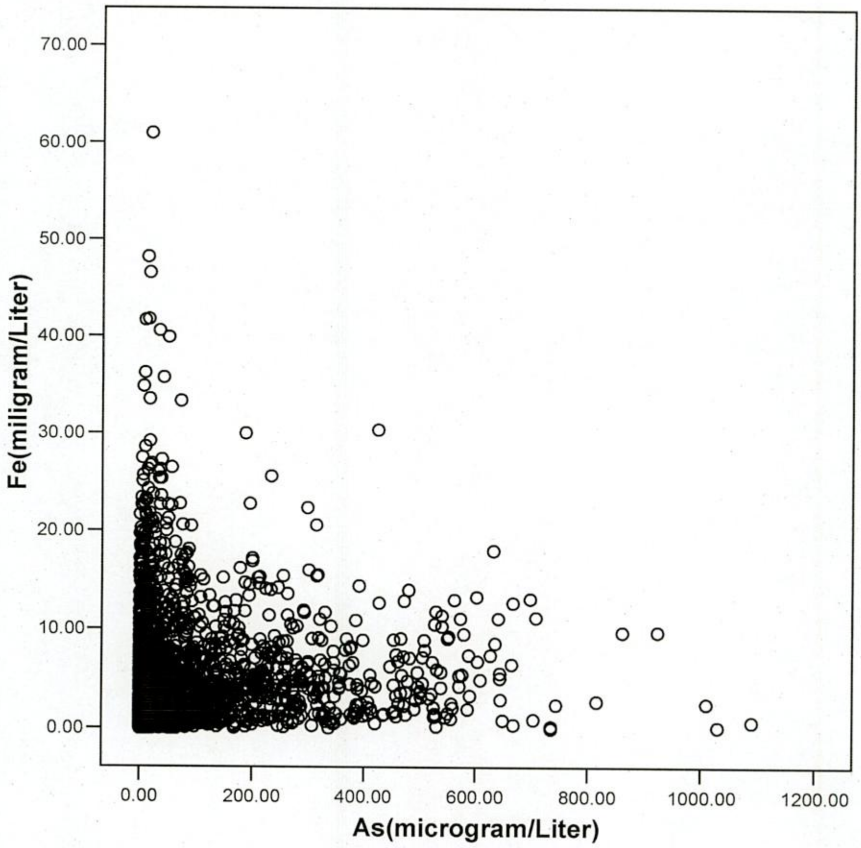

Fig: 3.6 Scatterplotting of data showing Arsenic vs Iron concentration of ground water

All the available data were separated as per their geographical locations. Bangladesh has 61 administrative districts and data were classified as per their zonal locations. Correlation analysis was performed.

In this research data analysis has been performed in four major steps. They are as following.

a. Cross tabulation of available data
b. Scatted plotting of *As* Vs *Fe*
c. Correlation analysis.
d. Regression analysis.

3.6.1 Crosstabulation

Crosstabulation is a statistical procedure which is used to display the common distribution of two variables. A crosstabulation (often abbreviated as crosstab) displays the joint distribution of two or more variables. They are usually presented as a contingency table in a matrix format. Whereas a frequency distribution provides the distribution of one variable, a contingency table describes the distribution of two or more variables simultaneously. Each cell shows the number of respondents that gave a specific combination of responses, that is, each cell contains single cross tabulation.

Now using the developed water matrix, all the data were categorized as per the predefined combinations of *As*, *Fe* and depth of well. This matrix provided 12 sets of data. For example one data set separated all the wells which contain Arsenic concentration more than 50μg/L, Iron concentration more than 5mg/L and well depth is bellow 50m.

Table 3.3 Depth and *As, Fe* combination Cross tabulation

			Arsenic and Iron Combinations				Total
			As<50 Fe<5	As>50 Fe<5	As<50 Fe>5	As>50 Fe>5	
Depth Range	Depth<50m	Count	1421.0	396.0	346.0	293.0	2456.0
		% within Depth Range	57.9	16.1	14.1	11.9	100.0
		% within combination	47.4	74.3	71.5	83.2	56.2
		% of Total	32.5	9.1	7.9	6.7	56.2
	Depth 50m to 150m	Count	576.0	131.0	111.0	59.0	877.0
		% within Depth Range	65.7	14.9	12.7	6.7	100.0
		% within combination	19.2	24.6	22.9	16.8	20.1
		% of Total	13.2	3.0	2.5	1.4	20.1
	Depth>150m	Count	1001.0	6.0	27.0	0.0	1034.0
		% within Depth Range	96.8	0.6	2.6	0.0	100.0
		% within combination	33.4	1.1	5.6	0.0	23.7
		% of Total	22.9	0.1	0.6	0.0	23.7
Total		Count	2998.0	533.0	484.0	352.0	4367.0
		% within Depth Range	68.7	12.2	11.1	8.1	100.0
		% within combination	100.0	100.0	100.0	100.0	100.0
		% of Total	68.7	12.2	11.1	8.1	100.0

Table 3.3 describes that 293 samples exceeds both *As* and *Fe* range their well depth is bellow 50m. It also describes that 83.2% of *As*>50 and *Fe*>5 combination lies with in the depth range of bellow 50m. It also describes that 11.9% sample of depth range bellow 50m possesses the combination of *As*>50 and *Fe*>5. After separation of data according to the new developed matrix 12 sets of data were ready for further analysis.

3.6.2 Scatter plotting of data:

A scatterplot is a useful summary of a set of bivariate data (two variables), usually drawn before working out a linear correlation coefficient or fitting a regression line. It gives a good visual picture of the relationship between the two variables, and aids the interpretation of the correlation coefficient or regression model. Each unit contributes one point to the scatterplot, on which points are plotted but not joined. The resulting pattern indicates the type and strength of the relationship between the two variables. A scatterplot is often employed to identify potential associations between two variables, where one may be considered to be an explanatory variable (such as Iron) and another may be considered a response variable (such as Arsenic). A **positive association** between education and income would be indicated on a scatterplot by an upward trend (positive slope), where higher Arsenic corresponds to higher Iron levels and vice versa. A **negative association** would be indicated by the opposite effect (negative slope), where the most iron contaminated area would have lower arsenic than the least iron contaminated area. Or, there might not be any notable association, in which case a scatterplot would not indicate any trends whatsoever.

All the 12 sets of data were scatter plotted to analyze the graphical representation of arsenic and iron. In this chapter one sample scatter plot is shown. Rest of them are shown and discussed in the result and discussion chapter (chapter 4).

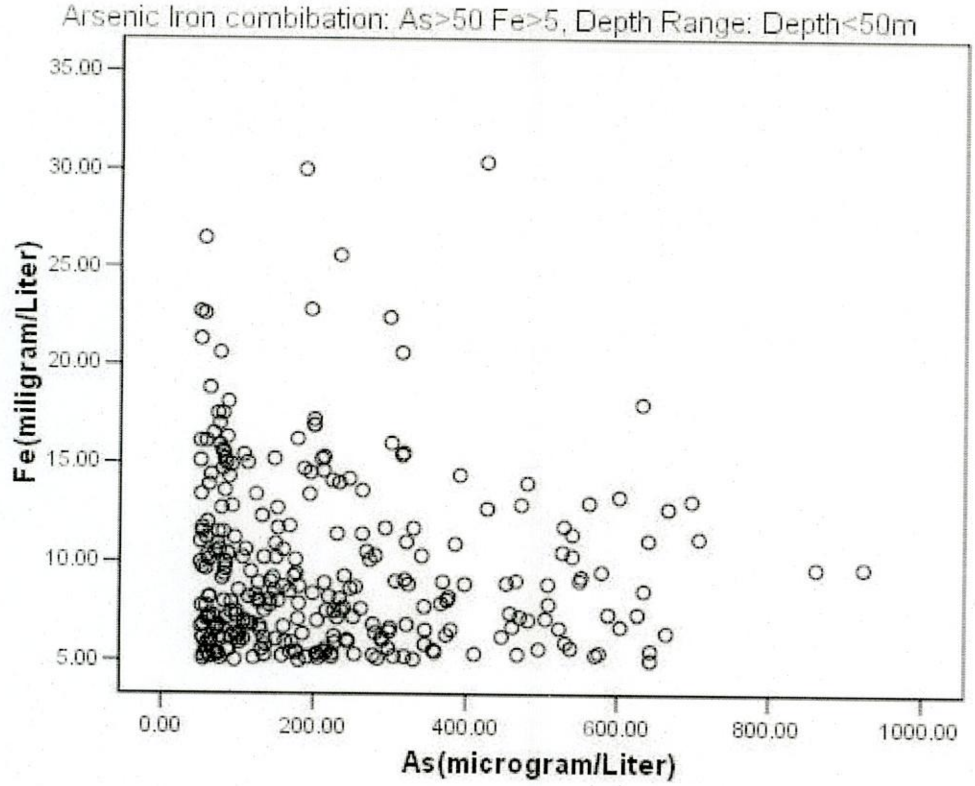

Fig 3.7 Scatterplotting of *As* Vs *Fe* for combination *As*>50μg/L, *Fe*>5mg/L and well depth bellow 50m.

Above figure represents the scatterplot of Arsenic and iron concentration of ground water for the combination *As*>50, *Fe*>5 and well depth bellow 50m.

3.6.3 Correlation analysis of data sets:

The correlation is one of the most common and most useful statistics. A correlation is a single number that describes the degree of relationship between two variables. The measurement scales used should be at least interval scales, but other correlation coefficients are available to handle other types of data. Correlation coefficients can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation.

All twelve data sets derived from the developed water matrix were separately analyzed for correlation. Correlation analysis of one data set is shown in this analysis chapter and rest of then are shown and discussed in the Result and discussion chapter (Chapter 4).

Table 3.4 correlation of *As* and *Fe* for combination zone of As>50 Fe<5 and Depth between 50m to 150m

Correlation coefficient	0.158
Number of Data	131
Significance	0.072

Above table indicates that 131 data belong to this category and correlation coefficient is 0.158 which is very less.

3.6.4 Regression analysis of data sets:

In a simple regression analysis, one dependent variable is examined in relation to only one independent variable. The analysis is designed to derive an equation for the line that best models the relationship between the dependent and independent variables. This equation has the mathematical form:

$Y = a + bX$

Where, Y is the value of the dependent variable, X is the value of the independent variable, a is the intercept of the regression line on the Y axis when X = 0, and b is the slope of the regression line.

Here Arsenic is used as a dependant variable and Iron is used as an independent variable. Reason behind this is that our objective of this research was to estimate the value of arsenic concentration of groundwater by using the Iron concentration value. . Regression analysis of one data set is shown in this analysis chapter and rest of them are shown and discussed in the Result and discussion chapter (Chapter 4).

Table 3.5 Regression of *As* and *Fe* for combination zone of As>50 Fe>5 and Depth between 50m to 150m

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	0.140(a)	0.020	0.002	91.82474

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
	(Constant)	151.734	22.749		6.670	.000
	Fe	-2.054	1.922	-.140	-1.069	.290

In this analysis arsenic is taken as the dependent variable. After analysis the equation becomes like the following one.

Arsenic (μg/L) = 151.734 + (-2.054) (Iron in mg/L)

For all the tube well having combination As>50 Fe>5 and Depth between 50m to 150m can be described by this equation.

3.7 District wise data analysis:

All the data were classified according to the district of Bangladesh. It gave 61 data sets. Each data set of a district was reclassified according to the developed matrix resulting in 12 data sets for each district. 732 data sets were scatterplotted and analyzed for correlation and regression. This analysis would provide detail correlation status of each district according to different *As Fe* combinations and different depth range.

Data were analyzed following the same steps that were followed in the previous national analysis. All the data sets of a district were scatter plotted and then analyzed for correlation and regression.

3.8 Development of GIS map for correlation of arsenic and iron concentration in ground water:

GIS is increasingly viewed as a key tool for the storage, display and analysis of spatial data . A geographic information system (GIS), also known as a geographical information system or geospatial information system, is any system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to Earth. As one of the major objective of this research was to produce a correlation map of Bangladesh, all the data were classified according to their geographic locations (district). Data of 61 districts are available. Data set of a district was then classified according to the above mentioned water matrix. Now 12 set of data for each district is ready for analysis.Total 16 number of GIS map was produced in this research. Table 3.6 shows their title and content of the maps.

Table no 3.6 List of GIS maps produced in this research.

SL no.	Map title	Data contained	Figure no.
1	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh	Arsenic and Iron concentration of ground water of 61 districts of Bangladesh.	Fig no 4.13
2	GIS map of Correlation between Arsenic and iron concentration of ground water (tube wells depth less than 50m, D1) of Bangladesh.	Arsenic and Iron concentration of ground water of tube wells depth less than 50m of 61 districts of Bangladesh.	Fig no. 4.14
3	GIS map of Correlation between Arsenic and iron concentration of ground water (tube wells depth between 50m to 150m, D2) of Bangladesh.	Arsenic and Iron concentration of ground water of tube wells depth between 50m to 150m of 61 districts of Bangladesh.	Fig no 4.15
4	GIS map of Correlation between Arsenic and iron concentration of ground water (tube wells depth greater than 150m, D3) of Bangladesh.	Arsenic and Iron concentration of ground water of tube wells depth greater than 150m of 61 districts of Bangladesh.	Fig no 4.16
5	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As>50μg/L, Fe>5mg/L depth< 50m (Group-01)	Arsenic and Iron concentration of Bangladesh for combination of As>50μg/L, Fe>5mg/L depth< 50m (Group-01)	Fig no 4.17

	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As>50µg/L, Fe>5mg/L depth between 50m to 150m (Group-02)	Arsenic and Iron concentration of Bangladesh for combination of As>50µg/L, Fe>5mg/L depth between 50m to 150m (Group-02)	Fig no 4.18
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As>50µg/L, Fe>5mg/L depth>150m (Group-03)	Arsenic and Iron concentration of Bangladesh for combination of As>50µg/L, Fe>5mg/L depth>150m (Group-03)	Fig no 4.19
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As<50µg/L, Fe>5mg/L depth<50m (Group-04)	Arsenic and Iron concentration of Bangladesh for combination of As<50µg/L, Fe>5mg/L depth<50m (Group-04)	Fig no 4.20
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As<50µg/L, Fe>5mg/L depth between 50m to 150m (Group-05)	Arsenic and Iron concentration of Bangladesh for combination of As<50µg/L, Fe>5mg/L depth between 50m to 150m (Group-05)	Fig no 4.21
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As<50µg/L, Fe>5mg/L depth>150m (Group-06)	Arsenic and Iron concentration of Bangladesh for combination of As<50µg/L, Fe>5mg/L depth>150m (Group-06)	Fig no 4.22
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As>50µg/L, Fe<5mg/L depth<50m (Group-07)	Arsenic and Iron concentration of Bangladesh for combination of As>50µg/L, Fe<5mg/L depth<50m (Group-07)	Fig no 4.23
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As>50µg/L, Fe<5mg/L depth between 50m to 150m (Group-08)	Arsenic and Iron concentration of Bangladesh for combination of As>50µg/L, Fe<5mg/L depth between 50m to 150m (Group-08)	Fig no 4.24
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As>50µg/L, Fe<5mg/L depth>150m (Group-09)	Arsenic and Iron concentration of Bangladesh for combination of As>50µg/L, Fe<5mg/L depth>150m (Group-09)	Fig no 4.25
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As<50µg/L, Fe<5mg/L depth<50m (Group-10)	Arsenic and Iron concentration of Bangladesh for combination of As<50µg/L, Fe<5mg/L depth<50m (Group-10)	Fig no 4.26

	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As<50μg/L, Fe<5mg/L depth between 50m to 150m (Group-11)	Arsenic and Iron concentration of Bangladesh for combination of As<50μg/L, Fe<5mg/L depth between 50m to 150m (Group-11)	Fig no 4.27
	GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for combination of As<50μg/L, Fe<5mg/L depth>150m (Group-12)	Arsenic and Iron concentration of Bangladesh for combination of As<50μg/L, Fe<5mg/L depth>150m (Group-12)	Fig no 4.28

The details of these maps are discussed in the result and discussion chapter.

CHAPTER-4

RESULT

AND

DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Concentration of Arsenic in different depth level

Total 4367 number of data is used for analysis in this research. Data of 61 administrative districts of Bangladesh were available for analysis. Total 38.2% of data exceed the WHO guideline value of *As* of 10µg/L. among these 34.5% data which are of shallow wells exceeds WHO guideline value of 10µg/L. For Bangladesh DoE (DoE, 1997) sets the arsenic guideline value as 50µg/L. For this 20.3% data exceeds the guideline value of 50µg/L. Problem is more acute in shallow wells as it shows 20.1% data exceeds the guideline value. Only 0.1% of deep wells exceeds guideline value. The results are shwn in the tabular form in the tables 4.1 and 4.2.

Table 4.1 Frequency and Percentage of wells exceeding Bangladesh standards of Arsenic

	Frequency	Percent	Cumulative Percent
As>50µg/L Depth<50m	689.0	15.8	15.8
As>50µg/L Depth 50m-150m	190.0	4.4	20.1
As>50µg/L Depth>150m	6.0	0.1	20.3
As<50µg/L Depth<50m	1767.0	40.5	60.7
As<50µg/L Depth 50m-150m	687.0	15.7	76.5
As<50µg/L Depth>150m	1028.0	23.5	100.0
Total	4367.0	100.0	

Table 4.2 Frequency and Percentage of wells exceeding WHO standards of Arsenic

	Frequency	Percent	Cumulative Percent
As>10µg/L Depth<50m	1097.0	25.1	25.1
As>10µg/L Depth 50m-150m	408.0	9.3	34.5
As>10µg/L Depth>150m	165.0	3.8	38.2
As<10µg/L Depth<50m	1359.0	31.1	69.4
As<10µg/L Depth 50m-150m	469.0	10.7	80.1
As<10µg/L Depth>150m	869.0	19.9	100.0
Total	4367.0	100.0	

4.2 Analysis of data according to Arsenic-Iron combinations:

If the available data are plotted according to the possible combinations of arsenic and iron without considering the depth variation, then it shows that a large portion of data belongs to the class *As*<0.05mg/L and *Fe*<5mg/L. Rest of the classes share almost same volume of data showing slightly large volume in *As*<0.05mg/L and *Fe*>5mg/L section. The tabular representation of this can be shown as in the table 4.3.

Table 4.3 Distribution of samples according to the possible arsenic and iron concentration

	Frequency	Percent
As<50 Fe<5	2998	68.7
As>50 Fe<5	533	12.2
As<50 Fe>5	484	11.1
As>50 Fe>5	352	8.1
Total	4367	100.0

Maximum 68.7% data falls in the group where both arsenic and iron concentration is within the limit, where minimum 8.1% data falls in the range where Arsenic concentration exceeds the Bangladesh standard and iron concentration exceeds 5mg/L. Bar chart shown in fig 4.1 is the graphical distribution of the analysis.

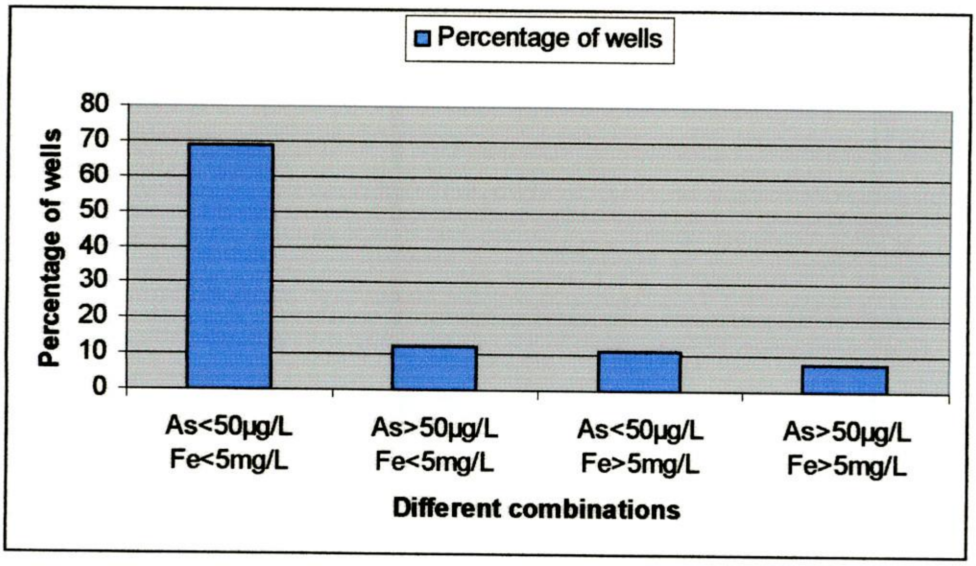

Fig: 4.1 Distribution of data samples in different combination zone.

All the 4 data groups were analyzed to find correlation between arsenic and iron concentration. Table 4.2 shows that by analyzing 352 data of combination group As>50 Fe>5, which is the most contaminated for both *As* and *Fe* correlation coefficient r is found to be (-) 0.080. r-square is the Coefficient of determination which is 0.0064. This indicates that only 0.64% of *As* concentration can be described by the *Fe* concentration in this combination group. Significance level of this value is 0.136 which means 13.6% possibility that this correlation is found by chance. Correlation coefficient using all the available data of this combination irrespective of geographic location shows that a very insignificant correlation exists between *As* and *Fe*.

Table 4.4 Correlation between arsenic and iron for combination of As>50 Fe>5

Correlation coefficient	-0.08
Number of Data	352
Significance	0.136

Table 4.3 shows that by analyzing 2998 data of combination group As<50 Fe<5, which is the least contaminated for both *As* and *Fe*, correlation coefficient r is found to be 0.381. r-square is the Coefficient of determination which is 0.145. This indicates that 14.5% of *As* concentration can be described by the *Fe* concentration in this combination group. Significance level of this value is 0.000 which means that less than 1% possibility that this correlation is found by chance. Correlation coefficient using all the available data of this combination irrespective of geographic location shows that a significant correlation exists between *As* and *Fe*.

Table 4.5 Correlation between arsenic and iron for combination of As<50 Fe<5

Correlation coefficient	0.381
Number of Data	2998
Significance	0.0001

Correlation coefficients for rest of the two combinations, As<50 Fe>5 and As>50 Fe<5 are also insignificant 0.083 and -0.031 respectively. Results of those two analyses are shown in the table 4.6 and table 4.7.

Table 4.6 Correlation between arsenic and iron for combination of As<50 Fe>5

Correlation coefficient	0.083
Number of Data	484
Significance	0.069

Table 4.7 Correlation between arsenic and iron for combination of As>50 Fe<5

Correlation coefficient	-0.031
Number of Data	533
Significance	0.473

When Depth variation is considered the correlation coefficients tends to change. If the results are shown in a matrix form they look like table 4.13

Table 4.8 Matrix presentation of the result

Combinations	Correlation Coefficient		
	Depth range		
	<50m	Between 50m to 150m	>150m
As>50µg/L, Fe>5mg/L	-0.07	-0.14	0
As>50µg/L, Fe<5mg/L	-0.055	0.158	0.951
As<50µg/L, Fe>5mg/L	0.122	-0.06	-0.185
As<50µg/L, Fe<5mg/L	0.396	0.453	0.266

If we analyze the above matrix it is clear that in the depth range 50m to 150m two possible combinations (As>50µg/L, Fe>5mg/L & As<50µg/L, Fe<5mg/L) is showing the highest correlation. Number of data of the As>50µg/L, Fe<5 mg/L group is only six which makes the correlation result less reliable.

On the other hand every combination differs with each other for correlation coefficient even in the same depth range.

Table 4.9 Comparison of correlation coefficients.

Combinations	Correlation Coefficient			
	Without Depth Variation	Depth range		
		<50m	Between 50m to 150m	>150m
As>50µg/L, Fe>5mg/L	-0.08	-0.07	-0.14	0
As>50µg/L, Fe<5mg/L	-0.031	-0.055	0.158	0.951
As<50µg/L, Fe>5mg/L	0.083	0.122	-0.06	-0.185
As<50µg/L, Fe<5mg/L	0.381	0.396	0.453	0.266

Table 4.9 shows that for most contaminated combination (As>50, Fe>5) correlation coefficient is -0.08 when data were not separated as per well depth. But when data were separated as per well depth range correlation coefficient increased to -0.14 for depth range 50m to 150m and decreased to -0.07 for depth range<50m.

4.3 Analysis of data according to the developed 3-Dimentional water matrix:

A 3-Dimentional water matrix is developed in this research which has been discussed in detail in chapter three. All the available data were categorized according to this matrix. There are four possible combinations of *As* and *Fe*. Each combination were also divided into three depth range, well depth bellow 50m, well depth between 50m to 150m and well depth greater than 150 meter. This categorization will provide 12 sets of data for analysis.

4.3.1 Crosstabulation analysis:

Cross tabulation analysis of data shows that 11.9% wells of depth less than 50m is contaminated for both iron and arsenic. On the other hand 83.2% of most contaminated combination (As>0.05mg/L, Fe>5 mg/L) exists in the wells whose depth are less than 50m. Another significant thing observed in the crosstabulation analysis is 96.8% of deep aquifers whose depth is greater than 150m are least contaminated (As<0.05mg/L, Fe<5 mg/L). None of the deep wells are in the most contaminated combination (As>0.05mg/L, Fe>5 mg/L). large percentage (65.7) of 50m to 150m wells lie in the least contaminated zone where as 6.7% of wells of this range lie in the most contaminated combination (As>0.05mg/L, Fe>5 mg/L).

Table 4.10 Depth and *As, Fe* combination Cross tabulation

			Arsenic and Iron Combinations				Total
			As<50 Fe<5	As>50 Fe<5	As<50 Fe>5	As>50 Fe>5	
Depth Range	Depth<50m	Count	1421	396	346	293	2456
		% within Depth Range	57.9	16.1	14.1	11.9	100.0
		% within combination	47.4	74.3	71.5	83.2	56.2
		% of Total	32.5	9.1	7.9	6.7	56.2
	Depth 50m to 150m	Count	576	131	111	59	877
		% within Depth Range	65.7	14.9	12.7	6.7	100.0
		% within combination	19.2	24.6	22.9	16.8	20.1
		% of Total	13.2	3.0	2.5	1.4	20.1
	Depth>150m	Count	1001	6	27	0	1034
		% within Depth Range	96.8	0.6	2.6	0.0	100.0
		% within combination	33.4	1.1	5.6	0.0	23.7
		% of Total	22.9	0.1	0.6	0.0	23.7
Total		Count	2998	533	484	352	4367
		% within Depth Range	68.7	12.2	11.1	8.1	100.0
		% within combination	100.0	100.0	100.0	100.0	100.0
		% of Total	68.7	12.2	11.1	8.1	100.0

If all the crosstabulation data are plotted in a graph (fig 4.2) for graphical representation then the statistics gives a little more clear view. This graph shows that arsenic contamination is acute in the shallow depth aquifers. Arsenic and iron both stays within the limit for almost every deep aquifer.

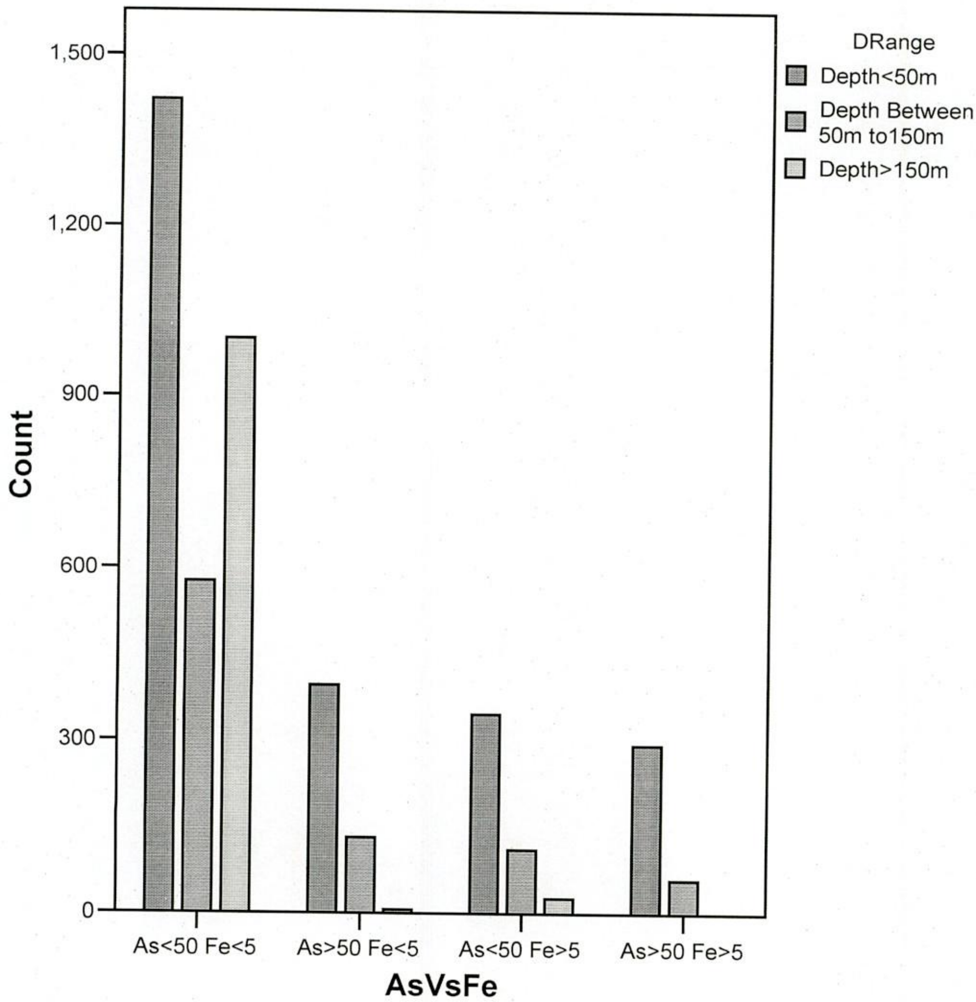

Fig: 4.2 Distribution of samples according to the 3-Dimentional water matrix.

4.3.2 Scatterplotting and correlation analysis of different categories:

Twelve possible combinations which have been derived from 3-Dimentional water matrix are given simplified names in chapter three (table 3.1). Most contaminated group of wells whose depth are less than 50m are named as Group-01 and least contaminated group of wells whose depth are more than 150m are named as Group-12.

All the results of correlation analysis and scatterplotting of these twelve groups are given in the appendix. Some of these results are shown and discussed in this chapter.

Result of Scatter plotting of Group-01 (As>50μgm/L, Fe>5mg/L, Well depth<50m) data is shown in table 4.11.

Table 4.11 Correlation coefficient for Group-01

Correlation coefficient	-0.07
Number of Data	293
Significance	0.23

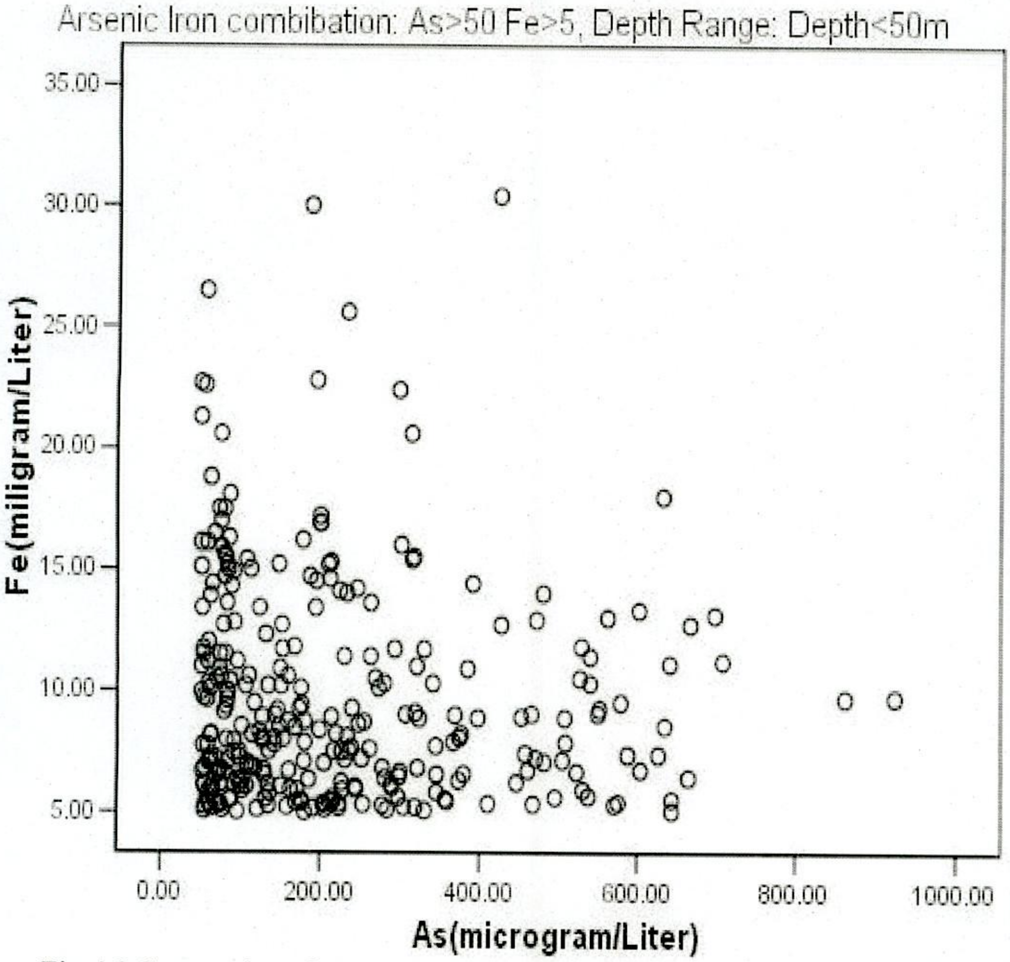

Fig 4.3 Scatterplot of *As* Vs *Fe* for combination *As*>50, *Fe*>5 and well depth bellow 50m

On the other hand the result of Scatter plotting of Group-07 (As>50μgm/L, Fe<5mg/L, Well depth<50m) data is shown in table 4.12.

Table 4.12 Correlation coefficient for Group-07

Correlation coefficient	-0.055
Number of Data	396
Significance	0.275

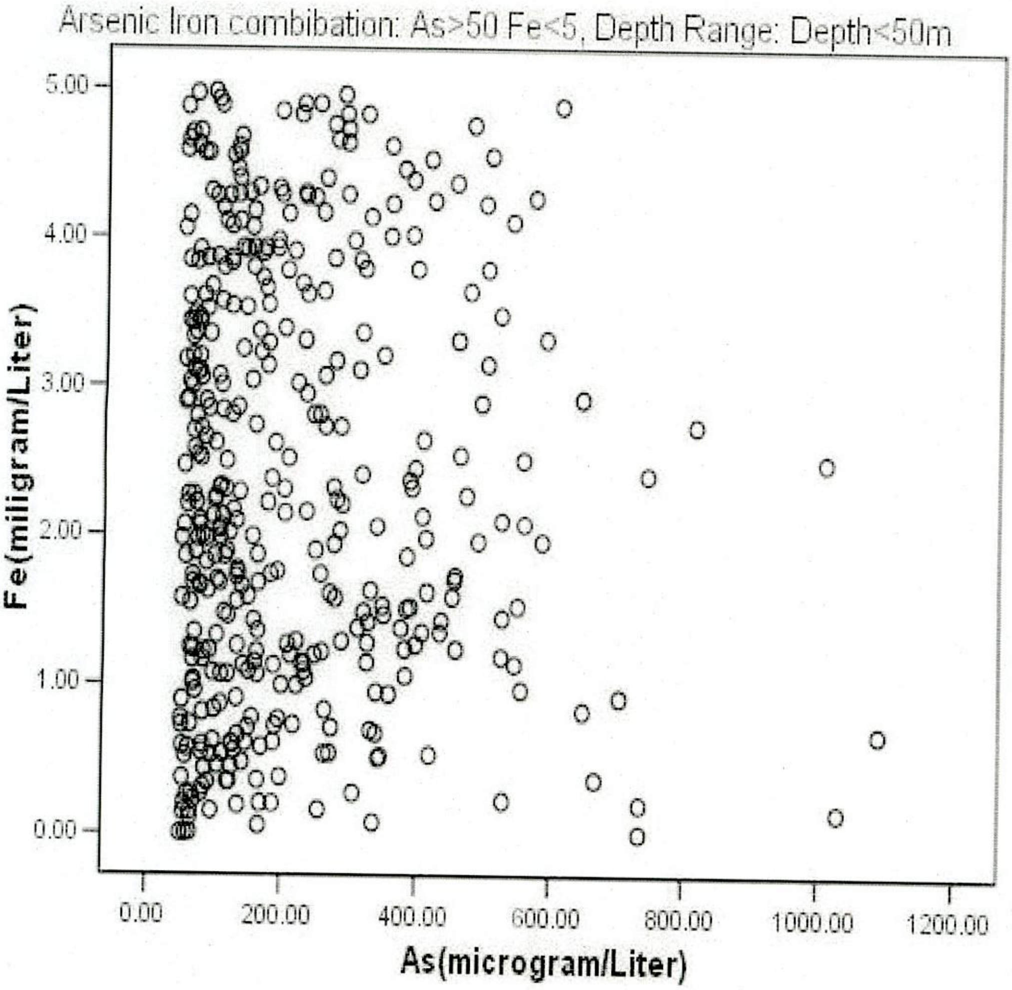

Fig 4.4 Scatterplot of *As* Vs *Fe* for combination *As*>50, *Fe*<5 and well depth bellow 50m

The result of Scatter plotting and correlation analysis of Group-10 (As<50μgm/L, Fe<5mg/L, Well depth<50m) data is shown in table 4.13.

Table 4.13 Correlation coefficient for Group-10

Correlation coefficient	0.396
Number of Data	1421
Significance	0.0001

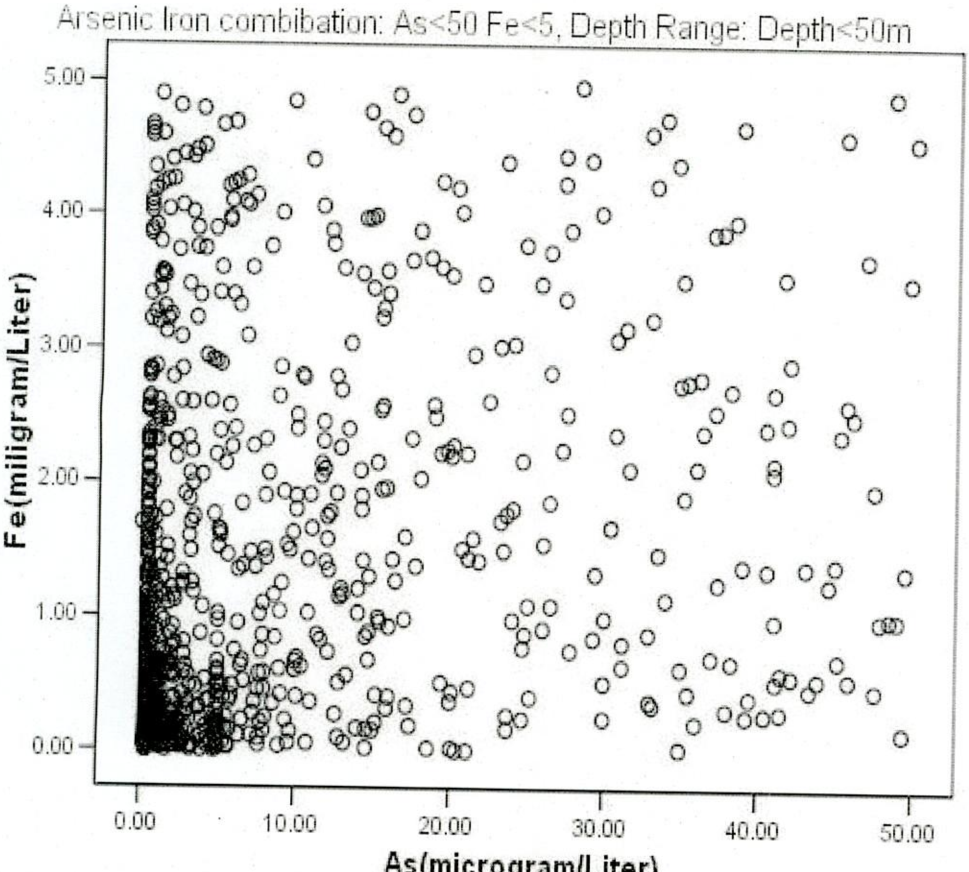

Fig 4.5 Scatterplot of *As* Vs *Fe* for combination *As*<50, *Fe*<5 and well depth bellow 50m

If these three results are discussed then it shows that at the same depth range three different combinations of *As* and *Fe* shows different correlation. In the same depth range (bellow 50m) combination *As*<50, *Fe*<5 shows the most significance correlation of 0.396 while *As*>50, *Fe*>5 combination shows the least correlation (-0.070). Sediment profile of Bangladesh is not same throughout the country.

Table 4.14 Correlation coefficient of different groups

Combinations	Name	Correlation coefficient
As>50µg/L, Fe>5mg/L, well depth<50m	Group-01	-0.07
As>50µg/L, Fe>5mg/L, well depth between 50m to 150m	Group-02	-0.14
As>50µg/L, Fe>5mg/L, well depth> 150m	Group-03	-
As<50µg/L, Fe>5mg/L, well depth<50m	Group-04	0.122
As<50µg/L, Fe>5mg/L well depth between 50m to 150m	Group-05	-0.06
As<50µg/L, Fe>5mg/L well depth>150m	Group-06	-0.185
As>50µg/L, Fe<5mg/L, well depth<50m	Group-07	-0.055
As>50µg/L, Fe<5mg/L, well depth between 50m to 150m	Group-08	0.158
As>50µg/L, Fe<5mg/L, well depth>150m	Group-09	0.951
As<50µg/L, Fe<5mg/L well depth<50m	Group-10	0.396
As<50µg/L, Fe<5mg/L well depth between 50m to 150m	Group-11	0.453
As<50µg/L, Fe<5mg/L well depth>150m	Group-12	0.266

4.4 Geological influence of correlation between arsenic and iron:

Analysis of data shows that correlation of arsenic and iron varies with the depth of aquifer. It leads to an idea that it may vary with the geographical location. Major source of arsenic and iron in ground water is the stored arsenic and iron in the bed rock which is discussed in the literature review chapter (chapter 2). To make the analysis more precise and to establish the concept that the correlation of Arsenic and iron is a Zonal phenomenon, correlation analysis was performed in various locations.

All available data were first categorized according to the geographic locations. Bangladesh has 64 administrative districts. In this research data of 61 among those 64 districts are available. As well location of every data is known, all available data were divided according to their locations. Frequencies of data set for each of these districts are shown in the table 4.15.

Table 4.15 Distribution of wells according to districts.

District	Frequency	Percent	District	Frequency	Percent
Bagerhat	78	1.8	Magura	62	1.4
Barguna	48	1.1	Manikganj	47	1.1
Barisal	92	2.1	Maulvibazar	60	1.4
Bhola	48	1.1	Meherpur	15	0.3
Bogra	94	2.2	Munshiganj	46	1.1
Brahamanbaria	93	2.1	Mymensingh	109	2.5
Chandpur	68	1.6	Naogaon	92	2.1
Chittagong	109	2.5	Narail	24	0.5
Chuadanga	34	0.8	Narayanganj	37	0.8
Comilla	173	4.0	Narsingdi	63	1.4
Cox's Bazar	62	1.4	Natore	51	1.2
Dhaka	57	1.3	Nawabganj	45	1.0
Dinajpur	94	2.2	Netrokona	76	1.7
Faridpur	74	1.7	Nilphamari	53	1.2
Feni	60	1.4	Noakhali	49	1.1
Gaibandha	71	1.6	Pabna	78	1.8
Gazipur	44	1.0	Panchagarh	39	0.9
Gopalganj	58	1.3	Patuakhali	61	1.4
Habiganj	82	1.9	Pirojpur	54	1.2
Jaipurhat	40	0.9	Rajbari	47	1.1
Jamalpur	63	1.4	Rajshahi	78	1.8
Jessore	250	5.7	Rangpur	86	2.0
Jhalakati	33	0.8	Satkhira	88	2.0
Jhenaidah	103	2.4	Shariatpur	81	1.9
Khulna	93	2.1	Sherpur	51	1.2
Kishoreganj	169	3.9	Sirajganj	89	2.0
Kurigram	77	1.8	Sunamganj	87	2.0
Kushtia	59	1.4	Sylhet	88	2.0
Lakshmipur	34	0.8	Tangail	91	2.1
Lalmonirhat	39	0.9	Thakurgaon	46	1.1
Madaripur	75	1.7	Total	4367	100.0

Minimum 15 data are available for Meherpur and maximum 250 data for Jessore. Now these district wise data set were analyzed to find correlation. Table 4.16 shows the district wise analysis of correlation coefficient.

Table 4.16 Correlation coefficients of different districts.

District	Correlation coefficient	District	Correlation coefficient
Bagerhat	0.547	Magura	0.61
Barguna	0.363	Manikganj	0.437
Barisal	0.6	Maulvibazar	0.021
Bhola	0.857	Meherpur	0.694
Bogra	0.433	Munshiganj	0.15
Brahamanbaria	0.189	Mymensingh	0.761
Chandpur	0.108	Naogaon	0.204
Chittagong	-0.075	Narail	0.657
Chuadanga	0.511	Narayanganj	0.429
Comilla	0.135	Narsingdi	0.53
Cox's Bazar	-0.05	Natore	0.472
Dhaka	0.441	Nawabganj	0.206
Dinajpur	0.724	Netrokona	0.309
Faridpur	0.581	Nilphamari	0.815
Feni	-0.072	Noakhali	0.051
Gaibandha	0.103	Pabna	0.325
Gazipur	0.273	Panchagarh	0.932
Gopalganj	0.584	Patuakhali	0.295
Habiganj	0.089	Pirojpur	0.601
Jaipurhat	0.21	Rajbari	0.555
Jamalpur	0.451	Rajshahi	0.532
Jessore	0.391	Rangpur	0.458
Jhalakati	0.876	Satkhira	0.481
Jhenaidah	0.362	Shariatpur	0.676
Khulna	0.358	Sherpur	0.17
Kishoreganj	0.622	Sirajganj	0.192
Kurigram	0.186	Sunamganj	-0.16
Kushtia	0.074	Sylhet	0.114
Lakshmipur	0.056	Tangail	0.326
Lalmonirhat	0.67	Thakurgaon	0.557
Madaripur	0.743		

The variation of coefficients according to districts can be well understood if they are shown graphically. Fig 4.6, 4.7, 4.8 and 4.9 are showing the district wise correlation coefficients.

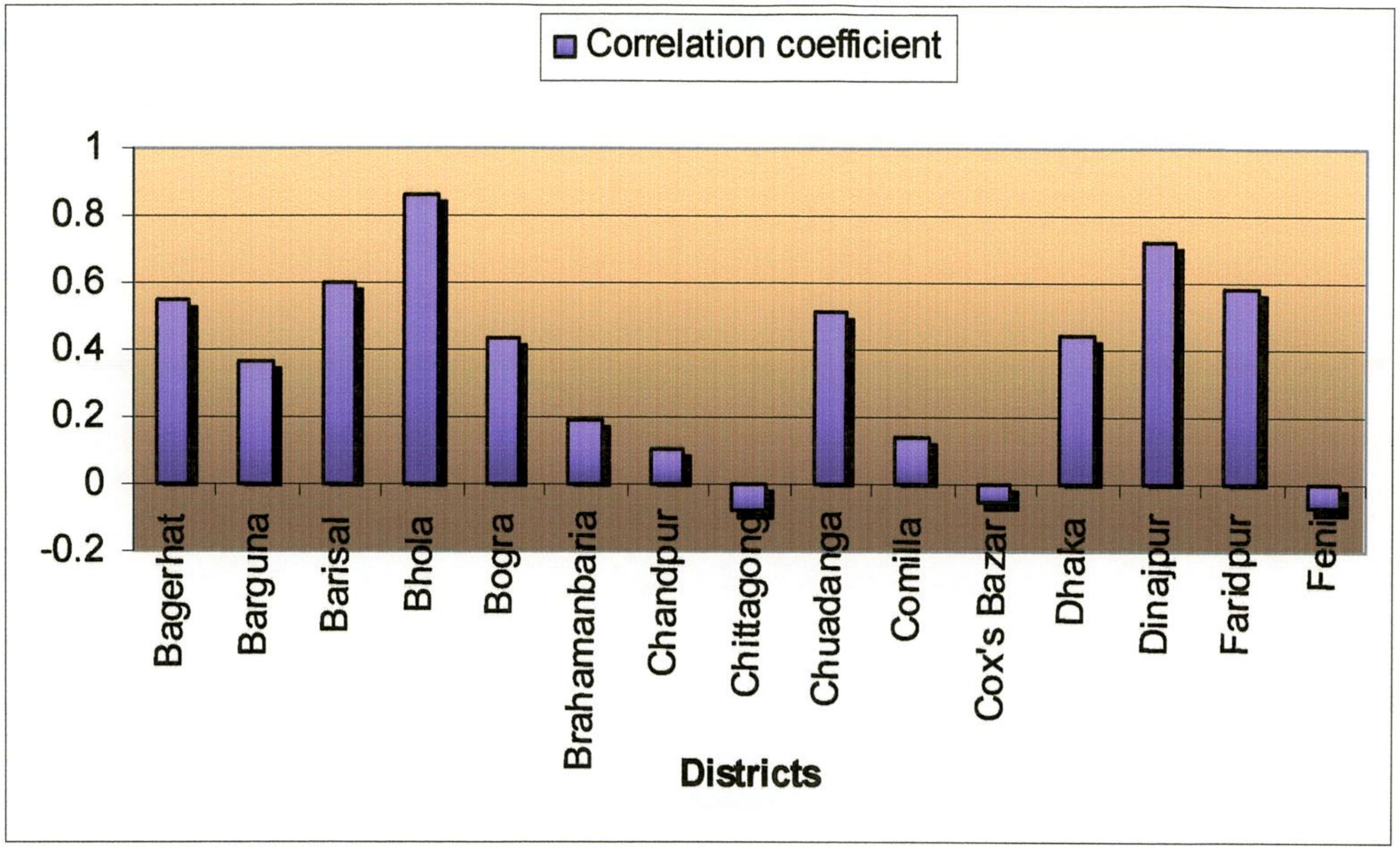

Fig 4.6 correlation coefficients of 1-15 districts

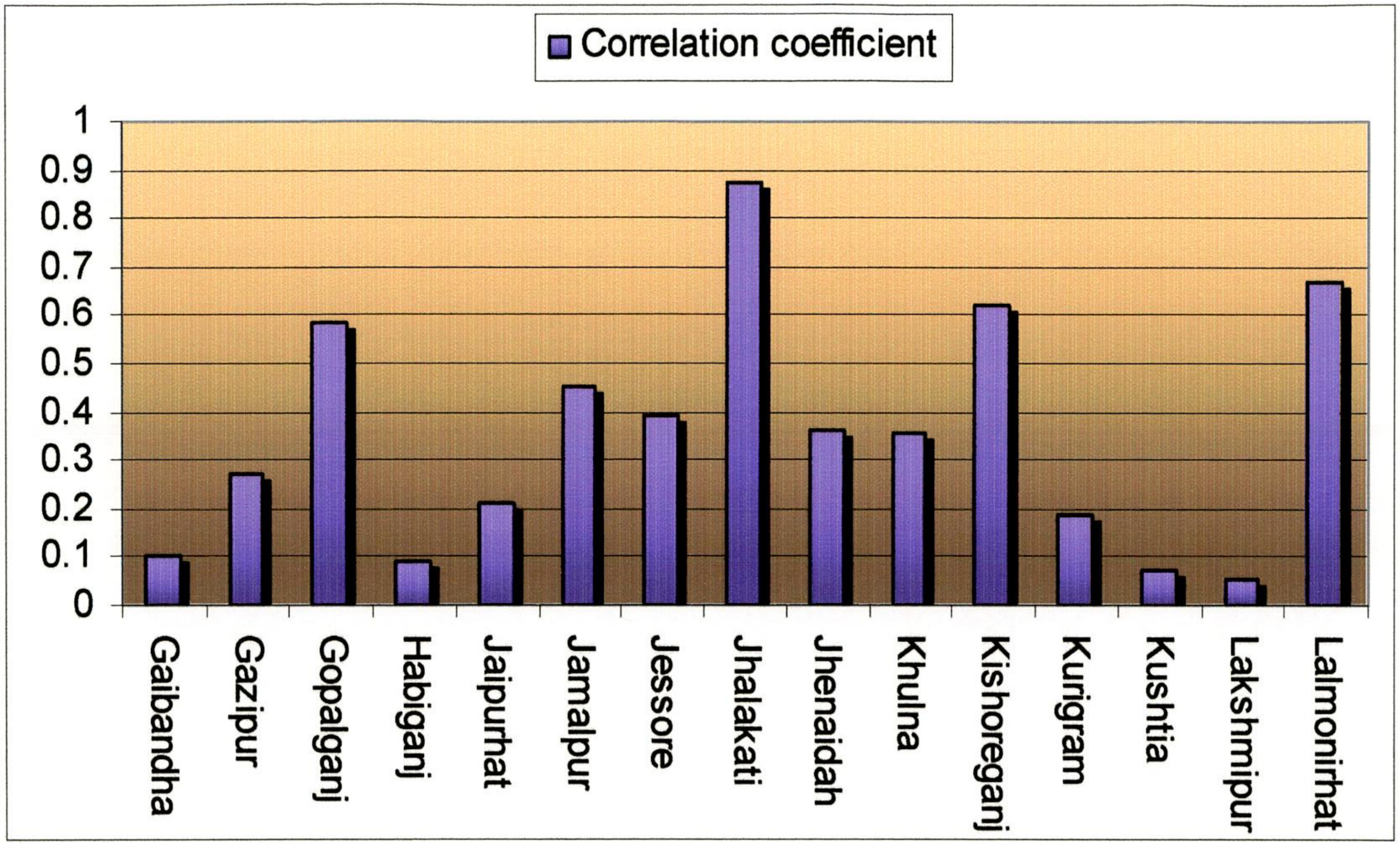

Fig 4.7 correlation coefficients of 16-30 districts.

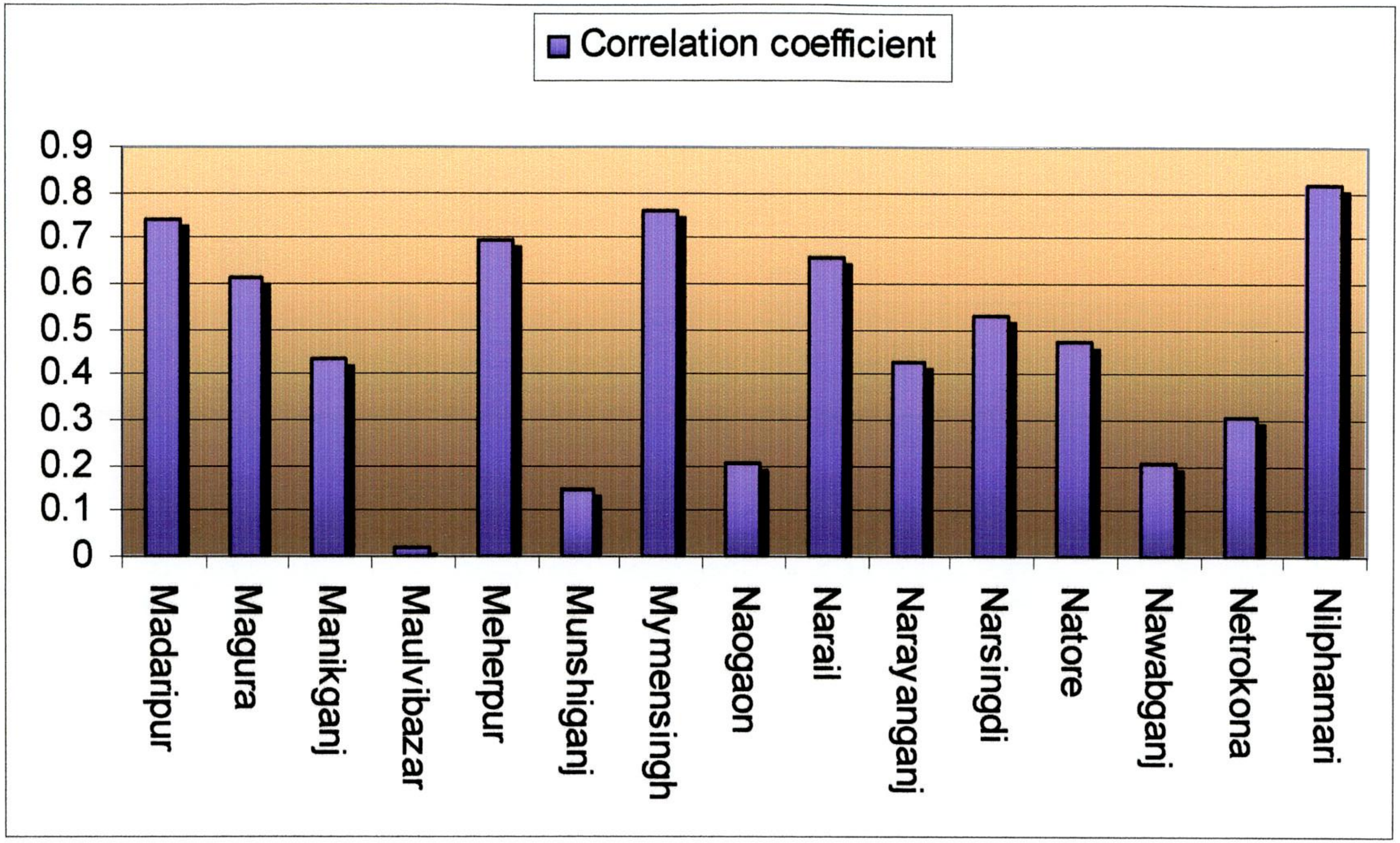

Fig 4.8 correlation coefficients of 31-45 districts.

4.5 Result analysis of District wise correlation analysis

In the fig 4.6 Bhola is showing maximum correlation of 0.857 followed by Dinajpur of coefficient 0.724. Bagerhat, Chuaganga and Faridpur exceeds 0.5 limit showing moderate to higher correlation.

In the fig 4.7 Jhalakathi shows maximum correlation coefficient of 0.876 followed by Lalmonirhat of 0.67. Kishoregonj and Gopalgonj also exceeds 0.5 limit of correlation coefficient showing moderate to higher correlation.

Similarly in fig 4.8 Nilphamari is showing maximum correlation coefficient of 0.815 followed by Mymensingh and Madaripur of 0.761 and 0.743. Meherpur, Narail, Magura and Narsingdi also exceeds 0.5 limit of correlation coefficient.

In fig 4.9 Panchagar shows correlation coefficient of 0.932 which is high among all the districts. Sariatpur, Thakurgaon, Pirojpur, Rajbari and Rajshahi also exceeds 0.5 value.

While correlation analysis was performed using all available 4367 data without categorizing as per district correlation coefficient was found to be 0.192 which is very insignificant. But when all the data were reorganized as per their location, correlation coefficient improved most of the district drastically. In Panchagar in reached up to 0.932 which shows strong correlation. Significance level of this value is 0.0001 which shows that less than 1% chance that this correlation occurred by chance. Correlation coefficient of 23 districts exceeds 0.5 which is 37% of all the districts, shows moderate to higher correlation.

Table 4.11 is showing the 23 districts and their coefficients. These districts exceed correlation coefficient of 0.5. Panchagar, Jhalakathi Bhola and Nilphamari is showing maximum correlation coefficient.

In this research initially correlation coefficient was calculated using all available data without any grouping as per location or depth variation. This gave a small correlation value of 0.195. When data were separated according to depth variation correlation coefficient changed. Correlation coefficient drastically changed when they were analyzed as per geographic locations. 37.7% districts are showing correlation coefficient as 0.5 or more.

Table 4.17(a) percentage of Correlation coefficient of 61 districts

	Frequency	Percent	Cumulative Percent
Correlation coefficient>0.5	23.0	37.7	37.7
Correlation coefficient<0.5	38.0	62.3	100.0
Total	61.0	100.0	

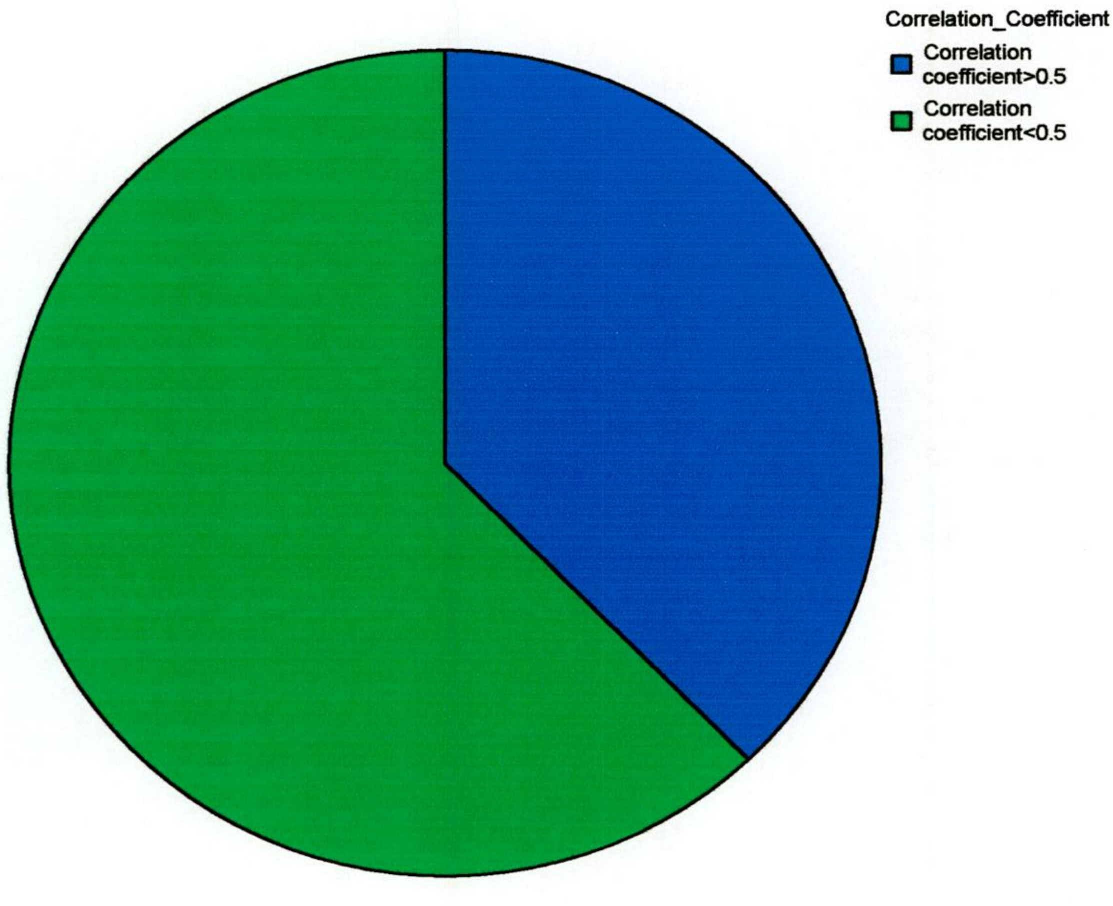

Fig 4.10(a) percentage of district showing correlation coefficient more than 0.5

This analysis indicates that correlation of *As* and *Fe* is not a national phenomenon rather it varies with the geographical location. Because soil profile changes with the geographical location.

Table 4.17(b) percentage of Correlation coefficient of 61 districts

	Frequency	Percent	Cumulative Percent
Correlation coefficient>0.4	31.0	50.4	50.4
Correlation coefficient<0.4	30.0	49.6	100.0
Total	61.0	100.0	

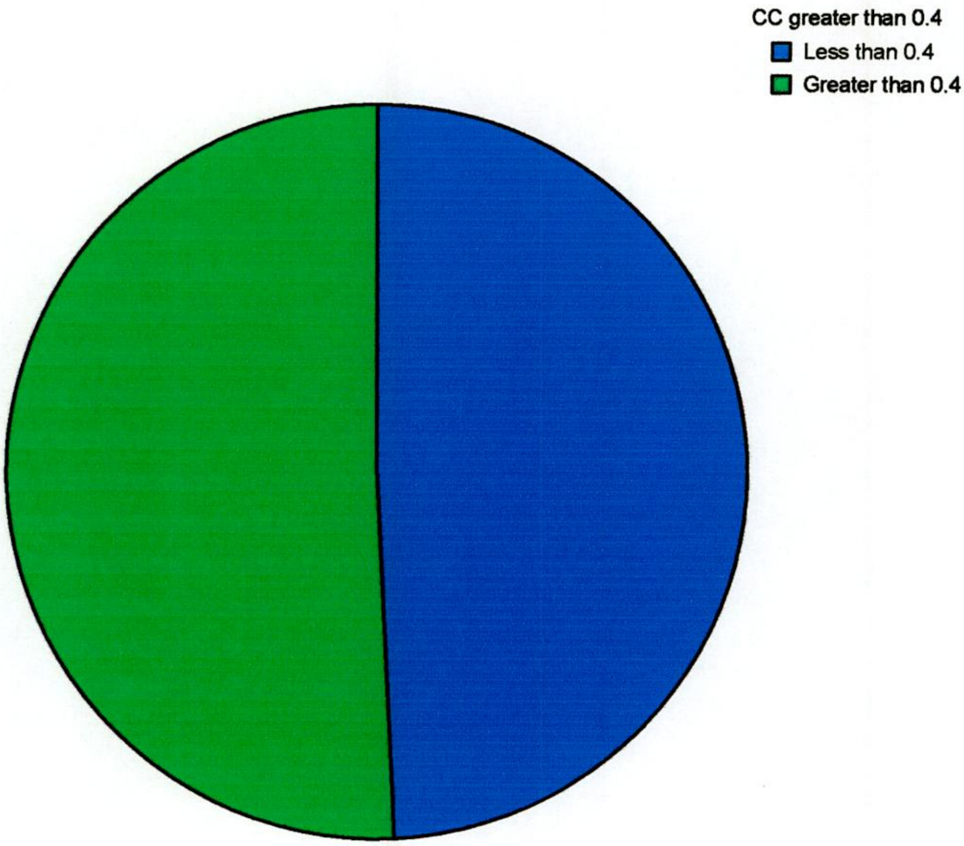

Fig 4.10(b) percentage of district showing correlation coefficient more than 0.4

Table 4.18 List of districts showing correlation coefficient more than 0.5

District	Correlation Coefficient	District	Correlation Coefficient
Panchagarh	0.932	Magura	0.61
Jhalakati	0.876	Pirojpur	0.601
Bhola	0.857	Barisal	0.6
Nilphamari	0.815	Gopalganj	0.584
Mymensingh	0.761	Faridpur	0.581
Madaripur	0.743	Thakurgaon	0.557
Dinajpur	0.724	Rajbari	0.555
Meherpur	0.694	Bagerhat	0.547
Shariatpur	0.676	Rajshahi	0.532
Lalmonirhat	0.67	Narsingdi	0.53
Narail	0.657	Chuadanga	0.511
Kishoreganj	0.622		

In Technical Report, BGS and DPHE (2001), Arsenic contamination of groundwater in Bangladesh 12 most and 12 least Arsenic contaminated districts are mentioned. Those are shown in the table 4.19

Table 4.19 Twelve Most and Twelve Least Arsenic contaminated districts.

Most Arsenic contaminated district	Least Arsenic contaminated district
Chandpur	Thakurgaon
Madaripur	Natore
Munshiganj	Barguna
Gopalganj	Jaipurhat
Lakshmipur	Lalmonirhat
Noakhali	Nilphamari
Bagerhat	Panchagarh
Shariatpur	Patuakhali
Comilla	Dinajpur
Faridpur	Cox's Bazar
Satkhira	Gazipur
Meherpur	Naogaon

Following table 4.12 shows correlation coefficient of 12 most arsenic contaminated districts. It is also shown graphically in figure 4.10. Correlation coefficient of seven out of these 12 districts is around or over 0.50.

Table 4.20 correlation coefficient of most *As* contaminated districts.

Chandpur	0.108
Madaripur	0.743
Munshiganj	0.15
Gopalganj	0.584
Lakshmipur	0.056
Noakhali	0.051
Bagerhat	0.547
Shariatpur	0.676
Comilla	0.135
Faridpur	0.581
Satkhira	0.481
Meherpur	0.694

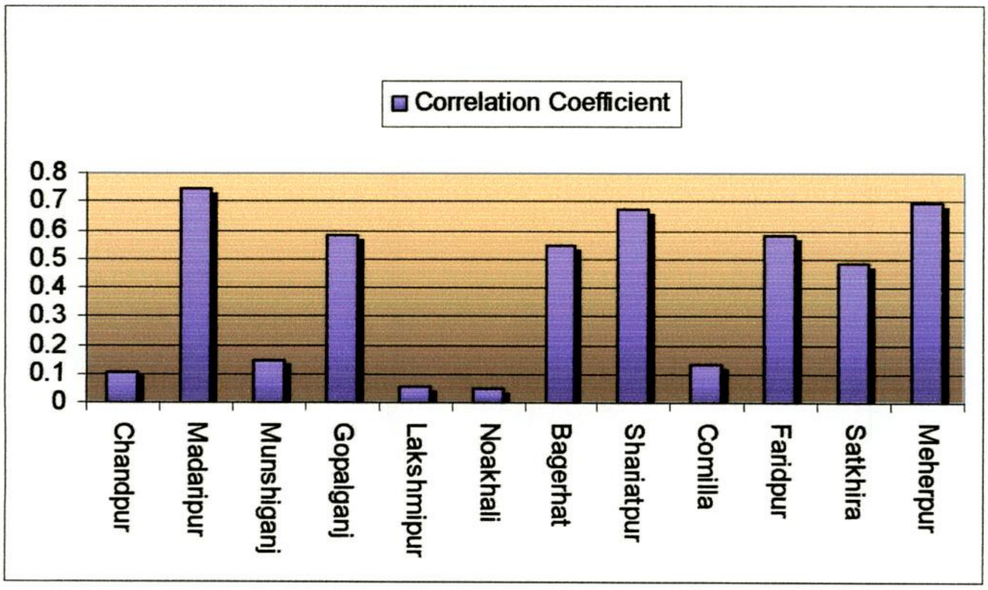

Fig 4.11 Correlation coefficient of 12 most *As* contaminated districts.

Following table 4.13 shows correlation coefficient of 12 least Arsenic contaminated districts. It is also shown graphically in figure 4.11. Correlation coefficient of six out of these 12 districts is around or over 0.50.

Table 4.21 correlation coefficient of least *As* contaminated districts.

Thakurgaon	0.557
Natore	0.472
Barguna	0.363
Jaipurhat	0.21
Lalmonirhat	0.67
Nilphamari	0.815
Panchagarh	0.932
Patuakhali	0.295
Dinajpur	0.724
Cox's Bazar	-0.05
Gazipur	0.273
Naogaon	0.204

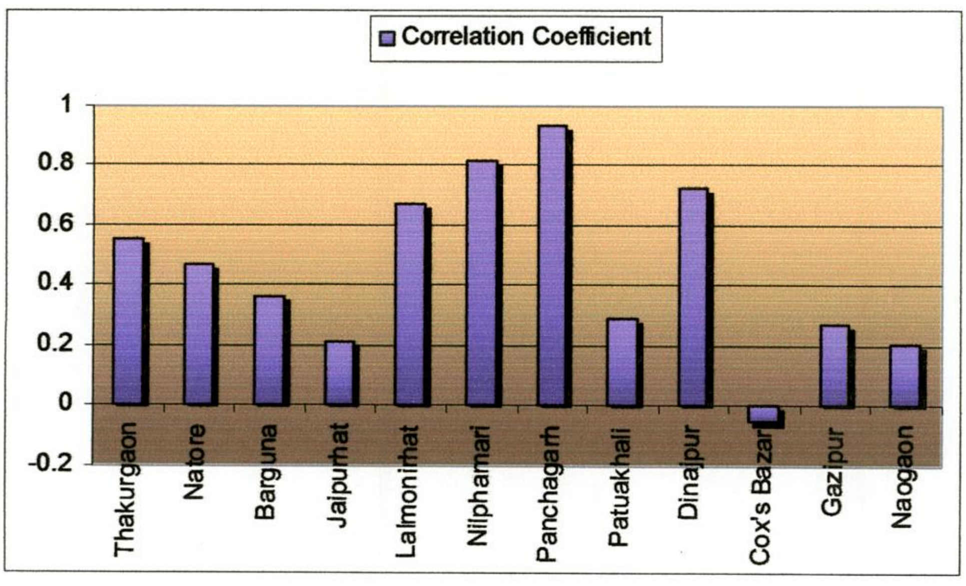

Fig 4.12 Correlation coefficient of 12 least *As* contaminated districts.

This district wise correlation analysis of Arsenic and Iron reveals that correlation of Arsenic and Iron in ground water is a zonal phenomenon. Soil profile is different in different portion of Bangladesh which leads to this difference in result of correlation analysis. In the technical report of BGS on Arsenic contamination of Ground water of Bangladesh published on 2001 this difference in sediment characteristics is discussed. Many soil samples from different parts of Bangladesh were drilled from different layers. Chemical analysis of those soil samples was performed. The general conclusions from the sediment studies are that the sediments are typical of alluvial and deltaic sediments with normal amounts of arsenic, mainly in the 1–10mg kg^{-1} range for total arsenic. However, even normal amounts of arsenic are sufficient to give excessive arsenic in the groundwater if dissolved or desorbed in sufficient quantity. Arsenic-rich ground waters tended to be found in areas with sediments containing relatively high concentrations of oxalate-extractable iron and arsenic. This is consistent with the iron oxides being a principal source of arsenic in the arsenic-rich ground waters.

4.6 District wise analysis of 3-Dimentional water matrix:

3-Dimentional water matrix which is developed in this research was used to categorize data of each of these 61 districts. It provided 12 data sets for each district which leads to 732 sets of data for analysis. All these distribution of data are given in a tabular form in the Appendix-1. A large number of groups of different districts remain data less. Being very specific most of the groups formed of deep tube wells remain data less as most of the wells depth>150m is arsenic free. All the groups containing combination *As*>50µg/L, of least arsenic contaminated districts remain data less.

Chandpur is the most arsenic contaminated district of Bangladesh (BGS Technical report, 2001). Table 4.14 shows the frequency distribution of 12 groups of Chandpur district. 50 wells are less than 50m depth among those 18 nos lie in the combination *As*>50µg/L *Fe*>5mg/L and 32 nos lie in the combination *As*>50µg/L *Fe*<5mg/L. No well in this depth range fall in any combination which is associated with *As*<50µg/L as this district is highly arsenic contaminated. Analyzing the table it becomes obvious that group-01 (*As*>50µg/L *Fe*>5mg/L, depth<50m) group-07 (*As*>50µg/L *Fe*<5mg/L, Depth<50m) are the main concerning groups of Chandpur.

Table 4.22 Frequency distribution of different combinations for Chandpur district

District	Depth Range			As>50 Fe>5	As<50 Fe>5	As>50 Fe<5	As<50 Fe<5	Total
Chandpur	Depth Range	Depth<50m	Count	18.0	0.0	32.0	0.0	50.0
			% within DRange	36.0	0.0	64.0	0.0	100.0
			% within combinations	100.0	0.0	94.1	0.0	74.6
		Depth Between 50m to150m	Count	0.0	1.0	2.0	1.0	4.0
			% within DRange	0.0	25.0	50.0	25.0	100.0
			% within combinations	0.0	50.0	5.9	7.7	6.0
		Depth>150m	Count	0.0	1.0	0.0	12.0	13.0
			% within DRange	0.0	7.7	0.0	92.3	100.0
			% within combinations	0.0	50.0	0.0	92.3	19.4
	Total		Count	18.0	2.0	34.0	13.0	67.0
			% within DRange	26.9	3.0	50.7	19.4	100.0
			% within combinations	100.0	100.0	100.0	100.0	100.0

Like Chandpur all the districts of Bangladesh showing different arsenic patterns. Least Arsenic contaminated districts have more data for analysis for *As*<50µg/L related combinations while Most Arsenic contaminated districts have more data for analysis for *As*>50µg/L related combinations. As a result due to scarcity of data it was not possible to find any correlation for few groups of each district. Few groups of some districts are showing absolute correlation of +1 or -1. This is also due to scarcity of data in that group. If only 2 nos data are available in any group the result of correlation analysis becomes very insignificant. In following pages table 4.14, 4.15 and 4.16 are showing correlation coefficients of 12 groups of 61 districts. Correlation coefficient of any group showing 0 means that there is no data available for that particular group of the district. Similarly correlation coefficient of any group showing (-) implies that particular group of the district has only one data. For that reason no correlation coefficient could be found.

Table 4.23 Correlation coefficients of 12 groups of 25 districts.

District	As>50Fe>5 <50m Group 01	As>50Fe>5 50-150m Group 02	As>50Fe>5 >150m Group 03	As<50Fe>5 <50m Group 04	As<50Fe>5 50-150m Group 05	As<50Fe>5 >150m Group 06	As>50Fe<5 <50m Group 07	As>50Fe<5 50-150m Group 08	As>50Fe<5 >150m Group 09	As<50Fe<5 <50m Group 10	As<50Fe<5 50-150m Group 11	As<50Fe<5 >150m Group 12
Bagerhat	0.177	0	0	-0.051	0	0	0.232	0	0	0.469	0	0.321
Barguna	0	0	0	0	0	0	0	0	0	0.219	0	0.022
Barisal	0.66	0	0	-	0	0	-0.264	0	-	0.314	1	0.127
Bhola	-	0	0	0	0	0	-	0	0	0	0	-0.053
Bogra	0.295	0	0	0.55	0	0	-	0	0	0.51	-	-
Brahamanbaria	-0.175	0	0	-0.306	0	0	0.006	0.205	-	0.474	0.124	0.378
Chandpur	-0.136	0	0	0	0	0	-0.142	1	0	0	-	0.62
Chittagong	1	0	0	0.256	0.533	0.537	-0.196		0	-0.128	-0.306	-0.069
Chuadanga	0.789	0	0	0	0	0	0.443	-1	0	0.663	-1	0
Comilla	0.137	-1	0	-0.998	0	0	0.025	-1	0	0.13	-0.011	0.232
Cox's Bazar	0	0	0	0.581	0.886	-1	0	0	0	-0.291	-0.415	0.016
Dhaka	-1	-0.232	0	0	-0.363	0	0	-1	0	0.567	-0.352	0.516
Dinajpur	-1	0	0	-0.079	0	0	0	0	0	0.474	0	0
Faridpur	0.133	-	0	-1	0	-	0.161	0.444	0	0.958	0.082	-0.426
Feni	-0.99	0	0	0.781	-	0	-0.24	0	0	-0.258	0.128	-0.179
Gaibandha	1	0	0	-0.168	-0.952	0	0.938	0	0	0.327	0	0
Gazipur	0	0	0	0	0	0	-	0	0	-	0.153	-
Gopalganj	0.115	-	0	1	0	0	0.254	0.159	0	0	-	0.773
Habiganj	-1	-	0	0.773	0.143	0	-1	-	0	0.244	0.309	-0.182
Jaipurhat	0	0	0	0.098	0	0	0	0	0	0.156	-	0
Jamalpur	-0.491	0	0	-0.148	0	0	0	0	0	-0.604	-	0
Jessore	-0.464	-1	0	0.212	-	-0.688	0.307	-0.507	0	0.799	0.638	0.185
Jhalakati	-	0	0	-	0	0	0	0	0	0.316	0	0.608
Jhenaidah	0.948	0	0	-0.992	-	0	-0.07	0.648	0	0.705	0.549	0.417
Khulna	-	0.993	0	0.36	0	0	0.394	0.297	0	-0.136	0.845	0.255

Table 4.24 Correlation coefficients of 12 groups of 21 districts.

District	Group 01	Group 02	Group 03	Group 04	Group 05	Group 06	Group 07	Group 08	Group 09	Group 10	Group 11	Group 12
	As>50Fe>5 <50m	As>50Fe>5 50-150m	As>50Fe>5 >150m	As<50Fe>5 <50m	As<50Fe>5 50-150m	As<50Fe>5 >150m	As>50Fe<5 <50m	As>50Fe<5 50-150m	As>50Fe<5 >150m	As<50Fe<5 <50m	As<50Fe<5 50-150m	As<50Fe<5 >150m
Kurigram	0.605	0	0	-0.08	-1	0	1	0	0	0.359	1	0
Kushtia	-0.067	0	0	0.131	-	0	-0.928	-	0	0.531	0.845	0
Lakshmipur	-0.943	0	0	0	0	-	-0.01	0	0	0.008	0	-0.42
Lalmonirhat	0	0	0	0.362	0	0	0	0	0	0.281	-	0
Madaripur	-0.2	0	0	0	0	-	0.355	0.881	-	-	-	-0.05
Magura	-1	-	0	-	-	0	0	0.665	0	0.612	0.676	0.283
Manikganj	0.468	0	0	0.597	-0.356	0	-	-	0	-0.086	0.284	0
Maulvibazar	-	-	0	0.45	-0.283	-	0	-0.704	0	-0.138	0.61	-0.734
Meherpur	-	0	0	0	0	0	0.708	-	0	0.574	-	0
Munshiganj	0.27	-0.189	0	0	0	0	0.439	0.1	0	-	0.196	0
Mymensingh	0.655	-1	0	-	0	0	0.336	-0.668	0	0.892	0.576	-
Naogaon	-	0	0	0.835	0	0	-	0	0	0.533	-	0
Narail	-1	0.977	0	0	1	0	-0.967	1	0	-1	0.719	-
Narayanganj	0.024	0	0	-	0	0	0.851	0	0	0.975	-0.16	-0.012
Narsingdi	0.018	0	0	-	0	0	0.443	0	0	0.277	0.999	0.365
Natore	0	0	0	-	0	0	0	0	0	0.803	-	0
Nawabganj	0	0	0	-	0	0	-1	0	0	0.292	-	0
Netrokona	-1	0.0001	0	-0.36	-0.278	0	-	0.289	0	-	0.616	-
Nilphamari	0	0	0	0.8	0	0	0	0	0	0.59	0.914	-
Noakhali	-1	0	0	0	0	-	0.319	0	0	0.445	0	-0.356

Table 4.25 Correlation coefficients of 12 groups of 15 districts.

	As>50Fe>5 <50m	As>50Fe>5 50-150m	As>50Fe>5 >150m	As<50Fe>5 <50m	As<50Fe>5 50-150m	As<50Fe>5 >150m	As>50Fe<5 <50m	As>50Fe<5 50-150m	As>50Fe<5 >150m	As<50Fe<5 <50m	As<50Fe<5 50-150m	As<50Fe<5 >150m
District	Group 01	Group 02	Group 03	Group 04	Group 05	Group 06	Group 07	Group 08	Group 09	Group 10	Group 11	Group 12
Pabna	0.108	0	0	0.304	0	0	-0.054	0	0	0.802	-1	0
Panchagarh	0	0	0	0.997	0	0	0	0	0	0.45	0	0
Patuakhali	0	0	0	-	0	0	0	0	0	-1	0	0.517
Pirojpur	1	0	0	-1	0	0	0.962	0	0	0.02	0	0.67
Rajbari	0.511	0	0	0.998	0	0	-0.828	0	0	0.898	0.704	0.615
Rajshahi	1	0	0	-	0	0	-0.103	0	0	0.403	-	0
Rangpur	-	0	0	0.296	-1	0	0	0	0	0.448	-	0
Satkhira	-0.05	-	0	1	0	0	0.248	0.267	-	0.491	-0.954	0.424
Shariatpur	-0.106	0	0	0	0	0	0.41	1	0	0.254	0	0.432
Sherpur	-0.778	0	0	0.238	0	0	-0.928	0	0	0.469	0	-
Sirajganj	0.208	-	0	0.167	-1	0	-0.446	-	0	0.242	1	0
Sunamganj	0	-0.815	0	-1	-0.26	0	0	-0.404	-	0.2	-0.205	-0.132
Sylhet	-0.973	-0.05	0	0.37	0.271	0	0	-0.923	0	0.301	0.135	-0.45
Tangail	-0.204	0	0	-0.086	-	0	-	0	0	0.551	0.73	0
Thakurgaon	0	0	0	-1	0	0	0	0	0	0.702	-	0

Data of each 12 most *As* contaminated districts and 12 least *As* contaminated districts district were grouped in 12 groups as per 3-Dimentional water matrix. Then they were analyzed for correlation. Correlation coefficient of these 24 districts found from the analysis is shown in the table 4.26 as tabular form.

Table 4.26 Correlation coefficient of the 12 most contaminated districts.

Correlation coefficient of 12 most contaminated districts.												
	As>50Fe>5 <50m	As>50Fe>55 0-150m	As>50Fe>5 >150m	As<50Fe>5 <50m	As<50Fe>5 50-150m	As<50Fe>5 >150m	As>50Fe<5 <50m	As>50Fe<55 0-150m	As>50Fe<5 >150m	As<50Fe<5 <50m	As<50Fe<55 0-150m	As<50Fe<5 >150m
District	Group 01	Group 02	Group 03	Group 04	Group 05	Group 06	Group 07	Group 08	Group 09	Group 10	Group 11	Group 12
Chandpur	-0.136	0	0	0	0	0	-0.142	1	0	0	-	0.62
Madaripur	-0.2	0	0	0	0	-	0.355	0.881	-	-	-	-0.05
Munshiganj	0.27	-0.189	0	0	0	0	0.439	0.1	0	-	0.196	0
Gopalganj	0.115	-	0	1	0	0	0.254	0.159	0	0	-	0.773
Lakshmipur	-0.943	0	0	0	0	-	-0.01	0	0	0.008	0	-0.42
Noakhali	-1	0	0	0	0	-	0.319	0	0	0.445	0	-0.356
Bagerhat	0.177	0	0	-0.051	0	0	0.232	0	0	0.469	0	0.321
Shariatpur	-0.106	0	0	0	0	0	0.41	1	0	0.254	0	0.432
Comilla	0.137	-1	0	-0.998	0	0	0.025	-1	0	0.13	-0.011	0.232
Faridpur	0.133	-	0	-1	0	-	0.161	0.444	0	0.958	0.082	-0.426
Satkhira	-0.05	-	0	1	0	0	0.248	0.267	-	0.491	-0.954	0.424
Meherpur	-	0	0	0	0	0	0.708	-	0	0.574	-	0

4.7 Analysis for least contaminated areas.

Above two tables shows the correlation coefficients of twelve most and twelve least contaminated districts. (-) sign indicates that there was no correlation found for that particular combination due to lack of data. Only one set of data was available to find correlation in those groups. 0 sign indicates that no data is available for that particular group. For least contaminated areas almost all the districts do not have any data for As>50μg/L Fe>5mg/L. For least contaminated areas As<50μg/L Fe<5mg/L combination is showing good correlation. For As<50μg/L Fe<5mg/L combination correlation is stronger for the depth range less than 50m (group-10) for least Arsenic contaminated districts. Patuakhali is showing correlation coefficient of -1 for group-10. this is due to lack of data (only 2 sets). Group-10 for Natore the coefficient is 0.803 and Thakurgaon it is 0.702. For Natore this result was produced by analyzing 49 data sets and for Thakurgaon 43 data sets were analyzed. After analyzing 40 data sets of Nilpphamari group10 shows correlation coefficient of 0.59 which is significant. Group-04 (As<50μg/L, Fe>5mg/L, depth<50m) of Naogaon is showing correlation coefficient of 0.835. It is significant but only 5 data sets are available in this group for analysis. Cox's bazaar of that group-04 is showing correlation coefficient of 0.581 which is also very significant. For most of the deep tube wells (Depth>150m) correlation between arsenic and iron concentration is insignificant for least contaminated areas.

4.8 Analysis for most contaminated areas.

Cross tabulation analysis of data shown in the table 4.3 shows that 11.9% wells of depth less than 50m is contaminated for both iron and arsenic. On the other hand 83.2% of most contaminated combination (As>0.05mg/L, Fe>5 mg/L) exists in the wells whose depth are less than 50m. But this group-01 shows very little correlation for most arsenic contaminated districts. Chandpur is the most arsenic contaminated district which shows small correlation coefficient of -0.136 for group-01 (As>50μg/L, Fe>5 mg/L, Depth<50m). For the same group Lakshmipur shows a high correlation of -0.943. But its significance level is 0.215 which indicates that 21.5% possibility that this correlation occurred by chance. The reason behind this small reliability is only 5 data sets were available for analysis. Group-01 of Munshigonj is showing correlation coefficient of 0.27. Group-07 (As>50μg/L, Fe<5 mg/L, Depth<50m) of Meherpur and Munshigonj district is showing correlation coefficient of 0.708 and 0.439 respectively. Singnificance level for Meherpur and Munshigonj is 0.075 and 0.205 which means probability of occurrence of this correlation is 7.5% and 20.5%. Group10, Group 11 and Group 12 of most contaminated areas show moderate to higher correlation for all depth range.

4.9 Comparison of the results:

Correlation coefficients of 12 groups of each 61 districts of Bangladesh are given in the table 4.14, 4.15 and 4.16. Analyzing all those results it is revealed that grouping of data as per 3-Dimentional water matrix has changed the correlation coefficient of most of the districts. Table 4.28 is showing the comparison between the results of the 12 most *As* contaminated districts which were analyzed by grouping with 3-Dimentional water matrix and without any grouping.

Table 4.28 Comparison of results of 12 most *As* contaminated districts grouping with 3-Dimentional water matrix and without any grouping.

	Correlation coefficient												
	As>50Fe>5 <50m	As>50Fe>5 50-150m	As>50Fe>5 >150m	As<50Fe>5 <50m	As<50Fe>5 50-150m	As<50Fe>5 >150m	As>50Fe<5 <50m	As>50Fe<5 50-150m	As>50Fe<5 >150m	As<50Fe<5 < 50m	As<50Fe<5 50-150m	As<50Fe<5 >150m	
District	Group 01	Group 02	Group 03	Group 04	Group 05	Group 06	Group 07	Group 08	Group 09	Group 10	Group 11	Group 12	Coefficient without grouping
Chandpur	-0.136	0	0	0	0	0	-0.142	1	0	0	-	0.62	0.108
Madaripur	-0.2	0	0	0	0	-	0.355	0.881	-	-	-	-0.05	0.743
Munshiganj	0.27	-0.189	0	0	0	0	0.439	0.1	0	-	0.196	0	0.15
Gopalganj	0.115	-	0	1	0	0	0.254	0.159	0	0	-	0.773	0.584
Lakshmipur	-0.943	0	0	0	0	-	-0.01	0	0	0.008	0	-0.42	0.056
Noakhali	-1	0	0	0	0	-	0.319	0	0	0.445	0	-0.356	0.051
Bagerhat	0.177	0	0	-0.051	0	0	0.232	0	0	0.469	0	0.321	0.547
Shariatpur	-0.106	0	0	0	0	0	0.41	1	0	0.254	0	0.432	0.676
Comilla	0.137	-1	0	-0.998	0	0	0.025	-1	0	0.13	-0.011	0.232	0.135
Faridpur	0.133	-	0	-1	0	-	0.161	0.444	0	0.958	0.082	-0.426	0.581
Satkhira	-0.05	-	0	1	0	0	0.248	0.267	-	0.491	-0.954	0.424	0.481
Meherpur	-	0	0	0	0	0	0.708	-	0	0.574	-	0	0.694

Correlation coefficient of Chandpur is found to be 0.108 without any grouping of data. But while it was grouped as per 3-Dimentional water matrix group-01, group-07, group-08 and group-12 became prominent. Group-01 and 02 is showing negative correlation of -0.136 and -0.142 respectively as arsenic contamination is very high in the region. Rest of the groups containing *As*<50 did not gave any result as there was no data in those groups.

Similarly for Noakhali (table 4.28) without grouping of data correlation coefficient was found to be 0.051. But after grouping of data both the groups (01 and 07) of shallow tube wells (D<50m) for combinations *As*>50μg/L Fe>5mg/L and *As*>50μg/L Fe<5mg/L provided improved correlation coefficient of -1 and 0.319. Significance level of the result -1 is very low as number of sample for the group is very small.

In table 4.29 results of three other districts (Jessore, Mymensingh and Rajbari) are compared. For Jessore without grouping of data correlation coefficient was found to be 0.391. After grouping of data results become more specific. For combination *As*>50μg/L Fe>5mg/L of shallow wells (D<50m) correlation coefficient found to be -0.464. Results improve more for combination of *As*>50μg/L Fe<5mg/L for wells between 50m to 150m as it shows -0.507. Correlation coefficient was found more prominent for less contaminated combinations (*As*<50μg/L Fe<5mg/L) as it shows 0.799 and 0.638 for D<50m and D between 50m- 150m respectively. This variation in result reveals more specific results for specific depth zone and combinations.

For Mymensingh without grouping if data the correlation coefficient was found to be 0.761. But for *As*>50μg/L Fe<5mg/L combination of shallow wells correlation coefficient was reduced to 0.336. This result indicates that for that particular combination in that depth level of Mymensingh district *As* and *Fe* shows less correlation.

Table 4.29 Comparison of results of 3 districts between data grouping with 3-Dimentional water matrix and without any grouping.

	Correlation coefficient												
	As>50Fe>5 <50m	As>50Fe>5 50-150m	As>50Fe>5 >150m	As<50Fe>5 <50m	As<50Fe>5 50-150m	As<50Fe>5 >150m	As>50Fe<5 <50m	As>50Fe<5 50-150m	As>50Fe<5 >150m	As<50Fe<5 < 50m	As<50Fe<5 50-150m	As<50Fe<5 >150m	
District	Group 01	Group 02	Group 03	Group 04	Group 05	Group 06	Group 07	Group 08	Group 09	Group 10	Group 11	Group 12	Coefficient without grouping
Jessore	-0.464	-1	0	0.212	-	-0.688	0.307	-0.507	0	0.799	0.638	0.185	0.391
Mymensingh	0.655	-1	0	-	0	0	0.336	-0.668	0	0.892	0.576	-	0.761
Rajbari	0.511	0	0	0.998	0	0	-0.828	0	0	0.898	0.704	0.615	0.555

4.10 GIS Mapping of correlation between Arsenic and Iron concentration of ground water of Bangladesh.

Fig 4.13 to Fig 4.28 shows the GIS map of different groups and categories. Fig 4.13, Fig 4.14 Fig 4.15 and Fig 4.16 shows GIS map of different district. In these four map data were not separated as per 3D matrix.

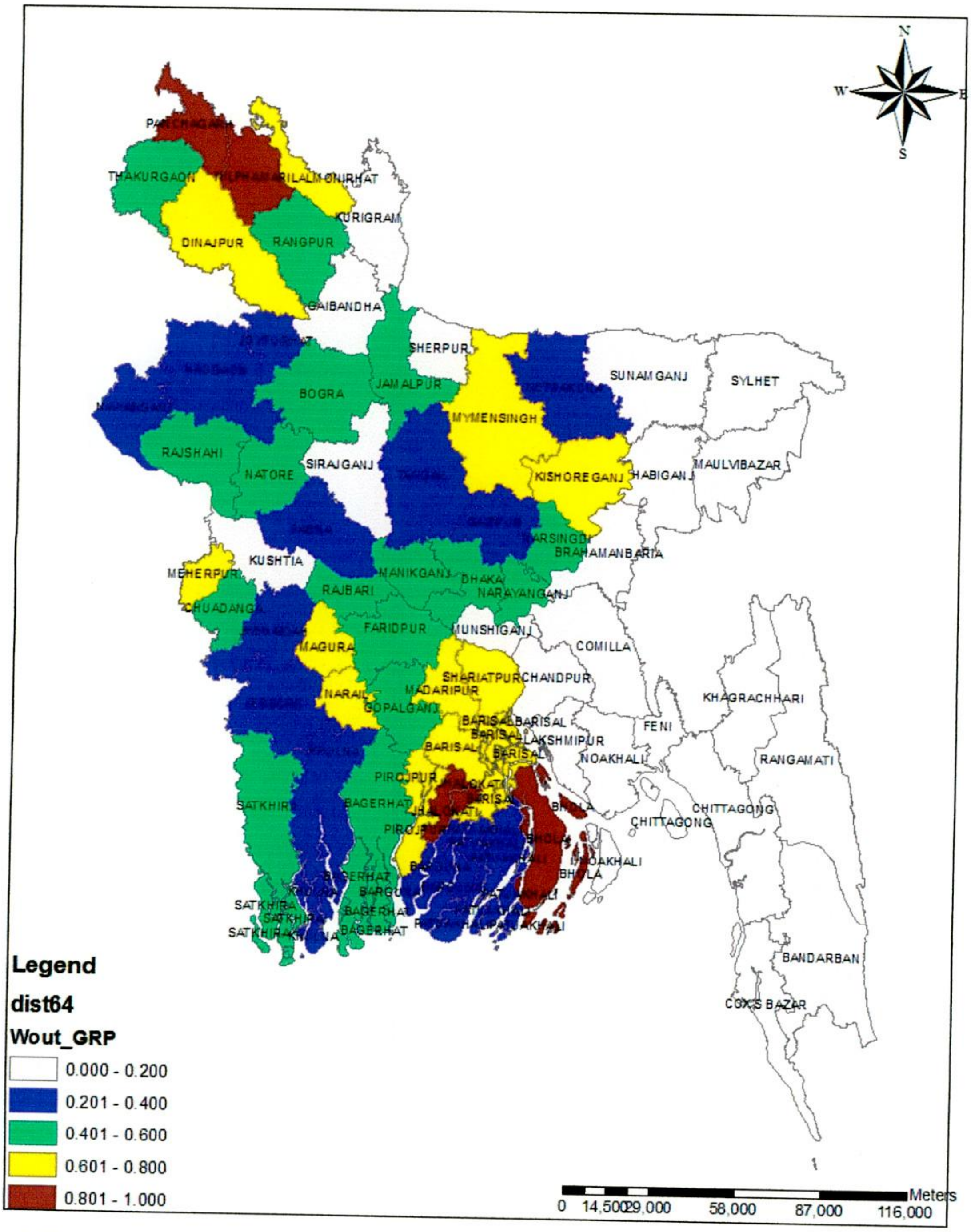

Fig: 4.13 GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh without grouping of data.

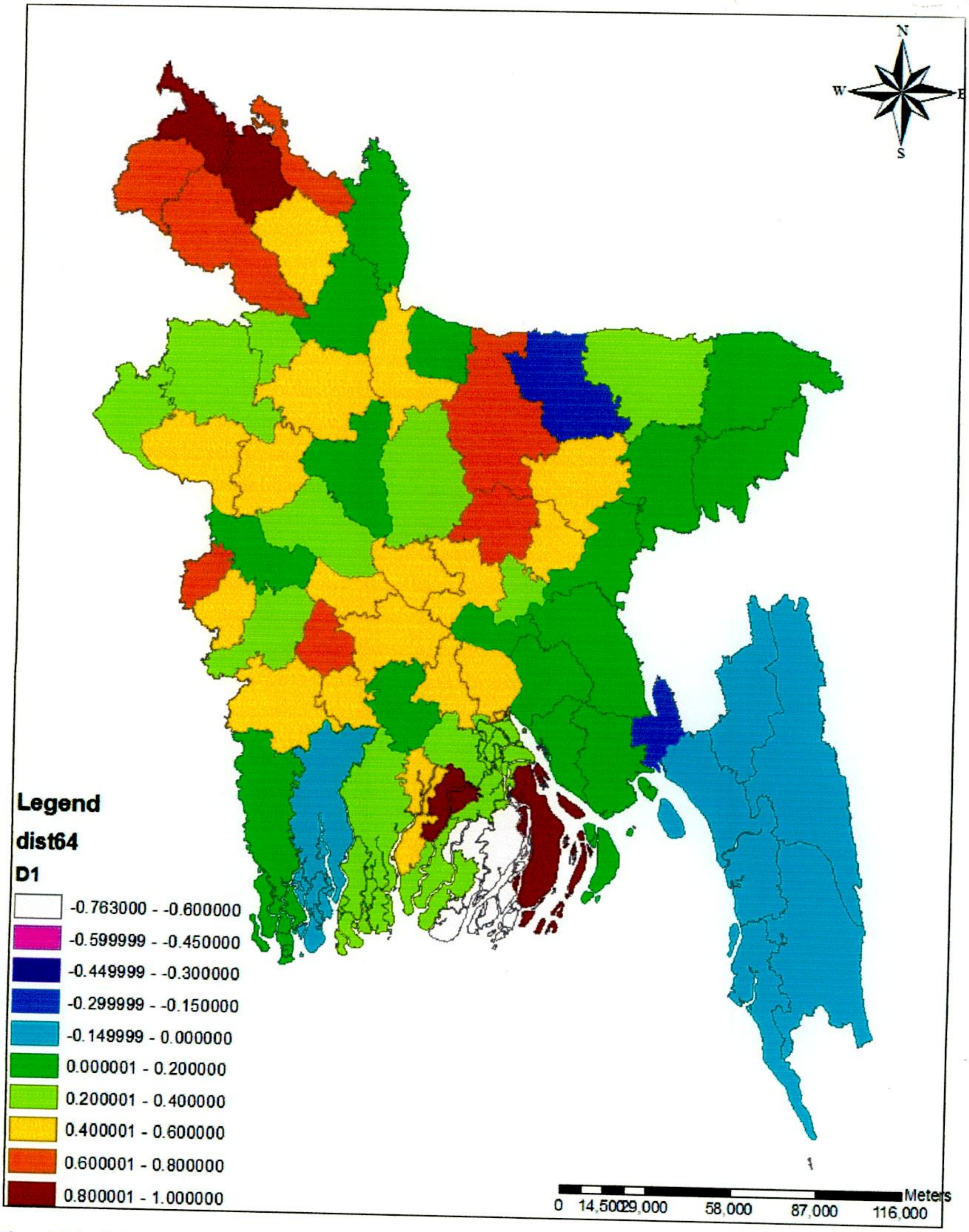

Fig: 4.14 GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for tube wells depth less than 50m (D1)

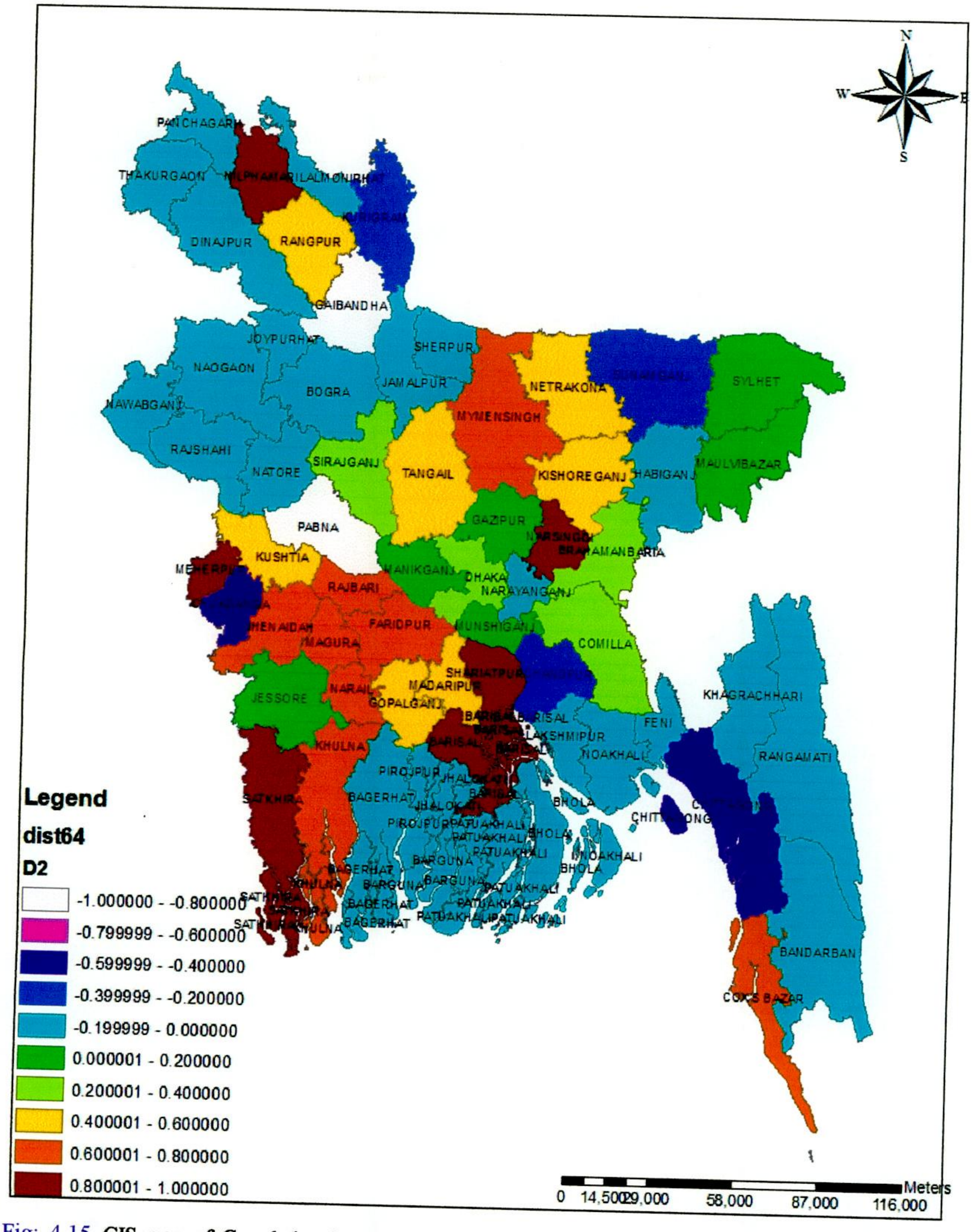

Fig: 4.15 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for tube wells depth between 50m to 150m (D2)**

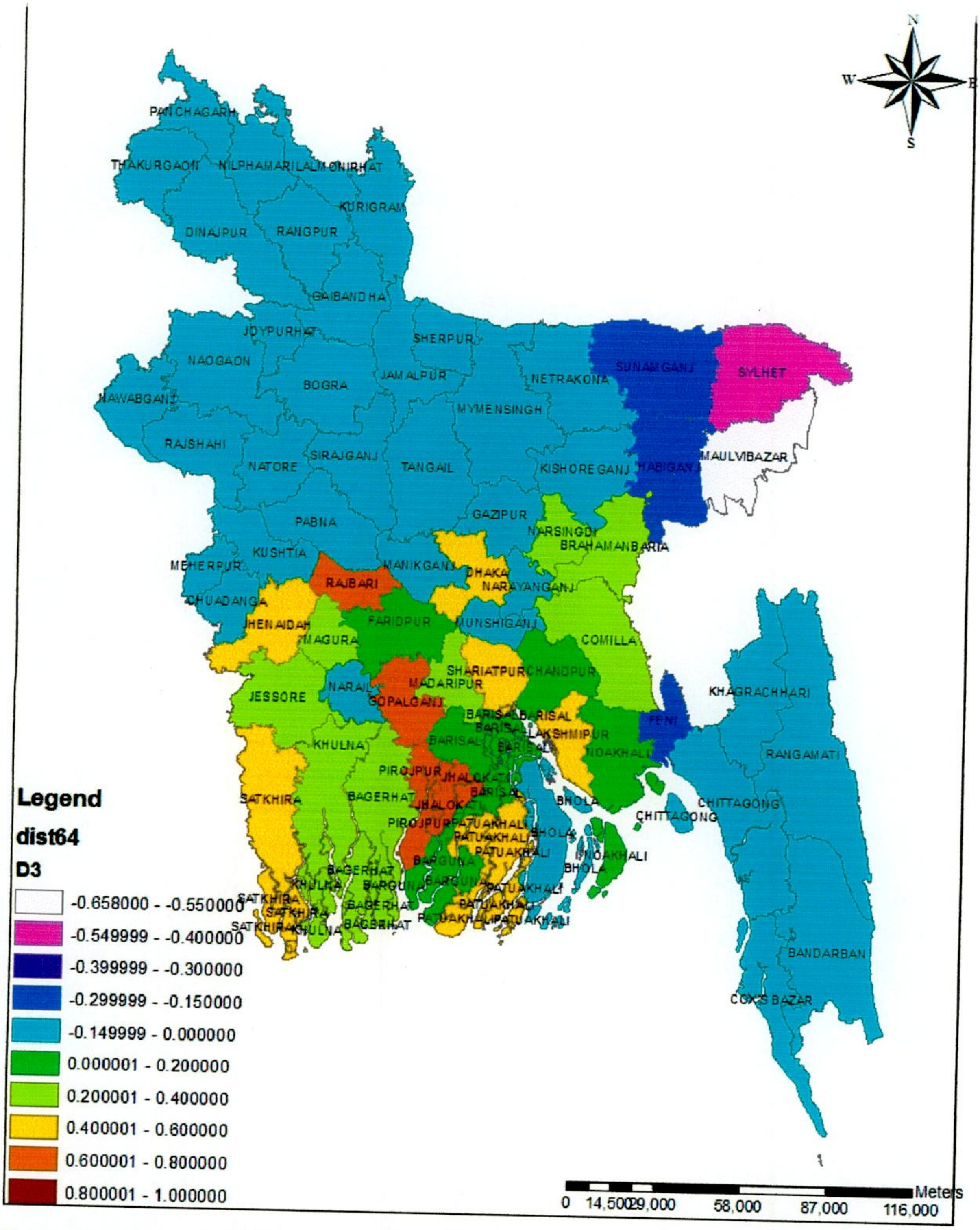

Fig: 4.16 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for tube wells depth greater than 150m (D3)**

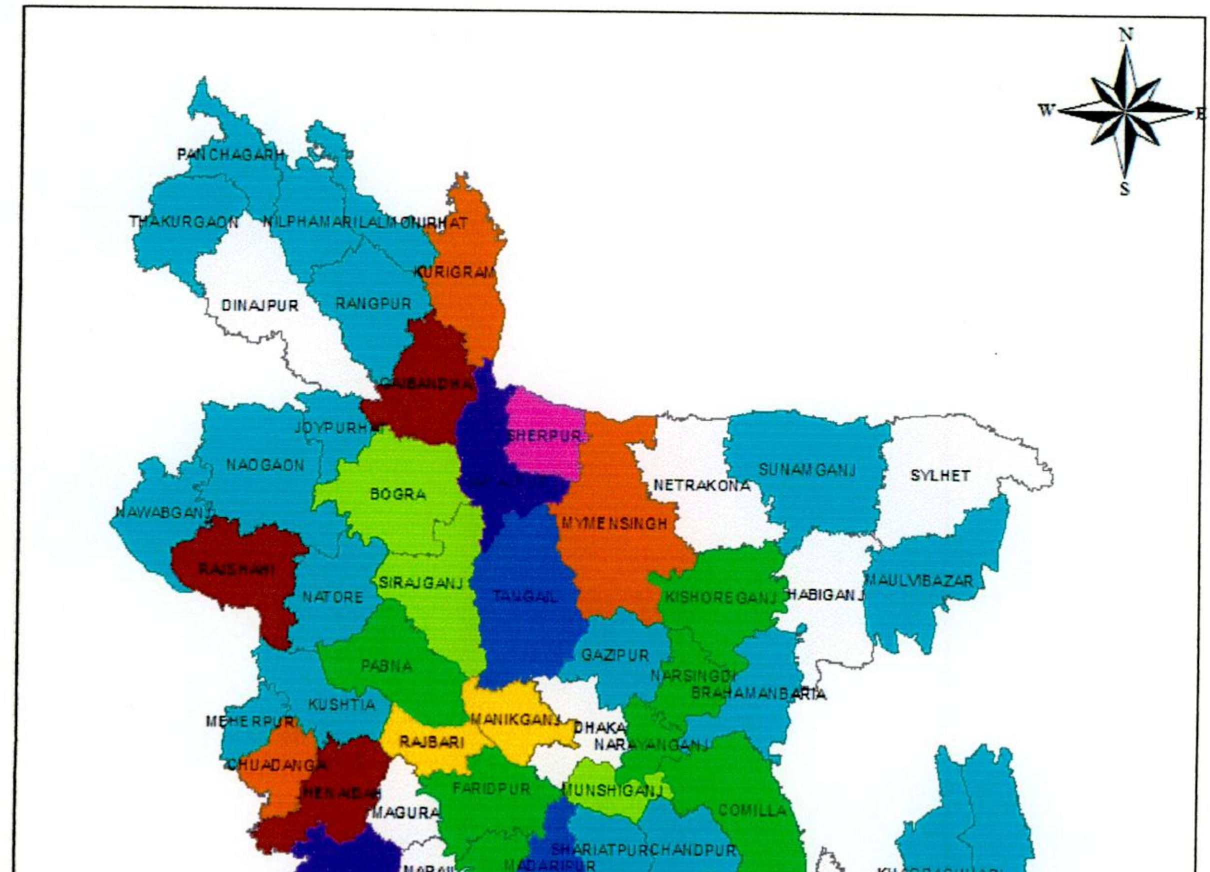

Fig: 4.17 GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-01

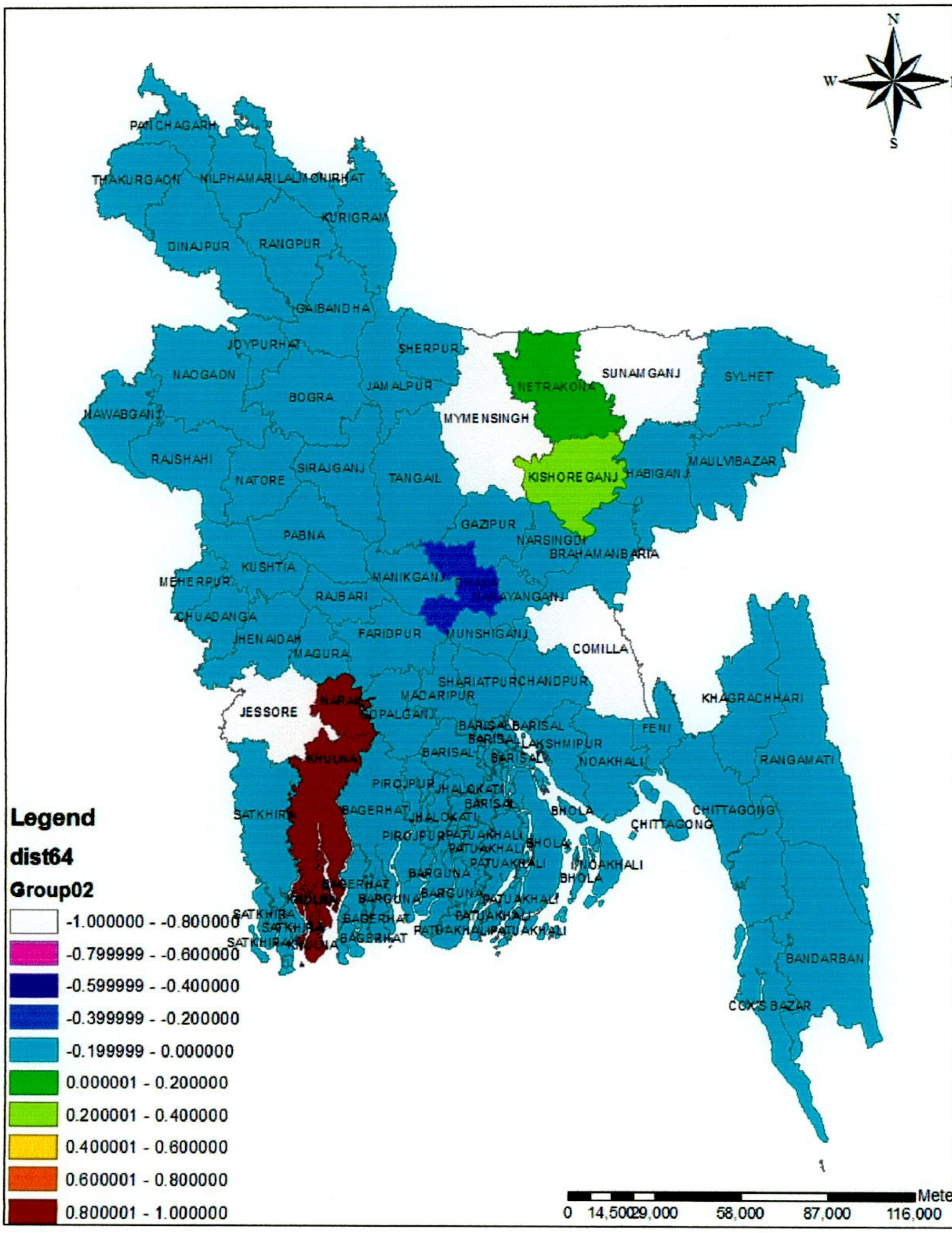

Fig: 4.18 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-02**

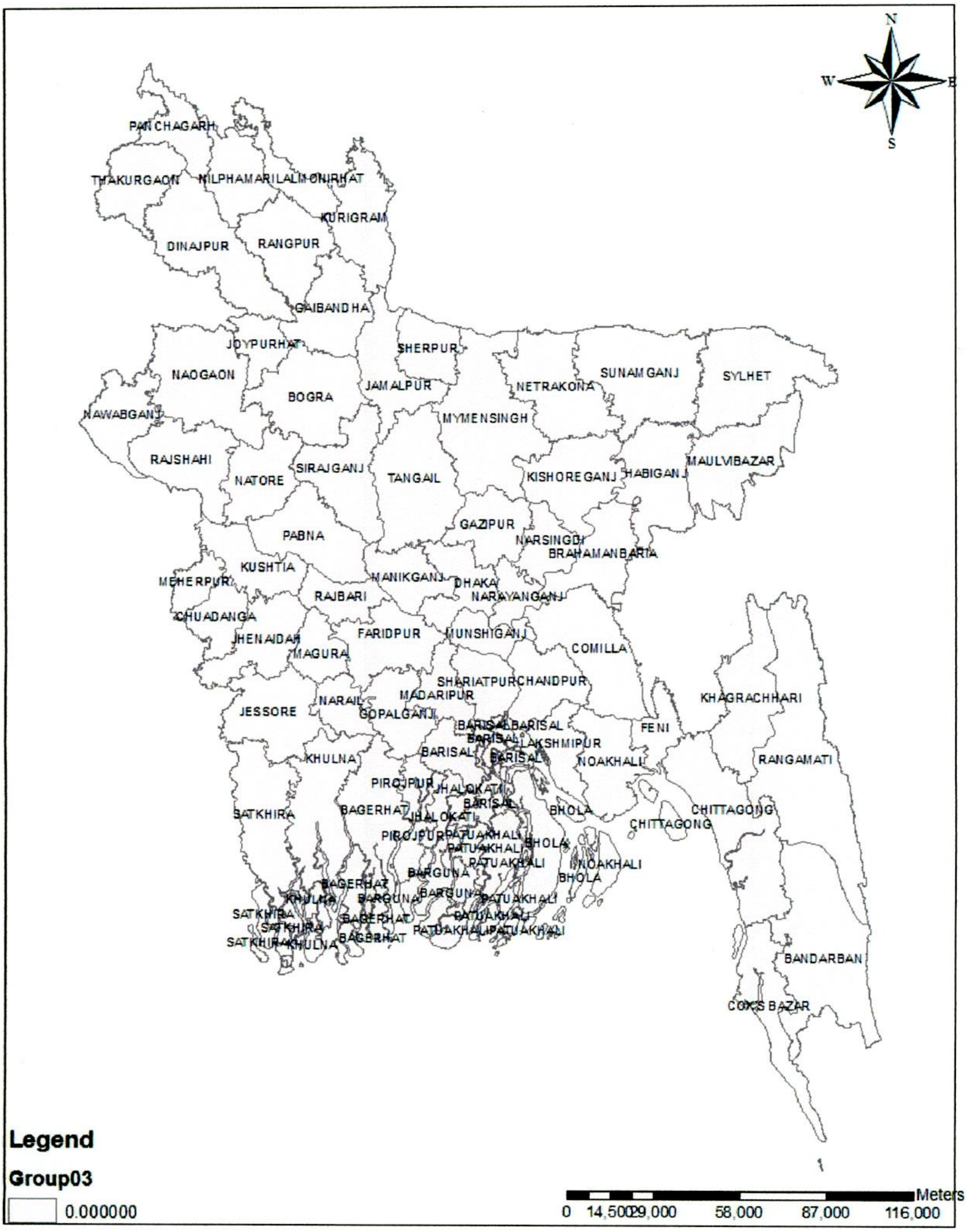

Fig: 4.19 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-03**

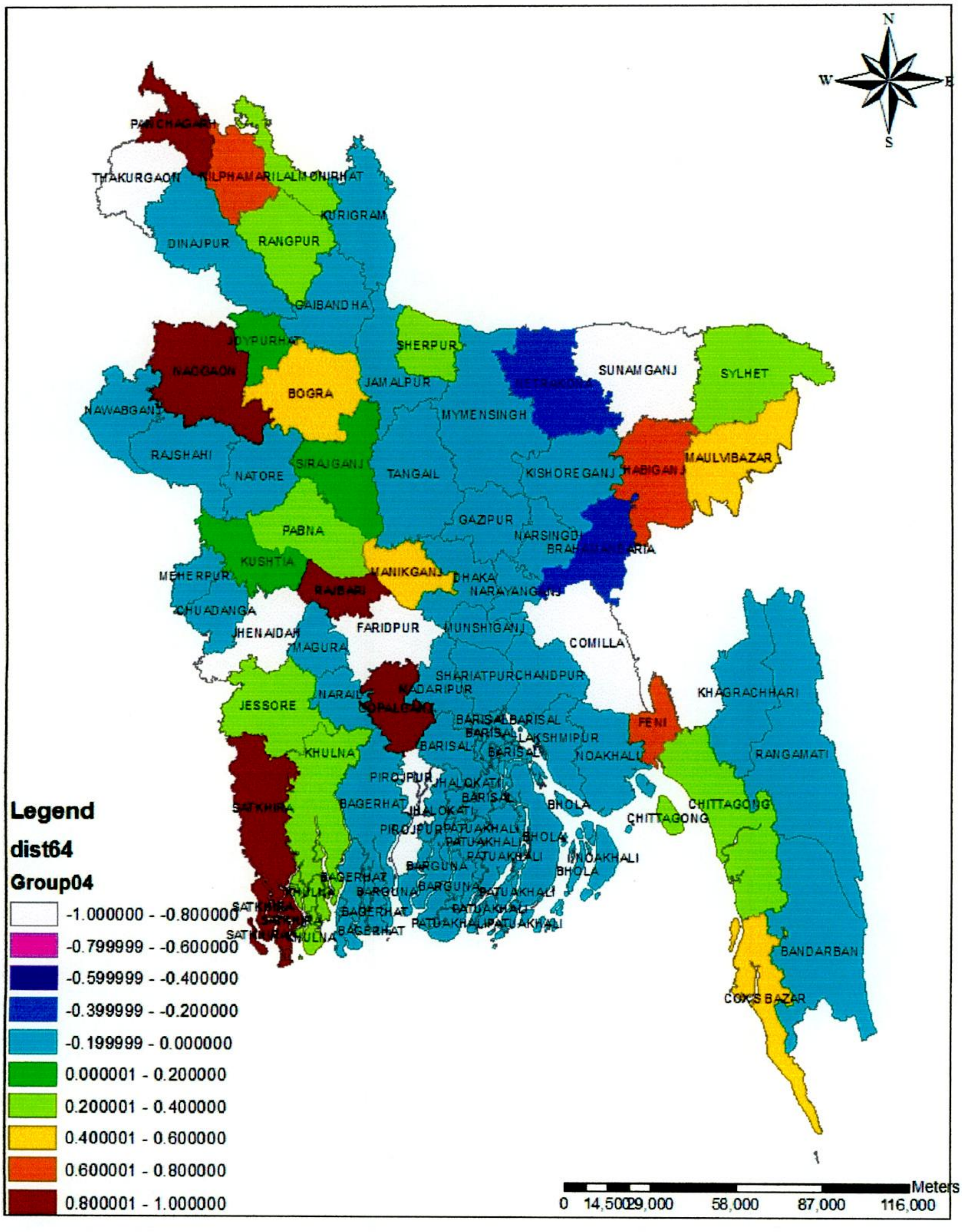

Fig: 4.20 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-04**

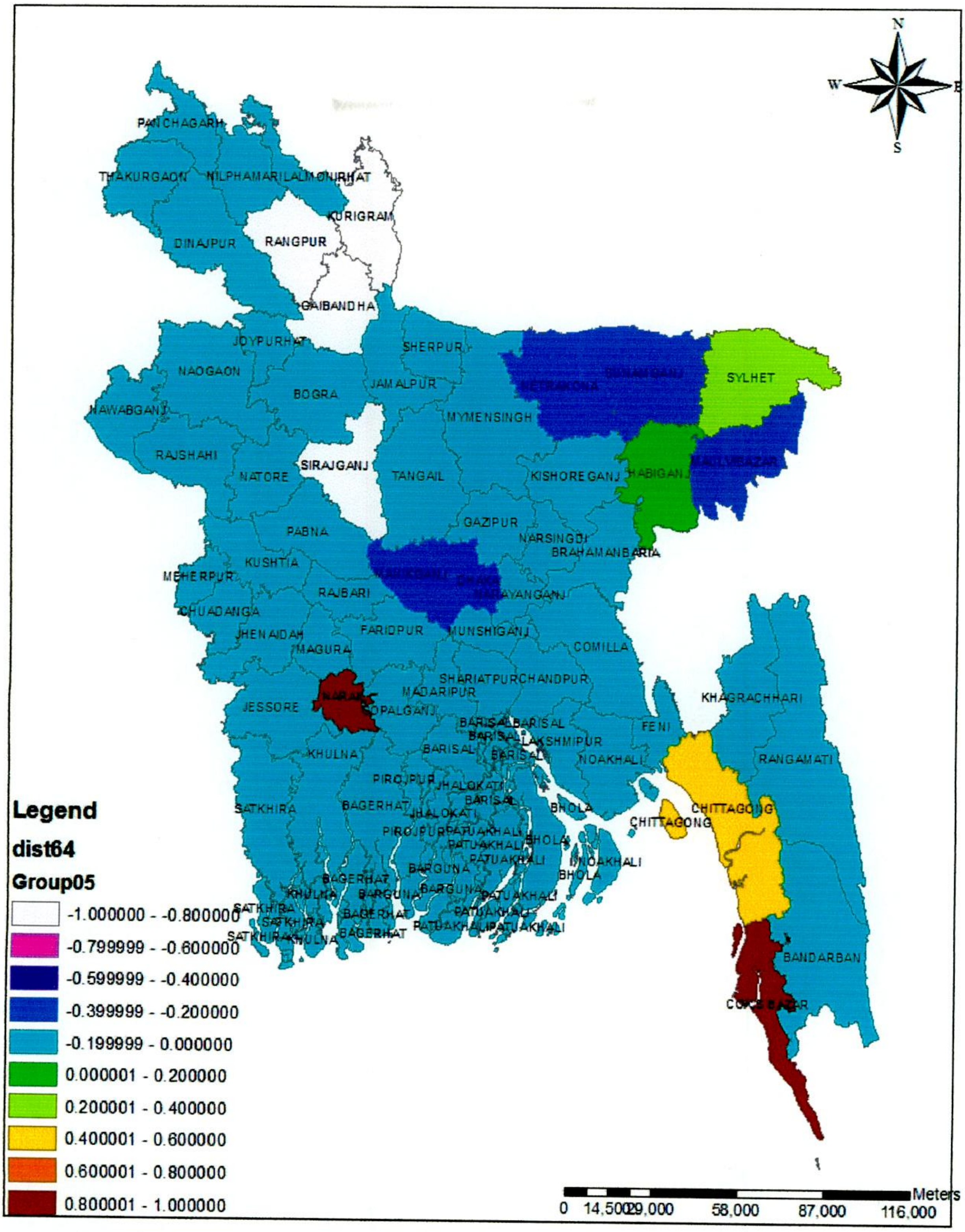

Fig: 4.21 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-05**

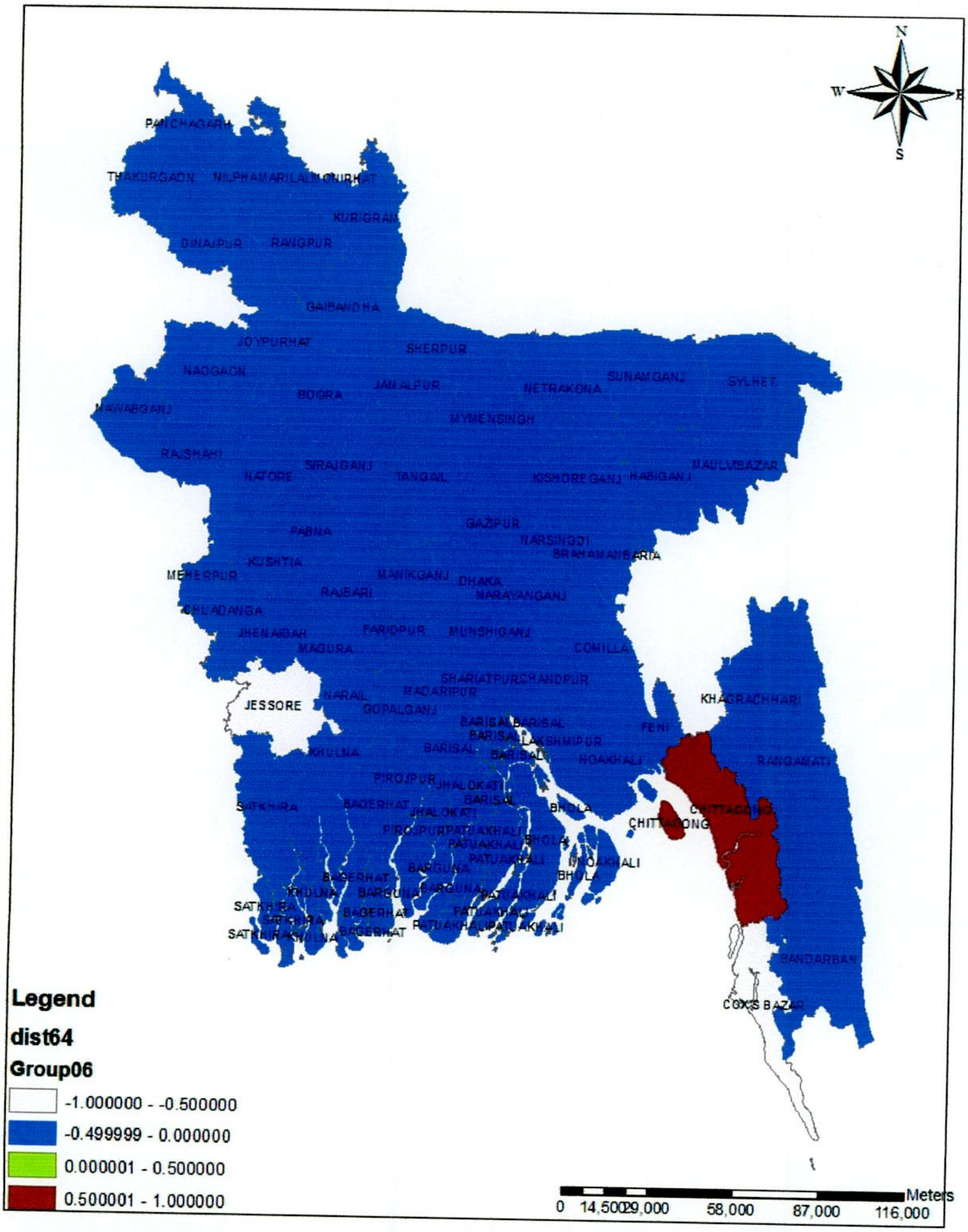

Fig: 4.22 GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-06

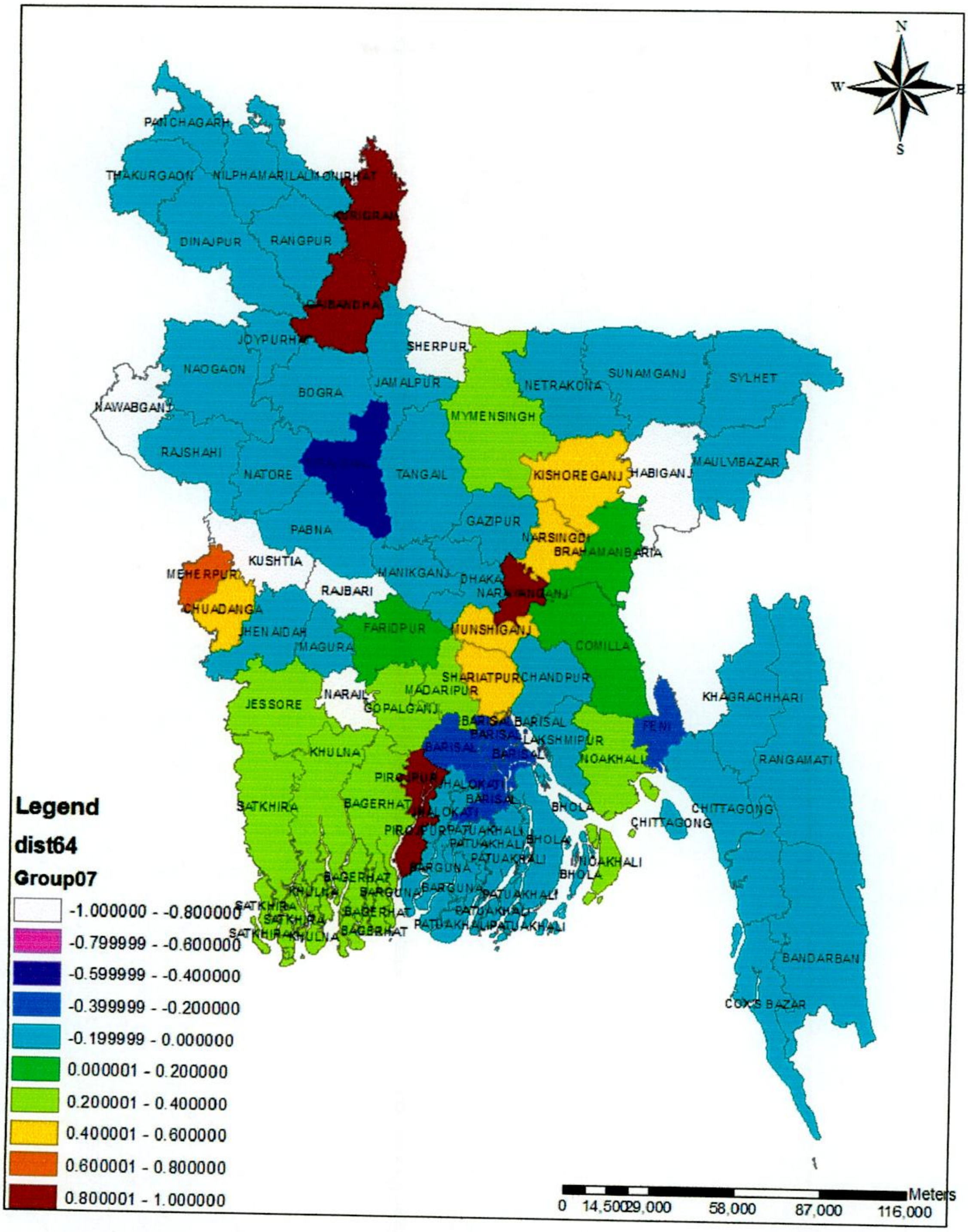

Fig: 4.23 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-07**

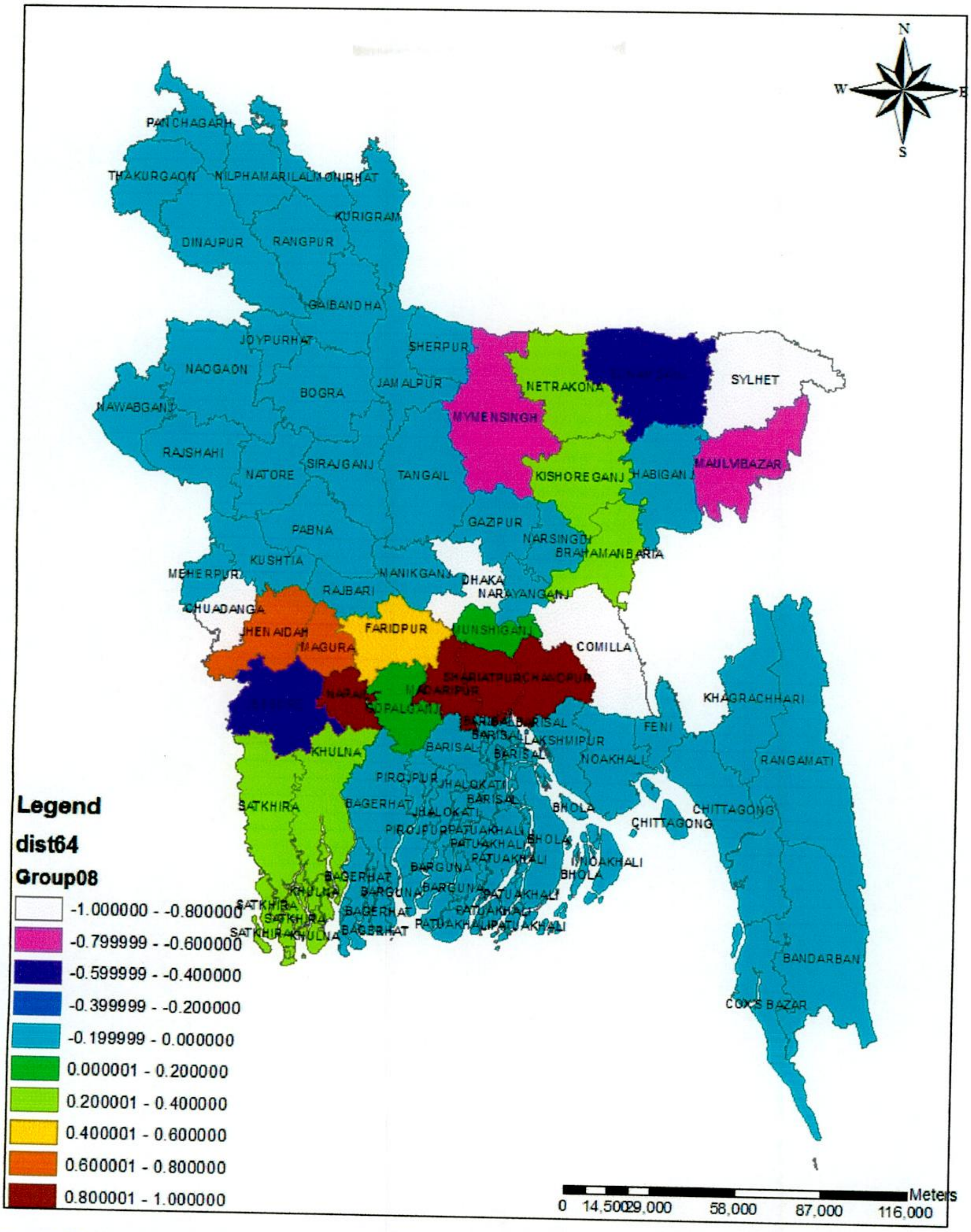

Fig: 4.24 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-08**

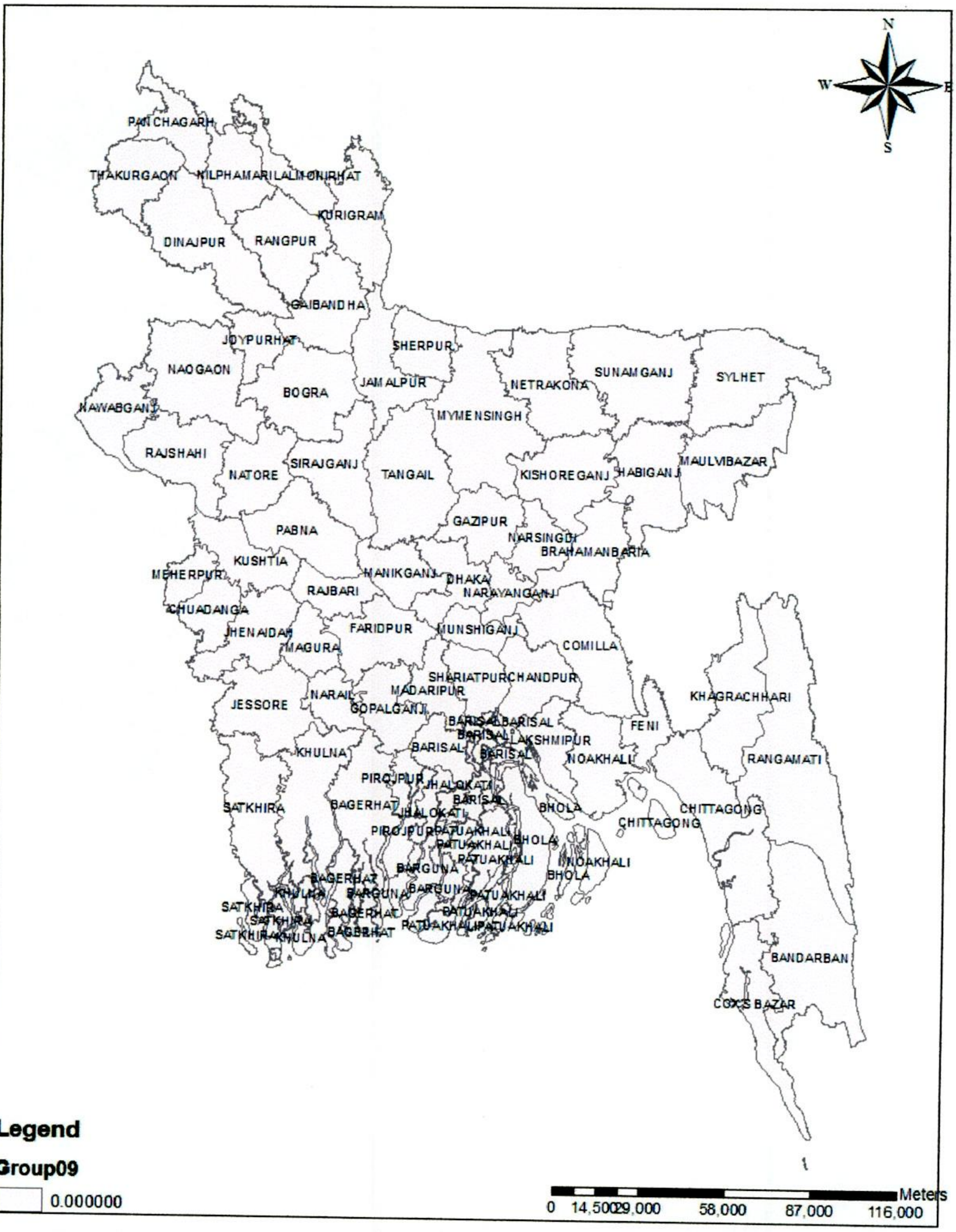

Fig: 4.25 GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-09

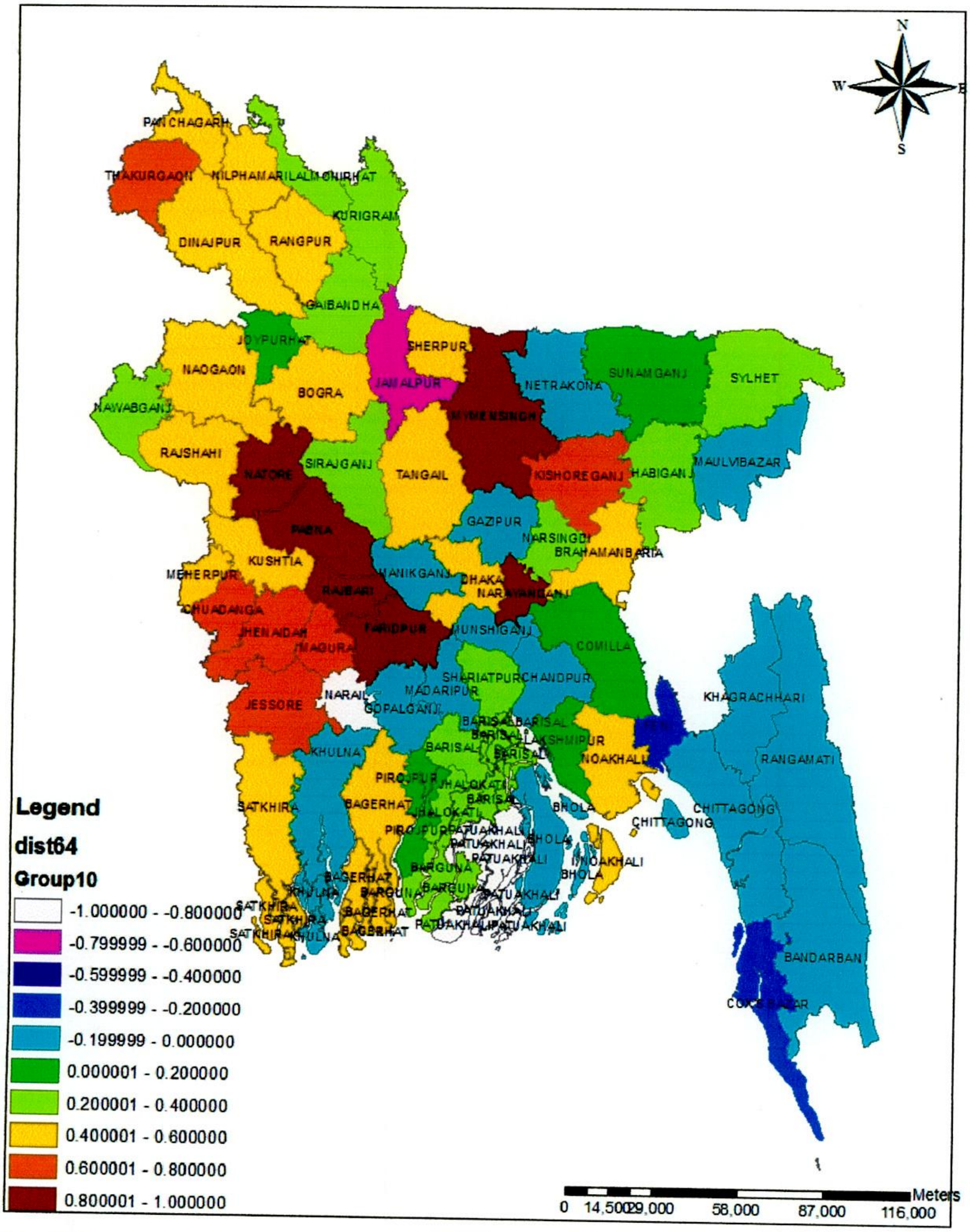

Fig: 4.26 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-10**

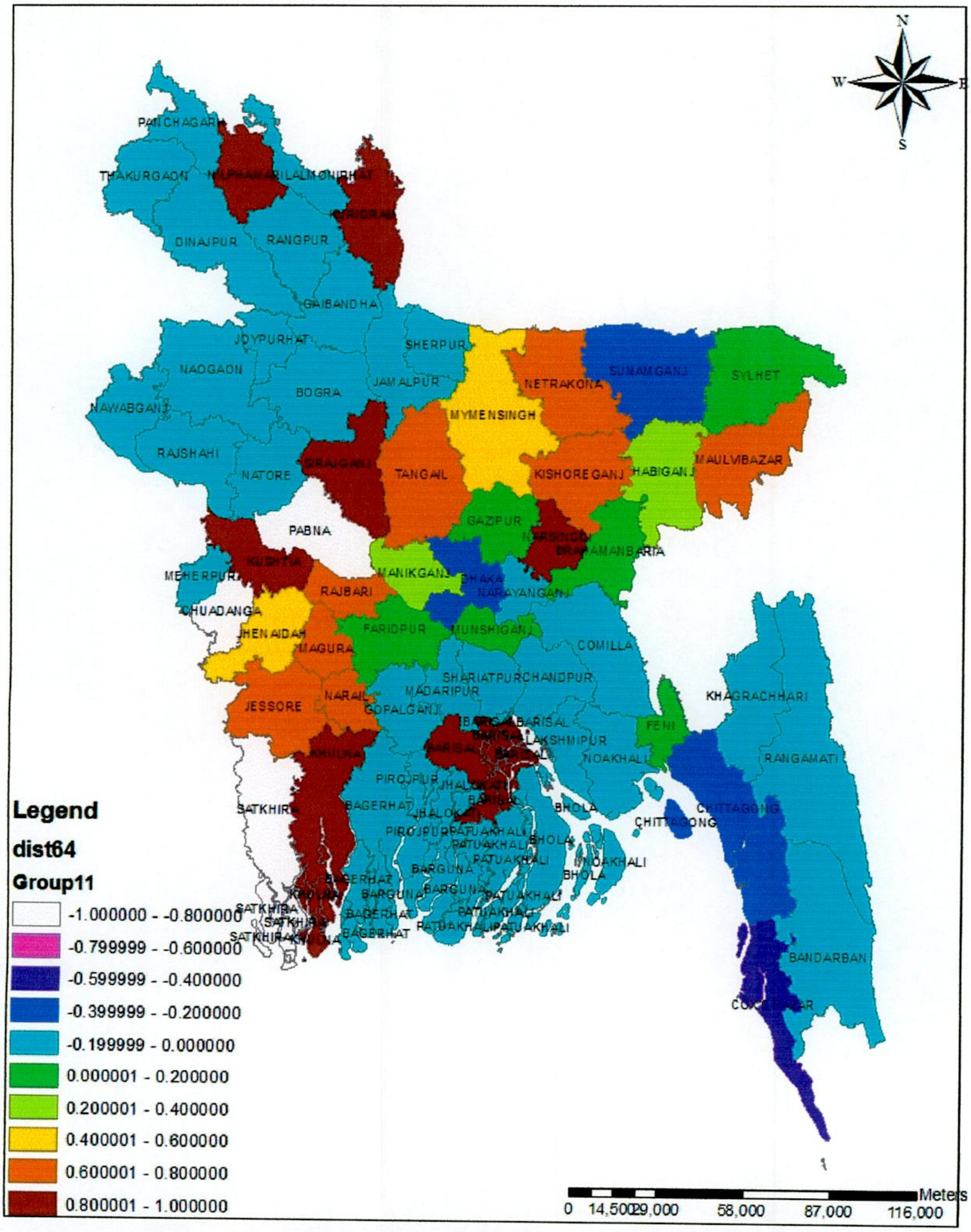

Fig: 4.27 **GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-11**

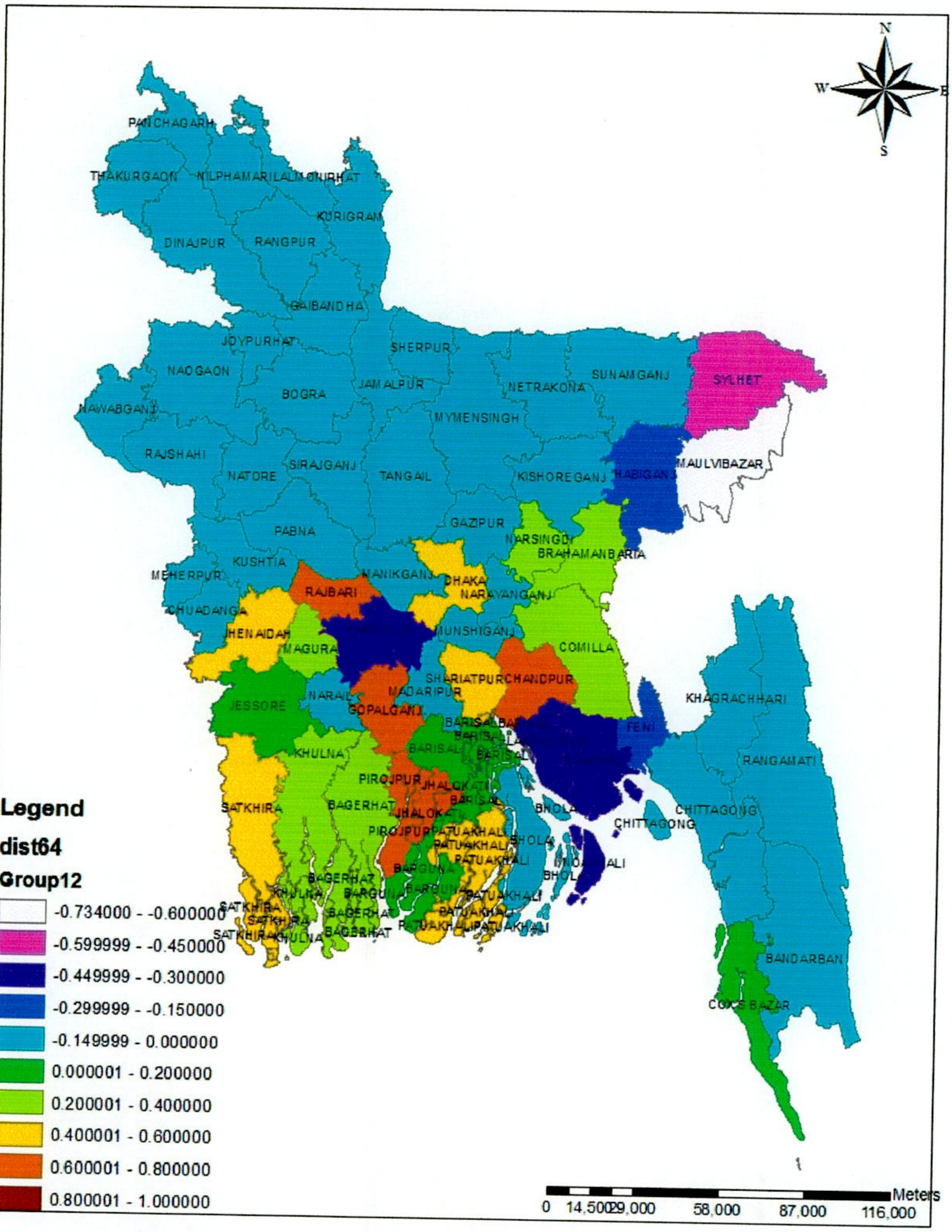

Fig: 4.28 GIS map of Correlation between Arsenic and iron concentration of ground water of Bangladesh for Group-12

4.11 Analysis of the developed GIS maps:

Fig 4.13 is showing the zonal correlation status of Bangladesh. Data of 61 districts were separated as per their geographical locations. When analyzed results were plotted in GIS some interesting features were noted. Fig 4.29 shows the districts which has correlation coefficient between 0.4 and 0.6. Bagerhat, Gopalganj Faridpur, Rajbari, Manikganj, Dhaka, Narayanganj and Narshingdi forms a belt which shows similar correlation between *As* and *Fe*. If we consider this 0.4-0.6 range consider moderate correlation then this belt shows moderate correlation. Another similar type of belt is found in Rajshahi, Natore, Bogra and Jamalpur districts.

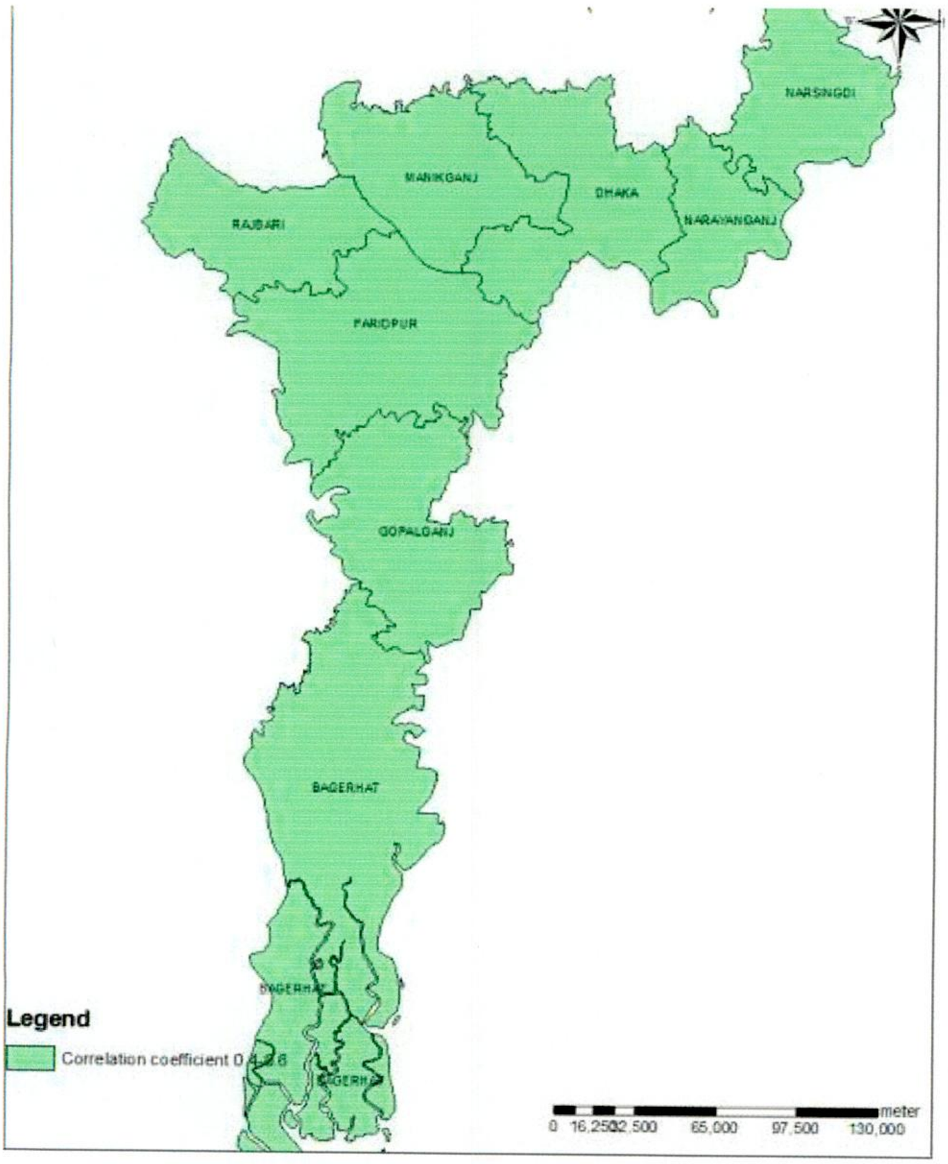

Fig 4.29 Districts showing correlation coefficient between 0.4 and 0.6.

If 0.6 to 1 is considered to be as high correlation coefficient then through fig 4.30 show the districts which has moderate to high correlation between *As* and *Fe*. This reveals that a geographical belt exists where correlation between arsenic and Iron concentration of ground water is moderate to High.

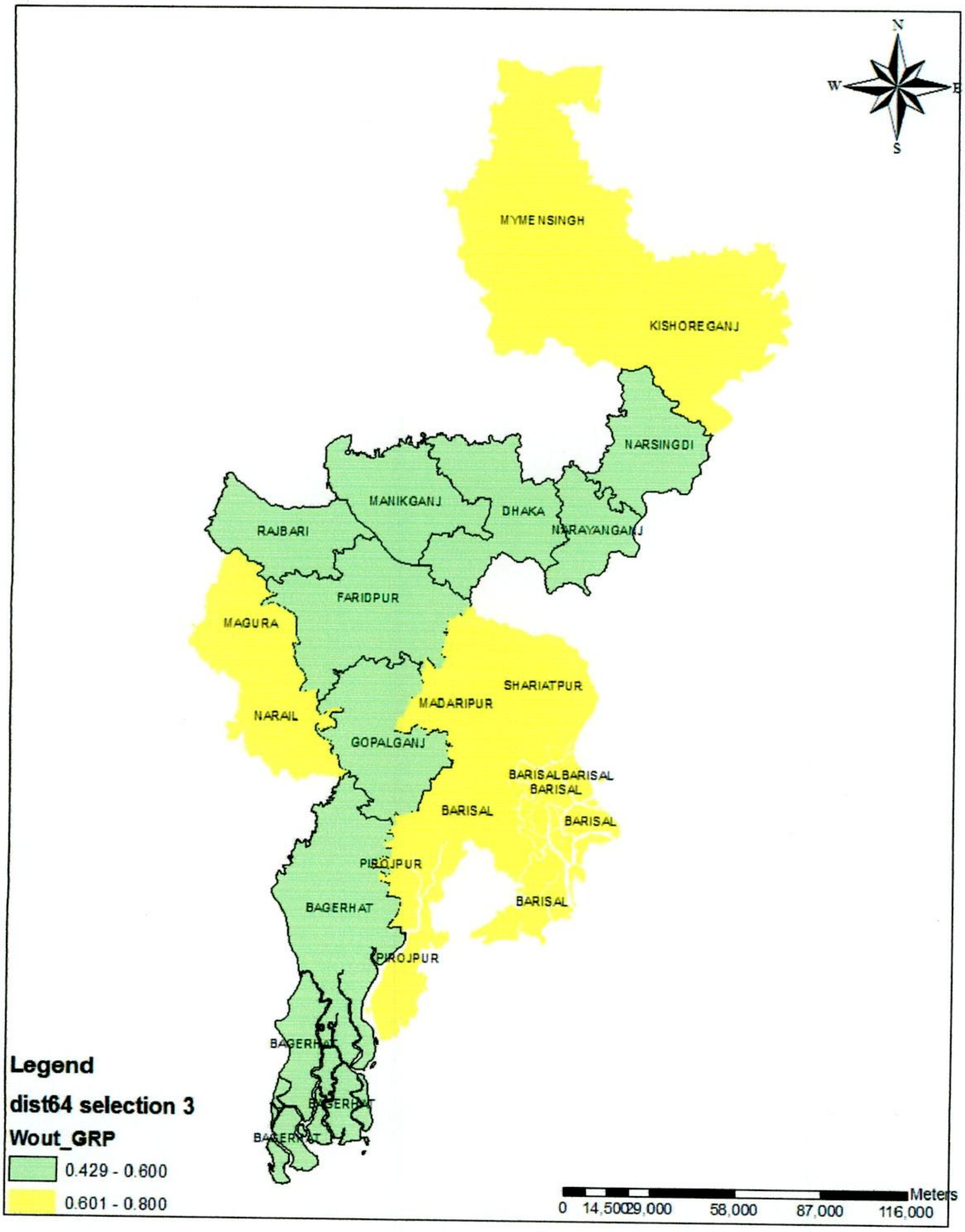

Fig 4.30 Districts showing correlation coefficient between 0.4 and 0.8.

Seven out of twelve most arsenic contaminated districts are showing moderate to high correlation. But Chandpur, the most *As* contaminated district is showing very little correlation (0.108). On the other hand six out of twelve least arsenic contaminated districts are showing very little correlation. A belt of districts showing less correlation can be found in Khulna, Jessore, Jhinaidah, Kustia, Pabna, Siraj ganj, Tangail Gazipur. One important this is observed from this GIS map is that correlation pattern is not scattered over the country. In most of the cases a belt of similar correlation pattern in observed. Such a less correlative zone is found in the eastern part on the country. Sylhel, Moulovibazar, Habiganj, Sumanganj, Brahmanbaria, Comilla, Cox's Bazar etc districts are forming a belt which shows almost no correlation (fig 4.31).

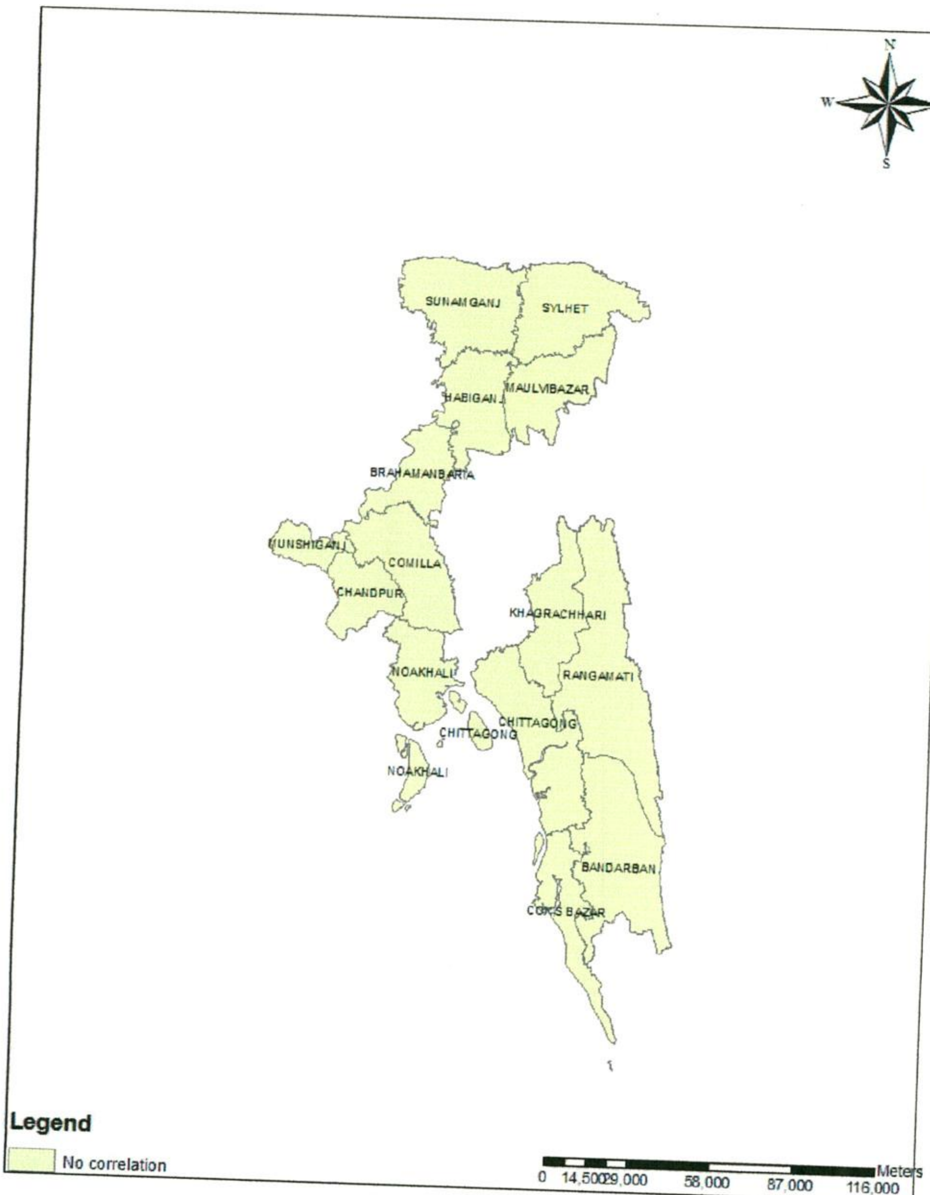

Fig 4.31 GIS map showing district of no correlation between arsenic and Iron.

4.12 Regression analysis of data:

It is evident from the analysis that correlation between arsenic and iron concentration is not a national phenomenon rather it is a zonal phenomenon. Therefore an attempt has been made to correlate arsenic and iron for the zones where correlation coefficient between arsenic and iron concentration is higher. When regression analysis was performed using the data separating them as per their geographical locations results were found as shown in Table 4.21 in th next page. In this analysis arsenic is taken as the dependent variable. After analysis this equation was produced.

Arsenic (µg/L) = A + (B) (Iron in mg/L) **A, B = Constants from regression model**

Table 4.30 Result of regression analysis.

District	A	B	r-square	District	A	B	r-square
Bagerhat	37.921	17.019	0.299	Magura	4.216	19.933	0.3721
Barguna	0.727	1.944	0.132	Manikganj	13.023	2.418	0.190969
Barisal	23.849	36.044	0.360	Maulvibazar	18.517	0.124	0.000441
Bhola	-4.21	31.634	0.734	Meherpur	-10.96	48.44	0.481636
Bogra	4.035	4.533	0.187	Munshiganj	164.95	5.195	0.0225
Brahamanbaria	43.071	6.531	0.036	Mymensingh	4.65	8.444	0.579121
Chandpur	287.119	7.598	0.012	Naogaon	2.819	2.376	0.041616
Chittagong	21.608	-0.599	0.006	Narail	38.443	14.29	0.431649
Chuadanga	5.12	30	0.261	Narayanganj	22.75	7.517	0.184041
Comilla	79.332	7.591	0.018	Narsingdi	20.2	11.046	0.2809
Cox's Bazar	4.84	-0.092	0.003	Natore	0.982	1.431	0.222784
Dhaka	16.211	5.051	0.194	Nawabganj	5.35	1.84	0.042436
Dinajpur	-0.217	2.231	0.524	Netrokona	28	4.077	0.095481
Faridpur	25.785	25.921	0.338	Nilphamari	-0.049	0.787	0.664225
Feni	50.865	-1.108	0.005	Noakhali	154.977	5.611	0.002601
Gaibandha	14.984	1.18	0.011	Pabna	17.138	6.78	0.105625
Gazipur	0.64	7.25	0.075	Panchagarh	0.493	0.83	0.868624
Gopalganj	46.778	20.671	0.341	Patuakhali	3.36	1.39	0.087025
Habiganj	15.289	0.562	0.008	Pirojpur	-1.925	14.61	0.361201
Jaipurhat	1.172	0.159	0.044	Rajbari	9.761	10.476	0.308025
Jamalpur	1.733	3	0.203	Rajshahi	3.199	6.2	0.283024
Jessore	9.4	9.789	0.153	Rangpur	-2.29	2.45	0.209764
Jhalakati	-19.909	48.5	0.767	Satkhira	27.959	20.78	0.231361
Jhenaidah	7.39	11.43	0.131	Shariatpur	11.497	32.352	0.456976
Khulna	12.44	9.54	0.128	Sherpur	18.466	0.762	0.0289
Kishoreganj	2.54	16.933	0.387	Sirajganj	21.907	1.174	0.036864
Kurigram	13.222	1.218	0.035	Sunamganj	47.24	-1.812	0.0256
Kushtia	68.211	7.453	0.005	Sylhet	19.12	0.339	0.012996
Lakshmipur	168.14	4.176	0.003	Tangail	9.66	2.038	0.106276
Lalmonirhat	0.357	0.441	0.449	Thakurgaon	0.553	0.462	0.310249
Madaripur	1.092	46.025	0.552				

Using this regression model if iron concentration of any well is known, arsenic concentration of that well can be tentatively measured.

For example,

The iron concentration of a well of Bagerhat district, Thana kochua, union Raripar and mouza Bandarkhola (Lat 22.606 Long 89.85) is found to be 9.4 mg/L. From table 4.21 the value found from regression model for Bagerhat district is found to be 39.37 and 17.019. the equation for this district becomes like the following one.

Arsenic (μg/L) = A + (B) (Iron in mg/L)

Arsenic (μg/L) = 39.37+ 17.019(9.4)

= 199.35

Correlation coefficient "r" found for this district is 0.54. r-square is the square of this value which represents the proportion of variance in one variable accounted for (or explained) by the other variable. R-square for this value is 0.3. This represents that Arsenic concentration of 30% of the wells of this Bagerhat district can be tentatively found through this regression model if Iron concentration is known.

4.13 Scope and features of the produced GIS map:

The produced GIS map represents the correlation coefficient of individual districts. Fig 4.13 represents the analysis result of district wise correlation coefficient. Fig 4.14 to fig 4.16 represents the district wise correlation coefficient for three different depth layers. Fig 4.17 to Fig 4.28 represents the group wise correlation analysis results.

These GIS maps and analysis results can be used for determining arsenic concentration of different wells of different locations. If arsenic concentration of a well of Madaripur district needs to be assessed GIS maps can be helpful for that. If depth of that well is known the desired map can be used for the specific depth range. If well depth is bellow 50m fig 4.14 can be used to know the correlation coefficient. Using the data of regression model from table 4.21 the equation can be formed. Through this equation the arsenic concentration can be tentatively verified. Reliability of this result should be assessed by r-squire value. This method can prove to be very economical if it is used in large scale. Because if in any large scale project it is required to know the arsenic concentration in a bulk no of wells this GIS map and correlation and regression model analysis can be helpful.

CHAPTER-5

CONCLUSION

AND

RECOMMENDATION

CHAPTER 5

Conclusion and Recommendation

5.1 Conclusion

Following conclusion can be drawn from the result analysis.

- Total 4367 number of data is used for analysis in this research. Data of 61 administrative districts of Bangladesh were available for analysis.

- When all the data were used collectively analyzed without any grouping the correlation coefficient was found to be very insignificant of 0.195.

- When the data were separated as per geographical location which is 61 districts of Bangladesh the correlation coefficient varied significantly in different districts. 37.7% Districts showed correlation coefficient more than 0.5 which is considered to be moderate to high correlation. 50.4% districts shows correlation coefficient more than 0.4

- GIS maps were produced with the results of the analysis. GIS map in Fig 4.29 shows the districts which has correlation coefficient between 0.4 and 0.6. Bagerhat, Gopalganj Faridpur, Rajbari, Manikganj, Dhaka, Narayanganj and Narshingdi forms a belt which shows similar correlation between *As* and *Fe*. If we consider this 0.4-0.6 range consider moderate correlation then this belt shows moderate correlation. Another similar type of belt is found in Rajshahi, Natore, Bogra and Jamalpur districts. If 0.6 to 1 is considered to be as high correlation coefficient then through fig 4.30 show the districts which has moderate to high correlation between *As* and *Fe*. This reveals that a geographical belt exists where correlation between arsenic and Iron concentration of ground water is moderate to High.

- Seven out of twelve most arsenic contaminated districts are showing moderate to high correlation. But Chandpur, the most *As* contaminated district is showing very little correlation (0.108). On the other hand six out of twelve least arsenic contaminated districts are showing very little correlation.

- A belt of districts showing less correlation can be found in Khulna, Jessore, Jhinaidah, Kustia, Pabna, Sirajganj, Tangail Gazipur.

- One important thing is observed from the produced GIS map is that correlation pattern is not scattered over the country. In most of the cases a belt of similar correlation pattern in observed. Such a less correlative zone is found in the eastern part on the country. Sylhel, Moulovibazar, Habiganj, Sumanganj, Brahmanbaria, Comilla, Cox's Bazar etc districts are forming a belt which shows almost no correlation (fig 4.31).

- Depth variation is also considered separately for correlation analysis. Three separate depth layers were considered as wells of depth than 50m, wells between 50m and 150m, wells depth more than 150m. Some districts like Faridpur, Rajbari, Madaripur, Sariatpur etc. show moderate to high correlation for shallow wells (depth bellow 150m). Among these districts, apart from Rajbari correlation coefficient reduces for deep tube wells than the shallow wells. Another belt of high correlation is found in the northern part of Bangladesh. Rangpur, Dinajpur, Thakurgaon, Lalmonirhat and Panchagar show high correlation coefficient for well depth less than 50m. But the correlation coefficient reduces in the deep layers. In Barishal, Satkhira, Meherpur and Narshingdi correlation is more significant for depth layer between 50m and 150m. In the western part on Bangladesh, Sylhet, Habiganj and Sunamganj correlation coefficient tends to increase with the increase in depth.

- It was considered that different combination of *As* and *Fe* may give different correlation status. For this a 3-Dimentional water matrix was developed which formed 12 groups of data sets were formed for different combination of arsenic and Iron. They were named from Group-01 to Group-12. 8% of data belonged to the most contaminated group where both arsenic and iron exceeded their desired limit. Maximum 68.7% data belonged to the least contaminated group. Correlation was analyzed for all these groups.

- A regression analysis was also performed and result of that can be combined with the correlation analysis results to tentatively assess the value of *As* of a well from the known *Fe* concentration. GIS map can be a helpful tool for this assessment. This model is valid for districts showing higher correlation coefficient.

5.2 Recommendations

Production of GIS map of Bangladesh needs extensive amount of data. This research was performed with a good amount of data from most of the districts. But few districts has very small amount of data which made the map less reliable for those districts. An extensive data acquisition for those districts and subsequent statistical analysis may reveal further information about correlation which will make the GIS map more reliable. The performance of AIRP (Arsenic Iron Removal Plant) should be assessed with the results of this correlation analysis.

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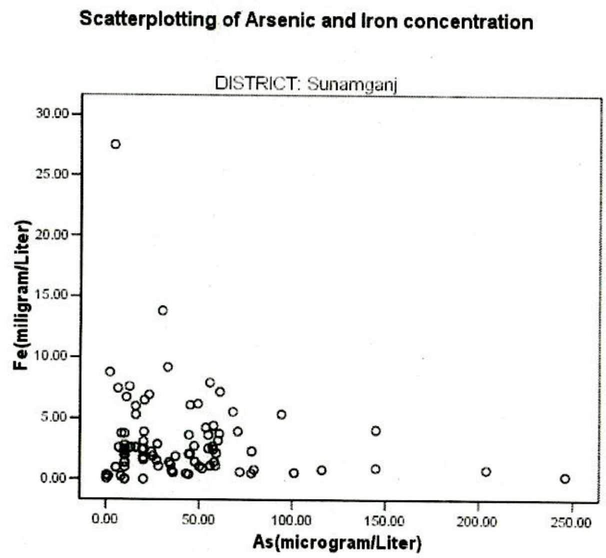
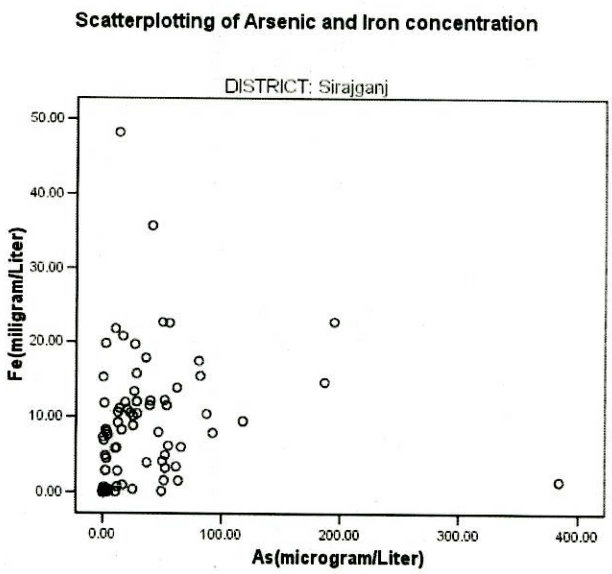
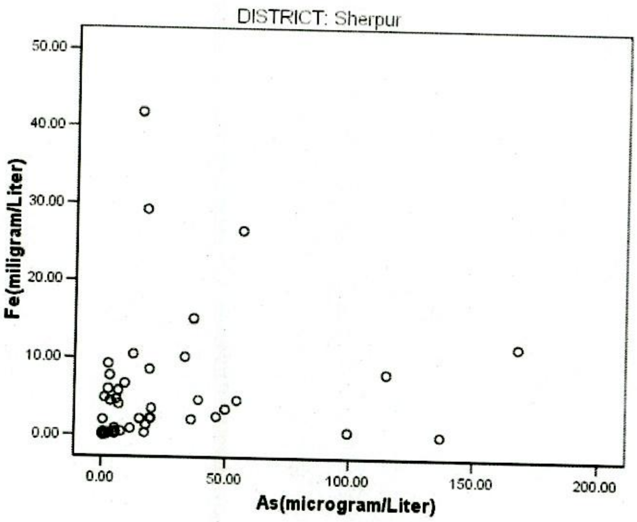
Appendix-1

Scatter plotting of Arsenic and Iron concentration data of 61 districts of Bangladesh.





Scatterplotting of Arsenic and Iron concentration



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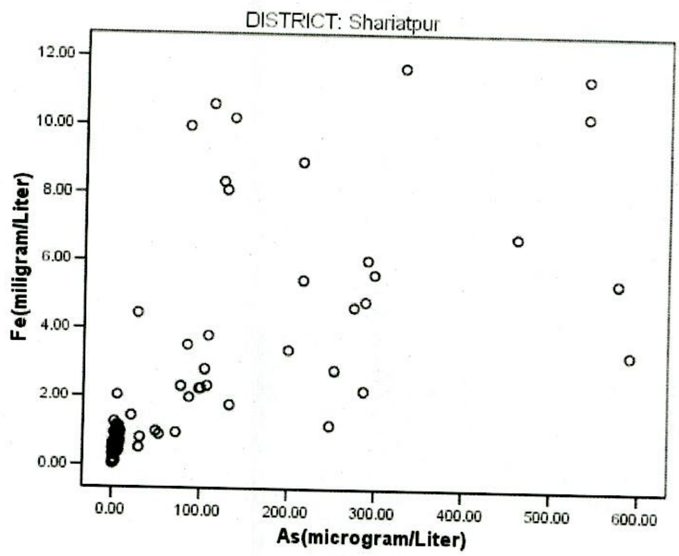

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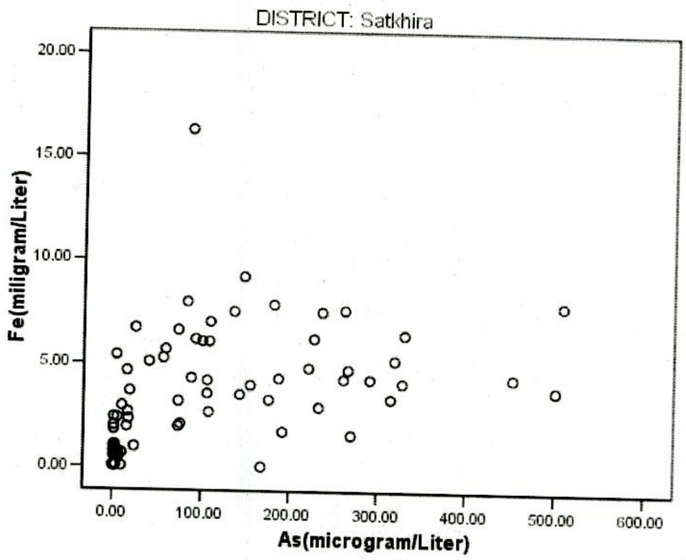
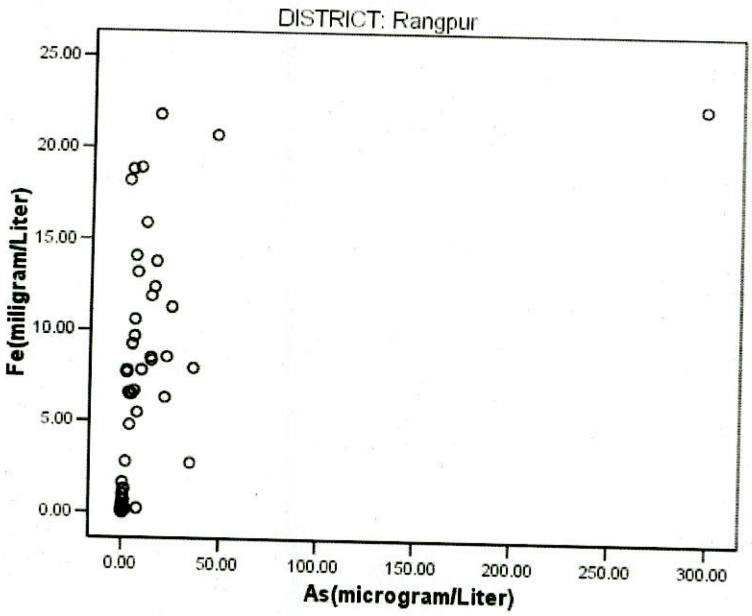
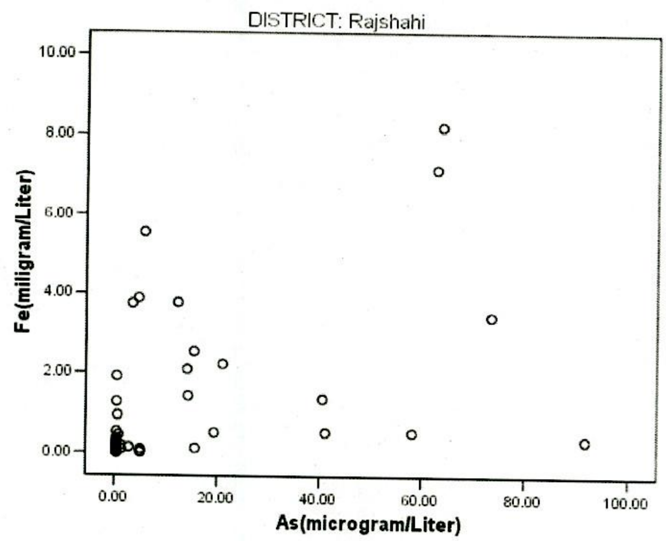


Scatterplotting of Arsenic and Iron concentration



Scatterplotting of Arsenic and Iron concentration



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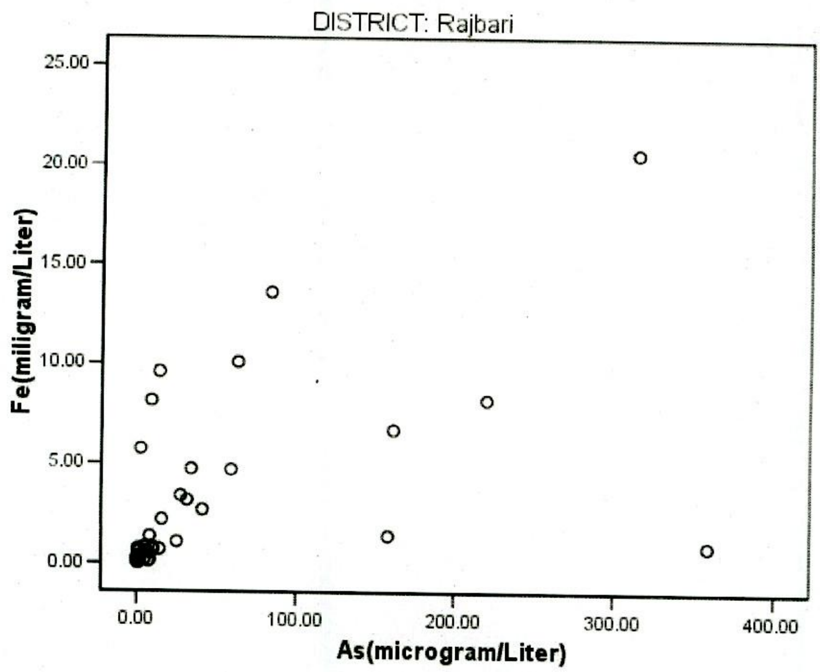

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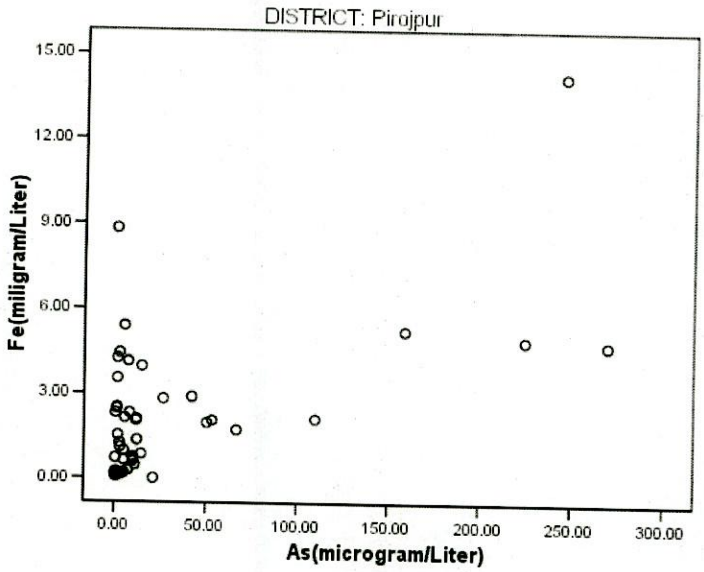

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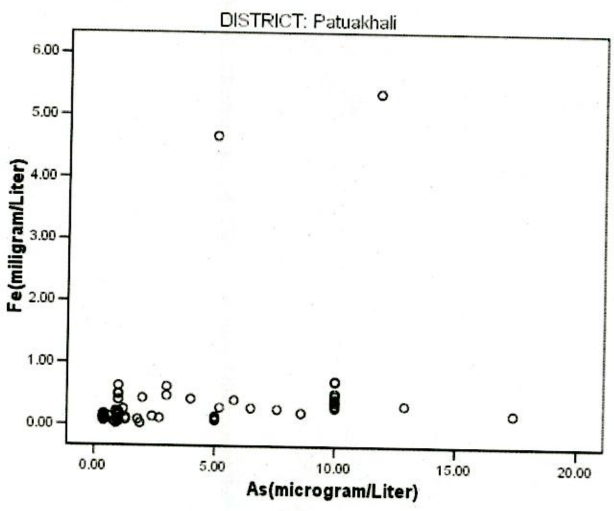

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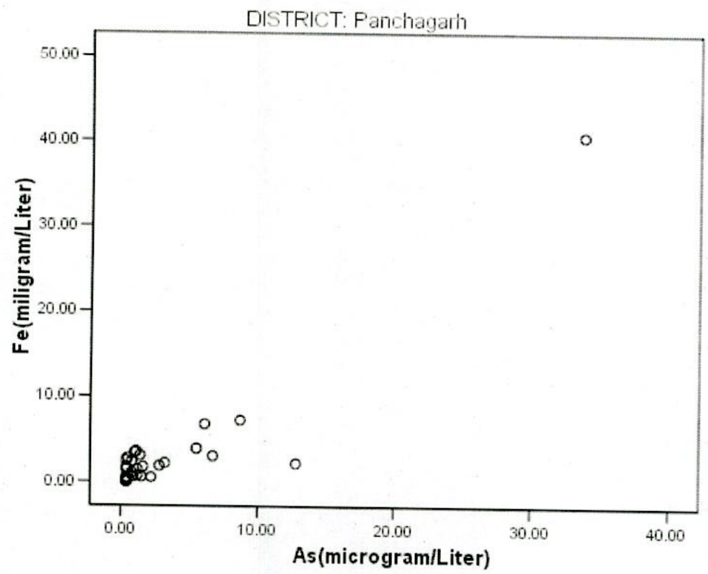

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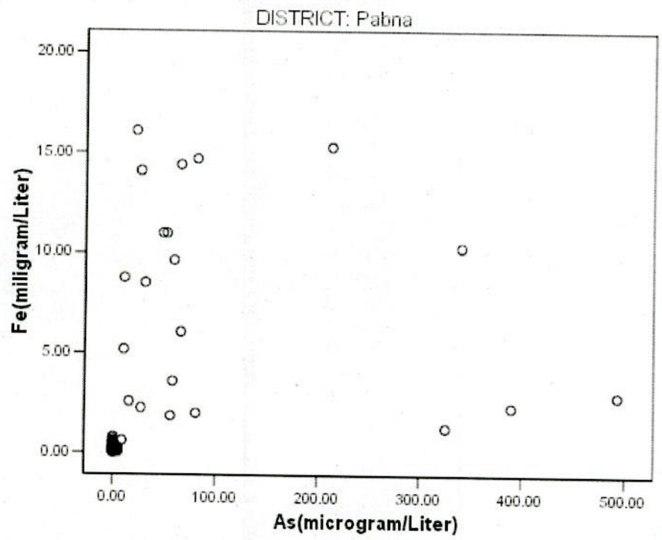

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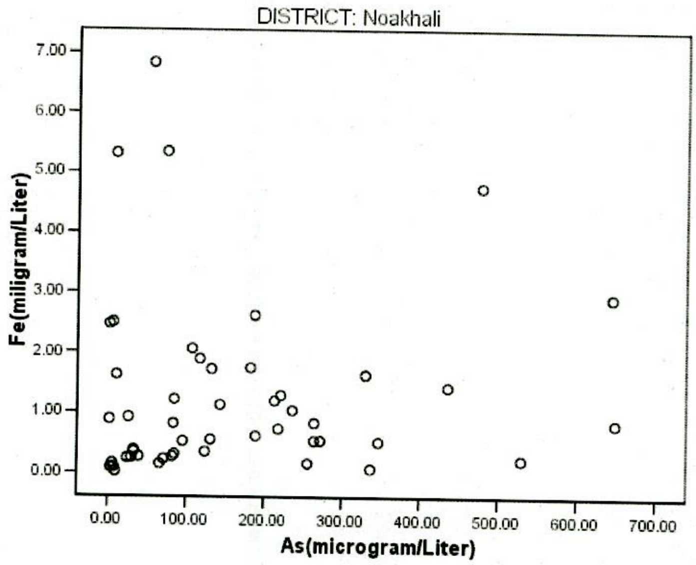

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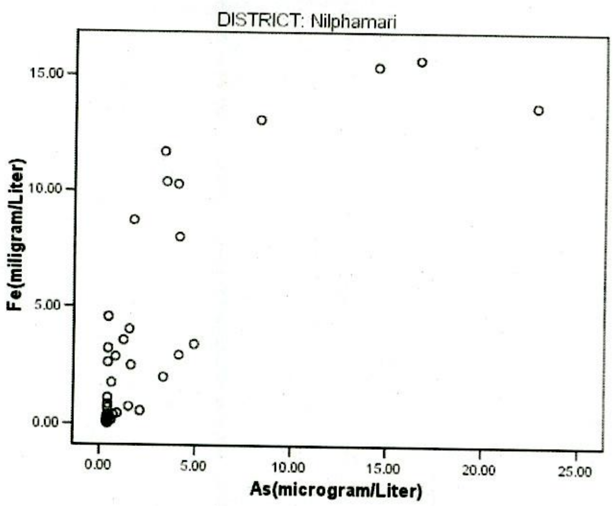

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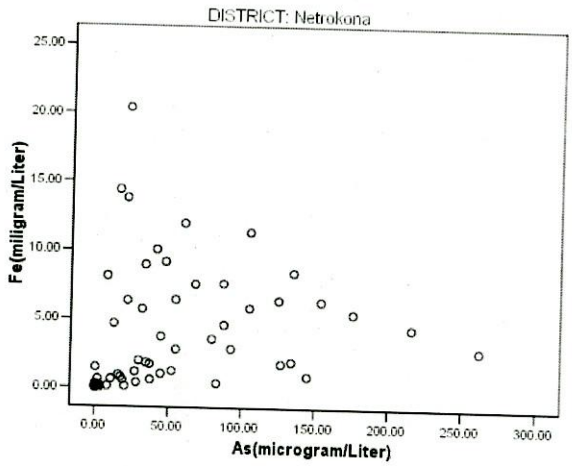

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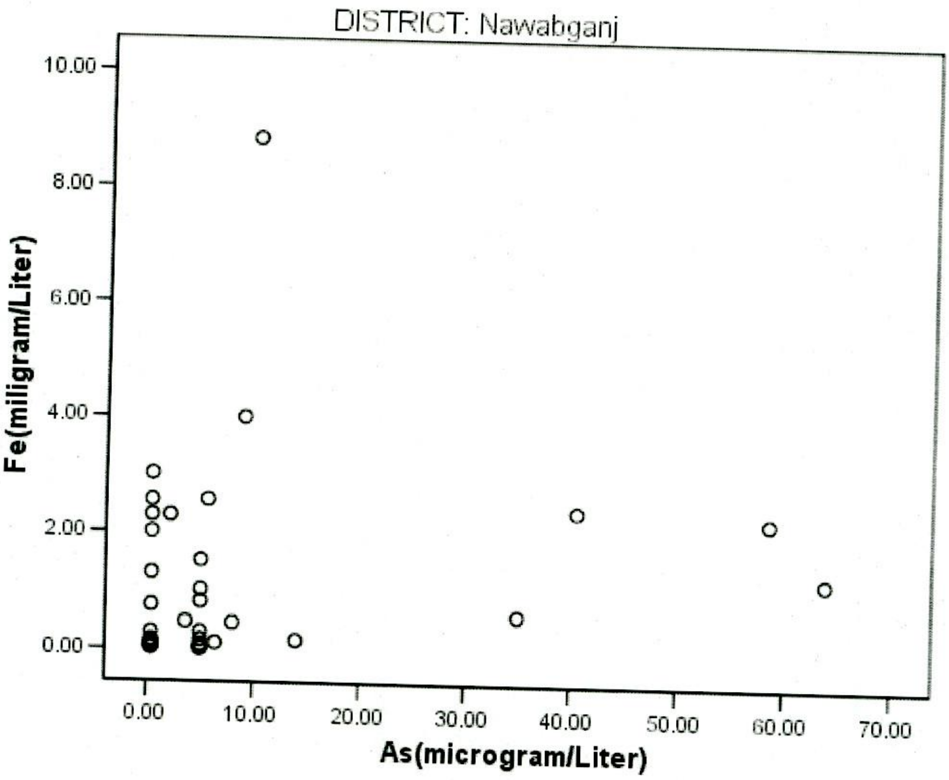

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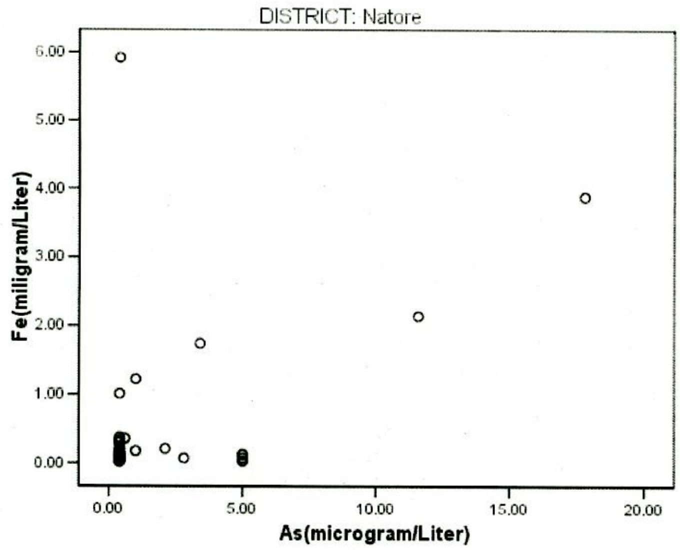

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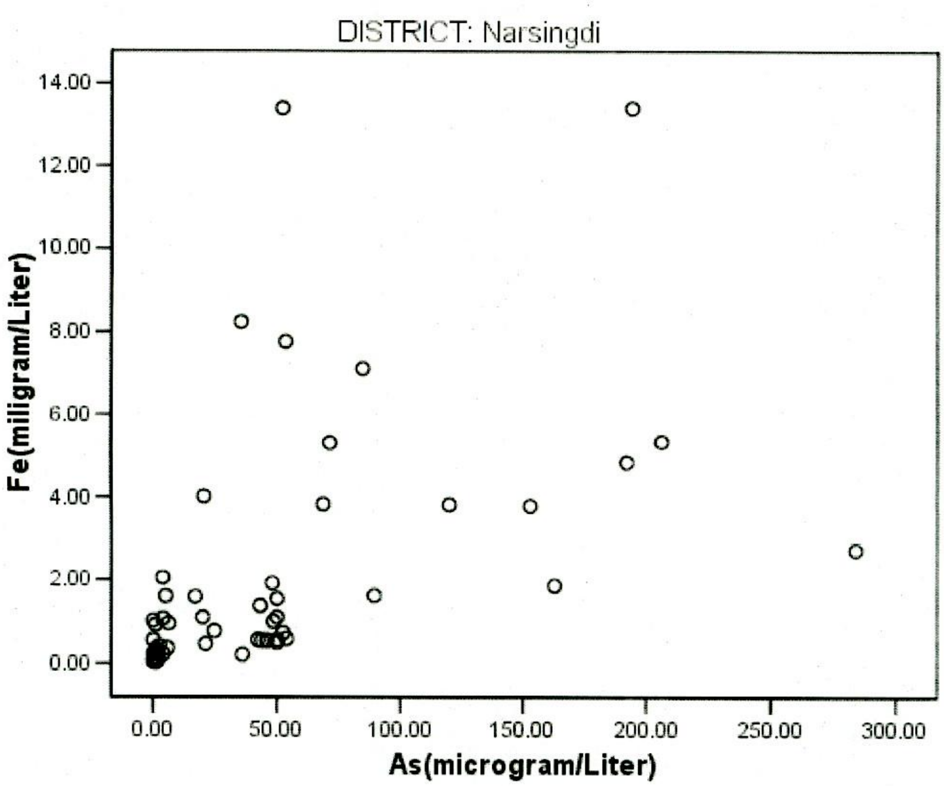

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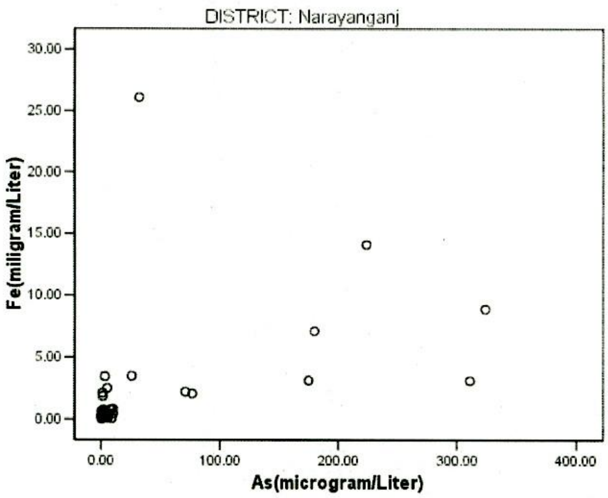

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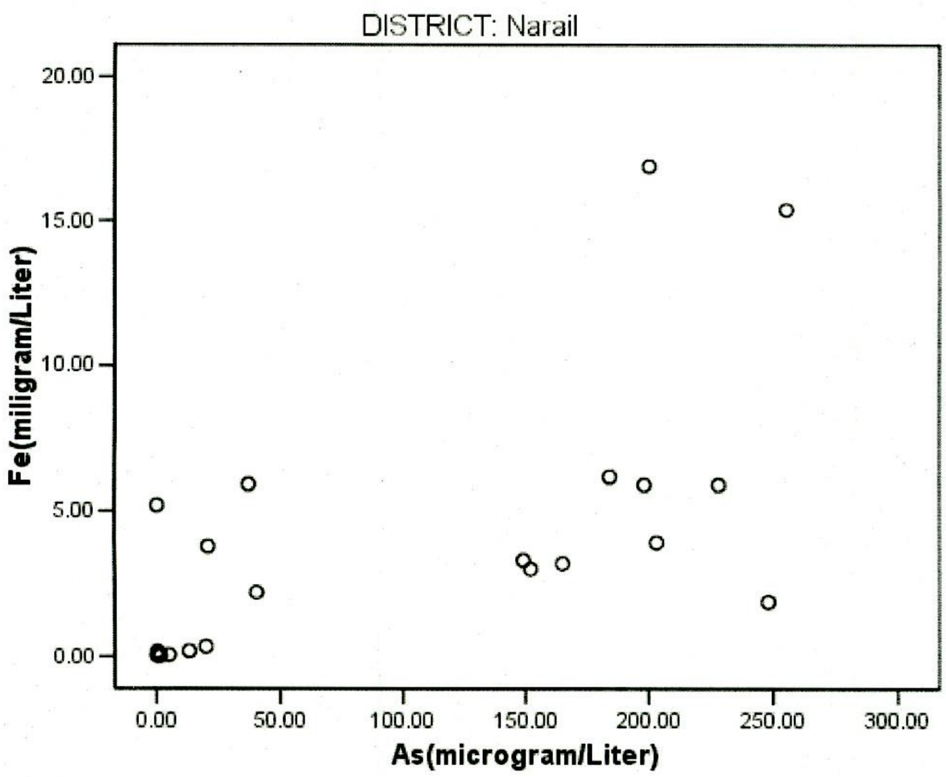

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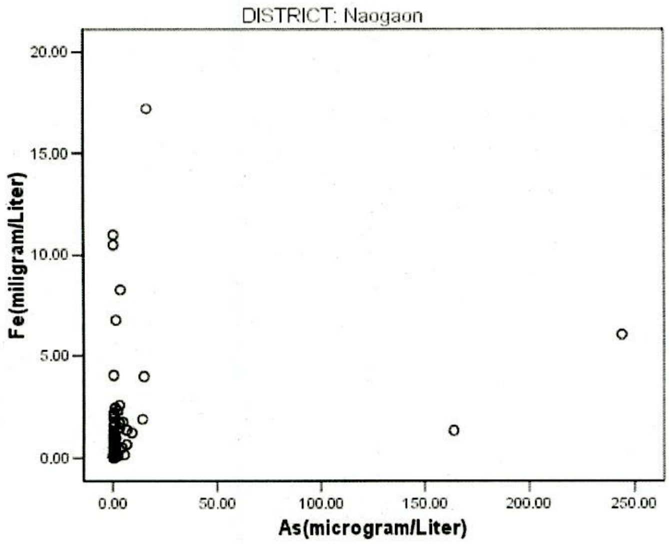

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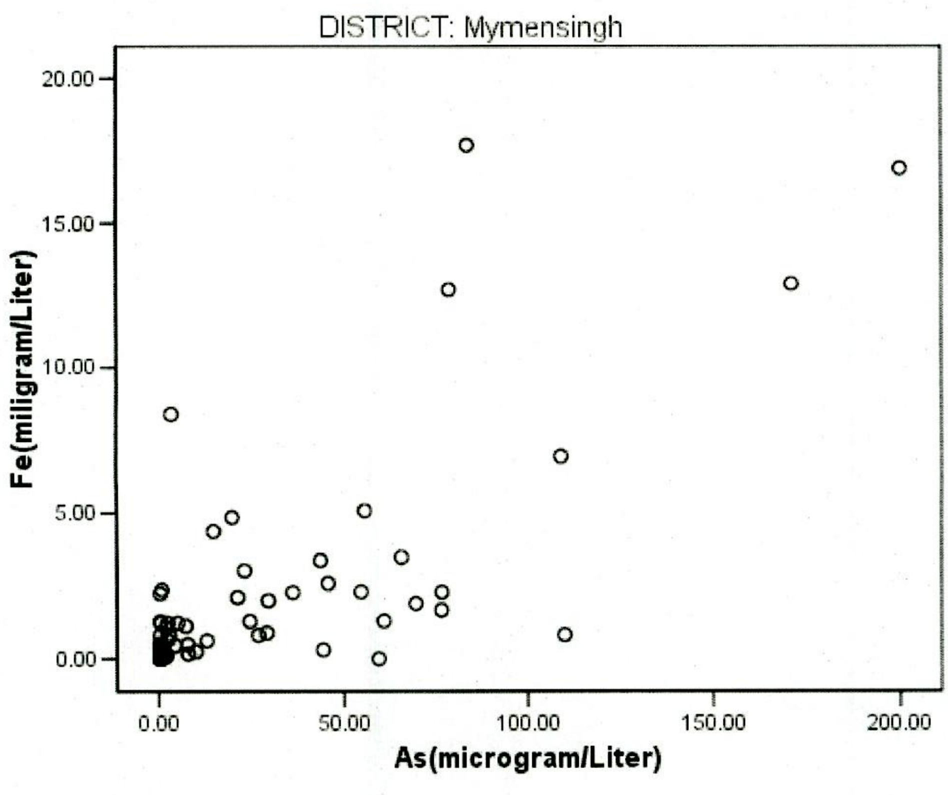

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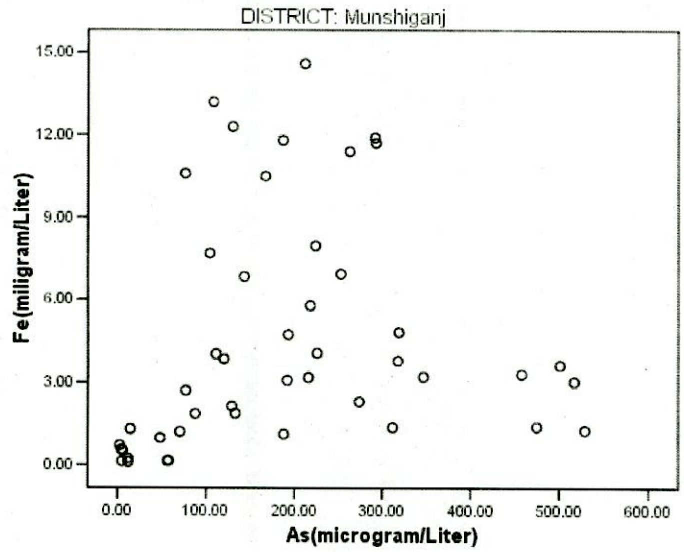

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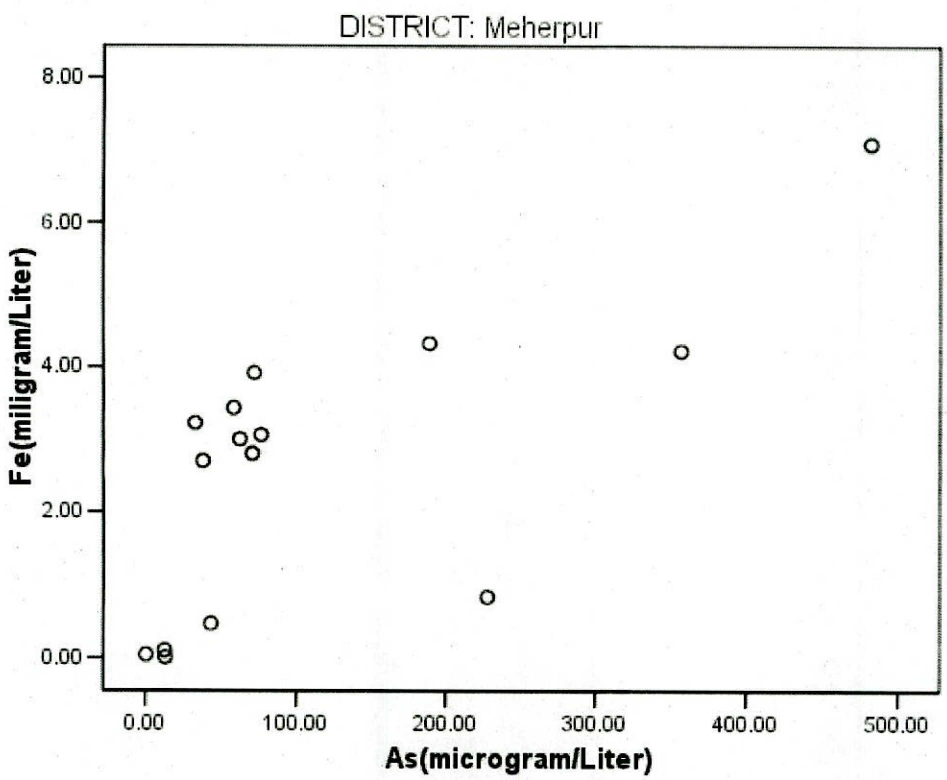

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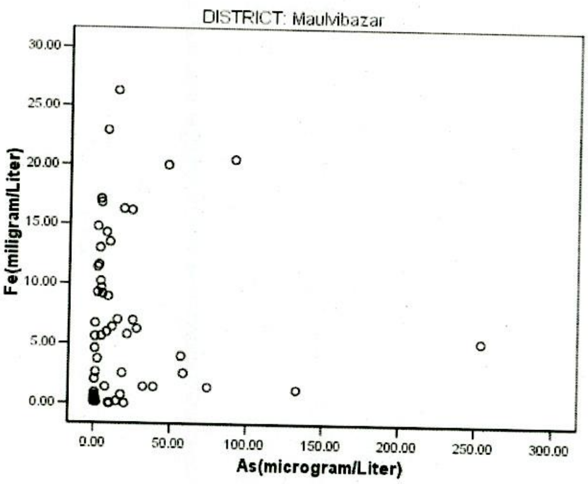

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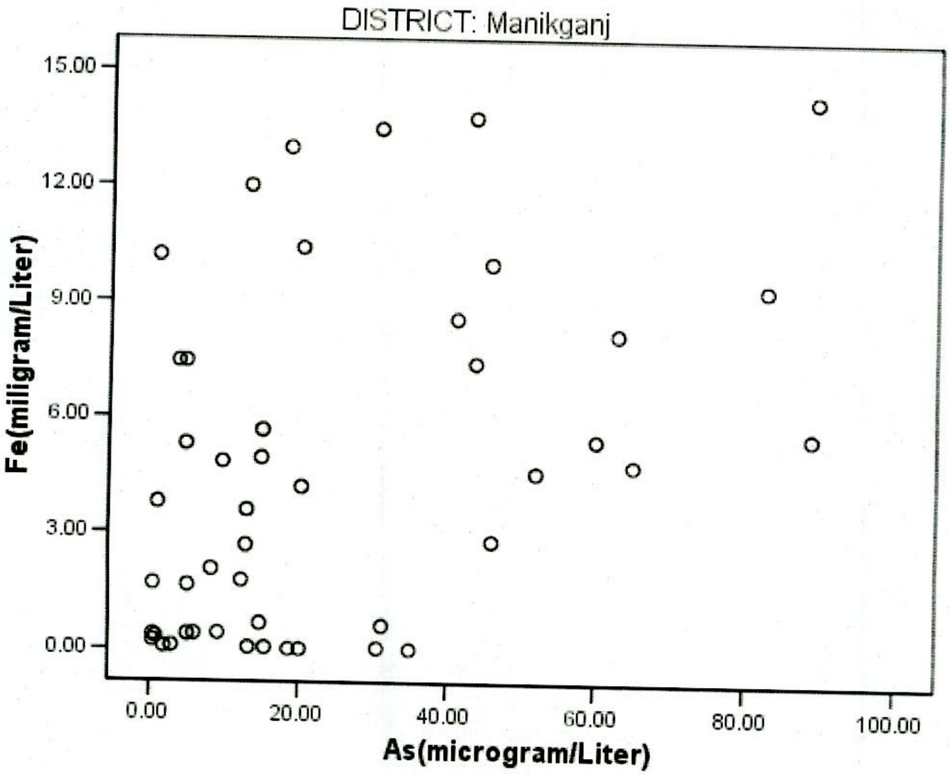

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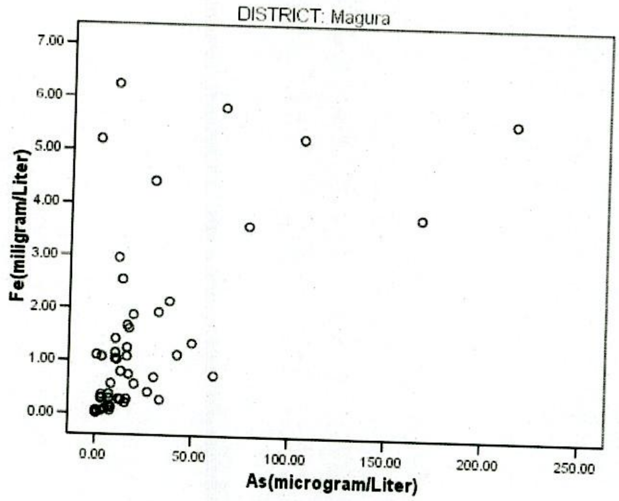

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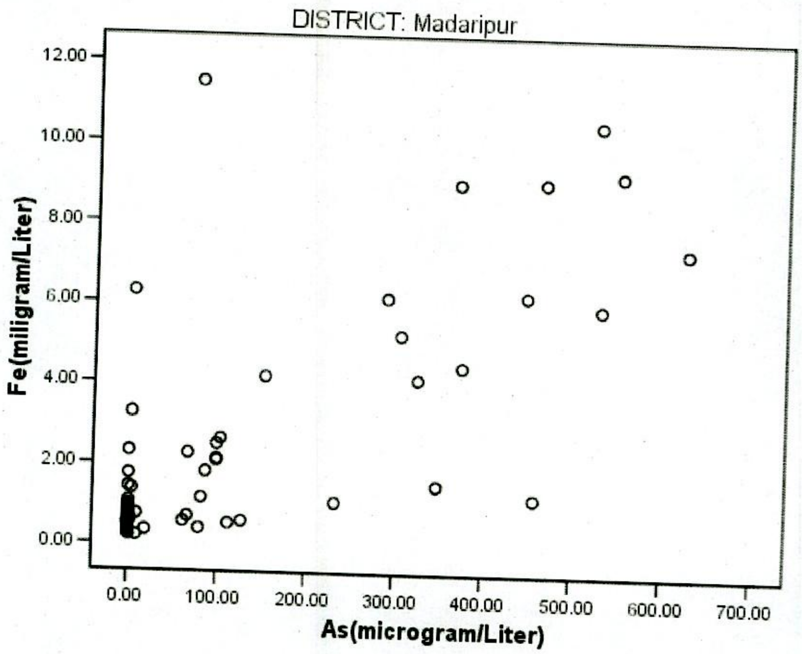

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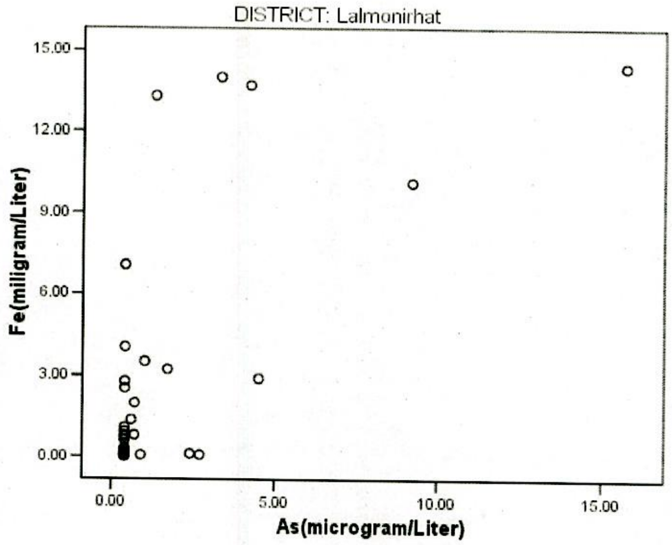

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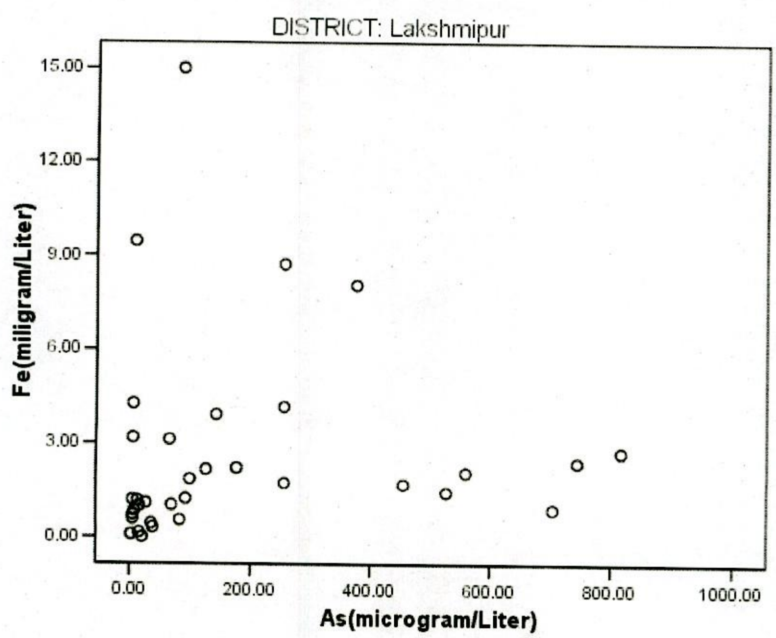

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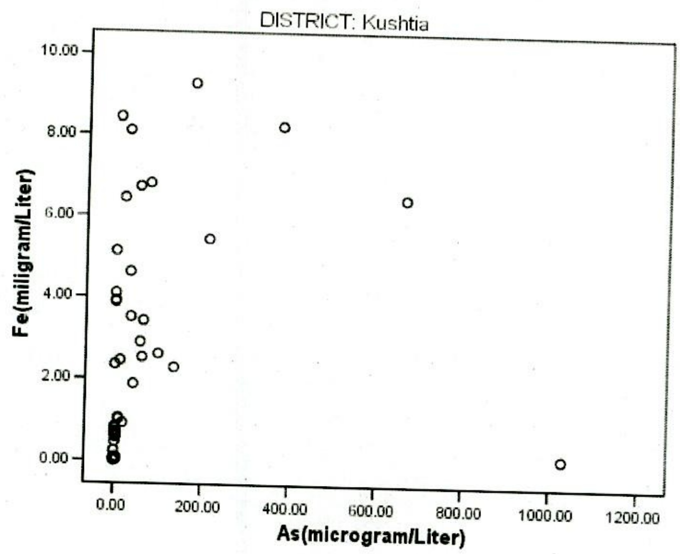

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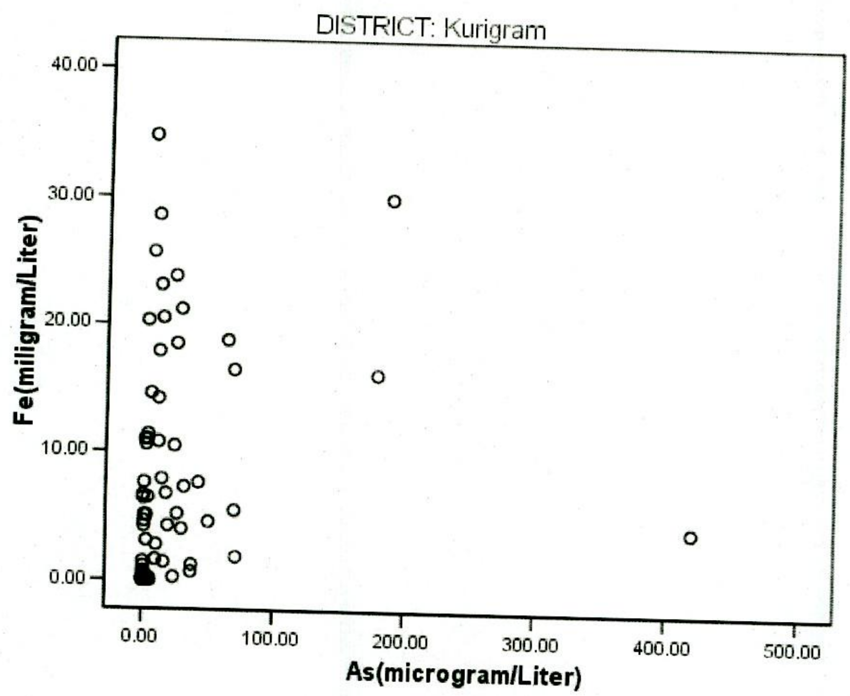

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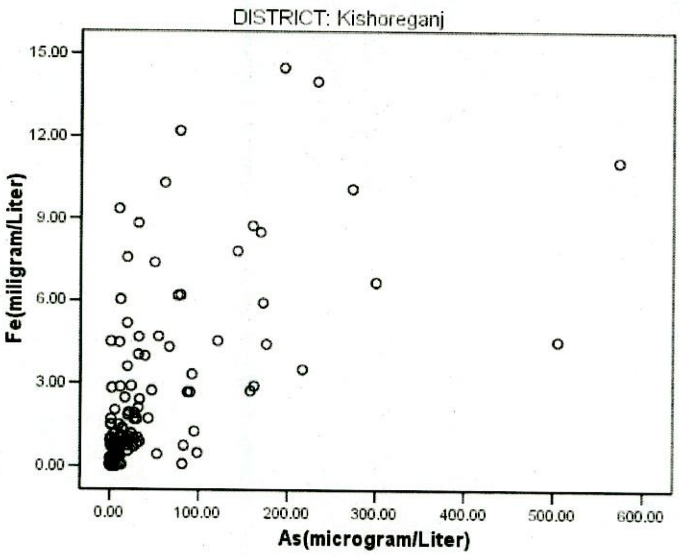

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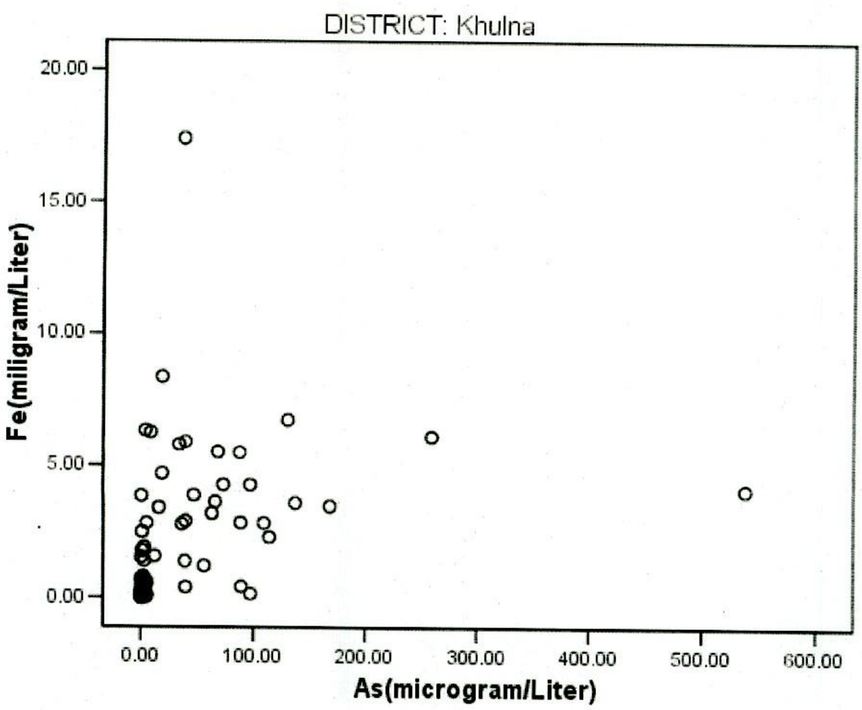

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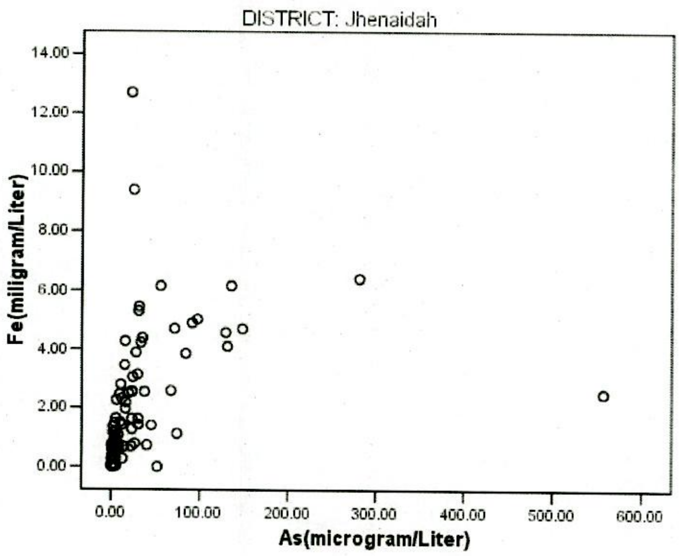

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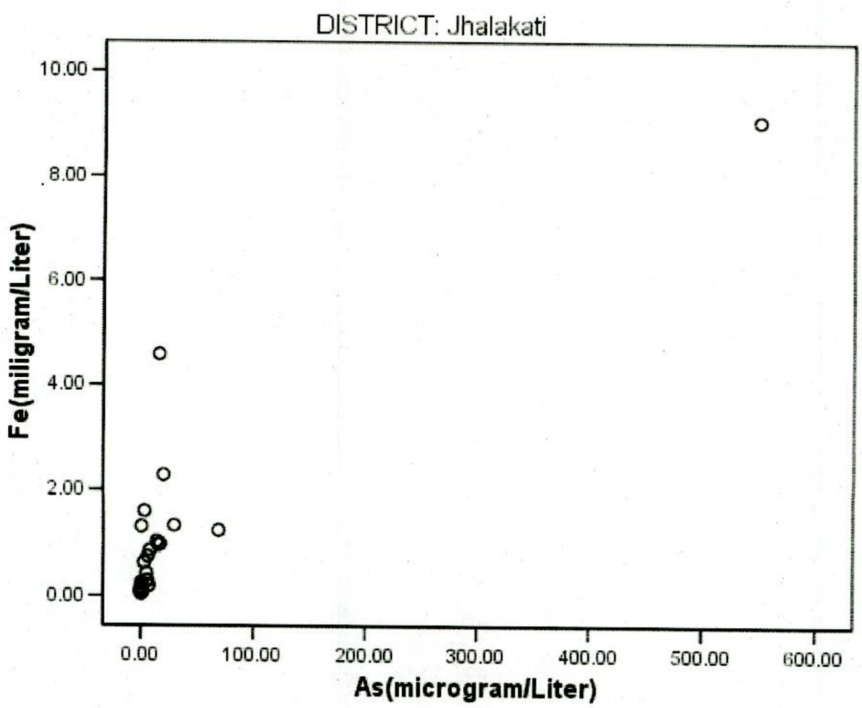

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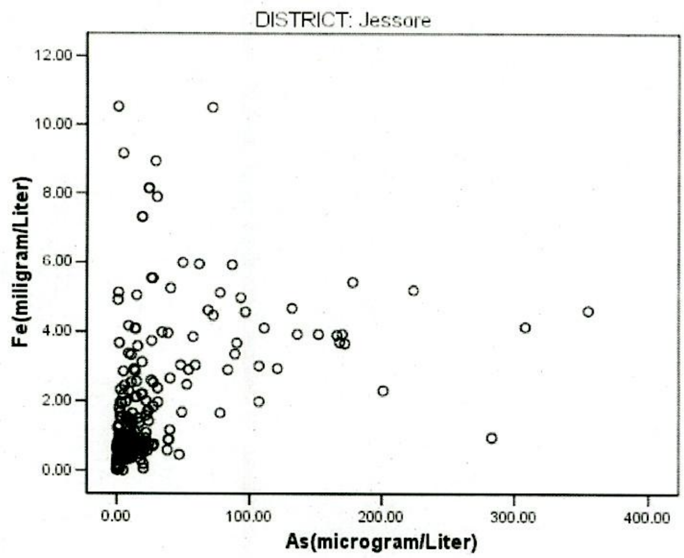

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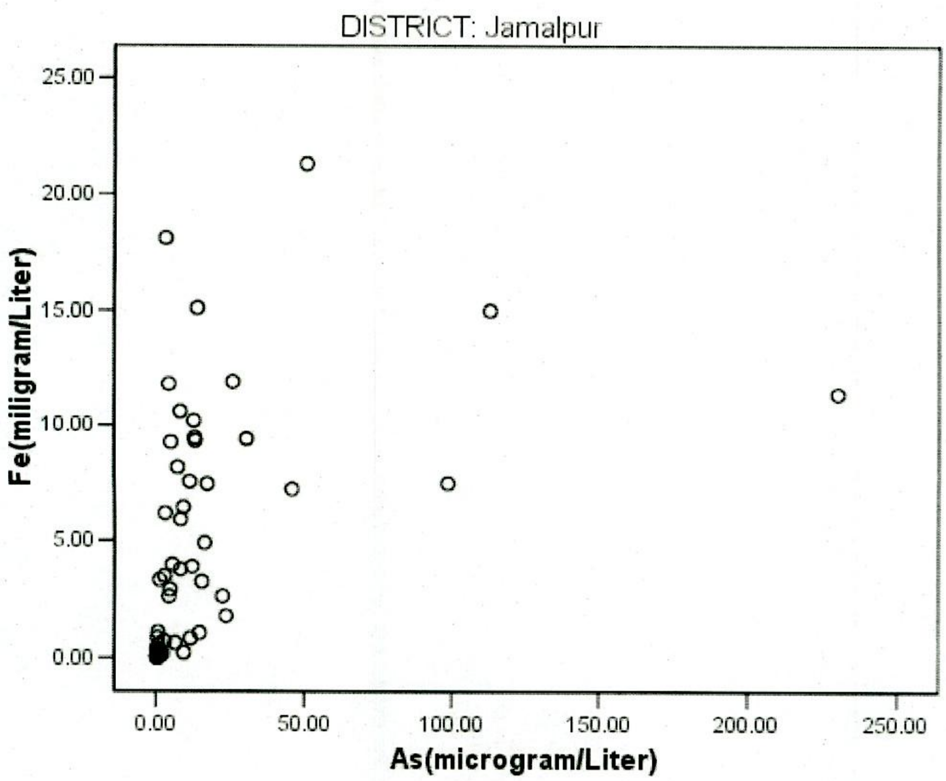

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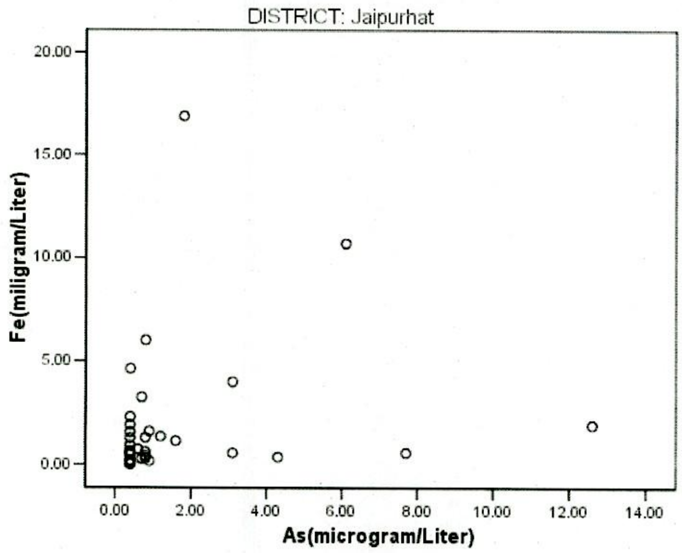

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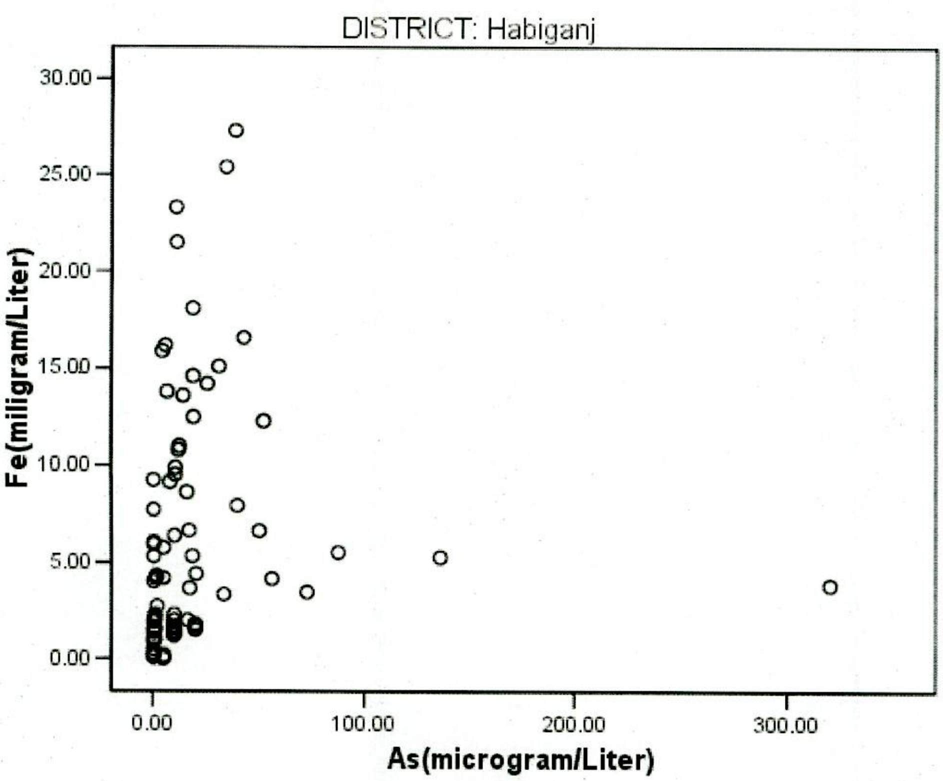

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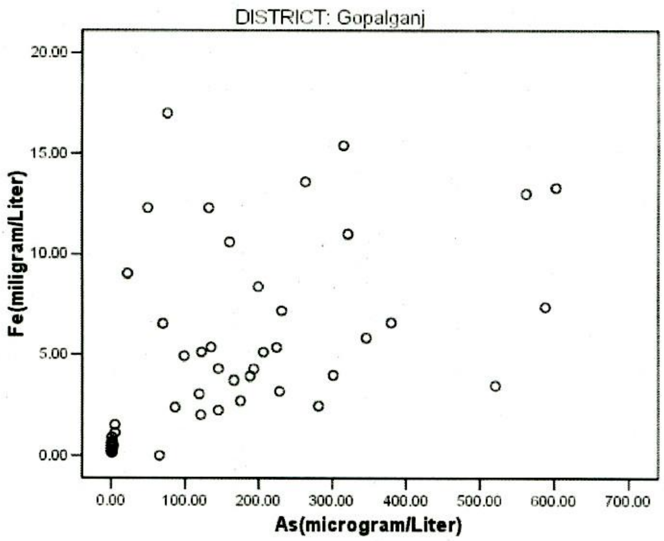

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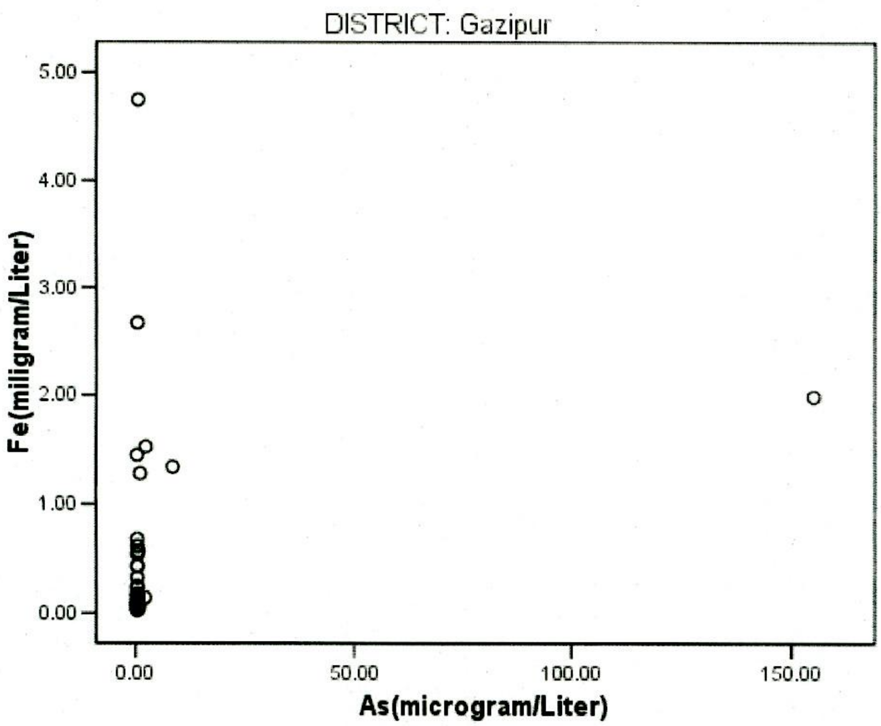

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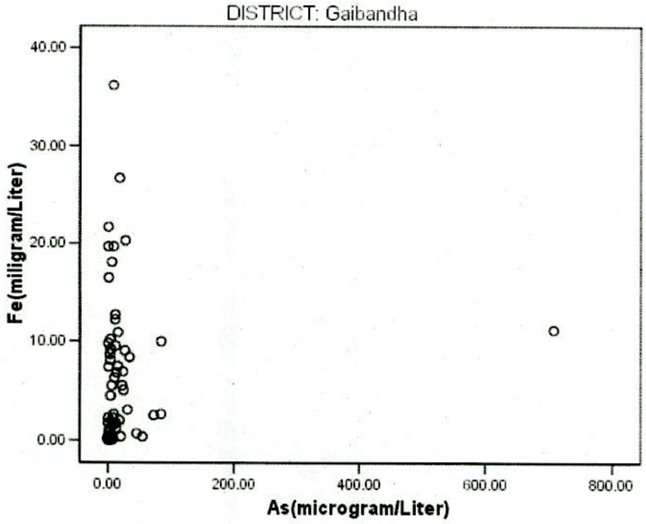

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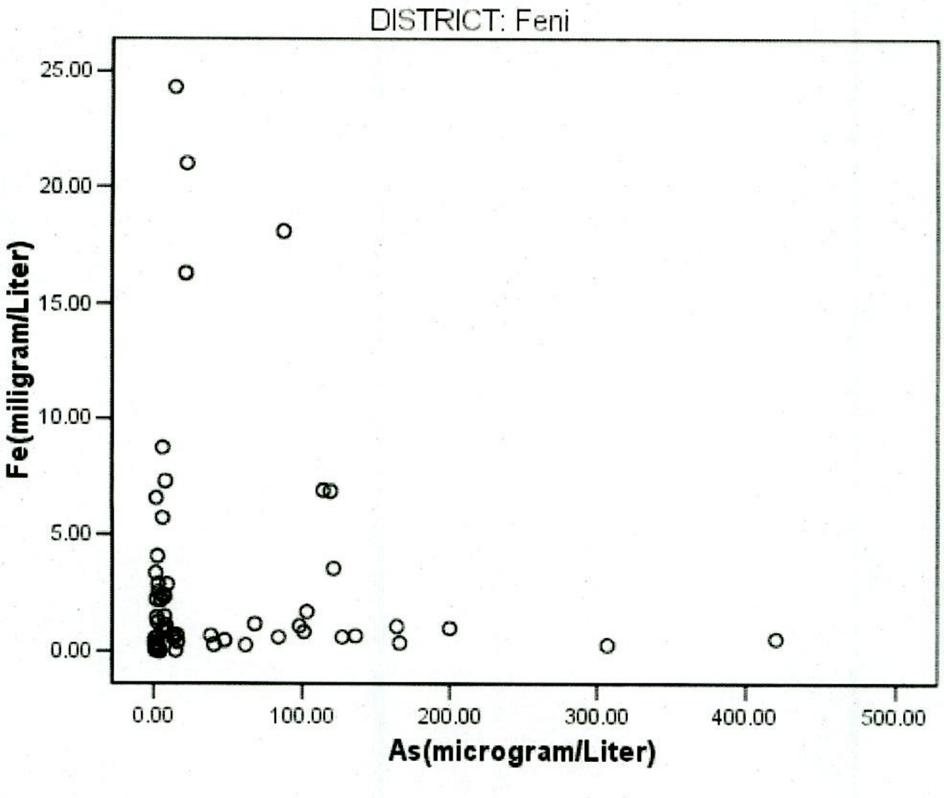

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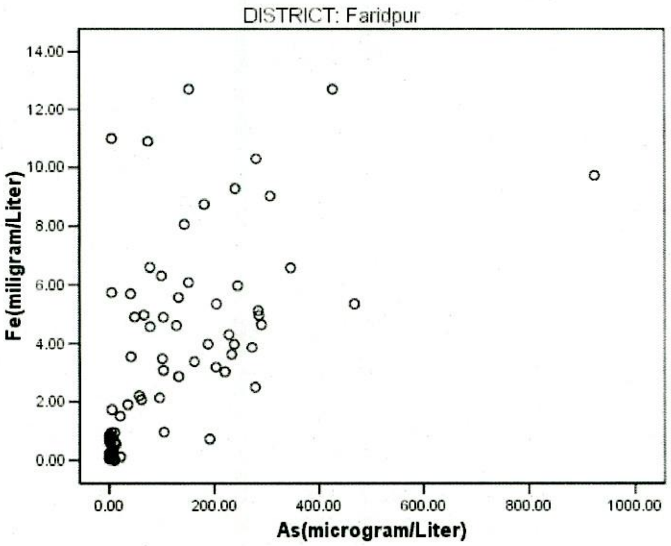

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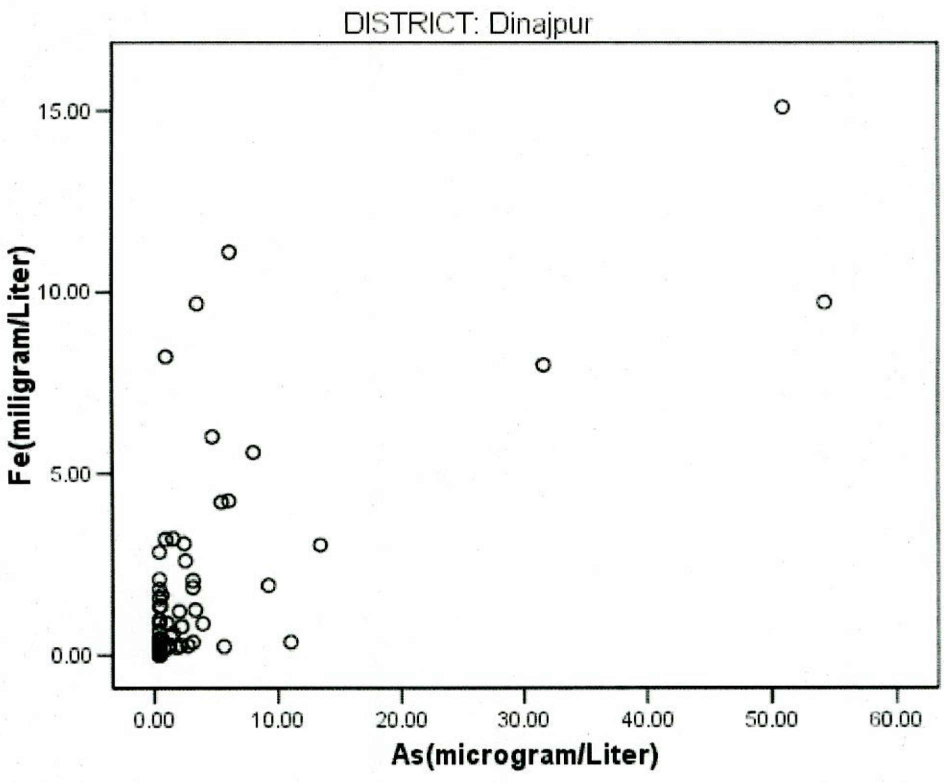

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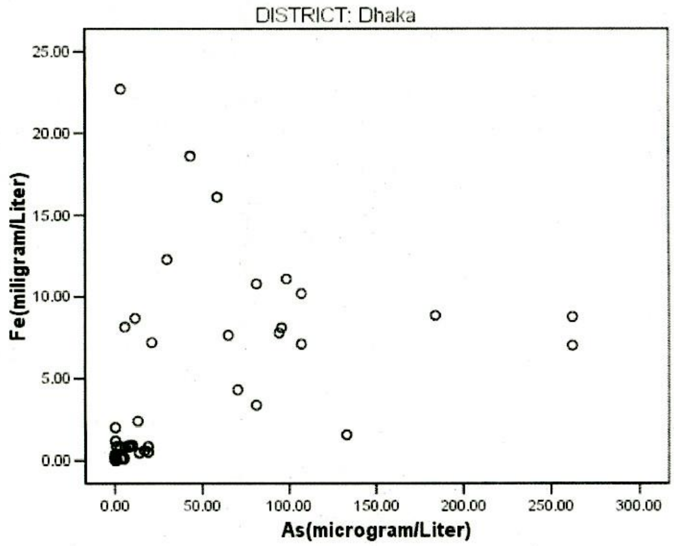

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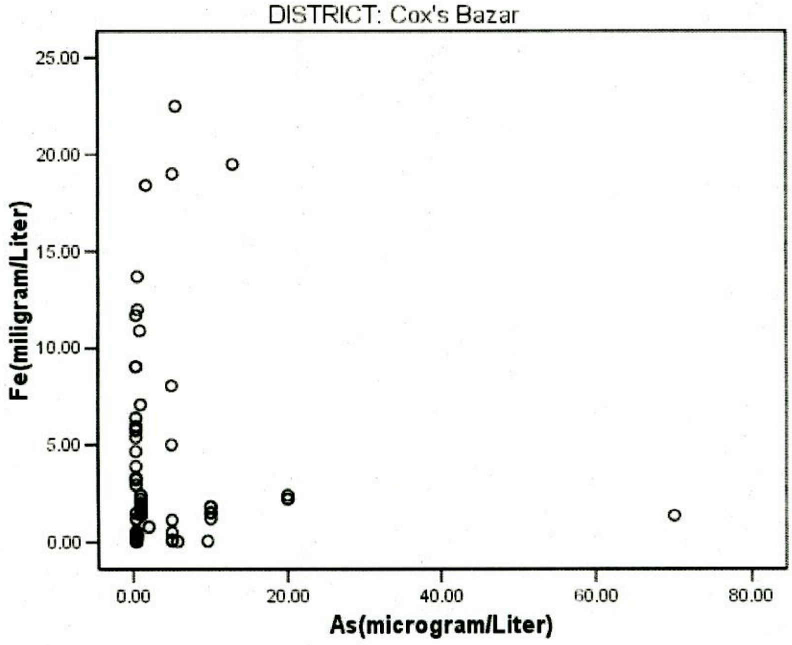

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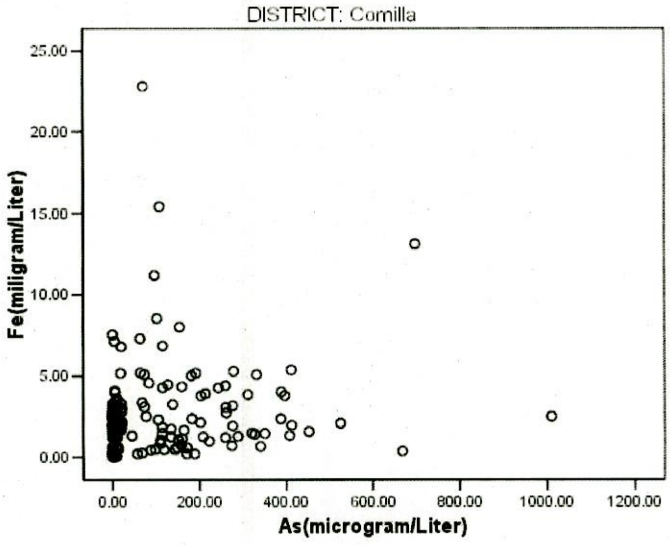

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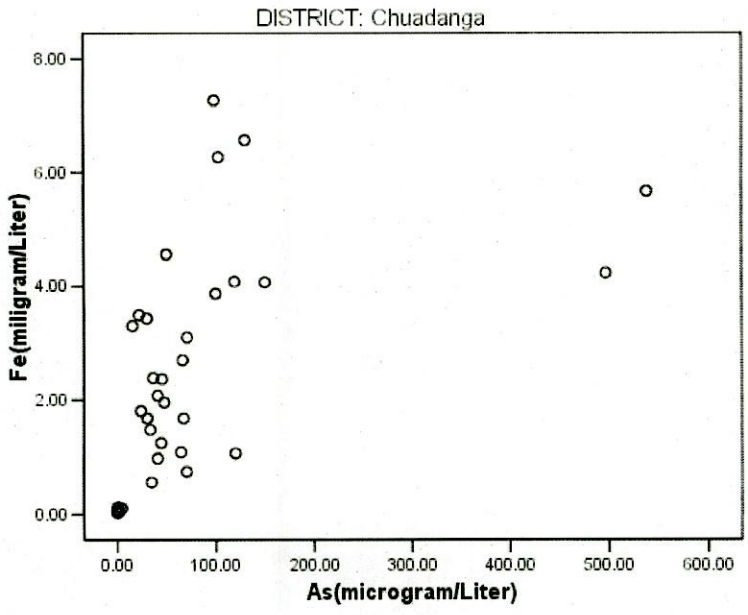

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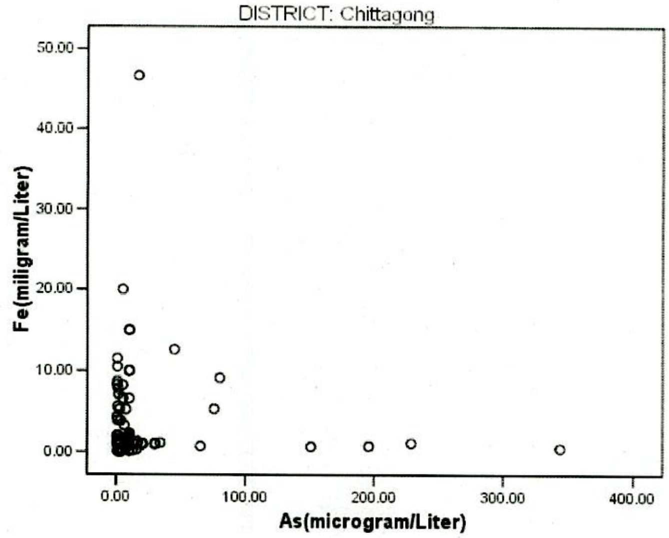

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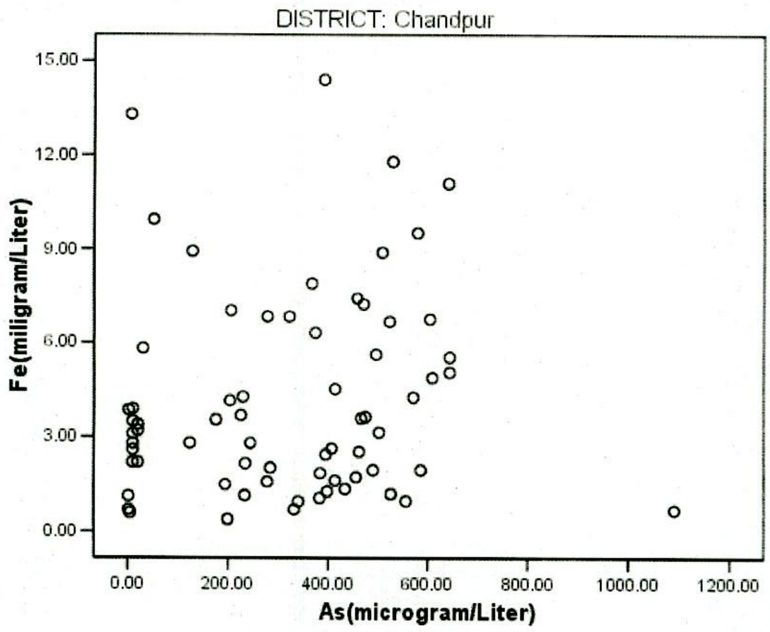

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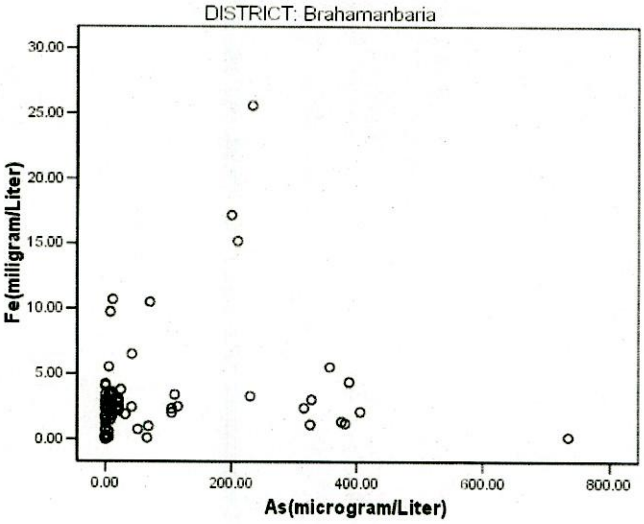

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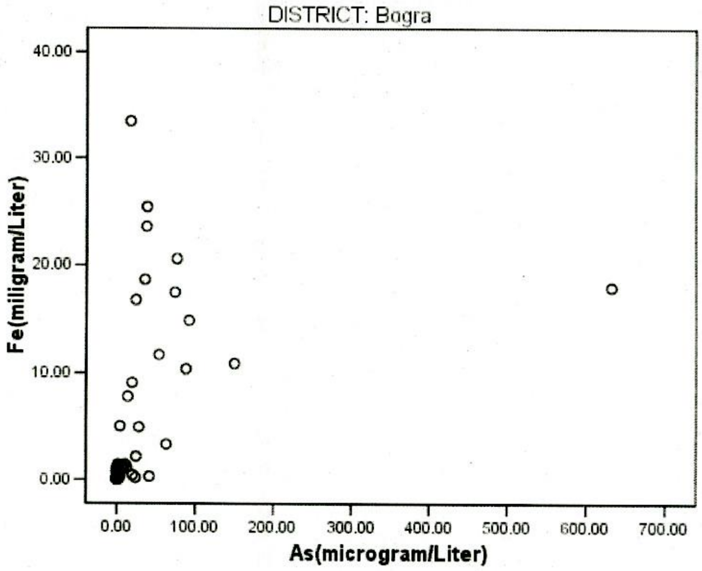

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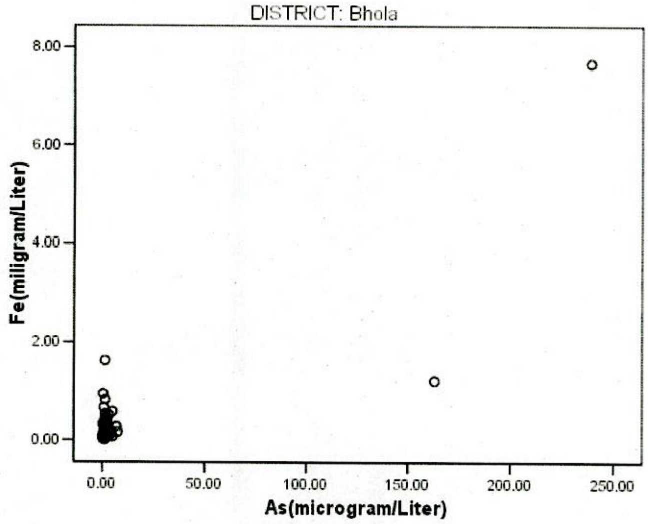

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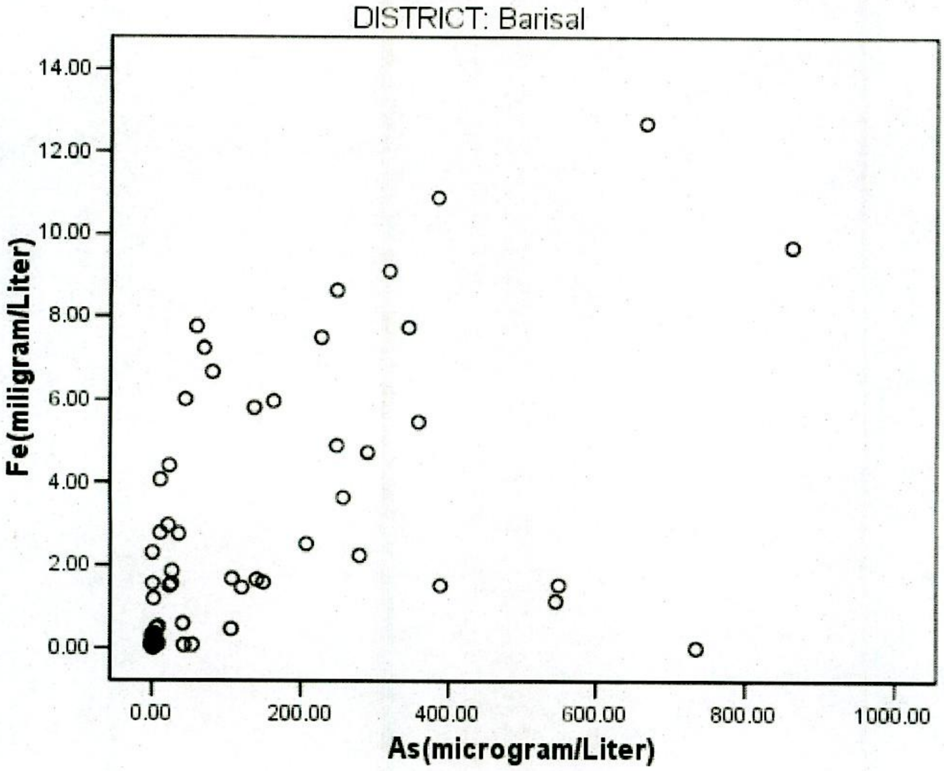

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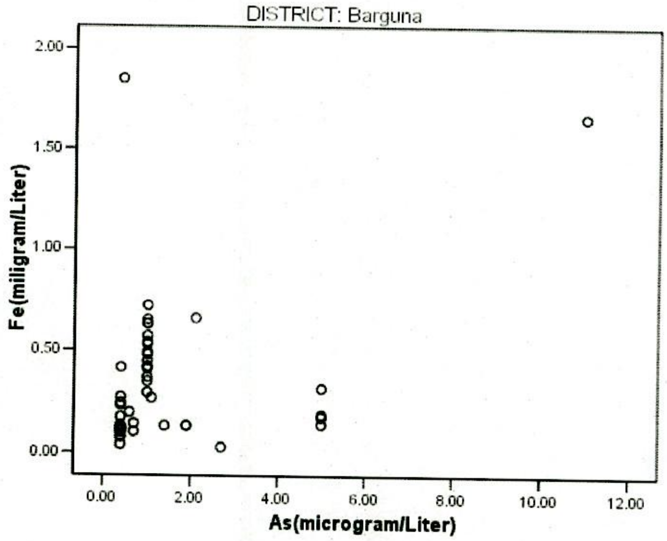

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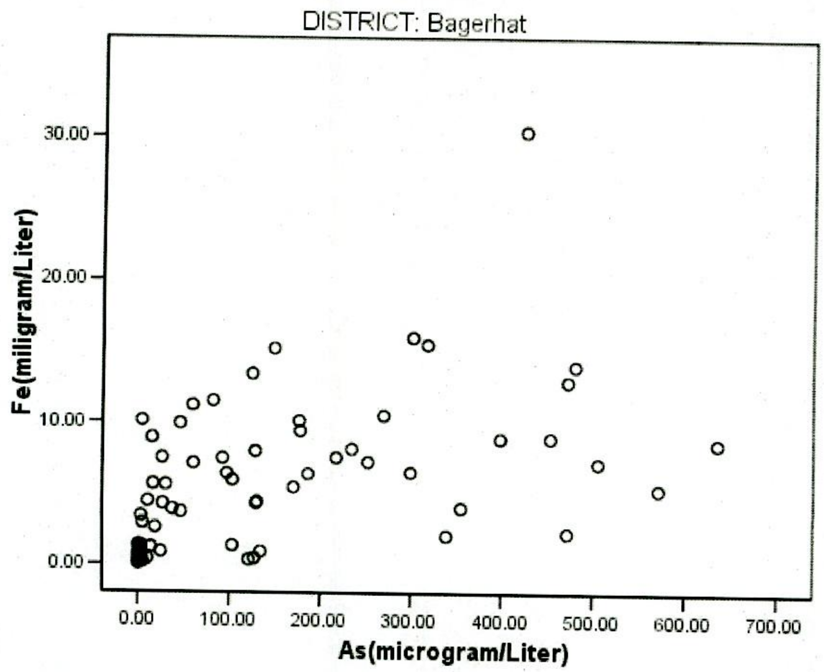

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