

**SPATIAL DISTRIBUTION OF ARSENIC, FLUORIDE, URANIUM  
AND ASSOCIATED WATER QUALITY PARAMETERS IN  
GROUNDWATER/DRINKING WATER FROM NADIA AND  
BARDHAMAN DISTRICT, WEST BENGAL**

**&**

**SUGGESTIVE OPTIONS TO MAKE IT POTABLE**

Thesis submitted for the partial fulfilment of the degree of  
**Master of Technology in Environmental Biotechnology** course  
of JADAVPUR UNIVERSITY for the session 2017-2019

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## To Whom It May Concern

It is hereby recommended that this thesis entitled “Spatial distribution of arsenic, fluoride, uranium and associated water quality parameters in Nadia and Bardhaman districts, West Bengal & suggestive options to make it potable” is prepared and submitted for the partial fulfilment of the continuous assessment of Master of Technology in Environmental Biotechnology course of Jadavpur University by Swarnendu Shekhar Das, a student of the said course for the session 2017 – 2019, under my supervision and guidance. It is also declared that no part of this thesis has been presented or published elsewhere.

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## Declaration

The thesis entitled “Spatial distribution of arsenic, fluoride, uranium and associated water quality parameters in Nadia and Bardhaman districts, West Bengal & suggestive options to make it potable” is prepared and submitted for the partial fulfilment of the continuous assessment of Master of Technology in Environmental Biotechnology course of Jadavpur University for the session 2016-2018.

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## CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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Final Examination for evaluation of Thesis

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(Signature of the Examiners)

## ACKNOWLEDGEMENT

I would like to sincerely express my heartfelt gratitude to Dr. Tarit Roychowdhury, Associate Professor, School of Environmental Studies, Jadavpur University for guiding, encouraging and providing me all necessary facilities to carry out my project work.

I would like to express my sincere gratitude to Dr. Joydeep Mukherjee, Associate Professor, School of Environmental studies, Jadavpur University for all his guidance and support during my project work. I am thankful to Dr. Subarna Bhattacharya, Assistant Professor, School of Environmental Studies, Jadavpur University, for her constant support during my work. I am thankful to Dr. Reshmi Das, Associated Professor, School of Environmental Studies, Jadavpur University, for her constant support during my work. I am thankful to Mr. Dilip Lodh, Technical Assisstent, Computer Science and Engineering Department, Jadavpur University, for her constant support during my work.

I am especially thankful to Antara Das, Ayan De, Nilanjana Roy Chowdhury, Madhurima Joardar, Shresthashree Swain (research scholars) and Dr. Soma Ghosh, of the respective department for helping and supporting me throughout the duration of my project work. I am especially grateful to Bishal Ghosh and Meenakshi Mukherjee (class mates) for their esteem help and assistance.

I am very much thankful to Mr. Debasish Maity along with other samplers for helping me with my sampling of water samples. I am also thankful to Mr. Mannan Das and Mr. Nilu Das. Finally, this research project would not have been possible without the confidence, encouragement and support of my parents and my sister.

---

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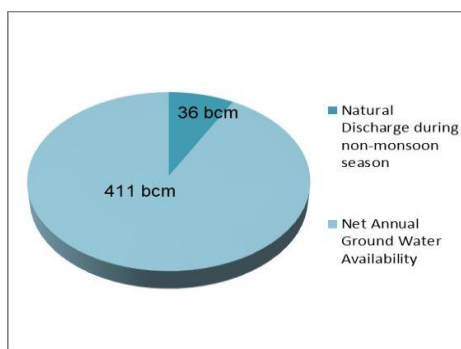
## Chapter 1

### INTRODUCTION

Human life is indispensable without water. From the dawn of civilization it is known through history and literatures that humanity thrived with the presence of water. In Indian literatures water is termed as an alternative of life. Thus water becomes the life-force for India and her people which comes from all available water resources. It is estimated that India has usable water resources as nearly as 1,123 Billion Cubic Meter/year. Out of which the surface water reserves share 690 Billion Cubic Meter/year and ground water reserves share and 433 Billion Cubic Meter/year respectively (Water and Related Statistics, 2015) but the availability of ground water majorly depends on the rainfall recharges as that is a great part of the hydrological cycle (Todd, 1959). The overall influence of rainfall to the country's annual ground water reserves is 67% and the portion of other resources, such as recharge from tanks, canal seepage, and return flow from irrigation, perennial flows, ponds and water conservation structures are 33%. (CGWB) Groundwater is extensively used in the agricultural sector of India. As a study suggests more or less 89% of the available groundwater is drawn out from underground for irrigation purposes and for the production of crops (MWRD).

As the expenditure and labour required in the development of surface water is much more as compared to groundwater, more stress is engaged on the exploitation of groundwater which can be developed within a little time (Nag and Ghosh, 2013). Thus the declination of the groundwater levels impair the overall quality of groundwater. Groundwater has become a significant concern particularly in rural areas where the population is extensively dependent on groundwater for drinking purposes (Batabyal and Chakraborty, 2015). In rural India, >700 million people in 1.42 million residences are dependent on groundwater. (MWRD) Rural parts along with thriving human population are greatly known for the "lack of hygiene" which can simply aid to the multiple problems of reduced water quality (Obi et al., 2002). Over exploitation of groundwater impairs human health. As a result, it leads to various waterborne diseases which has affected ~37.7 million people each year in India. An estimation says that approximately 1.5 million children die of diarrhoea every year (indiawaterportal.org). It is reported that more than 33% of groundwater resources in India is unhealthy for drinking. (Times of India, March 12, 2010). The quality of groundwater depends upon the surrounding aquifers, hard rock layers and hard strata. Hard rock aquifers of central peninsular India contribute to 65% of the overall aquifer surface area, which has

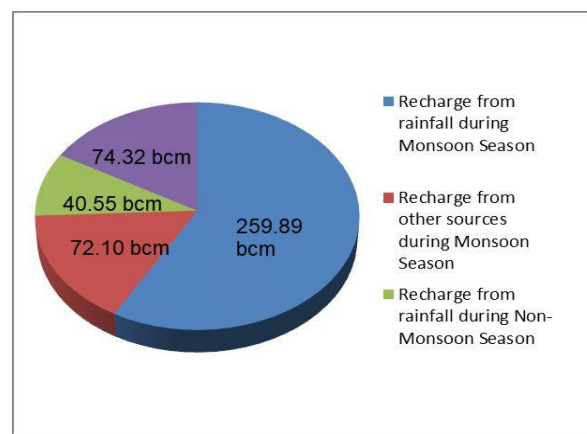
low permeability, low groundwater storage and recharge capacity. Alluvial aquifers of Gangetic plains of Northern India comprises of significant ground water storage capacity but excessive extraction and low recharge rates are leading these excellent freshwater sources towards the risk of irreversible over exploitation. (prsindia.org). The rapid pace of industrialisation and greater emphasis on agricultural growth combined with financial and technological controls and non-enforcement of laws have led to generation of huge quantities of waste and water pollution. (Indiawaterportal.org) Unplanned and improper waste management system leads to the generation and intrusion of toxic chemicals subject to leaching into the ground water (Wu and Sun, 2016).



**Fig 1.1 (a):** Non-monsoonal discharge



**Fig 1.1 (b):** Usage of groundwater



**Fig 1.1 (c):** Overall groundwater availability

**Fig 1.1 (a, b, c):** Groundwater Resource Availability and Utilization (Image Source: CGWB 2016-2017)

## Chapter 2

### LITERATURE REVIEW

Apart from the water borne diseases a great number of people in our country are at a risk of excessive arsenic (As) and fluoride (F<sup>-</sup>) contamination in ground water. In other hand, Uranium is a radioactive element that causes massive ground water pollution. The source of contamination for these elements are majorly geogenic but the contamination may begin with anthropogenic activities (Chakraborti et al., 2004; Kumar et. al., 2017). Arsenic, being a group I carcinogen, poses health hazards to humans, creates unhealthy effects such as keratosis, skin pigmentation problems, black foot diseases, diabetes and in some serious cases, cancers of the skin, lung, and bladder (Wang et al. 1998). In India groundwater arsenic contamination is reported in the states of Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh, Assam and West Bengal (CGWB 2010; Chakraborti et al., 2004). It is reported that six districts of West Bengal are severely affected by chronic arsenic exposure where the groundwater arsenic concentration is found to be more than BIS limit of 0.01 mg/l. These six districts are South 24-Parganas, North 24-Parganas, Nadia, Bardhaman, Murshidabad and Malda (Das et al., 1996). F<sup>-</sup> contamination has been long recognised as one of the greatest noteworthy natural groundwater-quality problems distressing arid and semi-arid regions of India (Kumar et al., 2016). In Indian continent the higher concentration of Fluoride in groundwater is linked with igneous and metamorphic rocks. Some anthropogenic activities such as use of phosphate based fertilizers, pesticides and sewage and sludge, depletion of groundwater table etc., and agriculture have also been indicated to cause an escalation in Fluoride concentration in groundwater (EPA 1997; Ramanaiah et al. 2006). In India, groundwater contamination with Fluoride is reported in the States of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Rajasthan, Chhattisgarh, Haryana, Orissa, Punjab, Haryana, Uttar Pradesh, West Bengal, Bihar, Delhi, Jharkhand, Maharashtra, and Assam (Keshari and Dhiman,2001; Jacks et al., 2005; CGWB, 2010). In West Bengal eight districts have been reported with a groundwater fluoride contamination with a concentration level >1.5 mg/l in Bankura, Bardhaman, Birbhum, Dakshindinajpur, Uttardinajpur, Malda, Nadia and Purulia (CGWB 2010). The reasons for co-occurrence of As and F in groundwater can be both geogenic and anthropogenic but the reported major population exposure worldwide is due to ingestion of contaminated groundwater mainly from geogenic occurrences. The co-

contamination of Arsenic and Fluoride is observed in Brhmaputra and Gangetic flood plains (Kumar et al., 2016). The co-existence of arsenic and fluoride can depend upon several factors.

As (0.96-720  $\mu\text{g/l}$ ) and  $\text{F}^-$  (0.30-2.57  $\text{mg/l}$ ) reveals a large spatial variation in the groundwater of Hetao basin, in Inner Mongolia. Dissolution and precipitation of Ca-minerals (such as fluorite and calcite), and adsorption-desorption are found to be probable factors controlling the concentration of these elements in their groundwater, though no significant correlation was seen between As and  $\text{F}^-$  concentrations (Guo et al., 2012). Zhang et al., 2013 suggested that low hydraulic gradient promotes As enrichment in the groundwater in Hetao Plain. He et al., 2013 found that long-term rock-water interaction plays major role in the release of  $\text{F}^-$  in the groundwater of silty clay aquifer of that area. In Datong basin, China desorption of Fe-(hydrox) oxides is suggested to be the most important mechanism of As (470  $\mu\text{g/l}$ ) enrichment into the samples collected from deep groundwater, where high  $\text{F}^-$  (~22  $\text{mg/l}$ ) is present in shallow groundwater with elevated  $\text{HCO}_3^-$  in the discharge area in the basin centre (Li et al., 2012). In an another study by Su et al., 2013, it was suggested that presence of alkaline conditions along with prevalence of processes like evapotranspiration and dissolution of fluorite can favour fluoride enrichment in groundwater due to its long residence time in Datong basin. High correlation coefficient can be observed in areas with arid and humid-continental climate (Chihuahua, Mexico) and lower average precipitation ranging from 338 to 403 mm. Moderately strong correlation coefficient is also found in places like Darrang and Lakhimpur districts from Assam, India where the climatic condition is humid and sub-tropical with an average precipitation of 1355 mm-2350 mm and 2855 mm (Guha Roy, 1969) respectively. A study by Kumar et. al., 2016, has found that at lower concentration both the chemical species have minor correlation and have affinity for other ionic species depending on their individual chemical nature. Both the species are found in Ca- $\text{HCO}_3$  and Ca- $\text{Cl}_2$  type of water and a positive correlation between Fluoride and  $\text{Ca}^{+2}$  which is due to the presence of limestone in aquifers of Diphu, Assam. Rasool et al., 2015, suggests that due to shallow water tables in arid regions, the evaporative concentration of phosphate and phosphate analog, in surface sediments play a major role in the As contamination of the groundwater. Arsenic (507  $\mu\text{g/l}$ ) and Fluoride (29.6  $\text{mg/l}$ ) are associated with a 60m – 65m tube-well depth with the presence of alkaline groundwater and aquifers of oxidizing nature. Their study prefers the adsorption of phosphate on sediments enhance the release of As in Punjab, Pakistan. In a study by Kim et al., 2012 it is found that in oxidizing aquifers with increased pH and alkaline

condition, the co-contamination links with the desorption from the Fe-(hydr)oxides and strong correlations between Arsenic and Fluoride are observed. In reducing environments, the reductive dissolution of Fe-(hydr)-oxides plays a major role in the co-contamination of As and F but with a poor correlation.

Uranium is a radioactive element that causes ground water pollution primarily from geogenic sources but may further mobilise due to various anthropogenic causes like groundwater declination and nitrate pollution. Uranium in groundwater primarily causes nephrotoxic effects in human body through high accumulation in kidneys and may lead to cancer. (Kumar et al., 2016; Orloff, et al., 2004). To protect against possible renal toxicity, the US Environmental Protection Agency has publicized a drinking water Maximum Contaminant Level (MCL) of 20 µg/l. (EPA 2000), the World Health Organization (WHO) has recommended the permissible limit of Uranium in drinking water as 30 µg/l (WHO 2004), though the Atomic Energy Regulatory Board, Department of Atomic Energy has mentioned the maximum limit to be 60 µg/l (AERB 2004). A study has found that drinking water has uranium levels of up to 40 µg/l has a weak but significant association between uranium and tumours, liver diseases and thyroid diseases in Germany's Bavaria state (Banning, A., & Benfer, M. (2017). The results of a study indicate that after long-term ingestion of uranium in drinking water, elevated concentrations of uranium in urine could be detected up to 10 months after exposure had stopped (Orloff, et al., 2004). A study made by researchers from Duke University has found that, correlation between Uranium and bicarbonates exists in such a way that higher concentrations of bicarbonate (~410 mg/l) causes Uranium concentration to rise up much higher than safe limit given by WHO which is 30 µg/l (Coyte et. al, 2018). As the study was conducted in Rajasthan's alluvium and crystalline basement aquifers it can be said that in most parts of India may favour the condition of geogenic uranium contamination. As most parts of India the presence of alluvial types of aquifers with a crystalline basement are found (CGWB 2012). It is reported that, uranium contamination in groundwater from aquifers across 16 states in India, much above the WHO provisional standard for the country. (The Hindu, June 9, 2018)

Nitrate ( $\text{NO}_3^-$ ) is an "anthropogenic pollutant" discharged from various non-point sources in the form of nitrogenous fertilizers, industrial effluents, and human and animal wastes and enters into the soil through the biochemical activity of nitrifying bacteria and finally leaches into and contaminates the groundwater (Agrawal et. al., 1999; Hansen & Djurhuus, 1997). In India, nitrate concentration more than BIS limit of 45 mg/l is reported in Andhra Pradesh,

Bihar, Chhattisgarh, Delhi, Goa, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Karnataka, Kerala, Maharashtra, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand and West Bengal (CGWB, 2010). It is reported that the groundwater pollution due to nitrates is increasing in India.

Nitrate contaminated groundwater causes Methemoglobinemia in children at a very early age. Methemoglobinemia or Blue baby syndrome is a serious condition that happens when the hemoglobin in an infant's red blood corpuscles is oxidized to methemoglobin. As methemoglobin is inept for the transportation of oxygen, thus the condition produces symptoms of cyanosis. Depending on the severity of the illness the affected infants develop an uncommon blue-gray or lavender skin color and becomes irritable or lethargic. Methemoglobin levels >50% can rapidly lead to coma and death if the severity of the condition is not recognized and treated. Two reported cases of infant Methemoglobinemia suggests that nitrate-contaminated water poses hazard to infants during the first 6 months of life (Knobeloch et al., 2000).  $\text{NO}_3^-$  concentration is responsible of several diseases as hypertension, cancer and birth defects (Spalding & Exner, 1993) thereby, a maximum of 45 mg/l for drinking water purpose is accepted by (WHO 1984) and BIS 10500:2012. Kostraba et al. 1992, suggested that low-level nitrate exposure may play a role in the origin of insulin-dependent diabetes mellitus. The authors theorized that ingested nitrate damages the insulin-producing cells in the pancreas through the generation of free radicals (Kostraba et al., 1992). A proper assessment for the suitability of groundwater for domestic water supplies are needed as the concentrations of some important parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), Calcium (Ca), Magnesium ( $\text{Mg}^{+2}$ ), Potassium (K), Sodium (Na), Chloride ( $\text{Cl}^-$ ), Bicarbonate ( $\text{HCO}_3^-$ ), and Sulphate ( $\text{SO}_4^{2-}$ ), should be compared with the guideline values (Nag and Ghosh, 2013). As a study by Batabyal and Chakraborty, 2015, suggests that dissolved cations and anions like Sodium, Potassium, Magnesium, Bicarbonate, Chloride, Nitrate, Sulphate, Iron and Manganese can determine the overall quality of water based on their calculated Water Quality Index and the quality of water changes from “good water” to “poor water” in their selected indices owing to the amount of leaching and subsequent infiltration of contaminants into the shallow aquifer zones during monsoonal periods in Kanksa-Panagarh area of Bardhaman district. A study suggests that higher values of iron, nitrate, hardness, bicarbonate, fluorides, chloride, manganese and total dissolved solids in the groundwater contributes to about 63.5% poor quality water in their selected indices of Water Quality Index. The study also suggests that “significant

interrelation” of Magnesium and Calcium contributes to the “permanent hardness” in the groundwater in Tumkur taluk, Karnataka (Ramakrishnaiah et al., 2009). A study by Krishan, et al, 2016, suggests that calculated Water Quality Index considering pH, Total Dissolved Solids, Total Hardness, Chloride, Fluoride, Sulphate and Nitrate, the corresponding indices state that majority of a 82.5% groundwater samples are in the “Good” category, 12.5% samples are in “Excellent” category and remaining 5% samples are in the “Fair” category in Haridwar, Uttarakhand. The result of the study also suggest that chloride and hardness are found to be higher as compared to the permissible limit given by BIS: 10500-2012 which is leading to higher TDS values because of anthropogenic sources from industrial areas in the Haridwar district.

Improper solid waste management leads to formation of leachate which travels unground and affects the quality of groundwater. Excessive chloride concentration (1174.2 mg/l) at a depth of 5m below a landfill facility with a landfill height of 22m is found in Bhalsawa, Delhi (Jhamnani & Singh, 2009).

The amount of potable fresh water is very low. Therefore, it should be a major concern for all of us to monitor and protect the quality of ground water.



## Chapter 3

# WATER QUALITY PARAMETERS

In this study ground water quality parameters are divided into four major groups depending upon every parameters fundamental characteristics and effects on human health and environment.

### 3.1. Physical Parameters of Groundwater

- **pH:** It is the measure of hydrogen ion concentration. The pH value of water is an indication of the alkalinity or acidity of the water on the scale of 0 to 14.
- **DO:** Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in the water and the amount of oxygen available to living aquatic organisms. The amount of dissolved oxygen in a stream or lake can tell us a lot about its water quality. As per WHO dissolved oxygen amount should be 4 – 6 mg/l. Maximum DO which can present in water is 18 mg/l.
- **EC:** Conductivity of a substance is defined as 'the ability or power to conduct or transmit heat, electricity, or sound'. Its units are Siemens per meter [S/m] in SI and millimhos per centimeter [mmho/cm]. (<https://thoughtco.com>)
- **ORP:** Oxidation reduction potential is an indication of the oxidizing or reducing power of water. High pH of water leads to negative values of ORP and vice versa.
- **Salinity:** Salinity is an aesthetic measure of water which is dependent on TDS.
- **TDS:** Total Dissolved Solids or TDS in groundwater formed due to decomposition of minerals and rocks due to various chemical reactions. Generally, the analysis of TDS is often made by determining the EC of water.

$(\text{EC in } \mu\text{Mho/cm at } 25^\circ\text{C}) \times k = \text{Dissolved solid content in mg/l}$

Where,  $k = 0.55$  to  $0.65$

### 3.2. Physico-chemical Parameters of Groundwater

- **TH:** Total Hardness is the measure of hardness in water caused by both carbonate or temporary and non-carbonate or permanent hardness. Carbonate and bicarbonate ions of multivalent metallic ions cause temporary hardness of water and non-carbonate

ions like nitrate, sulphate, chloride etc. ions of multivalent metallic ions cause permanent hardness.

- **Ca:** Calcium is an alkaline earth metal of atomic number 20. Calcium ions ( $\text{Ca}^{+2}$ ) in groundwater contributes to the hardness.
- **Mg:** Magnesium is an alkaline earth metal of atomic number 12. Magnesium ions ( $\text{Mg}^{+2}$ ) in groundwater contributes to the hardness.
- **Cl:** Chlorine is a non-metal of atomic number 17. Chloride ions are formed from Chlorine. Chloride ions ( $\text{Cl}^-$ ) in groundwater contributes to the TDS.
- **Fe:** Iron (Fe) is a transition metal of atomic number 26. Fe ions in groundwater primarily comes from oxidation of iron minerals.
- **$\text{SO}_4^{-2}$ :** Sulphur (S) is a non-metal of atomic number 16. Sulphate ions ( $\text{SO}_4^{-2}$ ) in groundwater are formed due to sulphur deposits or anthropogenic causes.
- **$\text{PO}_4^{-3}$ :** Phosphorus (P) is a non-metal of atomic number 15. Phosphorus is a non-toxic and do not cause direct health threat. But indirectly, it facilitates growth of aquatic plants.
- **TA:** It is defined as the quantity of ions in water that will react to hydrogen ion. It means, alkalinity is the ability of the water to neutralize acids Major compounds cause alkalinity are:  **$\text{CO}_3^{-2}$ :** Carbonate ions which cause **Carbonate Alkalinity**.
- **$\text{HCO}_3^-$ :** Bicarbonate ions which cause **Bicarbonate Alkalinity**.
- **$\text{OH}^-$ :** Hydroxyl ions which cause **Caustic Alkalinity**.
- The alkalinity in water comes due to minerals or due to atmospheric  $\text{CO}_2$  mixed in water or due to microbial decomposition of organic matter.

### 3.3 Toxic Parameters of Groundwater

- **As:** Arsenic is a metalloid of atomic number 33 and naturally forms in water. Arsenic in groundwater mainly comes from As (III) (Arsenate) and As (V) (Arsenite) form.
- **F:** Fluorine is a non-metal of atomic number 9 and naturally occurs in water.
- **$\text{NO}_3^-$ :** Nitrogen is a non-metal of atomic number 7 which forms Nitrite ( $\text{NO}_2^-$ ), Nitrate ( $\text{NO}_3^-$ ) and Ammonical Nitrogen ( $\text{NH}_3\text{-N}$ ) in groundwater due to various bio-chemical reactions.
- **U:** Uranium is an actinide of atomic number 92. Highly unstable and radioactive properties make uranium a threat to health. The origin of uranium in groundwater is geogenic as well as anthropogenic.

### 3.4. Radiological Parameters of Groundwater

- **Radiation:** Radiation comes from the radio nuclides present in ground water. It is measured in mSv (millisievert) or nSv (nanosievert).

$$1 \text{ mSv} = 10^6 \text{ nSv}$$

**Table 3.1.** Water Quality Parameters

Physical Parameters					
Parameter Name	Unit	Safe Limit	Organization providing safe limit	Possible Sources	Effects
<b>pH</b>	-----	6.5 - 8.5	BIS	Natural	Low pH - corrosion, metallic taste High pH – bitter/soda taste, deposits
<b>DO</b>	mg/l	4 - 6 up to 18	WHO	Natural	Low DO - Death of aquatic life forms
<b>Salinity</b>	mg/l	1000	Fetter et al, 1990	Majorly saline water intrusion into the groundwater from sea, Nature of aquifer	Bitter Taste, Brackish and Saline water - impossible usage for drinking and irrigation purpose
<b>TDS</b>	mg/l	500	BIS	Livestock waste, septic system Landfills, nature of soil Hazardous waste landfills Dissolved minerals, iron and manganese	Hardness, scaly deposits, sediment, cloudy colored water, staining, salty or bitter taste, corrosion of pipes and fittings

<b>Physico-chemical Parameters of Ground water</b>					
<b>Parameter Name</b>	<b>Unit</b>	<b>Safe Limit</b>	<b>Organization providing safe limit</b>	<b>Possible Sources</b>	<b>Effects</b>
<b>TH</b>	mg/l	200	BIS	Dissolved calcium and magnesium from soil and aquifer minerals containing limestone or dolomite	Scale in utensils and hot water system, soap scums
<b>Ca</b>	mg/l	75	BIS	Natural, Rocks	Poor lathering and deterioration of the quality of clothes; incrustation in pipes; scale formation
<b>Mg<sup>+2</sup></b>	mg/l	30	BIS	Natural, Rocks	Poor lathering and deterioration of clothes; with sulfate laxative
<b>Cl<sup>-</sup></b>	mg/l	250	BIS	Fertilizers Industrial wastes Minerals, seawater	High blood pressure, salty taste, corroded pipes, fixtures and appliances, blackening and pitting of stainless steel
<b>Fe</b>	mg/l	0.3	BIS	Leaching of cast iron pipes in water distribution	Brackish color, rusty sediment, bitter or metallic taste, brown- green

				systems Natural	stains, iron bacteria, discolored beverages
$\text{SO}_4^{-2}$	mg/l	200	BIS	Animal sewage, septic system, sewage By- product of coal mining, industrial waste Natural deposits or salt	Bitter, medicinal taste, scaly deposits, corrosion, laxative effects, "rotten-egg" odor from hydrogen sulfide gas formation
$\text{PO}_4^{-3}$	mg/l				Algal growth
TA	mg/l	200	BIS	Pipes, landfills Hazardous waste landfills	Low Alkalinity (i.e. high acidity) causes deterioration of plumbing and increases the chance for many heavy metals in water are present in pipes, solder or plumbing fixtures.
<b>Toxic Parameters of Groundwater</b>					
<b>Parameter Name</b>	<b>Unit</b>	<b>Safe Limit</b>	<b>Organization providing safe limit</b>	<b>Possible Sources</b>	<b>Effects</b>
As	mg/l	0.01	BIS	Previously used in pesticides (orchards), Improper waste disposal or product storage of glass or electronics, Mining, Rocks	Weight loss; Depression; Lack of energy; Skin and nervous system toxicity

<b>F</b>	mg/l	1	BIS	Industrial waste Geological	Brownish discoloration of teeth, bone damage
<b>NO<sub>3</sub><sup>-</sup></b>	mg/l	45	BIS	Livestock facilities, septic systems, manure lagoons, fertilizers, Household waste water, fertilizers Fertilizers, Natural Deposits	Methemoglobinemia or blue baby disease in infants
<b>U</b>	mg/l	20, 30, 60	EPA, WHO, AERB	Radioactive waste disposal, Mining, Rock minerals	Nephrotoxic syndromes, Damage in urinary tracts, Cancer
<b>Radiological Parameter of Groundwater</b>					
<b>Parameter Name</b>	<b>Unit</b>	<b>Safe Limit</b>	<b>Organization providing safe limit</b>	<b>Possible Sources</b>	<b>Effects</b>
<b>RADIATION</b>	nSv	0.1 mSv	WHO	Sun, Wave emitters, Radio nuclides	Stochastic health effects, which include fatal cancer, non-fatal cancer and severe hereditary effects for the whole population

## Chapter 4

### AIMS AND OBJECTIVES

The ground water resources are very detrimental. As in many parts of rural India ground water is used directly for drinking purposes and other household purposes. People get affected due to various waterborne diseases. The uncategorised ground water resources should be thus monitored and its quality must be assured before consumption. Our study involves the assessment of ground water parameters. This study has some prime aims and objectives.

- The prime objective of this study is to study the ground water and creation of a categorized and well defined model which will describe the quality of the ground water. Water Quality Index is such a method through which the quality of the ground water can be assessed. Since ground water is consumed as a source for drinking water. Thus the quality should be maintained.
- Using the WQI the overall quality of a ground water can be monitored. The categorized ground water should be identified for the suitability of the water as if it can be used as drinking or other household or irrigation and agricultural purposes.
- Another major objective of this study is to check if the ground water quality parameters have any common characteristics in between them. To study the common characteristics of the ground water the correlation of the ground water will be checked. The correlation of the ground water parameters will be able to indicate if the leaching in the groundwater, aquifer constituent, source of the ions or the mobility of each ion can be identified or not.

## Chapter 5

### MATERIALS AND METHODS

#### 5.1. Study Area

##### 5.1.1. Nadia

- **Location**

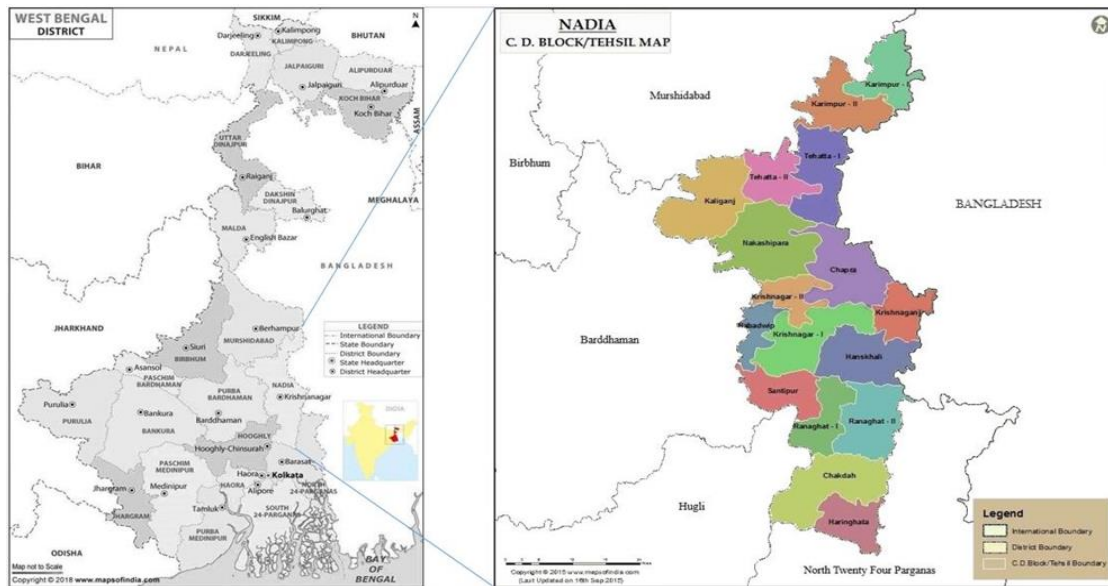
The study area is situated in the eastern bank of the Bhagirathi River. The geographical extent lies within 22°41' 23" North latitude and 72°51' 24" East longitudes, which covers an area of about 3927 km<sup>2</sup> in Survey of India (SOI) topographical survey sheets 78D/12, 79A/2, 79A/5, 79A/6, 79A/7, 79A/8, 79A/9, 79A/10, 79A/11, 79A/12, 79B/5 and 79B/9.

The district has 4 Sub-divisions, viz. Krishnanagar Sadar, Ranaghat, Kalyani and Tehatta. There are 17 Blocks, 8 Municipalities and 2 Notified Areas in the district.

<b>Table 5.1.1. NADIA</b>		
<b>Sub-Division</b>	<b>Block</b>	<b>Municipalities / GPs</b>
Krishnanagar	(i) Kaliganj, (ii) Nakashipara, (iii) Chapra, (iv) Krishnanagar-I, (v) Krishnanagar-II, (vi) Nabadwip and (vii) Krishanganj	(i) Krishnanagar (M), (ii) Nabadwip (M)
Ranaghat	(i) Hanskhali, (ii) Santipur, (iii) Ranaghat-I and (iv) Ranaghat-II	(i) Shantipur (M), (ii) Ranaghat (M) and (iii) Birnagar (M)
Kalyani	(i) Chakdaha and (ii) Haringhata	(i) Chakdaha 9 (M), (ii) Kalyani (M), (iii) Gayeshpur (M) and (iv) Haringhata (M)
Tehatta	(i) Karimpur-I, (ii) Karimpur-II, (iv) Tehatta-I and (v) Tehatta-II	-----

(District census handbook, 2011)





**Fig 5.1.1** Study area of Nadia

- **Demographics**

As per the reports of Census India 2011, the total population of the Nadia District is 5,168,488, out of which the male and female were 2,653,768 and 2,513,832 respectively. The district has a population density of 1,316 inhabitants per square kilometers. The population growth rate of Nadia District over the decade 2001 to 2011 was 12.24 percent. The Nadia District has a sex ratio of 947 females for every 1000 males and the literacy rate of the district is 75.58 percent. The total literate in Nadia District were 3,480,555 of which male and female were 1,878,866 and 1,601,689 respectively. The child sex ratio as per census 2011 was 960 compared to 972 of census 2001. In 2011, children under the ages of 0 to 6 years old formed 10.16 percent of Nadia District compared to 13.17 percent of 2001. The reports also state that, Hinduism is the majority religion of the district followed by 72.15 percent of the total population. ([https://www.indianetzone.com/7/nadia\\_west\\_bengal.html](https://www.indianetzone.com/7/nadia_west_bengal.html))

- **Climate**

The climate of Nadia district is characterized by an oppressive hot summer; high humidity all the year round and well distributed rainfall during the south west monsoon season. The cold season is from about the end of November to the end of February. The annual rainfall (average for the period 2009 – 2018) is 390 mm. A soil moisture budget approach to estimate groundwater recharge resulted in a mean annual value of 60 mm/year, albeit that different calculation methods resulted in diverging estimates. Most recharge occurs during the rainy season from July to September.

### 5.1.2. Bardhaman

The study is carried out in East Burdwan and West Burdwan consisted within an area of 7024 km<sup>2</sup> in the Survey of India map (SOI) topographical survey sheets 73I/13, 73I/14, 73M/1, 73M/6,73M/7, 73M/10, 73M/11, 73M/13, 74M/14, 73M/15, 73M/16, 73N/13, 73N/9, 79A/2, 79A/3 and 79A/4 within the gps coordinates of 23° 13' 57.0468" N and 87° 51' 48.3084" E. (GPS co-ordinate source: <https://www.latlong.net/place/burdwan-west-bengal-india-11628.html>)

The district has 6 (six) Sub-divisions: Asansol, Durgapur, Burdwan Sadar (North), Katwa, Kalna and Burdwan Sadar (South).

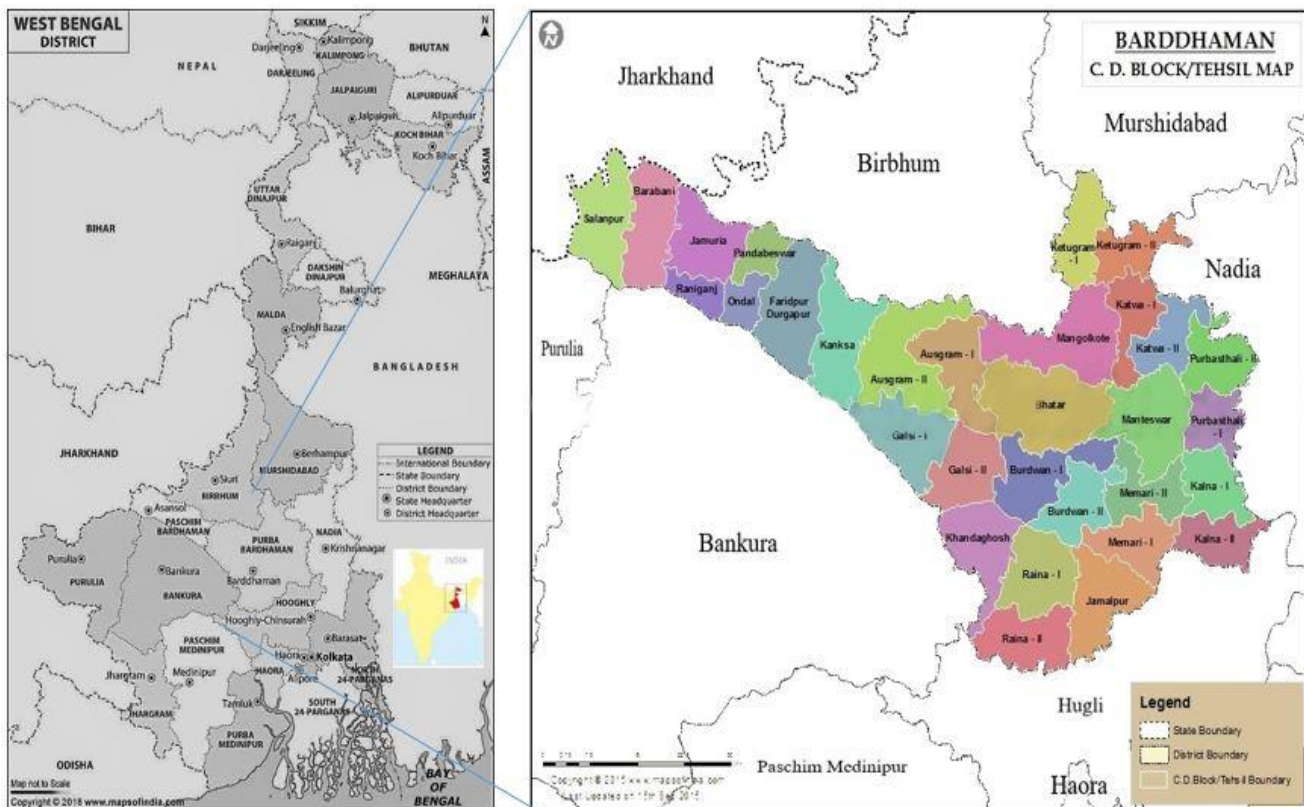
There are 31 (Thirty-One) Community Development (C.D.) Blocks, 9 (Nine) Municipalities and 2 (Two) Municipal Corporation in the district.

<b>Table 5.1.2: BARDHAMAN</b>		
<b>Sub-Division</b>	<b>Block</b>	<b>Municipalities / GPs</b>
Asansol	(i) Salanpur, (ii) Barabani, (iii) Jamuria and (iv) Raniganj	(i) Salanpur, (ii) Barabani, (iii) Raniganj, (iv) Raniganj(M), (v) Jamuria, (vi) Jamuria(M), (vii) Asansol(MC) and (viii) Kulti(M)
Durgapur	(i) Ondal, (ii) Pandabeswar, (iii) Faridpur-Durgapur, (iv) Kanksa and (v) Galsi-I	(i) Galsi-I, (ii) Andal, (iii) Faridpur-Durgapur, (iv) Pandabeswar, (v) Kanksa and (vi) Durgapur (MC)
Burdwan Sadar (North)	(i) Ausgram-II, (ii) Ausgram-I, (iii) Galsi-II, (iv) Burdwan-I,	(i) Burdwan-I, (ii) Burdwan-II, (iii) Burdwan(M), (iv) Ausgram-I,

	(v) Burdwan-II and (vi) Bhatar	(v) Guskara(M), (vi) Ausgram-II, (vi) Bhatar and (vii) Galsi-II
Katwa	(i) Mangalkote, (ii) Ketugram-I, (iii) Ketugram-II, (iv) Katwa-I, and (v) Katwa-II	(i) Mongolkote, (ii) Ketugram-I, (iii) Ketugram-II, (iv) Katwa-I, (v) Katwa-II, (vi) Katwa(M) and (vii) Dainhat(M)
Kalna	(i) Purbasthali-I, (ii) Purbasthali-II, (iii) Manteswar, (iv) Kalna-I and (v) Kalna-II	(i) Purbasthali-I, (ii) Purbasthali-II, (iii) Kalna-I, (iv) Kalna-II, (v) Kalna(M) and (vi) Monteshwar
Burdwan Sadar (South)	(i) Memari-I, (ii) Memari-II, (iii) Jamalpur, (iv) Raina-I, (v) Khandaghosh and (vi) Raina-II	(i) Memari-I, (ii) Memari-II, (iii) Memari(M), (iv) Jamalpur, (v) Raina-I, (vi) Raina-II, (vii) Khandaghosh

(District census handbook, 2011)

(Among all these blocks Kulti and Asansol were exempted from sampling and analysis.)



**Fig 5.1.2. Study area of BARDHAMAN**

- **Demographics**

As per the reports of Census India 2011, the total population of the Bardhaman District is 7,717,563, out of which the male and female were 3,966,889 and 3,750,674 respectively. The district has a population density of 1,099 inhabitants per square kilometers. The population growth rate of Bardhaman District over the decade 2001 to 2011 was 11.92 percent. The Bardhaman District has a sex ratio of 945 females for every 1000 males and the literacy rate of the district is 76.21 percent. The total literate in Bardhaman District were 5,247,208 of which male and female were 2,918,040 and 2,329,168 respectively. The child sex ratio as per census 2011 was 951 compared to 956 of census 2001. In 2011, children under the ages of 0 to 6 years old formed 10.78 percent of Bardhaman District compared to 13.10 percent of 2001. The reports also state that, Hinduism is the majority religion of the district followed by 77.85 percent of the total population. (District census handbook, 2011)

- **Climate**

The average minimum temperature ranges from 16° C to 20° C in December-January and maximum temperature varies from 33°C to 38°C in April-May. High temperature stays steady till the monsoon arrives. (Shodhganga)

The maximum temperature and minimum temperature is observed as 39°C and 7°C. (<http://bardhaman.gov.in/distataglance.html>) The average annual temperature is 26.3 °C in Bardhaman (<https://en.climate-data.org/asia/india/west-bengal/bardhaman-5067/>).

The climatic condition in the district differs from west to east. The south-west (i.e. Trans - Damodar region) comprises low- lying lands and more humid. In the south- eastern part (Burdwan-Memari areas) of the district, the average rainfall is high. In the north- eastern and south- western parts, the mean of annual rainfall is more or less medium.

Rainfall in the district is influenced by the monsoons. Monsoon is usually uncertain. Its arrival is either early or late. The economic wellbeing of the district, in spite of the great industrial progress, still depends on agriculture and thus on rainfall. (Shodhganga)

## **5.2. Methodology**

### **5.2.1. Physico-Chemical methods**

#### **(I) Determination of pH, DO, ORP, Temperature, EC, Salinity and TDS**

Determination of above parameters were done by the use of the instrument:

HANNA, HI 98194, pH/EC/DO Multiparameter probe.

### **5.2.2. Physical methods**

#### **(I) Determination of alkalinity of a given water sample**

##### **Reagents:**

- Carbon dioxide free distilled water with pH > 6 to prepare all stock and standard solutions.
- Sulphuric acid with 0.02(N) stock was prepared by diluting 36 (N) laboratory grade – H<sub>2</sub>SO<sub>4</sub> by adding 0.55ml of 36 (N) and making volume up to 1000ml. This 0.02 (N) H<sub>2</sub>SO<sub>4</sub> solution is to be standardized against 0.02 (N) Na<sub>2</sub>CO<sub>3</sub> solution.
- Standard Sodium carbonate solution of 0.02 (N) is prepared by dissolving 1.06 gm anhydrous Na<sub>2</sub>CO<sub>3</sub> (primary grade standard) in 1000 ml of CO<sub>2</sub> free distilled water.
- Indicators: Methyl orange [colour change: yellowish orange → pink].

##### **Method:**

Acid titration

**Procedure:****(a) Standardization of 0.02(N) H<sub>2</sub>SO<sub>4</sub>:**

- 10ml of Na<sub>2</sub>CO<sub>3</sub> is taken in a conical flask.
- It is then titrated against 0.02(N) H<sub>2</sub>SO<sub>4</sub> present in the burette, after 5 drops of Methyl orange had been added to, till the yellowish orange colour changes to the end point: pink.
- The process is repeated twice & level of 0.02 (N) H<sub>2</sub>SO<sub>4</sub> in the burette is noted.

**(b) Determination of Alkalinity:**

- 50 ml of a given water sample is taken in a conical flask.
- 5 drops of methyl orange is added to it, till the colour of the solution becomes yellowish orange.
- It is then titrated against 0.02 (N) H<sub>2</sub>SO<sub>4</sub> present in the burette till it reaches the end point: pink.
- The process is repeated thrice and the levels of 0.02 (N) H<sub>2</sub>SO<sub>4</sub> in the burette are noted.

**(II) Estimation of carbonate and bicarbonate ions:**

For carbonate and bicarbonate estimation, calculations were done from estimation of Total Alkalinity (TA) and Phenolphthalein Alkalinity (PA) by use of the formula  $[\text{CO}_3^{2-}] = 2 \cdot \text{PA}$ ;  $[\text{HCO}_3^-] = \text{TA} - \text{PA}$  (when  $\text{PA} < 1/2\text{T}$ ).

([http://www.soe.uoguelph.ca/webfiles/rzytner/WQ/calculate\\_alkalinity.pdf](http://www.soe.uoguelph.ca/webfiles/rzytner/WQ/calculate_alkalinity.pdf))

([http://mimoza.marmara.edu.tr/~kyapsakli/enve201/13\\_Alkalinity.pdf](http://mimoza.marmara.edu.tr/~kyapsakli/enve201/13_Alkalinity.pdf))

**(III) Estimation of chloride in water****Reagents and Materials:-**

- Chloride containing water sample
- AgNO<sub>3</sub> (secondary standard)
- K<sub>2</sub>CrO<sub>4</sub> indicator
- NaCl solution (M/100)
- Burette
- Conical flasks
- Beakers

**Method:**

Argentometric titration

**Procedure:-****Determination of strength of AgNO<sub>3</sub>:**

- 10ml of NaCl solution was taken in a conical flask.
- 5 drops of K<sub>2</sub>CrO<sub>4</sub> indicator was added to it.
- It was titrated against AgNO<sub>3</sub> solution until the end point changes from white to reddish brown in colour.

**Precautions:-**

The pH should be between 7 and 8. At higher pH Ag<sup>+</sup> ions are precipitated as AgOH.

At lower pH, K<sub>2</sub>CrO<sub>4</sub> is converted to K<sub>2</sub>CrO<sub>7</sub>.

**(IV) Estimation of Iron in a given water sample****Reagents and Materials:**

- Stock solution of Fe (III).
- Sodium acetate- acetic acid buffer
- Hydroxylamine hydrochloride [NH<sub>4</sub>OH.HCl]
- O-phenanthroline Reagent.
- 25ml volumetric flask
- UV- spectrometer
- Distilled water

**Instruments:**

UV-Vis Spectrophotometer

**Preparation of Reagents****I. Buffer**

- 3.8 gm CH<sub>3</sub>COONa + 48 ml CH<sub>3</sub>COOH/1000 ml

**II. O-phenanthroline**

- 0.25% of Total Volume

**III. Hydroxylamine Hydrochloride**

- 10% of total volume

**Procedure:-**

- From a stock solution of 100 ppm, a 10 ppm solution was prepared. From 10 ppm, solutions of 1 ppm, 1.5 ppm, 0.5 ppm and 2 ppm as well as blank were prepared along with two unknowns were prepared.
- In 25 ml volumetric flask, 10 ml of sodium acetate – acetic acid buffer solution was added.
- 2.5 ml of  $\text{NH}_2\text{OH}\cdot\text{HCl}$  and 2 ml of reagent o-phenanthroline was added.
- The volume was made up to 25 ml using distilled water.
- A blank was prepared in which stock solution of Fe was absent, all other reagents added.
- The absorbance of the standards were measured and a calibration curve was obtained.
- Similarly the concentration of unknown solutions were measured at 510 nm.

**(V) Determination of Sulphate in water****Reagents and Materials:-**

- Conditioning reagent – NaCl, HCl, any alcohol,  $\text{CH}_3\text{OH}$
- $\text{SO}_4^{2-}$  stock solution from  $\text{Na}_2\text{SO}_4$  salt (100 ppm)
- $\text{BaCl}_2$  salt
- Distilled water
- Magnetic stirrer
- Spatula
- UV- spectrometer
- Conical flask
- Measuring cylinder

**Instruments:**

UV-Vis Spectrophotometer

**Procedure:-**

- 10 ml of  $\text{SO}_4^{2-}$  solution was taken from 100 ppm stock solution and 90 ml of  $\text{H}_2\text{O}$  was mixed to form 100 ml of 10 ppm  $\text{SO}_4^{2-}$  solution in a conical.
- To each 5 ml of conditioning reagent was added.
- A pinch of  $\text{BaCl}_2$  salt was added to the conicals using spatula.
- Distilled water was added to each conical to make up the volume to 100 ml.



- The conical flask was placed over magnetic stirrer
- The standards were measured and a calibration curve was obtained.
- Similarly the unknown solutions were measured using the quartz cuvettes.
- Absorbance was measured at 570 nm.

## **(VI) Determination of Total hardness of water**

### **I. Reagents required for Total Hardness**

- M/100 EDTA or M/100 Na<sub>2</sub> EDTA
- NH<sub>4</sub>Cl-NH<sub>4</sub>OH Buffer (pH 10)

### **II. Reagents required for Calcium Hardness**

- Erichrome Black T (EBT)
- 10% NaOH solution
- Murexide Indicator
- Water sample (given)

### **Method:**

Complexometric titration

### **Preparation of Reagents**

#### **I. Preparation of (M/100) Na<sub>2</sub>-EDTA solution:-**

- 1000 ml 1(M) solution contains 372.25 gm of EDTA.
- M/100 solution contains = 3.72 g of EDTA

#### **II. NH<sub>4</sub>Cl-NH<sub>4</sub>OH buffer :**

- 17.5 gm of solid NH<sub>4</sub>Cl was taken.
- 142 ml of concentrated NH<sub>3</sub> was added.
- Volume made up to 250 ml with distilled water.

#### **III. Murexide:**

- 0.05 g murexide + 4.9 g KNO<sub>3</sub>

#### **IV. EBT indicator:**

- 0.5 gm of EBT + 4.9 gm of KNO<sub>3</sub> grinding with mortar

**Procedure:-****For total hardness:**

- 50 ml of the given water sample was measured and poured in a conical flask.
- 5ml of  $\text{NH}_4\text{Cl-NH}_4\text{OH}$  buffer was added to the conical flask and pH was checked to be  $\sim 10$
- A pinch of Eriochrome Black T was added.
- M/100  $\text{Na}_2\text{-EDTA}$  solution was poured into the burette.
- The titration was carried out until the end point or the colour change from wine red to blue was observed.
- The above steps were repeated two times and the level of  $\text{Na}_2\text{-EDTA}$  was noted each round.

**For calcium hardness:**

- 50 ml of given water sample for determination was taken in a conical flask.
- 5ml of 10% NaOH was added to the flask and the pH was checked to be around  $\sim 12$ .
- A pinch of murexide indicator was added to the conical.
- M/100  $\text{Na}_2\text{EDTA}$  was poured into the burette.
- The titration was carried out until the colour changed from pink to purple.
- The above steps were repeated two more times and the levels of  $\text{Na}_2\text{EDTA}$  was noted.

**Derivation of Mg Hardness:**

$\text{Mg-Hardness} = (\text{Total Hardness} - \text{Ca-Hardness})$

**Determination of  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  ions:**

$\text{Ca}^{+2}$  ion concentration was calculated from Calcium Hardness (Ca-H),  $\text{Mg}^{+2}$  ion concentration was calculated from Magnesium Hardness (Mg-H), i.e. the difference of TH and Ca-H). (<https://www.mrwa.com/WaterWorksMnl/Chapter%2015%20Hardness.pdf>)

**(VII) Determination of Phosphate in water:-****Reagents and Materials:-**

- Phosphate Salt -  $\text{KH}_2(\text{PO}_4)$

**Instrument:**

UV-Vis Spectrophotometer

### **Preparation of reagents:**

#### **I. (NH<sub>4</sub>)<sub>2</sub>MoO<sub>4</sub> solution:**

Dissolve 2.5 gm of Ammonium molybdate in 17.5 ml distilled water.

- 25 ml H<sub>2</sub>SO<sub>4</sub> (Concentrated) was added to 40 ml distilled water.
- Both solutions were mixed and diluted to 100 ml.

#### **II. SnCl<sub>2</sub> Preparation:**

- 2.5 gm of fresh SnCl<sub>2</sub>.2H<sub>2</sub>O was dissolved in 100 ml glycerol.
- Heated in water bath (Hot Plate) and stirred with a glass rod for dissolution.

### **Procedure:**

- 50 ml volumetric flask was taken.
- 1000 ppm of stock solution taken. From 1000 ml stock solution 100 ppm, 10 ppm and 1 ppm of stock solutions prepared by serial dilution.
- Concentrations of 20 ppb, 40 ppb, 60 ppb, 80 ppb from 1 ppm stock solution by serial dilution.
- 1 ml 1 ppm PO<sub>4</sub><sup>-3</sup> solution in a 50 ml volumetric flask + 2ml ammonium molybdate solution + 5 ml/ drops of SnCl<sub>2</sub> solution + Rest H<sub>2</sub>O.
- Blue colour was formed.
- Absorbance was measured at 690 nm.

### **5.2.3 Toxic methods**

#### **(I) Estimation of arsenic in water sample**

##### **Reagents and Materials:**

- Commercial 1000 ppm As (V)
- 1000ppm Sodium Arsenite (NaAsO<sub>2</sub>)
- Concentrated HCl solution
- KI Solution
- Sodium Borohydrate

##### **Instrument:**

FI-HG-AAS method, (Hydride generation Atomic Absorption Spectrophotometer)

##### **Procedure:**

- From stock solutions of 1000 ppm, 100ppb of As (III) and As (V) are prepared.

- From the 100 ppb solution of As (III) and As (V) 10ppb, 20ppb, 30ppb, 40ppb standard solutions of 25ml each are prepared respectively using 10% KI and concentrated HCl solution in volumetric flasks.
- A blank solution of 200 ml was prepared using 10% KI and concentrated HCl solutions in volumetric flask.
- All standard solutions and unknown samples were kept untouched for 45 minutes.
- After 45 minutes colour turns into yellowish.
- The atomic absorption spectrometer (AAS) is run with the known standards and the absorbance is measured at 193.7 nm.
- The unknown samples were run and the corresponding absorbance as well as concentration were noted.

## **(II) Estimation of fluoride in water**

### **Reagents and Materials:-**

- 1000 ppm stock solution of NaF
- TISAB (III) Buffer

### **Instrument:**

Ion selective electrodes (Thermo Scientific Orion Star A214)

### **Procedure:-**

- 1000ppm mother stock (NaF) solution was provided commercially. From this stock solution, using serial dilution method ( $V_1S_1=V_2S_2$ ) 100 ppm, 10 ppm and 1 ppm standards were prepared respectively.
- In each standard TISAB (III) buffer was added in 1:10 ratio e.g. for 5ml standard solution 0.5ml buffer was added.
- The instrument was calibrated.
- Similarly, concentration of the samples were measured using ion selective electrode (Thermo Scientific Orion Star A214).

### **(III) Nitrate**

#### **Reagents and Materials:-**

- 1000ppm stock solution of Potassium Nitrate ( $\text{KNO}_3$ )
- Suppressor Solution
- ISA Solution [Orion Ionic Strength Adjuster, Nitrate ISA, 2 M  $(\text{NH}_4)_2\text{SO}_4$  ]

#### **Instrument:**

Ion selective electrodes (Thermo Scientific) Orion Star A214

#### **Procedure:-**

- 1000 ppm stock ( $\text{KNO}_3$ ) solution was prepared. From this stock solution, using serial dilution method ( $V_1S_1=V_2S_2$ ) 100 ppm, 10 ppm standards were prepared respectively.
- In each standards suppressor solution was added in 1:1 ratio e.g. for 3ml standard solution 3ml suppressor solution was added.
- The instrument was calibrated.
- Similarly, concentration of the samples were measured using ion selective electrode (Thermo Scientific Orion Star A214).

### **(IV) Uranium Estimation**

#### **Reagents and Materials:-**

- Uranium stock solution
- $\text{HNO}_3$  solution
- Teflon Flask (200 ml)
- $\text{SiO}_2$  (500 gm)

#### **Instrument:**

Fluorat-02-4M, LUMEX

#### **Preparation of Sodium Polysilicate Solution:**

- Water-bath heat for 2 hours.
- 7.15g  $\text{SiO}_2$  + 2.5g NaOH pallets + 50 ml double distilled water
- 14.3g  $\text{SiO}_2$  + 5g NaOH pallets + 100 ml double distilled water

### **Preparation of Nitric acid Solution:**

- 500 ml of double distilled water + 3.5 ml HNO<sub>3</sub> => Total = 503.5 ml

### **Procedure:**

Uranium measurement is always done in HNO<sub>3</sub> acid solution because metallic uranium cannot be extracted with double distilled water. So sampling is done with HNO<sub>3</sub> acid.

#### ➤ **Preparation of standards:**

- 1 ppm (1000 ppb) → 0.5 ml stock Uranium + 499.5 ml HNO<sub>3</sub> solution
- 100 ppb →  $1000 \times x = 100 \times 50 \Rightarrow x = 5 \text{ ml} \therefore 5 \text{ ml } 1000 \text{ ppb} + 45 \text{ ml HNO}_3$
- 50 ppb →  $1000 \times x = 50 \times 50 \Rightarrow x = 2.5 \text{ ml} \therefore 2.5 \text{ ml } 1000 \text{ ppb} + 47.5 \text{ ml HNO}_3$
- 20 ppb →  $1000 \times x = 20 \times 50 \Rightarrow x = 1 \text{ ml} \therefore 1 \text{ ml } 1000 \text{ ppb} + 49 \text{ ml HNO}_3$
- 10 ppb →  $1000 \times x = 10 \times 50 \Rightarrow x = 0.5 \text{ ml} \therefore 0.5 \text{ ml } 1000 \text{ ppb} + 49.5 \text{ ml HNO}_3$
- 5 ppb →  $1000 \times x = 5 \times 50 \Rightarrow x = 0.25 \text{ ml} \therefore 0.25 \text{ ml } 1000 \text{ ppb} + 49.75 \text{ ml HNO}_3$

#### ➤ **Instrument calibration:**

- In each standard solution of 6 ml, 5ml double distilled water, 0.5 ml polysilicate solution and 0.5ml standard were added.

#### ➤ **Measurement of samples:**

- Similar like the standards, samples were measured.

## **5.3 Data Treatment using Statistical Methods**

The samples were tested in the laboratory to find the values of: pH, Total Dissolved Solids, Electrical Conductivity, Oxidation Reduction Potential, Temperature, Salinity, Dissolved Oxygen, Fluoride, Chloride, Nitrate, Sulphate, Phosphate, Uranium, Total Hardness, Calcium Hardness, Magnesium Hardness, Total Alkalinity, Bi-carbonates and Radiation. The laboratory test data was first documented and a database is formed.

### **5.3.1 Normal Distribution and Histogram**

For an unknown distribution of available dataset, the statistical approaches were made. Normality tests were performed to gain knowledge about the distribution of the dataset. In statistics, normality tests are used to determine if a data set is well-modelled by a normal distribution and to compute how likely it is for a random variable underlying the data set to be normally distributed. (Razali & Wah, 2011; Judge et al., 1988). The nature of distribution of the data is assumed for water quality parameters is Normal (Alberto et al., 2001; Singh et

al., 2004; Cloutier et al., 2008; Wu et al., 2017) While using descriptive statistics method, the measurement will be of goodness of fit of a normal model to the data. If the fit is poor then the data are not well modelled in that respect by normal distribution. The model is stated without making a judgment on any underlying variable.

While using frequentist statistics statistical hypothesis testing, data are tested against the null hypothesis that it is normally distributed. (Razali and Wah, 2011)

### (a) Probability Distribution Functions

The occurrence and distribution of water quality parameters are taken into account as completely random. To understand the occurrence and distribution probability distribution functions are considered. Probability distributions are defined in terms of probability density functions (PDFs). Two types of probability density functions are considered in general. First is Continuous function and later is discrete function.

The probability density function of random variable (or, variate)  $\mathcal{X}$  can be calculated in any of the following way:-

- For a continuous distribution, the probability that the variate  $\mathcal{X}$  has values in an interval  $(a, b)$  is precisely the area under its PDF. Since, for continuous distributions probability at a single point is zero, this is often expressed in terms of an integral between two points  $(a, b)$ .

$$\int_a^b f(x)dx = Pr[a \leq \mathcal{X} \leq b]$$

- For a discrete distribution, the probability that the variate  $\mathcal{X}$  has values in an interval  $(a, b)$  is exactly the sum of the PDF of the possible discrete values of  $\mathcal{X}$  in  $(a, b)$ . The sum of the PDF is also called the probability mass function.

$$f(x) = Pr[\mathcal{X} = x]$$

### (b) Normal Distribution

In theory of probability, Normal distribution or Gaussian or Laplace – Gaussian distribution is a type of continuous distribution. In general form, it states that the averages of samples of observations of random variables independently drawn from independent distributions converge in distribution to the normal. Thus sufficiently large number of observations is to be normally distributed.

The general formula of probability density function of Normal distribution is as follows

$$f(x) = \frac{e^{-\frac{(x-\mu)^2}{2\sigma^2}}}{\sigma\sqrt{2\pi}}$$

Where,  $\mu$  = Mean of the distribution = Median of the distribution = Mode of the distribution

$\sigma$  = Standard Deviation

$\sigma^2$  = Variance

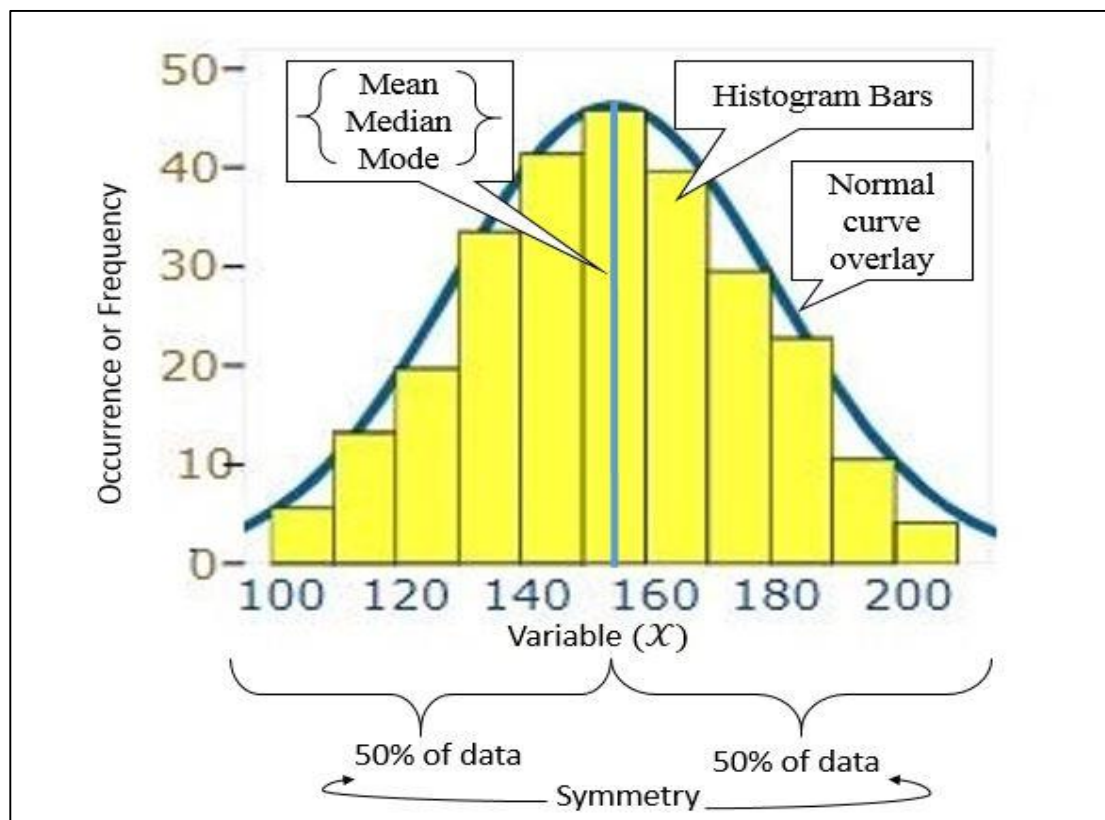
Standard Deviation is determined taking into the account of two considerations.

- When all the observations are considered as a whole ,  $\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$
- When one sample is randomly considered from all observations,

$$S = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2}$$

Where, N= Sample size

The Normal distribution is easier to explain with the help of central limit theorem. As per central limit theorem, in some cases when independent random variables are added their properly normalized sum tends toward a normal distribution even if the original variables are not normally distributed. When the number of occurrences are plotted against the given set of values a histogram graph is plotted. As an example some random variables are taken into account and plotted in the following.



**Fig 5.3.1:** Histogram and Normal Curve is plotted considering random variables (numbers)



From the figure it is well defined that randomly taken variables are normally distributed. The curve is symmetrical about the centre. 50% of the values are greater than the centre and 50% of the values are lesser than the centre. Centre lies at the value of 450.

The shape of a normally distributed curve takes resemblance with the shape of a bell. Thus the normal curve is also called “Bell Curve”.

(Engineering Mathematics Volume – II by Pal and Das)

Histograms of all analysed physical and chemical parameters are created and corresponding values of Mean, Standard deviations and considered n is shown below. Software used for this operation is Minitab (version 15).

### **5.3.2. Normality Tests – Skewness and Kurtosis**

- **Tests of Normality**

Normality tests assess the likelihood that the given data set  $(x_1, \dots, x_n)$  originates from a normal distribution. In general, the test analyses if the dataset follows null hypothesis ( $H_0$ ) or alternate hypothesis ( $H_a$ ). Null hypothesis is that the observations are normally distributed with unspecified mean ( $\mu$ ) and variance ( $\sigma^2$ ). The alternative ( $H_a$ ) is that the distribution is arbitrary. The types of normality tests varies with the objectives and nature of available data. Basically analytical and visual tests are performed. Analytical test results determine if the dataset follows normality or not. On the other hand, visual tests are more intuitively appealing but subjective at the same time, as they rely on informal human judgement to accept or reject the null hypothesis. (Das and Imon, 2016)

We have conducted some normality tests based upon statistical methods.

- **Normality test based on Skewness and Kurtosis**

#### **5.3.2.1. Skewness**

A frequency distribution is said to be ‘symmetrical’, if the frequencies are symmetrically distributed about mean, i.e. when values of the variable equidistant from mean have equal frequencies. The word “skewness” is used to denote the ‘extent of symmetry’ in the data. When the frequency distribution is not symmetrical, it is said to be ‘skew’. The word ‘skewness’ literally denotes ‘asymmetry’, or ‘lack of symmetry’, and ‘skew’ denotes

‘asymmetrical’. Therefore a symmetrical distribution has zero skewness. Skewness may also be positive or negative.

Skewness is measured by the following formulae:

1) Pearson’s first measure:

$$\text{Skewness} = \frac{\text{Mean} - \text{Mode}}{\text{Standard Deviation}}$$

2) Pearson’s second measure :

$$\text{Skewness} = \frac{3(\text{Mean} - \text{Median})}{\text{Standard Deviation}}$$

3) Bowley’s measure (also known as Galton’s skewness):

$$\begin{aligned} \text{Skewness} &= \frac{(Q_3 - Q_2) - (Q_2 - Q_1)}{(Q_3 - Q_2) + (Q_2 - Q_1)} \\ &= \frac{Q_3 - 2Q_2 + Q_1}{Q_3 - Q_1} \end{aligned}$$

Where,  $Q_1$ ,  $Q_2$  and  $Q_3$  denote the first, second and third quartiles of the distribution.

4) Moment measure:

$$\text{Skewness } (\gamma_1) = \frac{m_3}{\sigma^3} = \frac{m_3}{(\sqrt{m_2})^3}$$

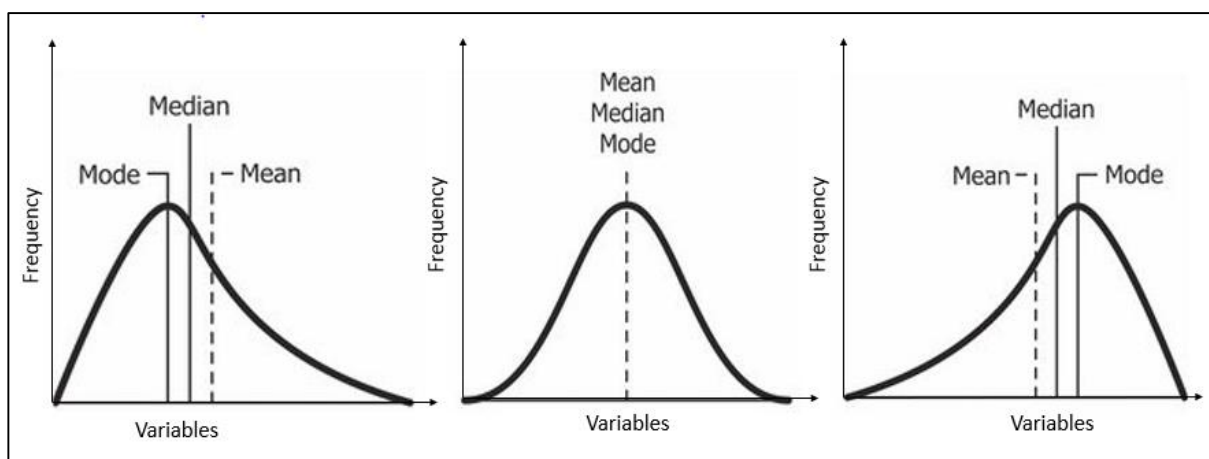
Where,  $m_2$  and  $m_3$  are the second and third central moments, and  $\sigma$  denotes S.D.

5) For univariate data,  $Y_1, Y_2, \dots, Y_N$  the formula for skewness is :

$$g_1 = \frac{\sum_{i=1}^N (Y_i - \bar{Y})^3 / N}{s^3}$$

Where,  $\bar{Y}$  = Mean

$s$  = Standard Deviation



$N$  = Number of data points.

(a) Positive Skewness

(b) Zero Skewness

(c) Negative Skewness

**Fig 5.3.2.1:** Positions of Mean, Median, Mode for different types of Skewness

For a symmetrical distribution Mean, Median and Mode are equal. The more the asymmetry in the data, the larger is the discrepancy between them. So the difference between Mean and Mode may be taken as a measure of skewness. This difference, when judged relative to S.D., gives Pearson's measure. If Mode is not known accurately, the approximate relation  $Mean - Mode = 3(Mean - Median)$  is utilized in Pearson's second measure. Skewness measured by Pearson's first and second measure is positive when Mean is larger than Median and Mode, and negative when Mean is less.

Bowley's measure of skewness has been developed from the following viewpoint. For a symmetrical distribution,  $Q_2$  (i.e. Median) lies exactly midway between  $Q_1$  and  $Q_3$ ; for a positively skew distribution (i.e. when the longer "tail" of the frequency curve lies towards the right, **Fig: 5.3.2.1(a)**)  $Q_3$  will be wider away from  $Q_2$  than  $Q_1$ , and for a negatively skew distribution **Fig: 5.3.2.1(c)** the reverse will be the case. The difference of the midpoint of  $Q_1$  and  $Q_3$  from the Median  $Q_2$ , taken relative to Quartile Deviation, gives Bowley's measure.

$$\text{Skewness} = \frac{\frac{1}{2}(Q_1 + Q_3) - Q_2}{\frac{1}{2}(Q_3 - Q_1)} = \frac{Q_3 - 2Q_2 + Q_1}{Q_3 - Q_1}$$

As regards the moment measure of skewness, it may be noted that in a symmetrical distribution, for each positive value of  $(x_i - \bar{x})$  there is a corresponding negative value. When these deviations  $(x_i - \bar{x})$  are cubed, positive values retain their positive sign and negative values the negative sign, so that  $m_3 = \sum f_i(x_i - \bar{x})^3 / N$  will be zero. For positively skew distributions (Fig. a), large positive values of  $(x_i - \bar{x})$  are magnified considerably when cubed, and ultimately the sum of positive cubed deviations outweighs the negative cubes, making  $m_3$  positive. In a similar manner, for negatively skew distributions (Fig: (c)),  $m_3$  becomes negative.

For computing skewness of univariate data  $s$  is computed with the  $N$  in denominator (Eq. 5) rather than  $N - 1$ . The formula for skewness is referred to as Fisher-Pearson Coefficient of skewness. Many software programmes compute adjusted Fisher-Pearson coefficient based on this formula.

$$G_1 = \frac{\sqrt{N(N-1)}}{N-2} \frac{\sum_{i=1}^N (Y_i - \bar{Y})^3 / N}{s^3}$$

This is an adjustment of sample size. The adjustment approaches 1 as  $N$  gets large.

Limit of different measures:

Bowley's measure lies between -1 and +1. There are no theoretical limits to Pearson's first measure; but in practice the value is rarely very high. The Pearson's second measure of skewness lies between -3 and +3. Although these limits are very seldom attained. No theoretical limits can be set for the moment measure of skewness for Bowley's measure.

The measures of skewness are pure numbers which do not depend upon the units of measurement.

### 5.3.2.2 Kurtosis:

Kurtosis refers to the degree of "peakedness" of the frequency curve. Two distributions may have the same average, dispersion and skewness; yet, in one there may be high concentration of value near the mode, showing a sharper peak in the frequency curve than in the other. This characteristic of the frequency distribution is known as "kurtosis". The only measure of kurtosis is based on moments, and can be applied for standard normal distributions viz.

$$\text{Kurtosis } (\gamma_2) = \frac{m_4}{\sigma^4} - 3 = \beta_2 - 3$$

Where  $m_4$  and  $\sigma$  denote the fourth central moment and S.D. respectively

For univariate data,  $Y_1, Y_2, \dots, Y_N$  the formula for skewness is: -

$$\text{Kurtosis} = \frac{\sum_{i=1}^N (Y_i - \bar{Y})^4 / N}{s^4}$$

Where,  $\bar{Y}$  = Mean

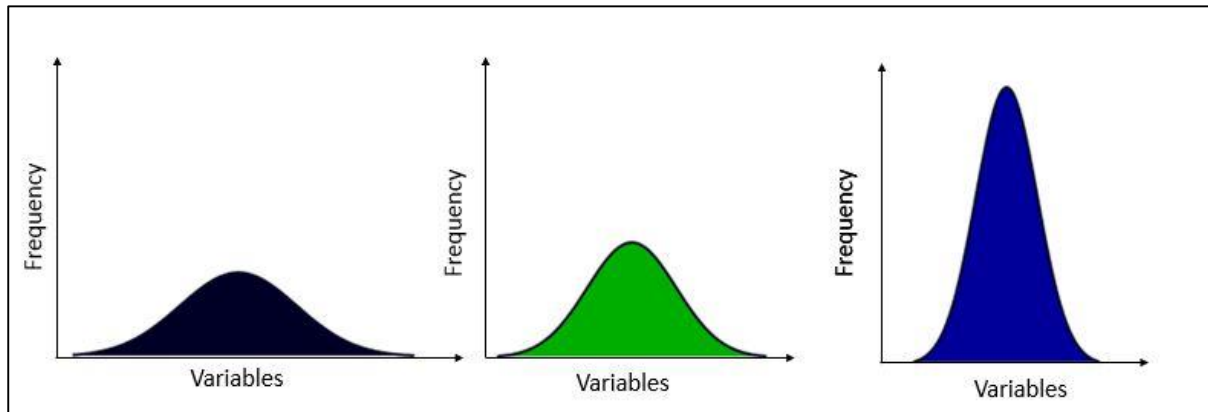
$s$  = Standard Deviation

$N$  = Number of data points.

For the 'Normal Distribution', which is neither very peaked nor flat-topped,  $\beta_2 = 3$ . This important distribution is taken as a standard for measuring kurtosis, and it has become customary to use  $\gamma_2 = \beta_2 - 3$  as a measure of kurtosis.

A distribution is said to be 'platykurtic', when  $\gamma_2$  is negative; it is said to be 'mesokurtic' when  $\gamma_2 = 0$  and 'leptokurtic' when  $\gamma_2$  is positive.

The frequency curve for a platykurtic distribution is relatively flat-topped, and for a leptokurtic distribution it has a relatively high peak. A mesokurtic distribution for Normal distribution is of moderate peakedness.



(a) Platykurtic

(b) Mesokurtic

(c) Leptokurtic

**Fig 5.3.2.2: Different Types of Kurtosis**

$\beta_2 < 3$ , for Platykurtic distribution

$\beta_2 = 3$ , for Mesokurtic distribution

$\beta_2 > 3$ , for Leptokurtic distribution

(Statistical Methods by N. G. Das)

- **Standard Error derived during analysis of Skewness using SPSS**

The ratio of skewness to its standard error can be used as a test of normality (that is, you can reject normality if the ratio is less than -2 or greater than +2). A large positive value for skewness indicates a long right tail; an extreme negative value indicates a long left tail.

- **Standard Error derived during analysis of Kurtosis using SPSS**

The ratio of kurtosis to its standard error can be used as a test of normality (that is, you can reject normality if the ratio is less than -2 or greater than +2). A large positive value for kurtosis indicates that the tails of the distribution are longer than those of a normal distribution; a negative value for kurtosis indicates shorter tails (becoming like those of a box-shaped uniform distribution)

([https://www.ibm.com/support/knowledgecenter/en/SS3RA7\\_15.0.0/com.ibm.spss.modeler.help/dataaudit\\_displaystatistics.htm](https://www.ibm.com/support/knowledgecenter/en/SS3RA7_15.0.0/com.ibm.spss.modeler.help/dataaudit_displaystatistics.htm))

Skewness and Kurtosis of Nadia and Bardhhaman data derived using SPSS (Version 20) which is as follows.

### **5.3.3. Tests of Normality using Visual Tests – Q-Q Plot**

"**Visual**" tests are more intuitively appealing but subjective at the same time, as they rely on informal human judgement to accept or reject the null hypothesis.

Q-Q Plot is a plot of the sorted values from the data set against the expected values of the corresponding quantiles from the standard normal distribution.

A quantile-quantile (Q-Q) plot compares the quantiles of a data distribution with the quantiles of a standardized theoretical distribution from a specified family of distributions. A normal Q-Q plot is that which we can shaped by plotting quantiles of one distribution versus quantiles of normal distribution. When quantiles of two distributions are met, plotted dots face with the line  $y = x$ . If it shows curve size with slope rising from left to right, it indicates the data distribution is skewed to the right and curve size with slope decreasing from left to right, it exposes skewness is to the left for the distribution.

In a Q-Q plot, a plot of point of the form  $(\Phi^{-1}(p_k), x_{(k)})$ , where plotting points  $p_k$  are equal to  $p_k = (k - \alpha)/(n + 1 - 2\alpha)$  and  $\alpha$  is an adjustment constant, which can be anything between 0 and 1. If the null hypothesis is true, the plotted points should approximately lie on a straight line. The abscissa of the plot is scaled in proportionally to the expected quantiles of a standard normal distribution so that a plot of  $(p, \Phi^{-1}(p))$  is linear.

A Q-Q plot is used in this study because my objective is to compare the data distribution with a family of distributions that vary only in location and scale.

### **5.3.4 Normality Test using Descriptive Statistics – K-S Test and S-W Test**

Normality of the data was checked by the Kolmogorov-Smirnov (K-S) test and Shapiro-Wilk. (Singh et al., 2004; Wu et al., 2017) Both of these tests were performed considering Descriptive statistics in SPSS. Whereas Shapiro - Wilk test is originally based on Frequentist statistics.

- **Details of K-S and S-W Test**

The test statistic was developed by Andrey Kolmogorov and Nikolai Smirnov. K-S Test is performed to compare the distribution of the data whether two sample distribution or one sample distribution with a theoretical distribution as a reference point. The test is a nonparametric approach for a given dataset. (Stephens, 1974) The distributions are compared in their cumulative form as empirical distribution functions. (Bagdonavičius et al, 2011; Rayner& Best, 2001; Stephens, 1974)

The K–S test statistic uses a procedure to quantify a distance between the empirical distribution function of the sample and the cumulative distribution function of the reference distribution. (Marsaglia et al., 2003). The statistic also uses the null distribution. The null distribution of this statistic is calculated under the null hypothesis that the sample is drawn from the reference distribution (in the one-sample case) or that the samples are drawn from the same distribution (in the two-sample case). In one sample case the test statistic considers only one sample data for testing with reference to an empirical dataset to check the goodness of fit of the dataset. It assesses the degree of agreement between an observed distribution and a completely specified theoretical continuous distribution to check if the data is continuous, discrete or mixed. (Kolmogorov A (1933))

#### **5.3.4.1 The key assumptions for one sample test are:-**

- 1) The sample considered should be a random sample.
- 2) The theoretical distribution should be continuous and fully defined. The critical values given in tables (and often by software packages) assume this to be the case.
- 3) If parameters are estimated from the data, the test result will be (much) too conservative.
- 4) If parameters are estimated from the sample, Lilliefors test should be used instead.
- 5) If theoretical distribution is assumed to be discrete, the results will be too conservative.
- 6) The sample distribution is assumed to have no ties.
- 7) If there are ties from rounding, or if the variable under consideration is discrete, the result will be too much liberal as the large steps give an excessively large magnitude of maximum deviation Kolmogorov statistic

(Kolmogorov A (1933))

#### 5.3.4.2 Kolmogorov-Smirnov Statistic

The empirical distribution function  $F_n$  for  $n$  number of independent and identically distributed ordered observations  $X_i$  is defined as

$$F_n(x) = \frac{1}{n} \sum_{i=1}^n I_{[-\infty, x]}(X_i)$$

Where,  $I_{[-\infty, x]}(X_i)$  is the indicator function, equal to 1 if  $X_i \leq x$  and equal to 0 otherwise.

The Kolmogorov-Smirnov Statistic for a given cumulative distribution function  $F_{(x)}$  is

$$D_n = \sup_x |F_n(x) - F_{(x)}|$$

Where,  $\sup_x$  = the supremum of the set of distances.

The supremum (abbreviated sup) of a subset  $S$  of a partially ordered set  $T$  is the least element in  $T$  that is greater than or equal to all elements of  $S$ , if such an element exists.

(McGraw-Hill)

#### 5.3.4.3 Lilliefors Test

Hubert Lilliefors used this technique as improvement of Kolmogorov-Smirnov Test. The Lilliefors test is a test of normality which checks the Null Hypothesis and corrects the K-S test results for small values at the tails of probability distributions. The test statistic is same as the Kolmogorov-Smirnov test - namely the maximum difference between the empirical distribution function and the theoretical cumulative distribution function. The critical values with which  $D$  is compared are different. The use of estimated parameters make the maximum difference smaller than it would be. If compared with a fully defined distribution. The null distribution of this test statistic was computed by Lilliefors using Monte Carlo methods, although analytical methods have since been proposed (Lilliefors 1967). Many statistical software combine the two tests as a “Lilliefors corrected” K-S test.

#### 5.3.4.4 Shapiro –Wilk Test

The Shapiro – Wilk test was first published by Samuel Sanford Shapiro and Martin Wilk. The test follows Frequentist statistics distribution.

Theory and Mathematical expression for Shapiro-Wilk test



The Shapiro – Wilk test tests the null hypothesis that a sample  $x_1, \dots, x_n$  came from a normally distributed population. The test static is

$$W = \frac{(\sum_{i=1}^n a_i x_{(i)})^2}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

Where,  $x_{(i)}$  (with parenthesis subscript index  $i$  is not same as  $x_i$ ) is the  $i$ th order statistic, i.e.  $i$ th smallest number in the sample

And,  $\bar{x} = (x_1 + \dots + x_n)/n$  is the sample mean

The coefficients  $a_i$  are given by

$$(a_1, \dots, a_n) = \frac{m^T V^{-1}}{C}$$

Where, C is a vector norm

$$C = \|V^{-1}m\| = (m^T V^{-1} V^{-1} m)^{1/2}$$

And the vector  $m = (m_1, \dots, m_n)^T$  is made of the expected values of the ordered statistics of the independent and identically distributed random variables sampled from the standard normal distribution.

V is the covariance matrix of those normal order statistics

(Shapiro & Wilk, 1965)

Kolmogorov-Smirnov Test and Shapiro-Wilk test analyses the dataset if the dataset follows normal distribution or not. Null hypothesis along with an alternate hypothesis is considered as a check of normality with the help of the tests. The test results show statistic of the data, degrees of freedom (df) and statistical significance (sig.). As per the requirement of the normality test, the determined statistical significance ( $p$ -value) is checked against chosen alpha level of 0.05. (Neyman & Pearson, 1967; Fisher, (1935); Wasserstein 2016; Fisher 1966) ()If determined significance value is less than chosen alpha level, then the null hypothesis is rejected and the dataset does not follow normal distribution. On the other hand if determined significance value is greater than chosen alpha level then the null hypothesis cannot be rejected and the dataset comes from a normal distribution. (Fisher, A. G. (1935).

**H<sub>0</sub> or Null Hypothesis:-** A statistical hypothesis, sometimes called confirmatory data analysis, is a hypothesis that is testable on the basis of observing a process that is modelled via a set of random variables.( Stuart et al., 1999) The null hypothesis of both of these tests check if the data follows normal distribution. Whereas Shapiro-Wilk test is considered as better than Kolmogorov-Smirnov test.

**H<sub>1</sub> or Alternative Hypothesis:** As per Fisher, (Fisher, A. G. (1935)) The central idea is to assess whether the observed dataset could have resulted from chance if the null hypothesis were assumed to hold, notionally without preconceptions about what other model might hold. (Razali & Wah, 2011)

### **5.3.5 Normality Test and cross-check of K-S and S-W Test: KMO and Bertlett's Test**

#### **5.3.5.1 Kaiser – Mayer - Olkin Test**

The Kaiser- Mayer – Olkin Test or KMO test is performed for a group of values or a dataset to find out the suitability of Factor analysis for available dataset. The test measures sampling adequacy for each variable in the model and for complete model. The statistic is a measure of the proportion of variance among variables that might be common variance. Lower proportion indicates higher suitability for Factor analysis.

(Cerny & Kaiser 1977)

Mathematical Expression for KMO Test:-

$$MO_j = \frac{\sum_{i \neq j} r_{ij}^2}{\sum_{i \neq j} r_{ij}^2 + \sum_{i \neq j} u}$$

Where, R = [r<sub>ij</sub>] is the correlation matrix

U= [u<sub>ij</sub>] is the partial covariance matrix

KMO Test results are always from 0 to 1 (See Table 5.5.1)

**Table 5.3.5.1: Result and Remark for KMO Test**

<b>KMO Result</b>	<b>Remark</b>
0.00 to 0.49	Unacceptable
0.50 to 0.59	Miserable
0.60 to 0.69	Mediocre
0.70 to 0.79	Middling
0.80 to 0.89	Meritorious
0.90 to 1.00	Marvellous

(Kaiser 1974)

### **5.3.5.2 Bartlett's Test of Sphericity**

Bartlett's test of sphericity tests the null hypothesis that correlation matrix is an identity matrix, which is an indication that variables are unrelated and therefore unsuitable for structure detection. Bartlett's test is done to detect if any hidden structure exists among the correlation coefficients. Small values (less than 0.05) of the significance level indicate that a factor analysis may be useful with available dataset (Garson 2012; Tobias & Carlson, 1969; Tobias, S., & Carlson, J. E. (1969), Nagao (1973).

### **5.3.6 Correlation**

The word 'correlation' is used to denote the degree of association between variables. If two variable  $x$  and  $y$  are so related that variations in the magnitude of one variable tend to be accompanied by variations in the magnitude of the other variable, they are said to be correlated. If  $y$  tends to increase as  $x$  increases, the variables are said to be positively correlated. If  $y$  tends to decrease as  $x$  increases, the variables are negatively correlated. If the values of  $y$  are not affected by changes in the value of  $x$ , the variables are said to be uncorrelated.

Correlation may also be linear or non-linear. If the amount of change in one variable tends to bear a constant ratio to the amount of change in the other variable, then correlation is said to be 'linear'; because the scatter diagram would show a linear path, Here, we shall be

concerned with linear correlation or simple correlation only. This is measured by ‘Correlation Coefficient’.

### Covariance

Given set of  $n$  pairs of observations  $(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$  relating to two variables  $x$  and  $y$ , the Covariance of  $x$  and  $y$ , usually represented by  $cov(x, y)$ , is defined as

$$cov(x, y) = \frac{1}{n} \sum (x - \bar{x})(y - \bar{y}) \dots \dots \dots \text{eq(1)}$$

Expanding the expression on the right, it can be shown that

$$cov(x, y) = \frac{\sum xy}{n} - \left(\frac{\sum x}{n}\right)\left(\frac{\sum y}{n}\right) \dots \dots \dots \text{eq(2)}$$

Covariance has properties similar to those of variance, i.e. the square of S.D.

(i) If  $X = x - c$  and  $Y = y - c'$ , where  $c, c'$  are constants, then

$$cov(x, y) = cov(X, Y) \dots \dots \dots \text{eq(3)}$$

(ii) If  $u = \frac{x-c}{d}$  and  $v = \frac{y-c'}{d'}$ , where  $c, c', d, d'$  are constants, then

$$cov(x, y) = dd'.cov(u, v) \dots \dots \dots \text{eq(4)}$$

While variance must always be positive, covariance may be positive, negative or zero.

By definition,

$$\text{Variance of } x = \sigma_x^2 = \frac{1}{n} \sum (x - \bar{x})^2 = \frac{1}{n} \sum (x - \bar{x})(x - \bar{x})$$

$$\text{Variance of } y = \sigma_y^2 = \frac{1}{n} \sum (y - \bar{y})^2 = \frac{1}{n} \sum (y - \bar{y})(y - \bar{y})$$

$$\text{Covariance of } x \text{ and } y = \frac{1}{n} \sum (x - \bar{x})(y - \bar{y})$$

For the variances, both the factors on the right are same, either both  $(x - \bar{x})$ , or both  $(y - \bar{y})$  but for the covariance one factor is  $(x - \bar{x})$  and another is  $(y - \bar{y})$ . Again,

$$\text{Variance of } x = \sigma_x^2 = \frac{\sum x^2}{n} - \left(\frac{\sum x}{n}\right)^2 = \frac{\sum x.x}{n} - \left(\frac{\sum x}{n}\right)\left(\frac{\sum x}{n}\right)$$

$$\text{Variance of } y = \sigma_y^2 = \frac{\sum y^2}{n} - \left(\frac{\sum y}{n}\right)^2 = \frac{\sum y.y}{n} - \left(\frac{\sum y}{n}\right)\left(\frac{\sum y}{n}\right)$$

$$\text{Covariance of } x \text{ and } y = \frac{\sum x^2}{n} - \left(\frac{\sum x}{n}\right)^2 = \frac{\sum x.x}{n} - \left(\frac{\sum x}{n}\right)\left(\frac{\sum x}{n}\right)$$

Thus it is seen that first covariance is a variance like quantity, but obtained by the combination of two variables. Therefore, covariance may be looked upon as a ‘conjoint variance’.

### Correlation Coefficient ( $r$ )

Let  $(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$  be a given set of  $n$  pairs of observations on two variables  $x$  and  $y$ . The Correlation Coefficient, or Coefficient of Correlation, between  $x$  and  $y$  (denoted by the symbol  $r$ ) is then defined as

$$r = \frac{\text{cov}(x, y)}{\sigma_x \sigma_y} \dots \dots \dots \text{eq(1)}$$

Where  $\sigma_x$  and  $\sigma_y$  are the standard deviations of  $x$  and  $y$  respectively, and  $\text{cov}(x, y)$  denotes the covariance of  $x$  and  $y$ . This expression is known as Pearson’s product-moment formula, and is used as a measure of linear correlation between  $x$  and  $y$ .

The formula of  $r$  may be written in various other forms. Putting the explicit expressions for  $\text{cov}(x, y)$ ,  $\sigma_x$  and  $\sigma_y$  in eq.(1), and multiplying both the numerator and the denominator by  $n$ , we have

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{[\sum(x - \bar{x})^2 \cdot \sum(y - \bar{y})^2]}} \dots \dots \dots \text{eq(2)}$$

Now , expanding the expressions

$$r = \frac{\sum xy - n\bar{x}\bar{y}}{\sqrt{[(\sum x^2 - n\bar{x}^2) \cdot (\sum y^2 - n\bar{y}^2)]}} \dots \dots \dots \text{eq (3)}$$

Multiplying the numerator and the denominator by  $n$  again, and since  $n\bar{x} = \sum x$  and  $n\bar{y} = \sum y$ , we may write

$$r = \frac{n \sum xy - (\sum x) (\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2] [n \sum y^2 - (\sum y)^2]}} \dots \dots \dots \text{eq(4)}$$

[Note:- In all the forms shown above, the denominator contains two factors under the square-root. They may be obtained on replacing  $y$  by  $x$ , and  $x$  by  $y$ , in the numerator]

Properties of correlations coefficient

(i) The correlation coefficient  $r$  is independent of the choice of both origin and scale of observations. This means that if

$$u = \frac{x - c}{d} \quad \text{and} \quad v = \frac{y - c'}{d'}$$

Where  $c, c', d$ , are arbitrary constants ( $d$  and  $d'$  positive), then

$$r_{xy} = r_{uv} \dots \dots \dots \text{eq(5)}$$

i.e.

$$\begin{aligned} &\text{Correlation coefficient between } x \text{ and } y \\ &= \text{Correlation coefficient between } u \text{ and } v \end{aligned}$$

In general, if  $X = a + bx, Y = a' + b'y$ , then

$$r_{XY} = \pm r_{xy} \dots \dots \dots \text{eq(6)}$$

According as  $b$  and  $b'$  have the same sign, or opposite signs.

(ii) The correlation coefficient  $r$  is a pure number and is independent of the units of measurement. This means that if, for example  $x$  represents height in inches and  $y$  weight in lbs, then the correlation coefficient between  $x$  and  $y$  will neither be in inches nor in lbs. or any other unit, but only a number.

(iii) The correlation coefficient  $r$  lies between -1 and +1; i.e.  $r$  cannot exceed 1 numeracially

$$-1 \leq r \leq +1 \dots \dots \dots \text{eq(7)}$$

Calculation of r

Correlation coefficient ( $r$ ) is unaffected by the choice of origin and scale of one or both the variables (property (i)) Therefore, it can be calculated from a given set of  $n$  pairs of observations  $(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$  as follows:

(I) If  $X = x - c$  and  $Y = y - c'$ , (here  $c, c'$  are constants), then

$$r_{xy} = r_{XY} = \frac{cov(X, Y)}{\sigma_X \sigma_Y} \dots \dots \dots \text{eq(8)}$$

Where

$$\sigma_X^2 = \frac{\sum X^2}{n} - \left(\frac{\sum X}{n}\right)^2$$

and

$$\sigma_Y^2 = \frac{\sum Y^2}{n} - \left(\frac{\sum Y}{n}\right)^2$$

$$cov(X, Y) = \frac{\sum XY}{n} - \left(\frac{\sum X}{n}\right)\left(\frac{\sum Y}{n}\right) \dots \dots \dots \text{eq(9)}$$

Thus, we can always reduce and given values of  $x$  and  $y$  on subtracting convenient numbers  $c$  and  $c'$ , and obtain deviations  $X = x - c$ ,  $Y = y - c'$ . From these reduced value  $X$  and  $Y$ , the two standard deviations and the covariance, viz.  $\sigma_X$ ,  $\sigma_Y$  and  $cov(X, Y)$ , are now calculated, and finally the correlation coefficient  $r_{XY}$  between them. This will be exactly equal to the correlation coefficient  $r_{xy}$  between the original values of  $x$  and  $y$ .

(II) If  $u = \frac{x-c}{d}$  and  $v = \frac{y-c'}{d'}$ , (here  $c, c', d, d'$  are constants and  $d, d'$  are positive), then

$$r_{xy} = r_{uv} = \frac{cov(u, v)}{\sigma_u \sigma_v}$$

Where,

$$\sigma_u^2 = \frac{\sum u^2}{n} - \left(\frac{\sum u}{n}\right)^2, \quad \sigma_v^2 = \frac{\sum v^2}{n} - \left(\frac{\sum v}{n}\right)^2$$

$$cov(u, v) = \frac{\sum uv}{n} - \left(\frac{\sum u}{n}\right) \left(\frac{\sum v}{n}\right) \dots \dots \dots \text{eq(10)}$$

In some cases the given value of  $x$  and  $y$  may be such that it is further possible to reduce the deviations  $x - c$  and  $x - c'$  on division by constant factors  $d$  and  $d'$  i.e

$$u = (x - c)/d, \quad v = (y - c') / d'$$

From these value of  $u$  and  $v$ , the two standard deviations  $\sigma_u, \sigma_v$  and the covariance  $cov(u, v)$  are calculated, and finally the correlation coefficient  $r_{uv}$  between  $u$  and  $v$  is obtained. This will be exactly equal to the correlation coefficient  $r_{xy}$  between the original value of  $x$  and  $y$ .

(Statistical Methods by N.G. Das)

### 5.3.7 Hierarchical Clustering Analysis

Cluster analysis is the process of grouping a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups. Cluster analysis uses some predefined selection criterion to classify the objects depending upon their characteristics. The resulting clusters should express high internal homogeneity and high external heterogeneity. Hierarchical agglomerative clustering is the most common approach, which provides similarity relationships between any one sample and the entire data set, and is typically illustrated by a dendrogram or tree diagram. (McKenna Jr., 2003) The expression of dendrogram provides a visual summary of the clustering processes which is a picture of the groups and their proximity, with a reduction in dimensionality of the original data. The reduction in the dimensionality helps in identifying any hidden structure among the selected data. It should be decided which clusters should be combined for clustering, a measure of similarity or dissimilarity between sets of observations is required. In most methods of hierarchical clustering, this is achieved by use of an appropriate measure of distance between pairs of observations, and a linkage criterion which specifies the dissimilarity of sets as a function of the pairwise distances of observations in the sets. The Euclidean distance gives the similarity between two samples and a distance can be represented by the difference between analytical values from the samples (Otto 1998O)



## Chapter 6

### RESULTS AND DISCUSSION

#### 6.1 Hydrochemistry

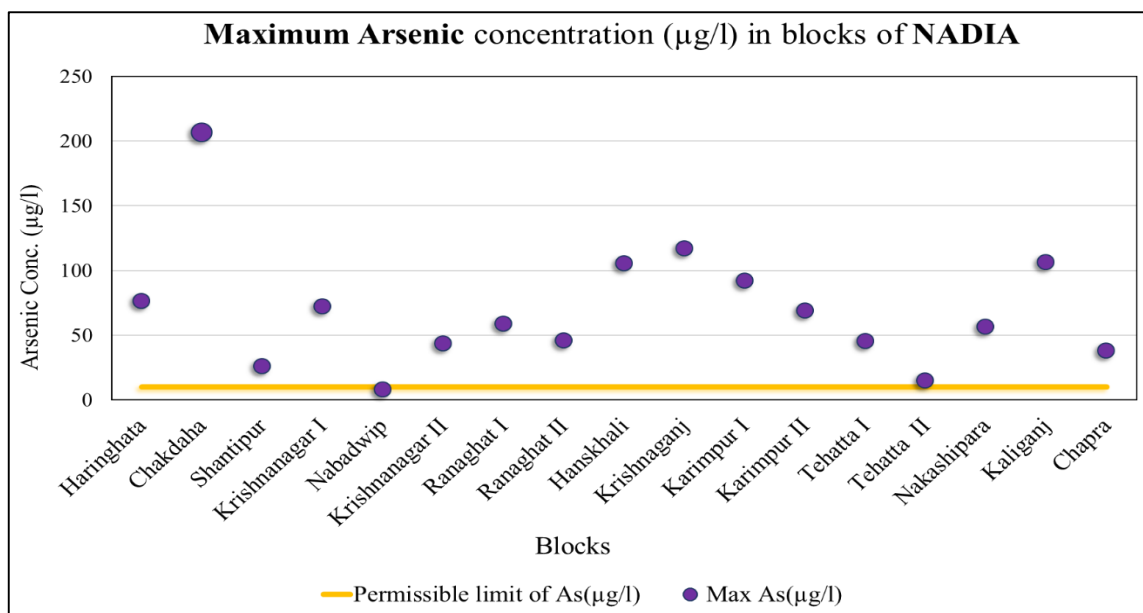
##### 6.1.1 Nadia

In the study area the pH value of groundwater ranges from 6.84 to 8.18 (mean 7.54), which indicates an alkaline type of groundwater. pH values of all the collected samples are well within the safe limit as prescribed by WHO 2004 and BIS 10500: 2012. The Electrical Conductivity value ranges from 404 to 2,250  $\mu\text{S}/\text{cm}$ . The variation in EC is mostly attributed to various geochemical processes in the groundwater of this district. Total Dissolved Solids in the study area varies in the range of 270–1,507 mg/l with a mean of 525.09 mg/l. 62.72% of groundwater samples have TDS values within the permissible limit given by BIS 10500:2012. As per the TDS classification by Fetter 1990, only 1.8% of groundwater samples collected from the study area are of brackish nature (TDS > 1,000 mg/l) and the rest of the samples are of fresh water (TDS < 1,000 mg/l) type. Concentration of Total Hardness increases with the increase in concentrations of  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  ions which can be suggested from the presence of positive correlations between them and stronger correlation of  $\text{Mg}^{+2}$  ions with TH (Table: Correlation Matrix) indicates the prevalence of  $\text{Mg}^{+2}$  ions over  $\text{Ca}^{+2}$  ions for the contribution of TH in the study area. Total Hardness as  $\text{CaCO}_3$  in the study area ranges from 20 to 570 mg/l with a mean of 328.62 mg/l. According to TH classification by Sawyer and Mc Carthy 1967), 31.8% samples indicate that groundwater is hard (150–300 mg/l) and 59% of the samples lie in the very hard (>300 mg/l) classification. It is observed that only 35.45% of groundwater samples have TH more than TA, which is an indication of the noncarbonated hardness classification in groundwater (Chow 1964). Such kind of hardness is difficult to remove easily from the waters. In the study area 91.8% of all collected samples have Total Hardness are under the acceptable limit as suggested by BIS 10500:2012. Chloride ( $\text{Cl}^-$ ) and Bicarbonate ( $\text{HCO}_3^-$ ) are the dominant anions followed by Sulphate ( $\text{SO}_4^{2-}$ ), Nitrate ( $\text{NO}_3^-$ ) and Phosphate ( $\text{PO}_4^{-3}$ ) concentrations of Bicarbonate and Chloride in the study area are 37–650 and 14.04–347.4 mg/l respectively. Great value of  $\text{Cl}^-$  content may be related to the some local anthropogenic activities because they are associated with high

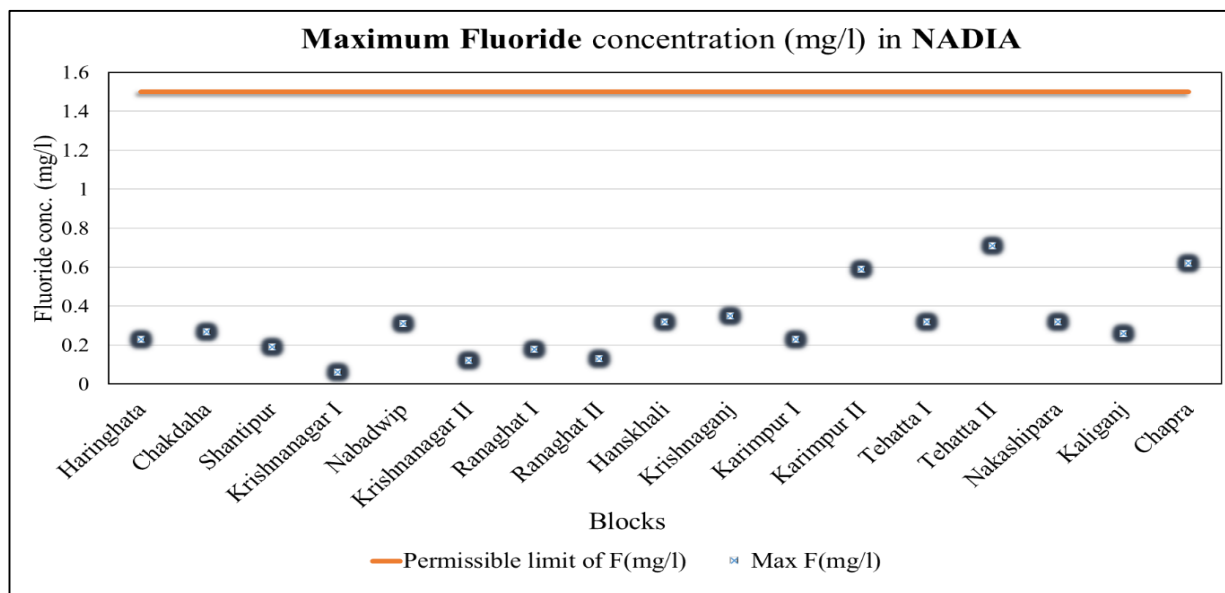
Nitrate and Sulphate concentration in ground water. Also positive correlations are found between the above said anions (Table: Correlation Matrix). No effort is made in this study to relate increased chloride concentration to specific anthropogenic sources. It is found from the study area that most samples collected from shallow depth wells have higher concentrations of Chloride, Nitrate and Sulphate ions. Concentration of Nitrate ions in the study area are in a range from 0.5 to 57.6 mg/l (mean 8.52 mg/l). Most of the samples (96.3%) are below the permissible limit and some of the samples have values very close to permissible limits. Maximum uranium content is found to be 20.9 µg/l in the study area which is nearly equal to the permissible limit set by EPA (EPA 2000) and under the permissible limit set by WHO (WHO 2004) and AERB (AERB 2004). Maximum radiation level is found to be well under the permissible limit set by WHO.

**Table 6.1.1.1:** Range of the toxic parameters in Nadia

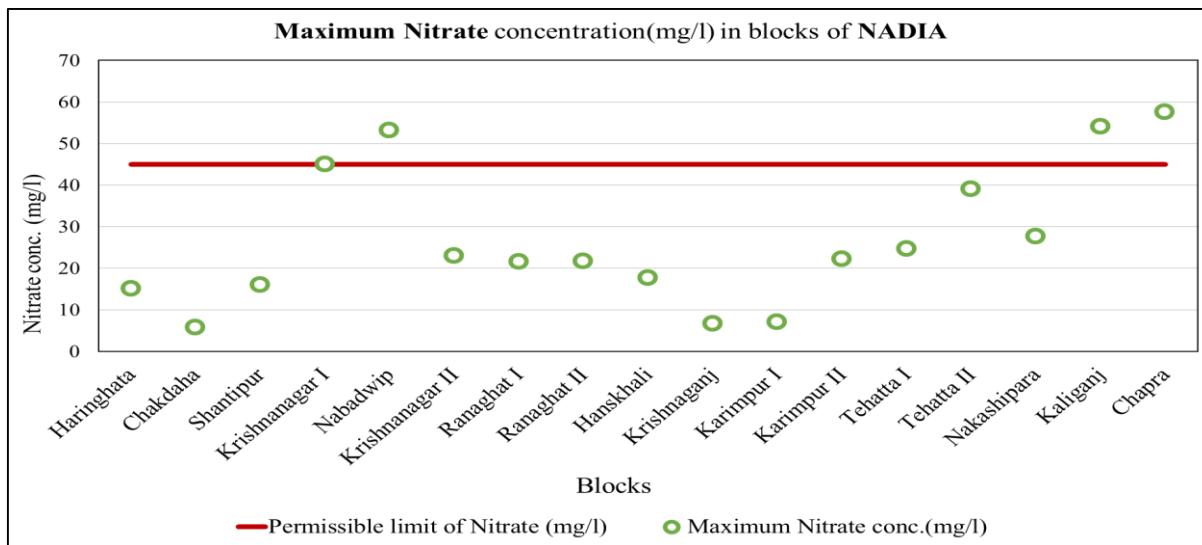
Blocks	Sample Number (n)	Arsenic	Fluoride	Nitrate	Uranium
		Range (Min-Max)	Range (Min-Max)	Range (Min-Max)	Range (Min-Max)
Chakdaha	6	0.69 - 206.3	0.05 - 0.27	1.8 - 5.72	0.34 - 1.7
Chapra	7	3 - 37.8	0.07 - 0.62	0.5 - 57.6	1.3 - 20.5
Hanskhali	7	0.55 - 105.4	0.05 - 0.32	0.5 - 17.7	1.39 - 20.5
Haringhata	6	0.625 - 76.2	0.05 - 0.23	1.76 - 15.05	0.35 - 4.44
Kaliganj	6	3 - 106.5	0.15 - 0.26	0.5 - 54	0.57 - 11.9
Karimpur I	6	1.28 - 92	0.16 - 0.23	0.5 - 7.07	1.54 - 9.82
Karimpur II	8	0.5 - 69	0.14 - 0.59	4.2 - 22.14	1.9 - 13.8
Krishnaganj	10	4.5 - 117	0.1 - 0.54	0.5 - 6.65	1.2 - 3.92
Krishnanagar I	6	0.23 - 72.3	0.01 - 0.06	0.5 - 45	0.21 - 10.2
Krishnanagar II	6	13.5 - 43.4	0.05 - 0.12	0.5 - 23.03	0.34 - 11
Nabadwip	6	0.11 - 7.65	0.05 - 0.31	15 - 53.14	1.4 - 10.6
Nakashipara	5	3 - 56.4	0.1 - 0.32	1.3 - 27.6	1.08 - 4.73
Ranaghat I	6	3 - 58.5	0.05 - 0.18	6.2 - 21.6	1.25 - 4.57
Ranaghat II	6	2.04 - 46	0.05 - 0.13	4.42 - 21.65	1.08 - 9.8
Shantipur	5	0.1 - 26.03	0.05 - 0.19	0.5 - 16	1.24 - 6.5
Tehatta II	6	0.8 - 14.9	0.1 - 0.71	0.5 - 39.02	1.58 - 20.9
Tehatta I	7	3 - 45.5	0.12 - 0.32	0.5 - 24.6	1.3 - 20.6



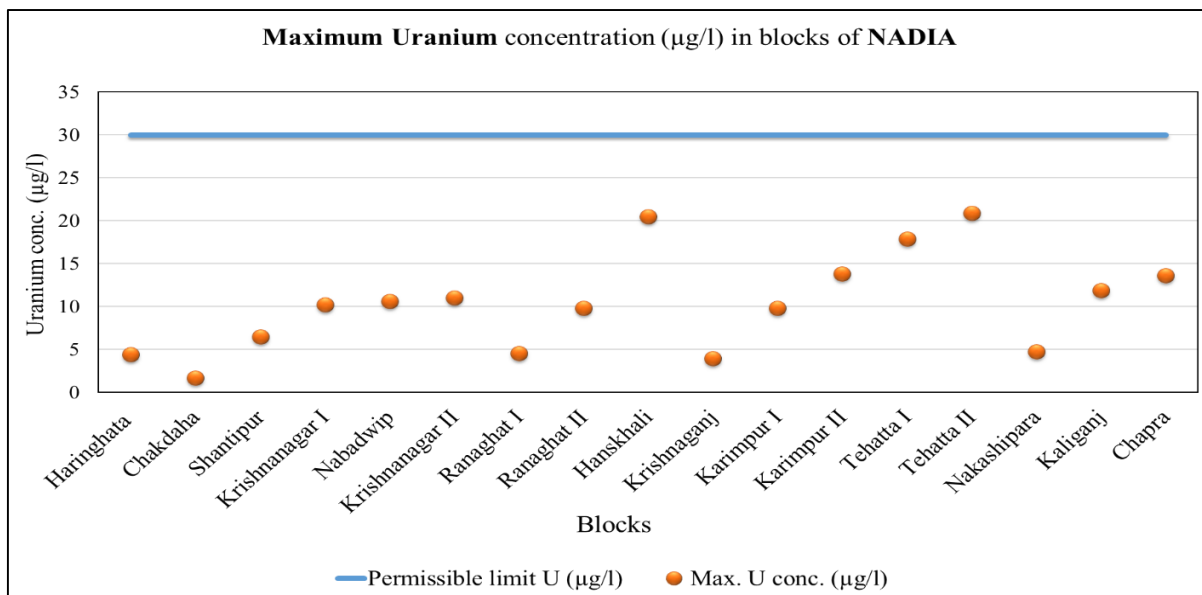
**Fig (a):** Block wise maximum arsenic distribution in Nadia



**Fig (b):** Block wise maximum fluoride distribution in Nadia



**Fig (c):** Block wise maximum nitrate distribution in Nadia



**Fig (d):** Block wise maximum uranium distribution in Nadia

**Fig 6.1.1** Distribution of toxic parameters in Nadia

**Table 6.1.1.2:** Elementary statistics of water quality parameters in Nadia

Parameter	Unit	Min*	Max*	A.M.*	S.D.*	C.V.*	Q1*	Q2*	Q3*
<b>pH</b>	-----	6.84	8.18	7.54	0.247	30.6	7.355	7.5	7.73
<b>TDS</b>	mg/l	270	1507	525.1	196.8	2.67	417.5	477	545.5
<b>EC</b>	µS/cm	404	2250	787.7	295.7	2.66	623.5	713	839.5
<b>ORP</b>	mV	103	248	159.8	33.51	4.77	132.5	155	188.8
<b>Salinity</b>	mg/l	180	1050	362.8	138.4	2.62	290	330	380
<b>DO</b>	mg/l	2.18	8.84	4.02	1.17	3.44	3.04	3.98	4.66
<b>F<sup>-</sup></b>	mg/l	0.01	0.71	0.18	0.15	83.33	0.05	0.16	0.24
<b>Cl<sup>-</sup></b>	mg/l	14	347	78.2	52.1	66.62	42.6	63.2	94.7
<b>NO<sub>3</sub><sup>-</sup></b>	mg/l	0.5	57.6	10.1	12.5	123.8	1.94	4.87	13.7
<b>SO<sub>4</sub><sup>-2</sup></b>	mg/l	1	200	26	26.9	103.5	10.65	16.7	33.5
<b>PO<sub>4</sub><sup>-3</sup></b>	mg/l	0.05	19.2	1.36	2.6	191.2	0.16	0.45	1.32
<b>U</b>	mg/l	0.21	20.9	3.88	4.55	117.3	1.36	1.64	4.57
<b>TH</b>	mg/l	20	570	329	119	36.2	270	320	400
<b>Ca</b>	mg/l	4	156	53.7	32.93	61.3	26.4	51.2	72
<b>Mg<sup>+2</sup></b>	mg/l	0.48	114.4	44.9	26.96	60.1	24.04	45.67	61.5
<b>TA</b>	mg/l	186	725	375	77	20.5	330	361	415
<b>CO<sub>3</sub><sup>-2</sup></b>	mg/l	0	229	56	42.2	75.4	31.6	42.4	68
<b>HCO<sub>3</sub><sup>-</sup></b>	mg/l	37	650	319	87	27.3	266	307	354
<b>As</b>	mg/l	0.3	206	22	30	136.4	3	10.8	31.5
<b>Fe</b>	mg/l	0.1	13.7	3.02	2.9	96.03	0.65	2.14	4.75
<b>RADIATION<sup>#</sup></b>	nSv	0	350	151.1	62.9	2.4	105.5	150	198

\*Min = Minimum of all the samples, Max = Maximum of all samples, A.M. = Arithmetic Mean, S.D. = Standard Deviation, C.V. = Coefficient of Variation\*\*, Q1 = First interquartile range\*\*\*, Q2 = Second interquartile range\*\*\* or median of all samples, Q3 = Third interquartile range\*\*\*

\*\*Coefficient of Variation is obtained by dividing the standard deviation by arithmetic mean.

\*\*\*First interquartile range indicates the median of first 25% of the samples when arranged in an ascending order of the numerical values. Correspondingly second and third interquartile range indicates the median of 50% and 75% of the samples when arranged in ascending order.

### 6.1.2. Bardhaman

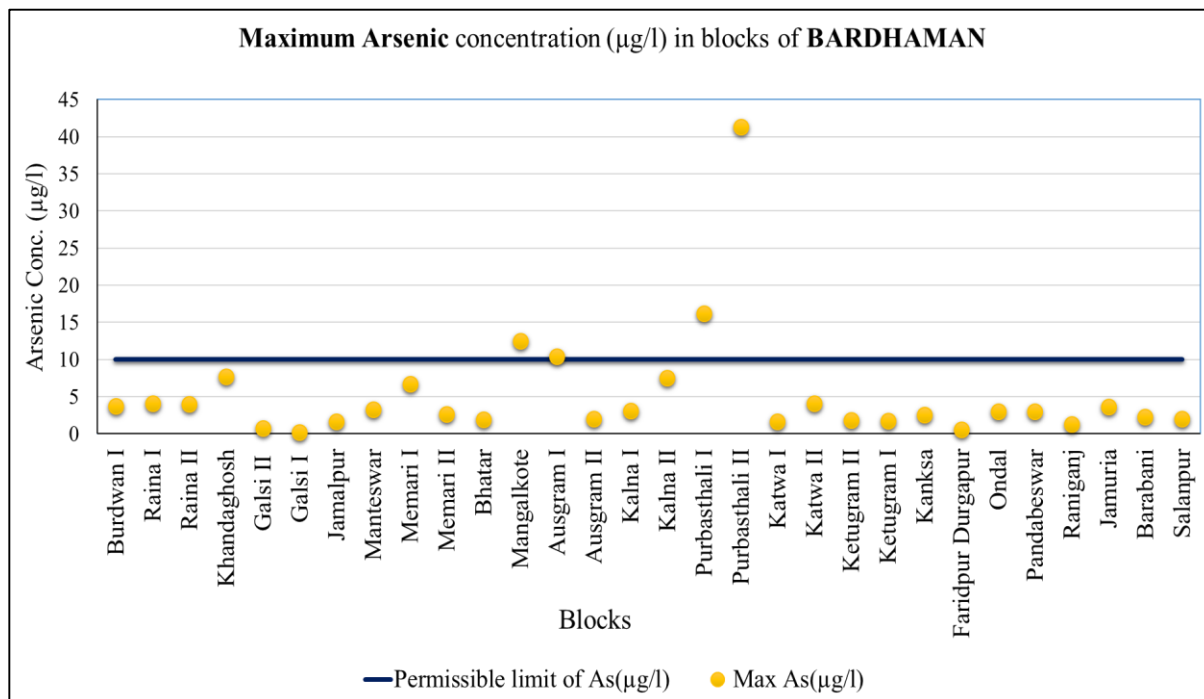
The pH value of groundwater in the study area ranges from 6.25 to 8.15 (mean 7.47), indicating an alkaline nature of groundwater. pH values of all the collected samples are well within the safe limit as recommended by WHO (1984) and BIS (10500 : 2012). EC value ranges from 66 to 2,549  $\mu\text{S}/\text{cm}$ . The large variation in EC is mainly ascribed to geochemical processes predominant in this region (Gupta et al., 2008). TDS in the study area varies in the range of 5–1,274 mg/l with a mean value of 324.98 mg/l. The variation of TDS in the district is an indication of unequal groundwater table in the region as higher the groundwater table and topography, the lower the concentration of TDS. Higher concentration of TDS is witnessed in the north-western part of the district. This is for the reason that most of these parts of the district have semi-arid climatic condition and be made of of hard rock and low groundwater table. This clearly suggests the role of direction and amount of groundwater flow for the differences in groundwater quality (Gupta et al., 2008). 86.67% of groundwater samples have TDS values within the permissible limit of BIS 10500:2012. As per the TDS classification by Fetter 1990, 2.22% of all the samples collected from the study area are of brackish nature (TDS > 1,000 mg/l) and the rest of the samples are in the category of fresh water (TDS < 1,000 mg/l). Total Hardness increases with the increase in concentrations of Calcium and Magnesium ions, which is also suggested by the presence of strong and good positive correlations between them and also the predominance of  $\text{Ca}^{+2}$  ions over  $\text{Mg}^{+2}$  ion towards the contribution of Total Hardness (Table 6.7.2) in the study area. Total Hardness as  $\text{CaCO}_3$  ranges from 20 to 760 mg/l with a mean of 215.83 mg/l in the study area. According to TH classification by Sawyer and Mc Carthy 1967, 58.33% samples indicate that groundwater is hard (150–300 mg/l) and 12.7% of the samples lie in the very hard (>300 mg/l) classification. 53.3% of all the collected samples Total hardness has crossed the safe limit given by BIS 10500:2012. 40% of groundwater samples have TH more than TA, (same as found by (Gupta et al., 2008) which indicates that the groundwater is categorized by noncarbonated hardness (Chow 1964). Such hardness is difficult to be removed from the waters. 36.67% of the collected samples have TH under the acceptable limit as suggested by WHO 1984 and 46.67% of the collected samples have TH under the acceptable limit as suggested by BIS 10500:2012 in the study area.  $\text{Cl}^-$  and  $\text{HCO}_3^-$  are the dominant anions followed by Sulphate Nitrate and Phosphate. Concentrations of Bicarbonate and Chloride ions in the study area are 9.46–494 and 14.06–347.09 mg/l respectively. High concentration of Chloride ion content is most likely to be connected with the local anthropogenic reasons of

groundwater pollution because it is associated with high  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  contamination. Also good positive correlations are found between the above said anions (Table 3). In this study, no effort is made to relate raised chloride concentration towards precise anthropogenic sources. In the study area it is found that most of the samples collected from shallow depth well have higher concentrations of Chloride, Nitrate and Sulphate ions. Concentration of Nitrate in the study area ranges from 0.4 to 164 mg/l (mean 8.63 mg/l). Only 5.5% of the samples have crossed permissible limit but majority of the samples are within permissible limits. Maximum uranium content is found to be 14.6  $\mu\text{g/l}$  in the study area which is well under the permissible limit set by EPA (EPA 2000), WHO (WHO 2004) and AERB (AERB, 2004). Maximum radiation level is found to be well under the permissible limit set by WHO

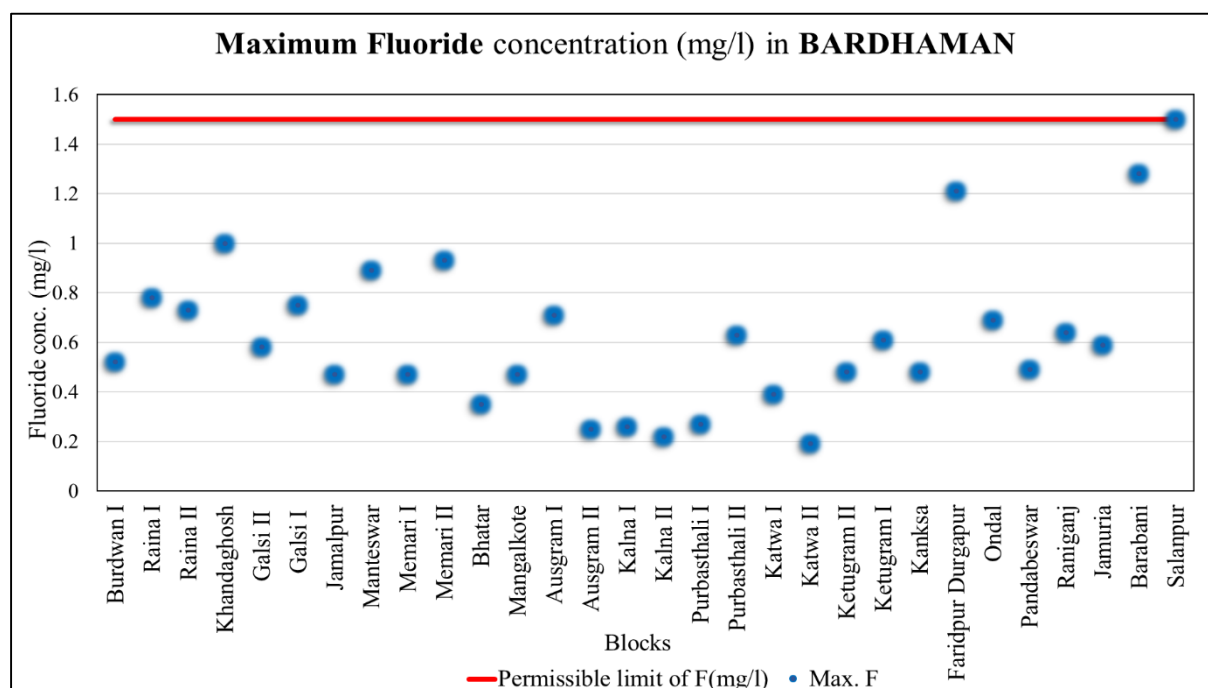
**Table 6.1.2.1: Range of the toxic parameters in Bardhaman**

Blocks	Sample Number (n)	Fluoride	Nitrate	Uranium	Arsenic
		Range (Min-Max)	Range (Min-Max)	Range (Min-Max)	Range (Min-Max)
Ausgram I	6	0.05 - 0.71	0.5 - 10.16	0.07 - 3.5	0.28 - 10.36
Ausgram II	6	0.05 - 0.25	0.5 - 40	0.1 - 2.45	0.3 - 1.95
Barabani	6	0.14 - 0.49	2.86- 160	0.47 - 3.14	0.96 - 2.29
Bhatar	6	0.11 - 0.35	0.4- 5.83	0.34- 4.65	0.64 - 1.92
Burdwan I	10	0.05- 0.58	0.5 - 164	0.51 - 5.01	0.46 - 3.7
Faridpur Durgapur	6	0.26- 1	0.5- 11.9	0.39 - 8.16	0.41 - 3
Galsi I	6	0.39 - 0.75	1.7 - 3.61	2.41- 4.4	0.01 - 0.18
Galsi II	6	0.37 - 0.58	1.32 - 3.56	1.2 - 5.05	0.15- 0.43
Jamalpur	6	0.17 - 0.41	0.5 - 0.66	0.33 - 2	0.4- 1.66
Jamuria	6	0.21 - 0.6	2.29 - 49.6	0.6 - 2.81	1.26 - 3.67
Kalna I	6	0.21 - 0.26	0 - 0.5	0.65 - 4	0.64 - 2.58
Kalna II	6	0.082 - 0.22	0 - 0.5	0.35 - 2.7	0.7 - 7.56
Kanksa	6	0.1 - 0.48	0.5- 3.54	0.13 - 2.46	1.11- 2.56
Katwa I	6	0.11 - 0.39	0.5 - 2.03	0.69 - 2.3	0.64- 5.78
Katwa II	6	0.1 - 0.19	0 - 0.5	1 - 7.15	0.44 - 4.1
Ketugram I	6	0.25 - 0.61	0.5- 4.8	0.5 - 2.4	0.86 - 1.8
Ketugram II	6	0.15 - 0.48	0.5 - 3.67	0.35 - 5.15	0.62 - 1.62
Khandaghosh	6	0.31 - 1	0.8 - 5.7	1.28 - 5.76	3.5 - 7.69
Mangalkote	6	0.1 - 0.47	0.5 - 1.63	0.27 - 5.72	0.61- 12.48
Manteswar	6	0.31- 0.89	0.5 - 3.53	0.35 - 3.92	0.53 - 3.26
Memari I	4	0.29 - 0.47	0 - 0.5	0.35 - 2.05	0.44 - 2.27
Memari II	5	0.35 - 0.93	0.5 - 0.62	1.66 - 3.91	0.56 - 6.72
Ondal	6	0.35 - 0.69	1.37 - 109	1- 2.07	0 - 3
Pandabeswar	6	0.26 - 1	0.5 - 12.82	0.4 - 2.1	0 - 3
Purbasthali I,	6	0.05 - 0.27	0.5 - 1.14	0.23- 4.2	1.36 - 16.23
Purbasthali II	6	0.062 - 0.63	0.5 - 18.1	0.5- 4.76	1.14 - 41.28
Raina I	6	0.31 - 0.78	0.75 - 9.24	1 - 6.38	3.64 - 4.14
Raina II	6	0.33 - 0.63	1.28- 4.4	2.42 - 4.94	3.45 - 4
Raniganj	6	0.2 - 0.64	5.28 - 70.4	0.8 - 5.28	0.7 - 2.83
Salanpur	6	0.4 -1.5	4.4- 62	0.42-14.6	1.13 - 2.01

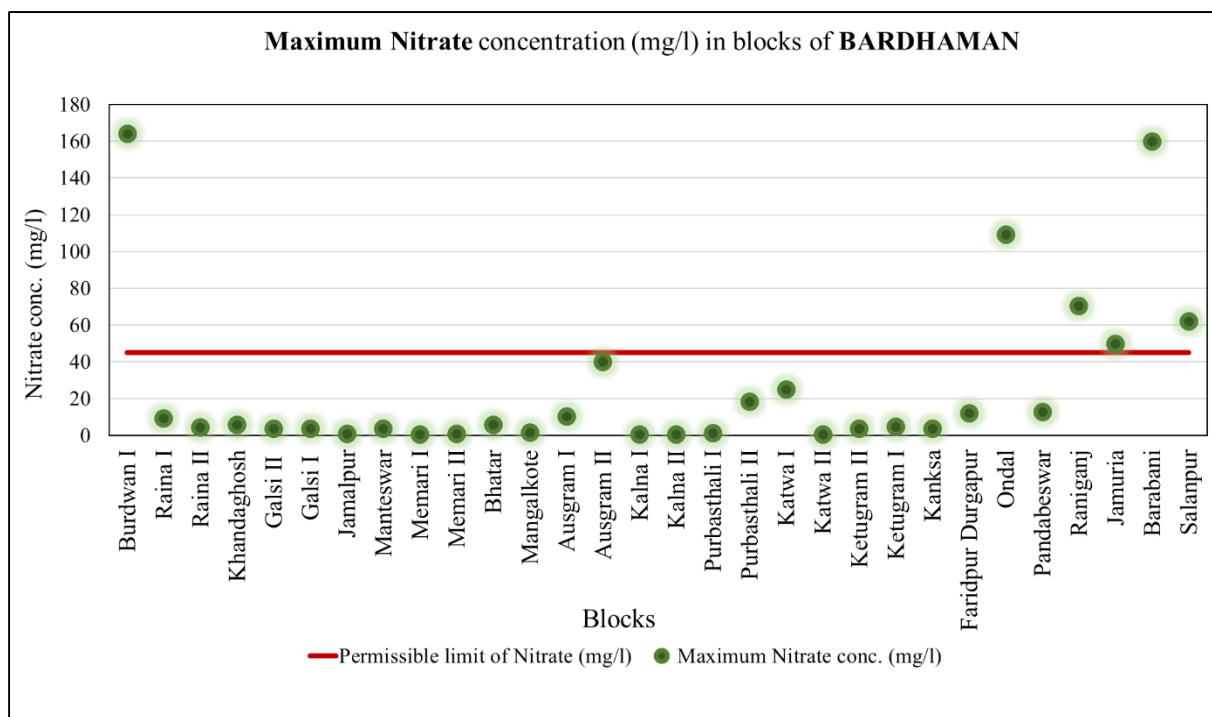




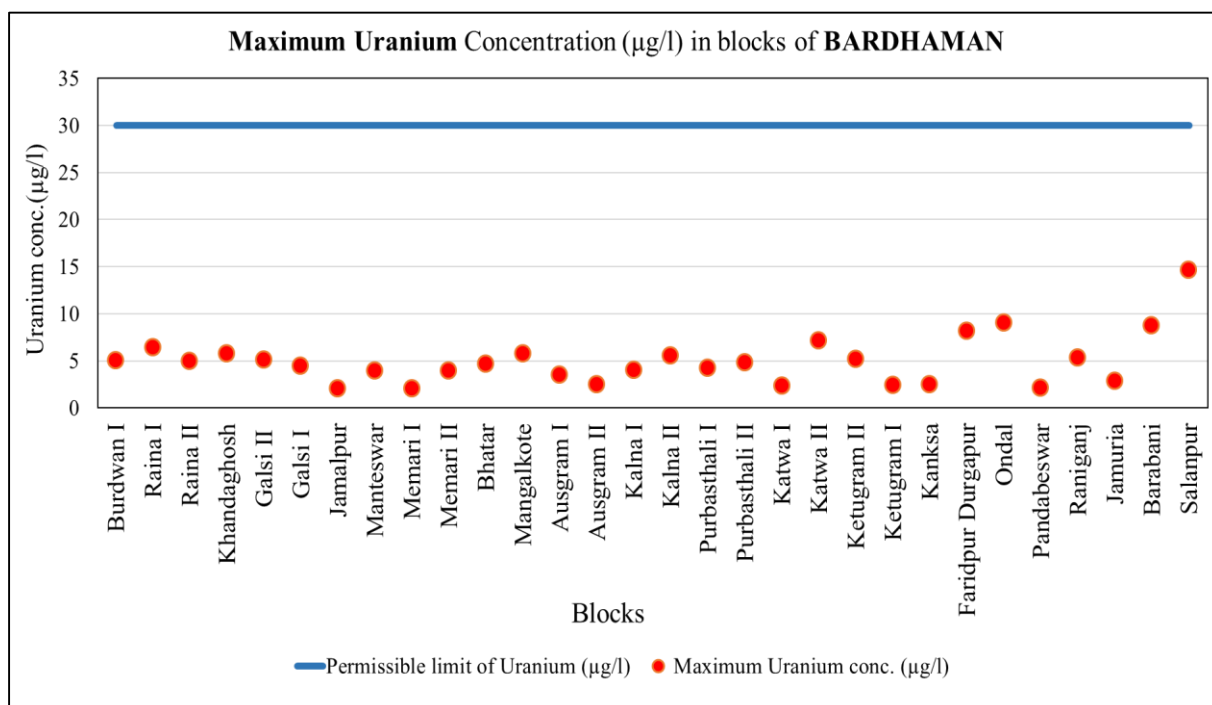
**Fig (a):** - Block wise maximum arsenic distribution in Bardhaman



**Fig (b):** Block wise maximum fluoride distribution in Bardhaman



**Fig (c):** Block wise maximum nitrate distribution in Bardhaman



**Fig (d):** Block wise maximum uranium distribution in Bardhaman

**Fig 6.1.2 :** Distribution of the toxic parameters in Bardhaman

**Table 6.1.2.2:** Elementary Statistics of Water Quality Parameters in Bardhaman District

Parameter	Unit	Min*	Max*	A.M.*	S.D.*	C.V.*	Q1*	Q2*	Q3*
<b>pH</b>	-----	8.15	6.25	0.4	0.05	7.47	7.28	7.54	7.76
<b>TDS</b>	mg/l	1274	5	201.08	0.62	325	187	321.5	442.25
<b>EC</b>	µS/cm	2549	66	368.66	0.53	700.4	439	669	895.5
<b>ORP</b>	mV	418	168	53.17	0.23	232.2	186	228	256
<b>Salinity</b>	mg/l	1310	0	211.03	0.71	296.2	160	285	410
<b>DO</b>	mg/l	8.36	4.55	0.75	0.12	6.33	5.80	6.21	6.74
<b>F<sup>-</sup></b>	mg/l	1.50	0.05	0.23	0.59	0.39	0.22	0.35	0.50
<b>Cl<sup>-</sup></b>	mg/l	347.9	14.06	54.14	0.84	64.2	32	45.68	72.92
<b>NO<sub>3</sub><sup>-</sup></b>	mg/l	164	0.4	24.15	2.80	8.64	0.5	0.99	4.01
<b>SO<sub>4</sub><sup>-2</sup></b>	mg/l	310	0.5	40.52	1.36	29.81	9	20.25	35.75
<b>PO<sub>4</sub><sup>-3</sup></b>	mg/l	8.98	0.05	0.75	1.79	0.42	0.1	0.27	0.5
<b>U</b>	µg/l	14.60	0.07	2.02	0.92	2.20	0.71	1.57	3.07
<b>TH</b>	mg/l	760	20	104.67	0.48	215.8	150	200	270
<b>Ca<sup>+2</sup></b>	mg/l	450	0	72.31	0.59	123.2	80	110	160
<b>Mg<sup>+2</sup></b>	mg/l	280	10	49.69	0.54	91.3	52.5	95	110
<b>TA</b>	mg/l	494	34.4	102.14	0.41	247.5	179	250.8	313.4
<b>CO<sub>3</sub><sup>-2</sup></b>	mg/l	137.6	0	34.84	0.91	38.4	0	34.4	62
<b>HCO<sub>3</sub><sup>-</sup></b>	mg/l	494.0	9.46	95.47	0.46	209.42	146.05	199.5	274
<b>As</b>	mg/l	0.04	0	0	1.64	0.00	0.00	0	0
<b>Fe</b>	mg/l	35.12	0	4.08	2.49	1.64	0.1	0.33	1.43
<b>RADIATION</b>	nSv	297	13	54.5	0.35	154.1	118	148.5	194

\*Min = Minimum of all the samples, Max = Maximum of all samples, A.M. = Arithmetic Mean, S.D. = Standard Deviation, C.V. = Coefficient of Variation\*\*, Q1 = First interquartile range\*\*\*, Q2 = Second interquartile range\*\*\* or median of all samples, Q3 = Third interquartile range\*\*\*

\*\*Coefficient of Variation is obtained by dividing the standard deviation by arithmetic mean.

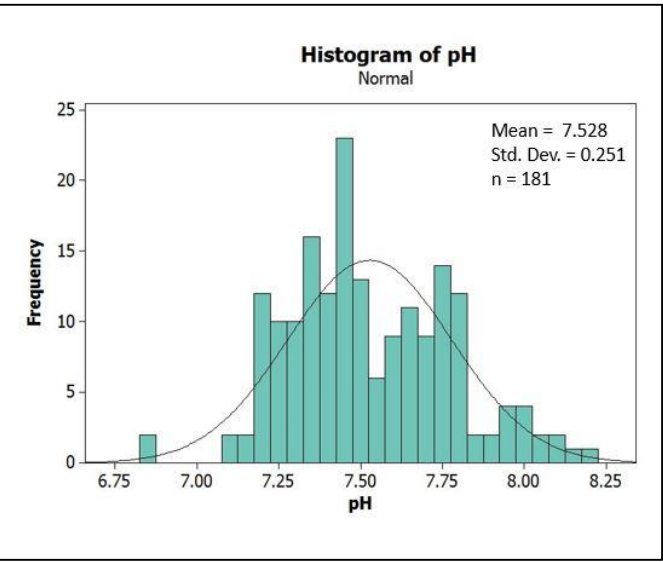
\*\*\*First interquartile range indicates the median of first 25% of the samples when arranged in an ascending order of the numerical values. Correspondingly second and third interquartile range indicates the median of 50% and 75% of the samples when arranged in ascending order.

## **6.2 Statistical Interpretation**

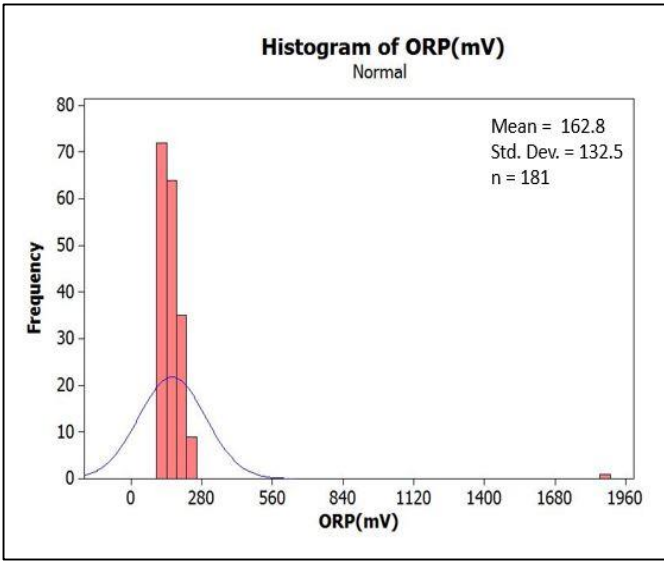
Normal distribution can best be expressed using the Histograms as they plots Frequency versus number of samples.

Values of Mean, Standard deviations and considered n is shown below. Software used for this operation is Minitab (version 15).

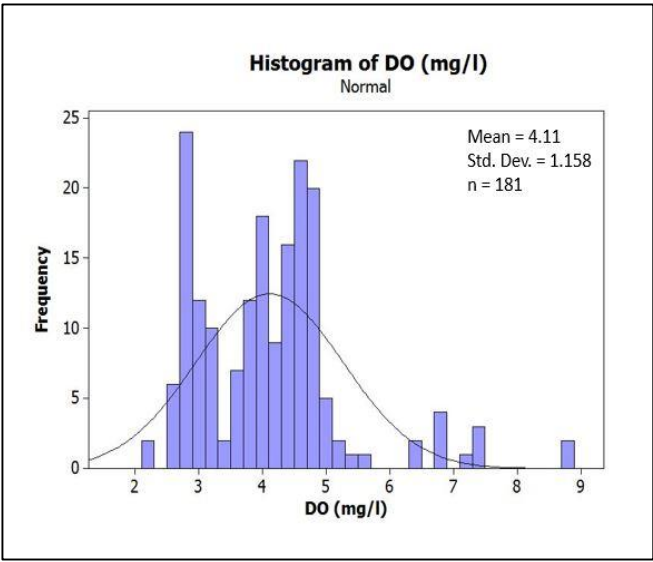
For Nadia (**Fig: 6.2.1**) and Bardhaman (**Fig: 6.2.2**) dataset:



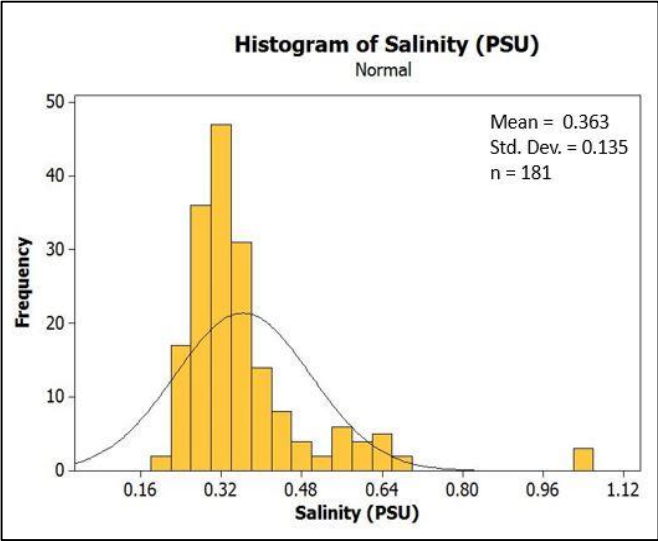
**Fig (a):** Histogram of pH (Nadia)



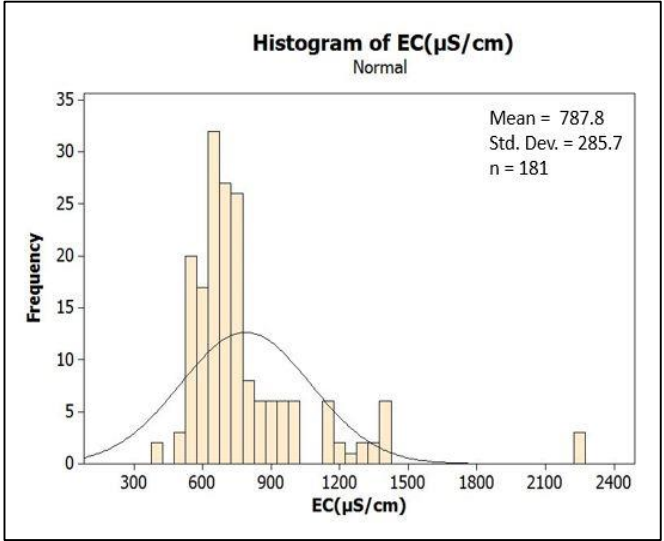
**Fig (b):** Histogram of ORP (Nadia)



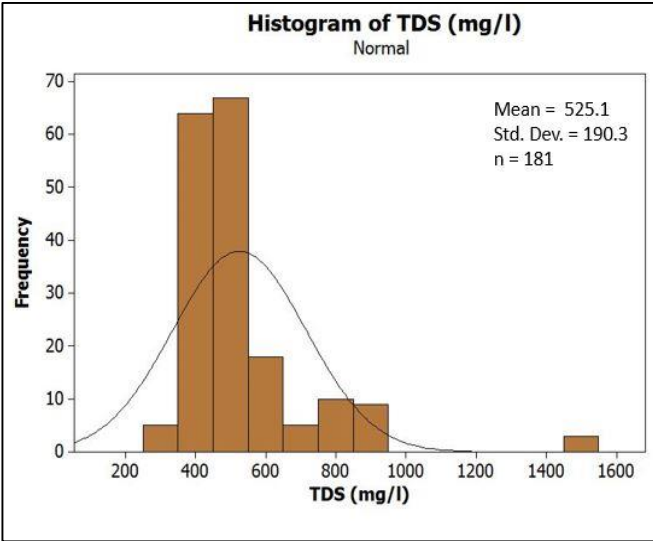
**Fig (c):** Histogram of DO (Nadia)



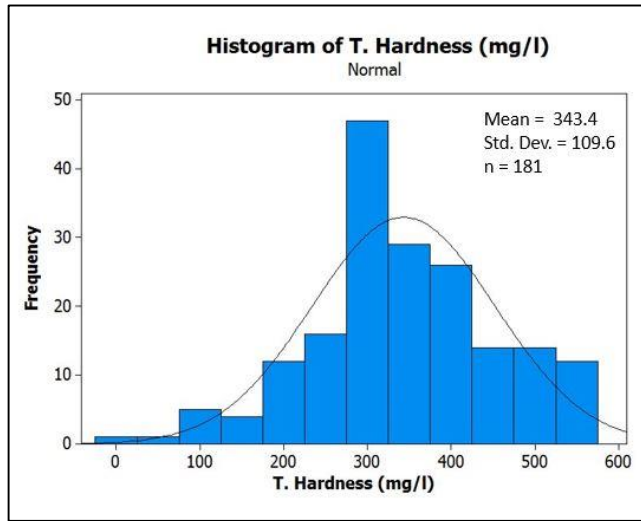
**Fig (d):** Histogram of Salinity (Nadia)



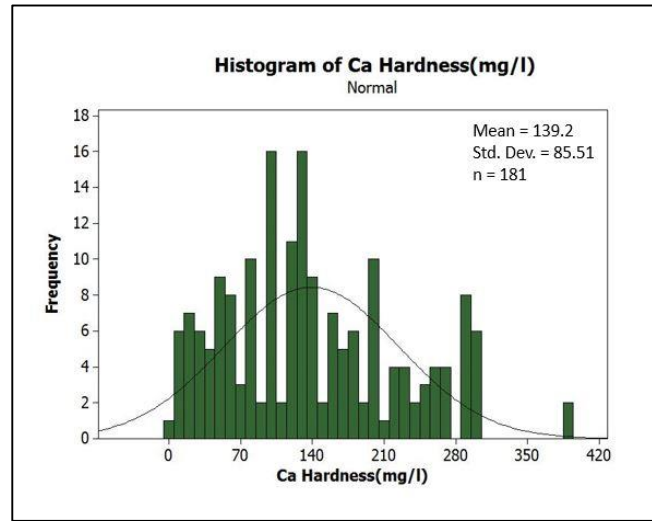
**Fig (e):** Histogram of EC (Nadia)



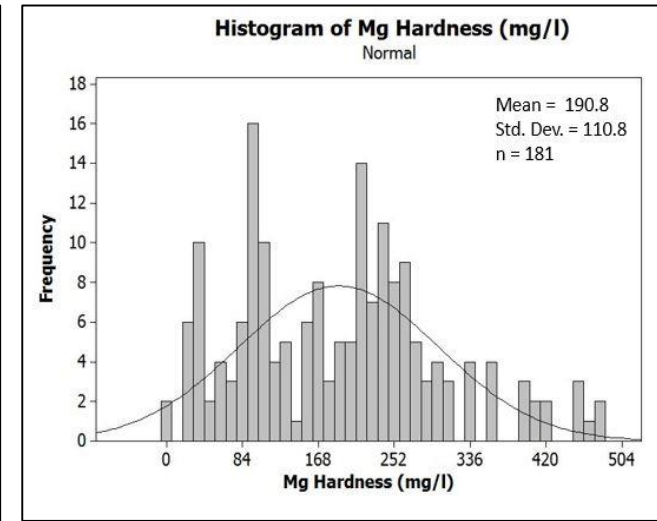
**Fig (f):** Histogram of TDS (Nadia)



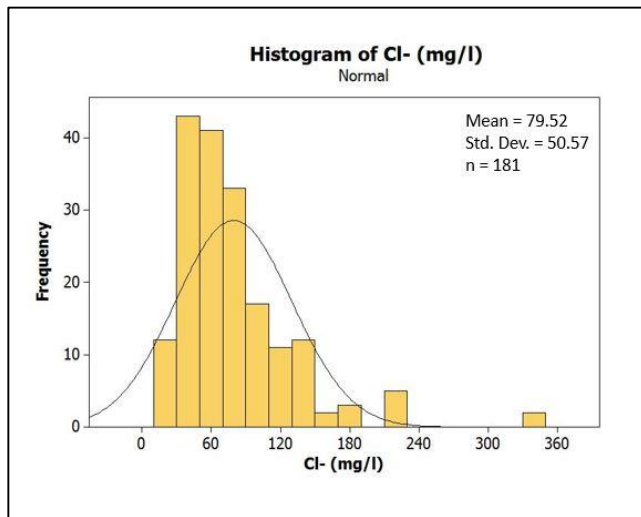
**Fig (g):** Histogram of Total Hardness (Nadia)



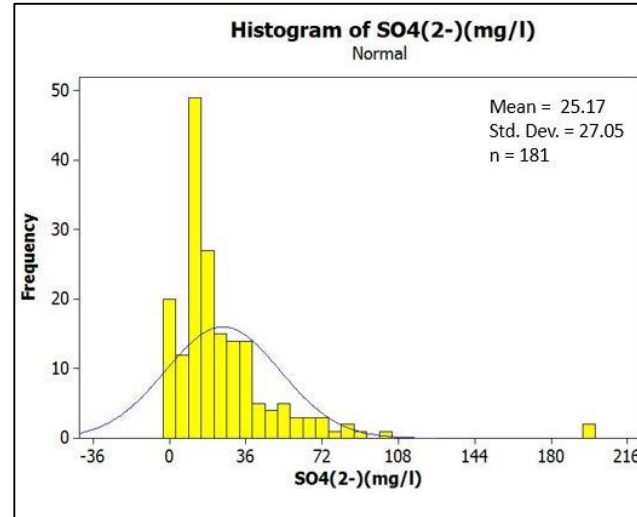
**Fig (h):** Histogram of Calcium Hardness (Nadia)



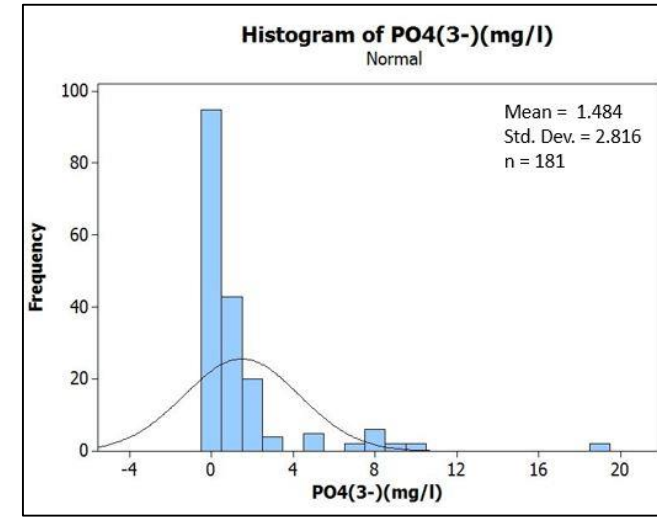
**Fig (i):** Histogram of Mg Hardness (Nadia)



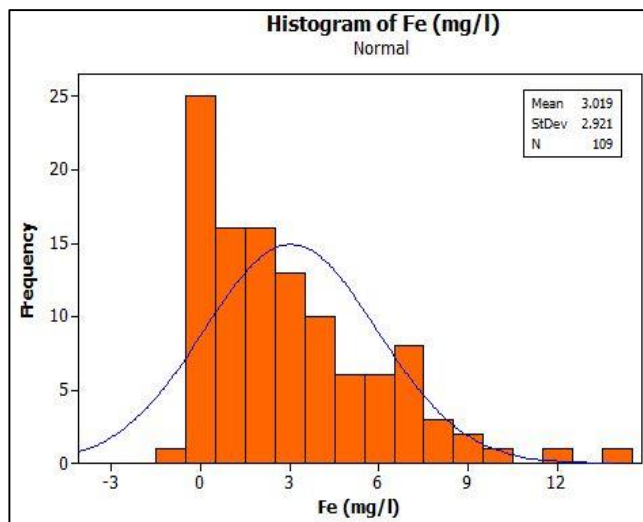
**Fig (j):** Histogram of Mg Hardness (Nadia)



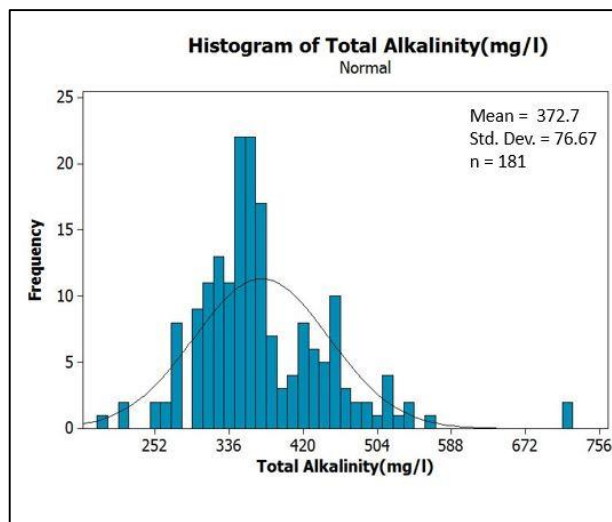
**Fig (k):** Histogram of Mg Hardness (Nadia)



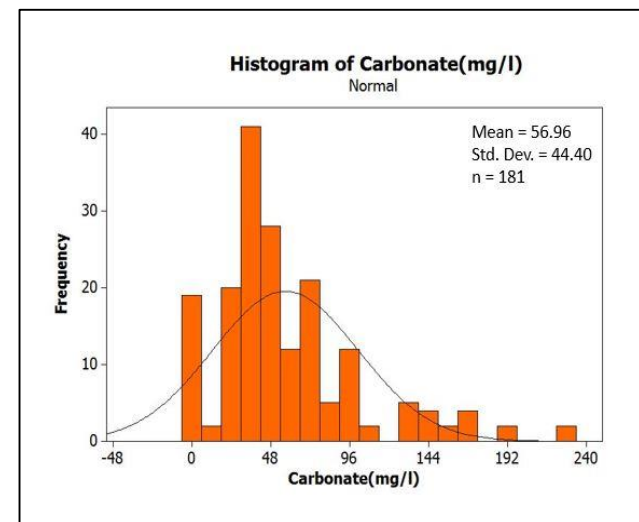
**Fig (l):** Histogram of Mg Hardness (Nadia)



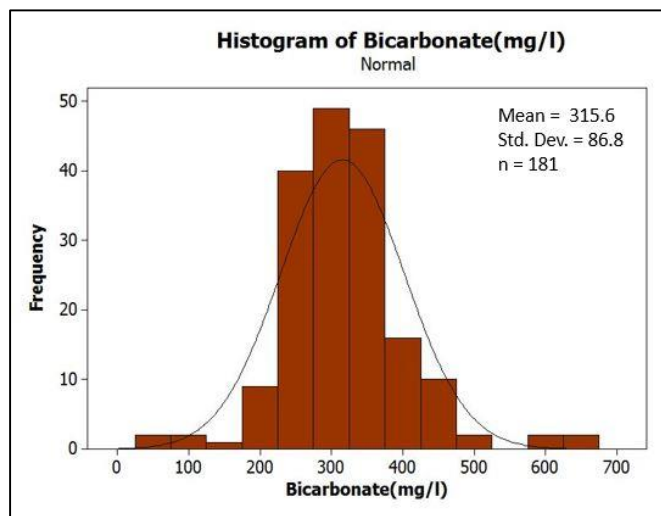
**Fig (m):** Histogram of Iron (Nadia)



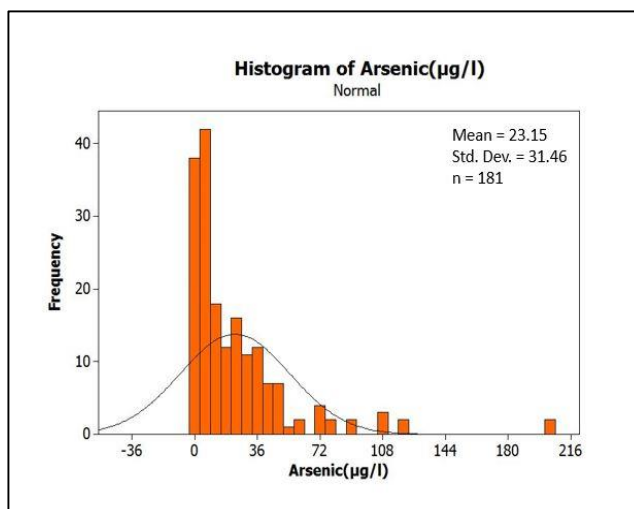
**Fig (n):** Histogram of Total Alkalinity (Nadia)



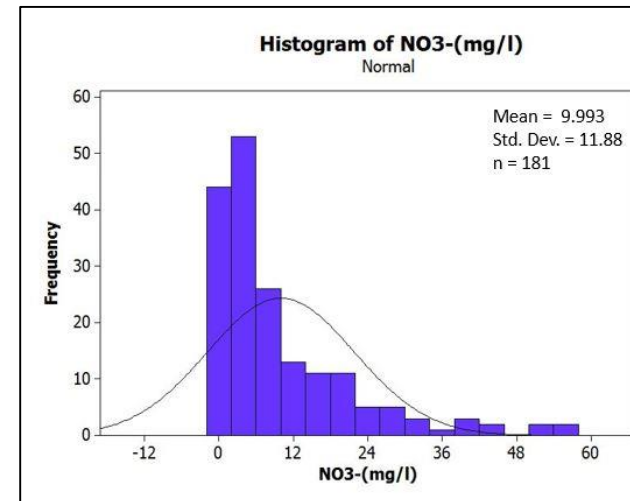
**Fig (o):** Histogram of Carbonate (Nadia)



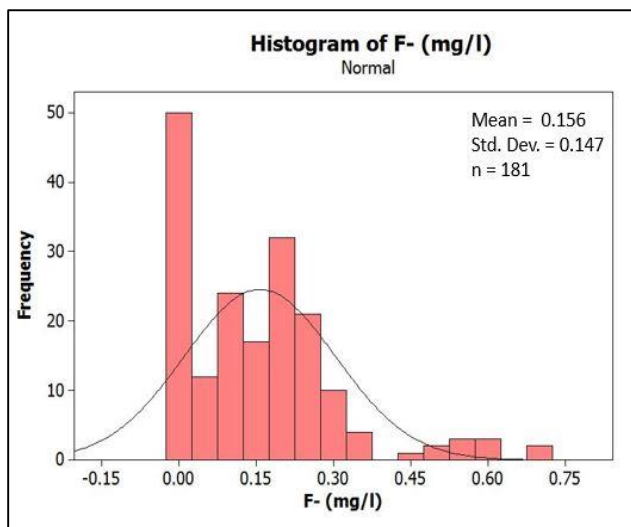
**Fig (p):** Histogram of Bicarbonate (Nadia)



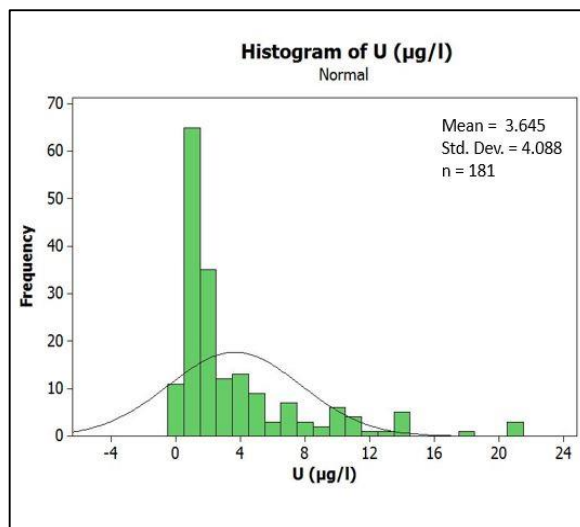
**Fig (q):** Histogram of Arsenic (Nadia)



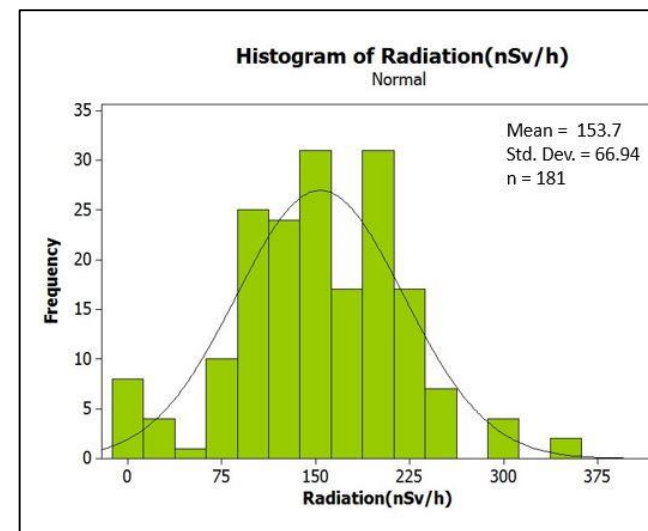
**Fig (r):** Histogram of Nitrate (Nadia)



**Fig (s):** Histogram of Fluoride (Nadia)



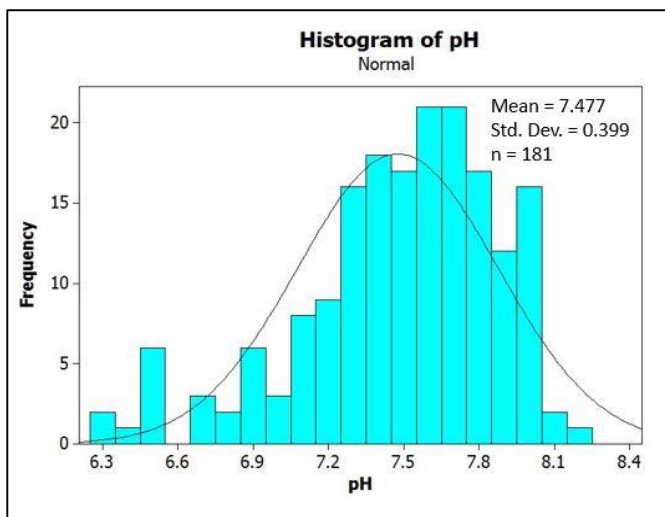
**Fig (t):** Histogram of Uranium (Nadia)



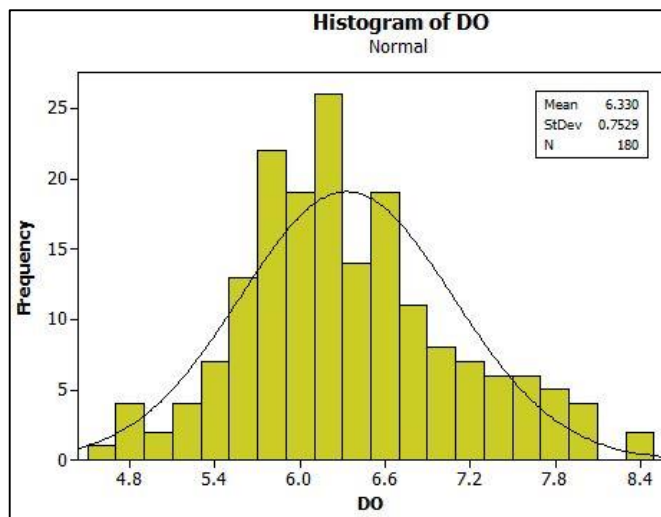
**Fig (u):** Histogram of Radiation (Nadia)

**Fig 6.2.1:** Histogram of Nadia

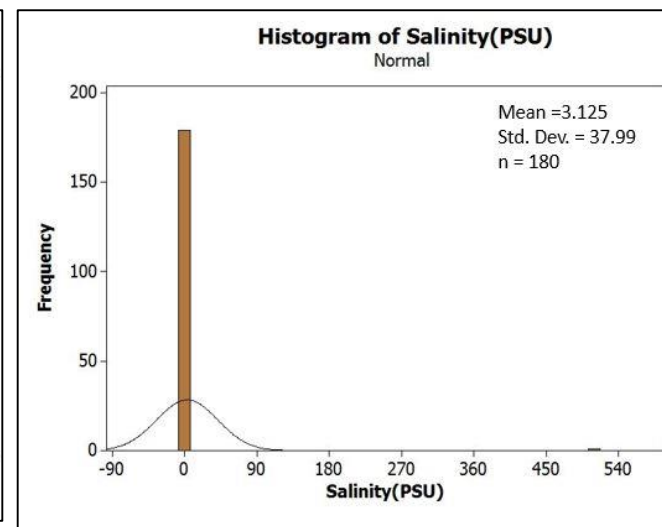




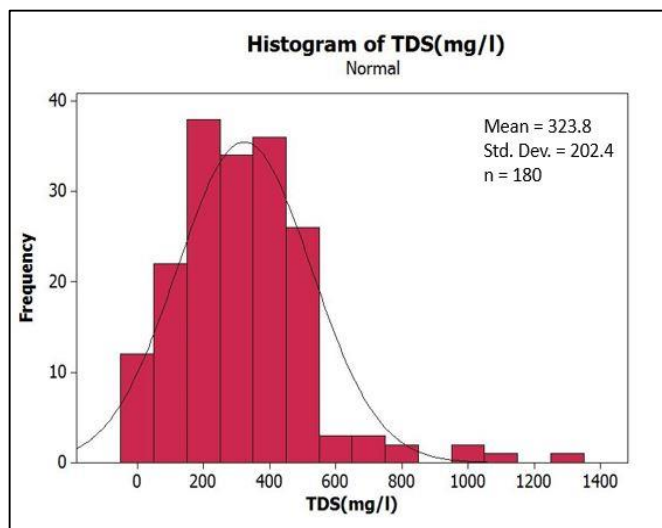
**Fig (a):** Histogram of pH (Bardhaman)



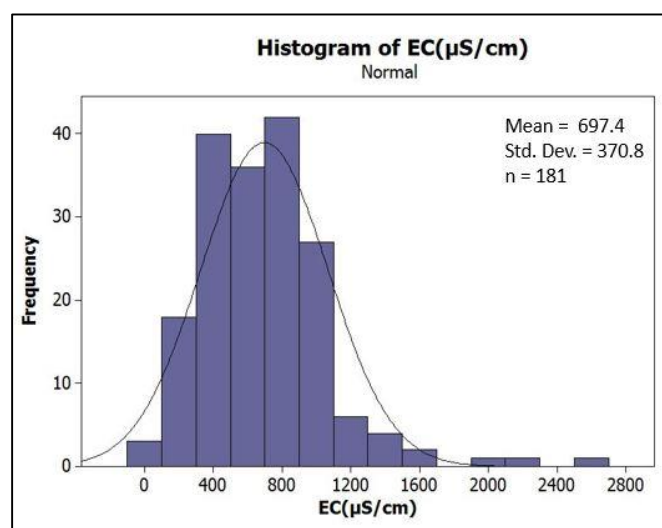
**Fig (b):** Histogram of DO (Bardhaman)



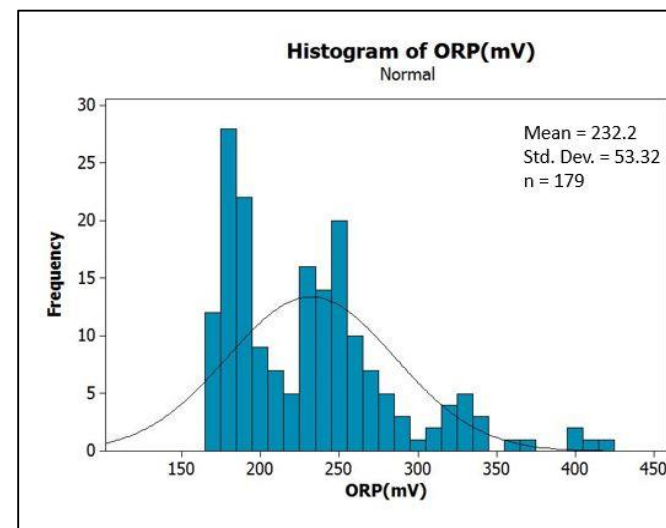
**Fig (c):** Histogram of Salinity (Bardhaman)



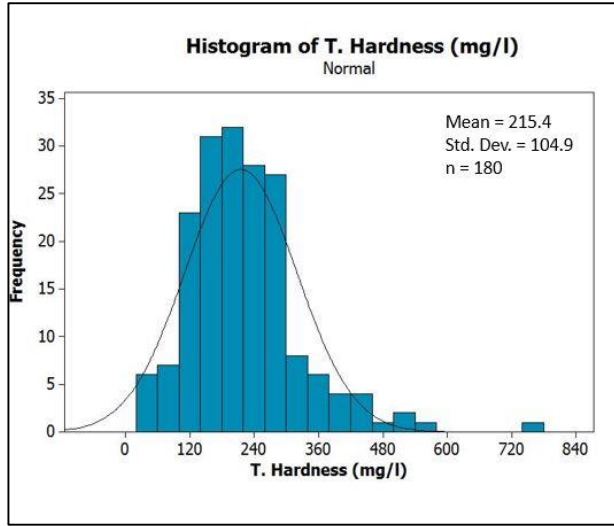
**Fig (d):** Histogram of TDS (Bardhaman)



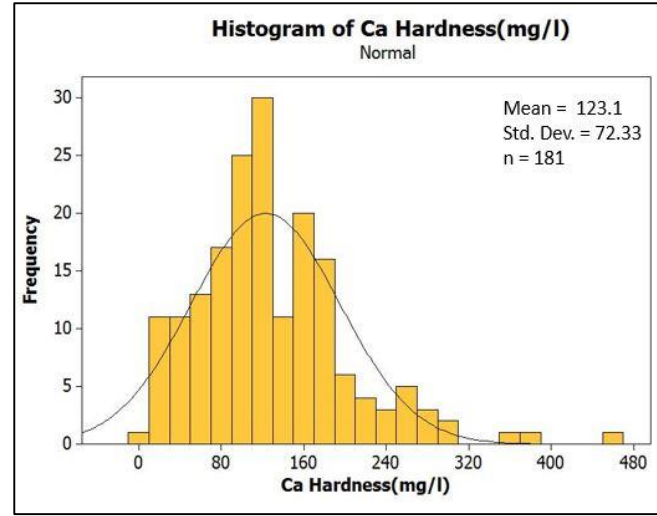
**Fig (e):** Histogram of EC (Bardhaman)



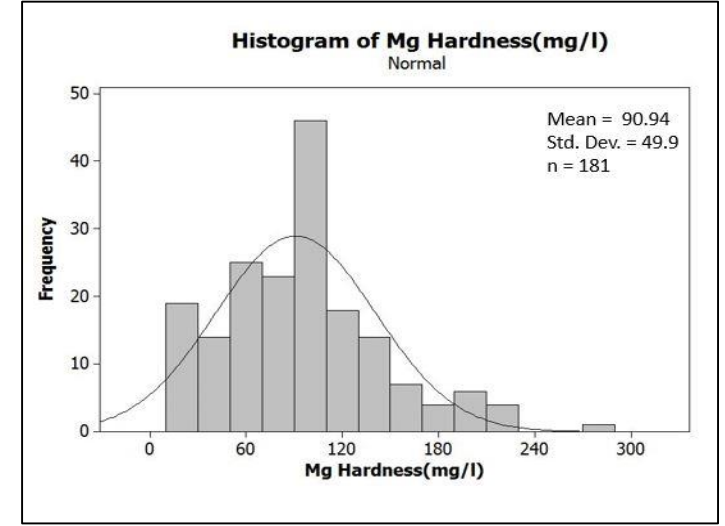
**Fig (f):** Histogram of ORP (Bardhaman)



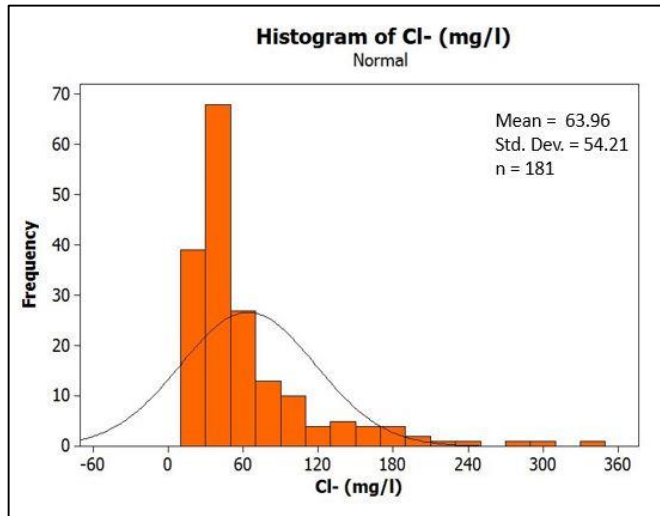
**Fig (g):** Histogram of TH (Bardhaman)



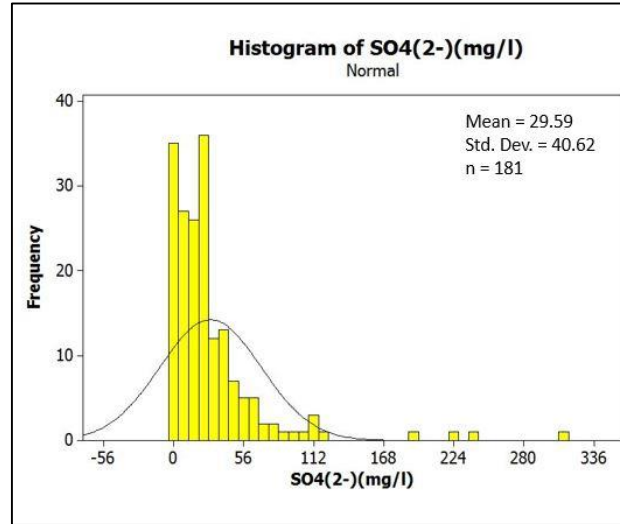
**Fig (h):** Histogram of Ca-Hardness (Bardhaman)



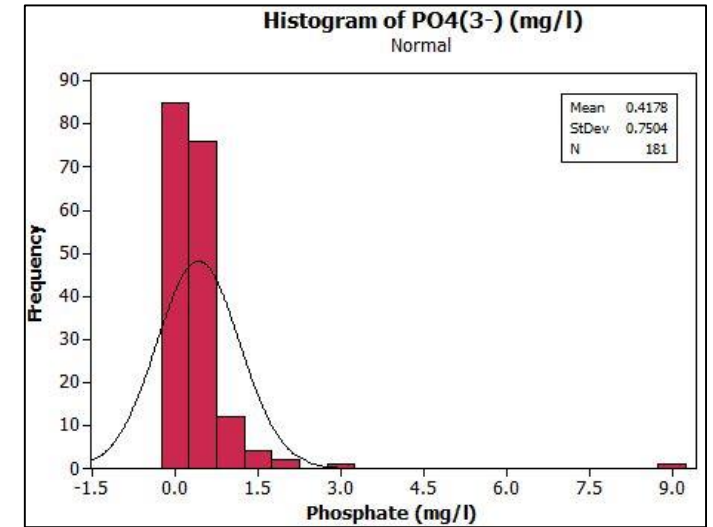
**Fig (i):** Histogram of Mg-Hardness (Bardhaman)



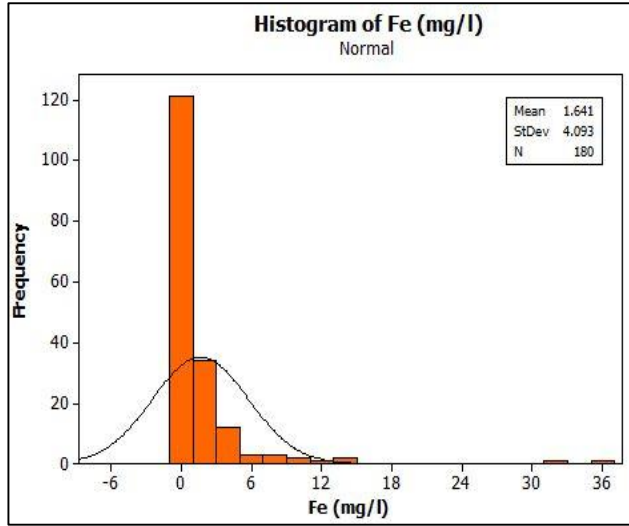
**Fig (j):** Histogram of Chloride (Bardhaman)



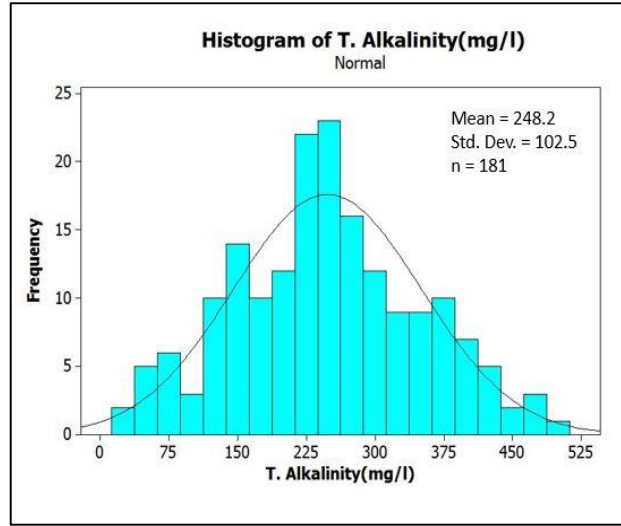
**Fig (k):** Histogram of Sulphate (Bardhaman)



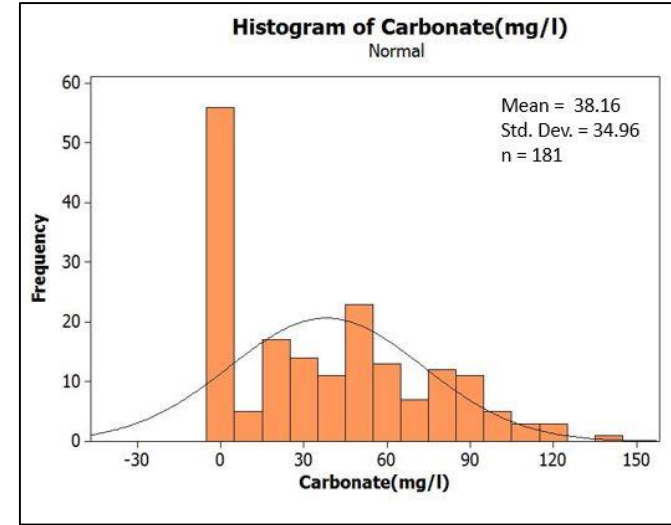
**Fig (l):** Histogram of Phosphate (Bardhaman)



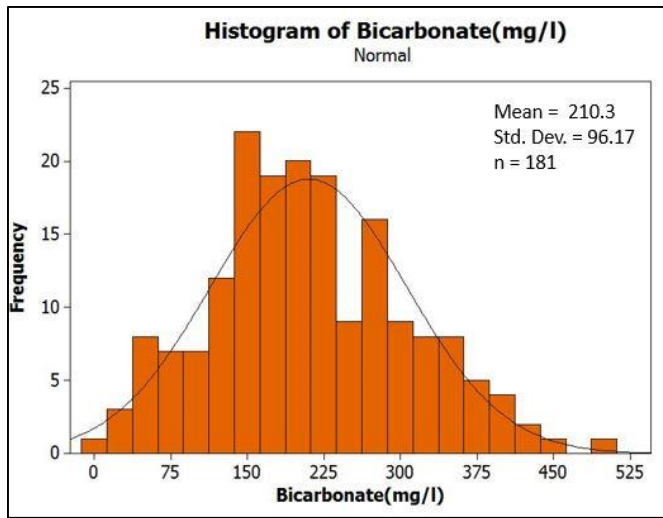
**Fig (m):** Histogram of Iron (Bardhaman)



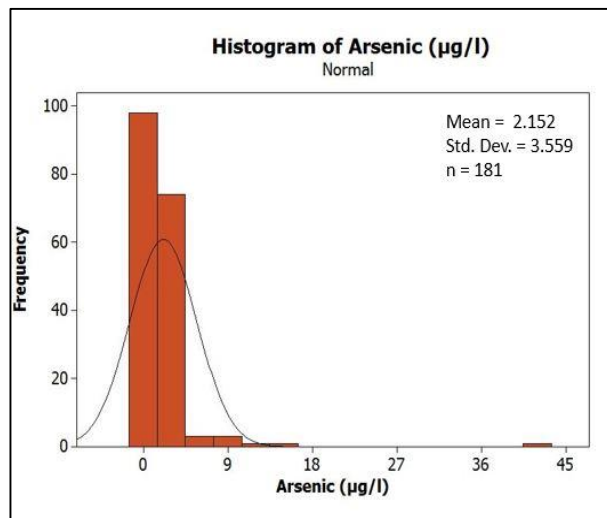
**Fig (n):** Histogram of Total Alkalinity (Bardhaman)



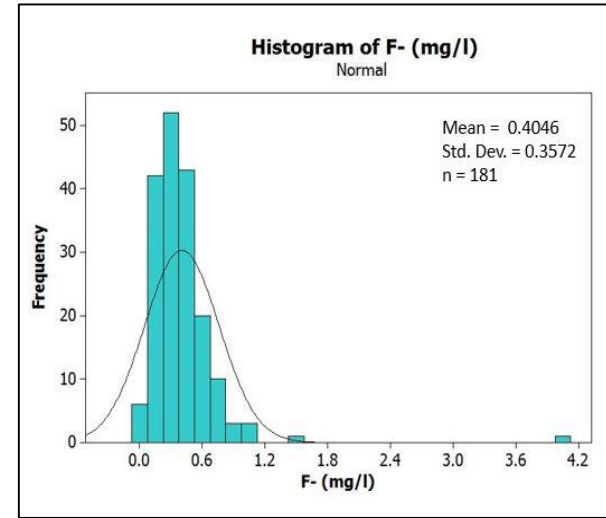
**Fig (o):** Histogram of Carbonate (Bardhaman)



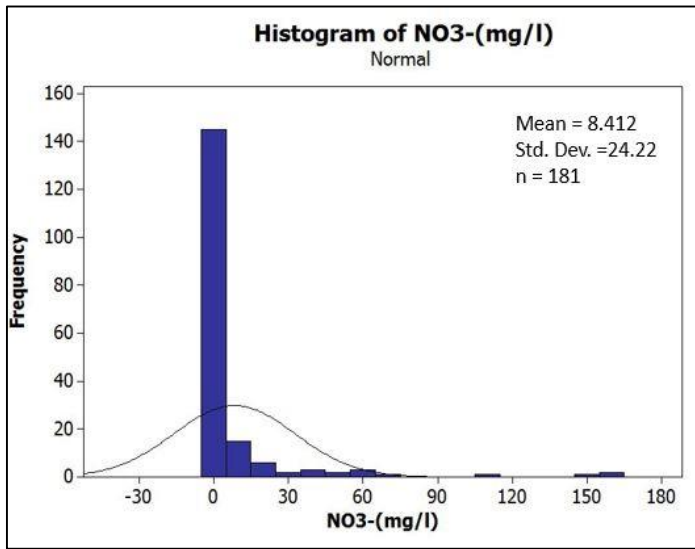
**Fig (p):** Histogram of Bicarbonate (Bardhaman)



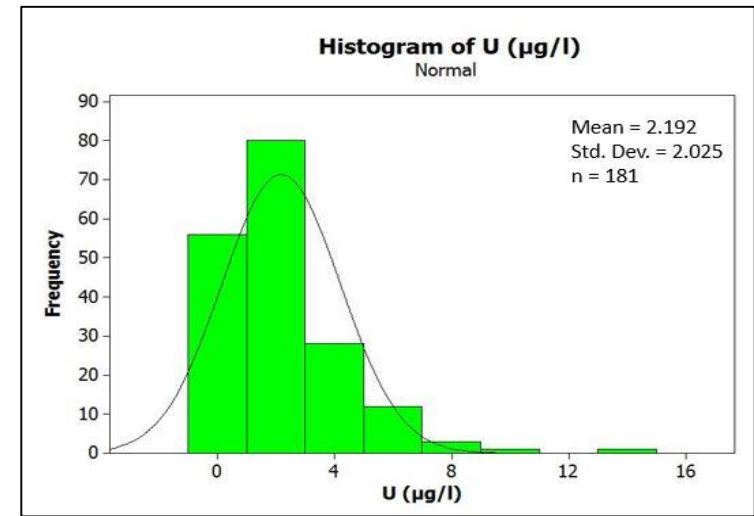
**Fig (q) -** Histogram of Arsenic (Bardhaman)



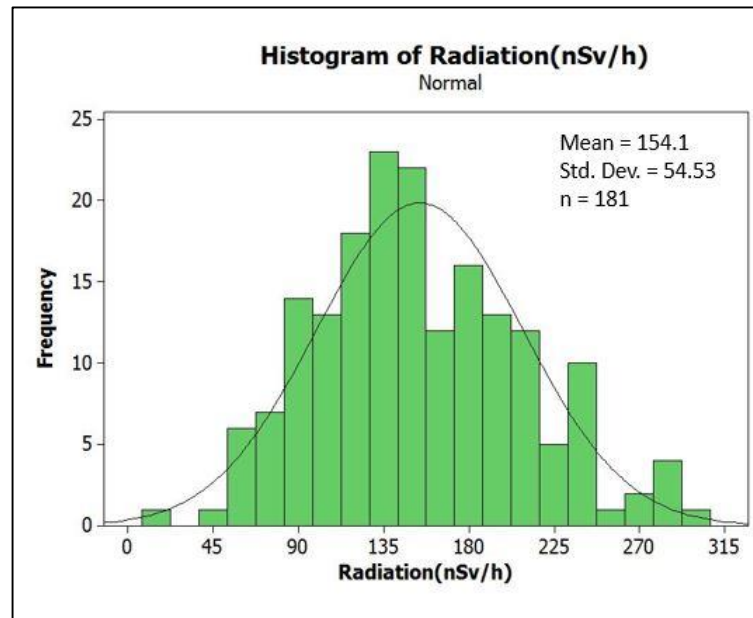
**Fig (r):** Histogram of Iron (Bardhaman)



**Fig (s):** Histogram of Nitrate (Bardhaman)



**Fig (t):** Histogram of Uranium (Bardhaman)



**Fig (u):** Histogram of Radiation (Bardhaman)

**Fig 6.2.2:** Histogram of Bardhaman

### 6.3 Normality Test analysis result – Skewness and Kurtosis

Skewness and Kurtosis results are shown and discussed below.

**Table 6.3.1:** Skewness and Kurtosis of Nadia

Water Parameter	Skewness		Kurtosis	
	Statistic	Std. Error	Statistic	Std. Error
As	3.019	0.23	13.217	0.457
Ca <sup>+2</sup>	0.614	0.231	-0.128	0.459
Cl <sup>-</sup>	2.014	0.231	6.268	0.459
CO <sub>3</sub> <sup>-2</sup>	1.352	0.231	2.769	0.459
DO	1.486	0.231	2.988	0.459
EC	2.689	0.231	9.554	0.459
F	1.65	0.231	3.044	0.459
Fe	1.165	0.231	1.192	0.459
HCO <sub>3</sub> <sup>-</sup>	0.559	0.231	2.418	0.459
Mg <sup>+2</sup>	0.529	0.231	-0.182	0.459
NO <sub>3</sub> <sup>-</sup>	1.95	0.231	3.649	0.459
ORP	0.386	0.231	-0.678	0.459
pH	0.27	0.231	0.02	0.459
PO <sub>4</sub> <sup>-3</sup>	4.109	0.231	21.602	0.459
RADIATION	0.145	0.231	0.449	0.459
Salinity	1.126	0.231	3.368	0.459
SO <sub>4</sub> <sup>-2</sup>	3.168	0.231	15.801	0.459
TA	2.749	0.231	9.963	0.459
TDS	-0.135	0.231	-0.045	0.459
TH	2.148	0.231	4.407	0.459
U	2.148	0.231	4.407	0.459

**Table 6.3.1.1:** Interpretation of Skewness for Nadia

Skewness				
Water Parameter	Ratio between Statistic and Standard Error	Measure	Remarks	Acceptance/Rejection of Normality
As	13.13	More than both of Bowley's and Pearson's	Large positive value. Long right tail	Normality is rejected

		Measures		
Ca <sup>2+</sup>	2.66	More than Bowley's but less than Pearson's Measures	Can have normal distribution	As per IBM normality is rejected; as per Pearson normality is accepted
Cl <sup>-</sup>	8.72	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
CO <sub>3</sub> <sup>-2</sup>	5.85	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
DO	6.43	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
EC	11.64	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
F	7.14	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
Fe	5.04	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
HCO <sub>3</sub> <sup>-</sup>	2.42	More than Bowley's but less than Pearson's Measures	Can have normal distribution	As per IBM normality is rejected; as per Pearson normality is accepted

Mg <sup>+2</sup>	2.29	More than Bowley's but less than Pearson's Measures	Can have normal distribution	As per IBM normality is rejected; as per Pearson normality is accepted
NO <sub>3</sub> <sup>-</sup>	8.44	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
ORP	1.67	More than Bowley's but less than Pearson's Measures	Can have normal distribution	As per IBM and Pearson normality is accepted; as per Bowley normality is rejected
pH	1.17	More than Bowley's but less than Pearson's Measures	Can have normal distribution	As per IBM and Pearson normality is accepted; as per Bowley normality is rejected
PO <sub>4</sub> <sup>-3</sup>	17.79	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
RADIATI ON	0.63	Less than both Bowley's and Pearson's Measures	Normal Distribution	As per IBM, Pearson and Bowley normality is accepted
Salinity	4.87	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
SO <sub>4</sub> <sup>-2</sup>	13.71	More than both of Bowley's and Pearson's	Large positive value. Long right tail	Normality is rejected

		Measures		
TA	11.90	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
TDS	-0.58	Less than both Bowley's and Pearson's Measures	Normal Distribution	As per IBM, Pearson and Bowley normality is accepted
TH	9.30	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
U	9.30	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected

As the result suggests (**Table 6.3.1.1**) among the twenty-one considered parameters only two parameters (Radiation and TDS) has a normal distribution in Nadia. Both of the parameters satisfies the criteria given by Bowley's measurements, Pearson's Second Measurements and the method given by IBM. Five parameters (Calcium, Bicarbonate, Magnesium, pH, ORP) from the rest follows normal distribution but satisfies only one or only two methods among the three. For calcium Pearson's second method is accepted but IBM method is rejected. Same goes for Magnesium and Bicarbonates. For pH and ORP Pearson's second measure and IBM method test of normality is satisfied but Bowley's measurements are rejected. Thus only 33.33% parameters follow the null hypothesis. The remaining 66.66 % parameters fails to satisfy normality test criteria and follows alternative hypothesis.



**Table 6.3.1.2: Interpretation of Kurtosis for Nadia**

Kurtosis				
Water Parameter	Ratio between Statistic and Standard Error	Measure	Remarks	Acceptance/ Rejection of Normality
As	28.92	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected
Ca <sup>+2</sup>	-0.28	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
Cl <sup>-</sup>	13.66	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected
CO <sub>3</sub> <sup>-2</sup>	6.03	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected
DO	6.51	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected
EC	20.81	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected
F <sup>-</sup>	6.63	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected

			longer than a normal distribution	
Fe	2.60	Kurtosis >(+2)	Can have normal distribution	Normality is rejected
HCO <sub>3</sub> <sup>-</sup>	5.27	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
Mg <sup>+2</sup>	-0.40	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
NO <sub>3</sub> <sup>-</sup>	7.95	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
ORP	-1.48	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
pH	0.04	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
PO <sub>4</sub> <sup>-3</sup>	47.06	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
RADIATION	0.98	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
Salinity	7.34	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
SO <sub>4</sub> <sup>-2</sup>	34.42	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
TA	21.71	Kurtosis >(+2)	The tails of the	Normality is

			distribution are longer than a normal distribution	rejected
TDS	-0.10	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
TH	9.60	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected
U	9.60	Kurtosis $>(+2)$	The tails of the distribution are longer than a normal distribution	Normality is rejected

Determined values from ratio of statistic and standard error indicates the possibility of normal distribution in Nadia.

Six parameters (Calcium, Magnesium, ORP, pH, Radiation, TDS) follow normal distribution in Nadia. Calcium, Magnesium, ORP and TDS has negative values. The negative values indicate shorter tails in normal distribution. pH and radiation has very small positive values. Yet these values prove that these data are normally distributed which makes up 28.57% normally distributed values. Remaining 71.43% of the dataset is rejected by the test of normality. Rejection by test of normality means these data suffices the alternative hypothesis.

On the other hand, iron (Fe) has a ratio of 2.60, which is slightly greater than the upper limit (+2). This can create doubts about the distribution of iron in Nadia. For better understanding other visual and analytical tests should be performed.

Skewness and Kurtosis analysis result for Bardhhaman is shown below.

**Table 6.3.2: Skewness and Kurtosis of Bardhaman**

Water Parameter	Skewness		Kurtosis	
	Statistic	Std. Error	Statistic	Std. Error
As	8.059	0.181	82.935	0.359
Ca <sup>+2</sup>	1.14	0.181	2.578	0.36
Cl <sup>-</sup>	2.403	0.181	6.977	0.36
CO <sub>3</sub> <sup>-2</sup>	0.551	0.181	-0.64	0.36
DO	0.408	0.181	0.016	0.36
EC	1.347	0.181	4.439	0.36
F <sup>-</sup>	1.166	0.181	2.551	0.36
Fe	5.852	0.181	41.378	0.36
HCO <sub>3</sub> <sup>-</sup>	0.319	0.181	-0.197	0.36
Mg <sup>+2</sup>	0.67	0.181	0.724	0.36
NO <sub>3</sub> <sup>-</sup>	4.727	0.181	24.6	0.36
ORP	1.149	0.182	1.277	0.361
pH	-0.938	0.181	0.701	0.36
PO <sub>4</sub> <sup>-3</sup>	8.71	0.181	95.183	0.36
RADIATION	0.285	0.181	-0.217	0.359
Salinity	1.518	0.181	4.282	0.36
SO <sub>4</sub> <sup>-2</sup>	3.832	0.181	19.164	0.36
TA	0.12	0.181	-0.348	0.36
TDS	1.316	0.181	3.839	0.36
TH	1.31	0.181	4.021	0.36
U	2.163	0.181	7.895	0.36

**Table 6.3.2.1: Interpretation of Skewness for Bardhaman Dataset**

Skewness				
Water Parameter	Ratio between Statistic and Standard Error	Measure	Remarks	Acceptance/Rejection of Normality
As	44.52	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
Ca <sup>+2</sup>	6.30	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
Cl <sup>-</sup>	13.28	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
CO <sub>3</sub> <sup>-2</sup>	3.04	More than both of Bowley's and Pearson's Measures	Can have normal distribution	Normality is rejected
DO	2.25	More than Bowley's but less than Pearson's Measures	Can have normal distribution	As per IBM normality is rejected; as per Pearson normality is accepted
EC	7.44	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
F <sup>-</sup>	6.44	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
Fe	32.33	More than both of Bowley's and	Large positive value. Long	Normality is rejected

		Pearson's Measures	right tail	
HCO <sub>3</sub> <sup>-</sup>	1.76	Less than both Bowley's and Pearson's Measures	Normal Distribution	As per IBM and Pearson normality is accepted; as per Bowley normality is rejected
Mg <sup>+2</sup>	3.70	More than both of Bowley's and Pearson's Measures	Can have normal distribution	Normality is rejected
NO <sub>3</sub> <sup>-</sup>	26.12	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
ORP	6.31	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
pH	-5.18	More than both of Bowley's and Pearson's Measures	Large negative value. Long left tail	Normality is rejected
PO <sub>4</sub> <sup>-3</sup>	48.12	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
RADIATION	1.57	Less than both Bowley's and Pearson's Measures	Normal Distribution	As per IBM and Pearson normality is accepted; as per Bowley normality is rejected
Salinity	8.39	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
SO <sub>4</sub> <sup>-2</sup>	21.17	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
TA	0.66	Less than both Bowley's and Pearson's Measures	Normal Distribution	As per IBM, Pearson and Bowley normality is accepted

TDS	7.27	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
TH	7.24	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected
U	11.95	More than both of Bowley's and Pearson's Measures	Large positive value. Long right tail	Normality is rejected

Among the twenty-one considered parameters only Total Alkalinity has a normal distribution in Bardhaman. The parameters satisfy the criteria given by Bowley's measurements, Pearson's Second Measurements and the method given by IBM. Three parameters (DO, Bicarbonate, and Radiation) from the rest follows normal distribution but satisfies only one or only two methods among the three. As for dissolved oxygen (DO) Pearson's second method accepts the normality but IBM method is rejects the same. For Bicarbonate and Radiation Pearson's second measure and IBM method accepts for the test of normality but Bowley's measurements reject the normality. Thus only 19.04% parameters follow the null hypothesis satisfying the tests of normality. The remaining 80.95 % parameters fails to satisfy normality test criteria and follows alternative hypothesis.

Conflict arises for two parameters namely magnesium ( $Mg^{+2}$ ) and carbonate ( $CO_3^{-2}$ ). As carbonate has a ratio of 3.04 which is slightly higher than Pearson's second measure. Same can be concluded for magnesium as it has a ratio of 3.70. The possibility of normal distribution of these parameters cannot be defined properly. Kurtosis interpretation of the dataset and others methods of normality tests should be performed for a proper knowledge of the pattern of distribution.

**Table 6.3.2.2:** Interpretation of Kurtosis for Bardhhaman Dataset

Kurtosis				
Water Parameter	Ratio between Statistic and Standard Error	Measure	Remarks	Acceptance/ Rejection of Normality
As	231.02	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
Ca <sup>+2</sup>	7.16	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
Cl <sup>-</sup>	19.38	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
CO <sub>3</sub> <sup>-2</sup>	-1.78	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
DO	0.04	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
EC	12.33	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
F <sup>-</sup>	7.09	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
Fe	114.94	Kurtosis >(+2)	The tails of the	Normality is



			distribution are longer than a normal distribution	rejected
HCO <sub>3</sub> <sup>-</sup>	-0.55	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
Mg <sup>+2</sup>	2.01	Kurtosis >(+2)	Can have normal distribution	Normality is rejected
NO <sub>3</sub> <sup>-</sup>	68.33	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
ORP	3.54	Kurtosis >(+2)	Can have normal distribution	Normality is rejected
pH	1.95	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
PO <sub>4</sub> <sup>-3</sup>	264.40	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
RADIATION	-0.60	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
Salinity	11.89	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
SO <sub>4</sub> <sup>-2</sup>	53.23	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
TA	-0.97	$(-2) \leq \text{Kurtosis} \leq (+2)$	Can have normal distribution	Normality is accepted
TDS	10.66	Kurtosis >(+2)	The tails of the distribution are	Normality is rejected

			longer than a normal distribution	
TH	11.17	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected
U	21.93	Kurtosis >(+2)	The tails of the distribution are longer than a normal distribution	Normality is rejected

Determined values from ratio of statistic and standard error indicates the possibility of normal distribution in Bardhaman.

Six parameters (Carbonate, Dissolved Oxygen, Bicarbonate, pH, Radiation, Total Alkalinity) follow normal distribution in Bardhaman. Carbonate, Bicarbonate, Radiation and Total Alkalinity has negative values. The negative values indicate shorter tails in normal distribution. Dissolved oxygen (DO) has very small positive value. Yet these values prove that these data are normally distributed which makes up 28.57% normally distributed values. Remaining 71.43% of the dataset is rejected by the test of normality. Rejection by test of normality means these data suffices the alternative hypothesis.

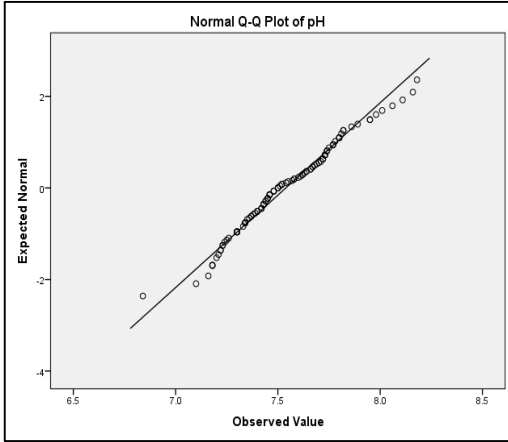
On the other hand, Magnesium ( $Mg^{+2}$ ) has a ratio of 2.01, which is slightly greater than the upper limit (+2). This can create doubts about the distribution of iron in Bardhaman. For better understanding other visual and analytical tests should be performed.

The skewness and kurtosis of the both the districts shows some similarities in distribution pattern. Yet the similarity does not match 100% for both the districts. Thus the conclusion which can be drawn is that Skewness and Kurtosis of a dataset alone is not good enough to determine if a given dataset follows Normal distribution or not. Thus other tests are performed for more convenience.

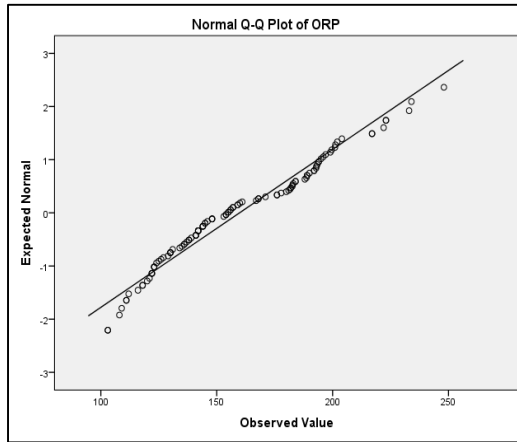
#### **6.4 Test of Normality using visual tests: Q-Q Plot**

Result of the Q-Q plot depends on informal human judgement to accept or reject the null hypothesis.

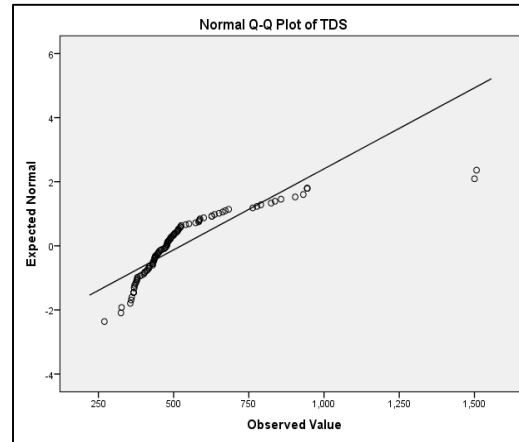
- Nadia



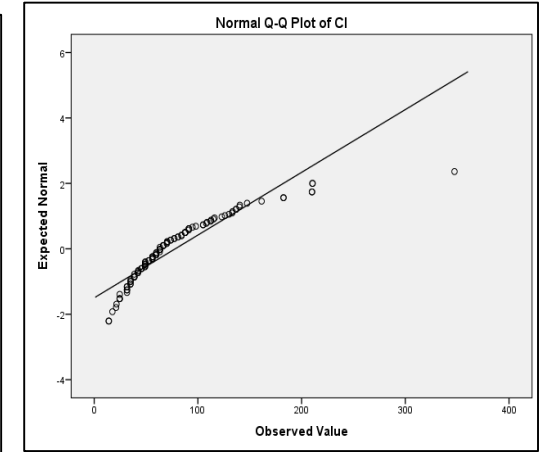
**Fig (a):**-Normal Q-Q plot of pH



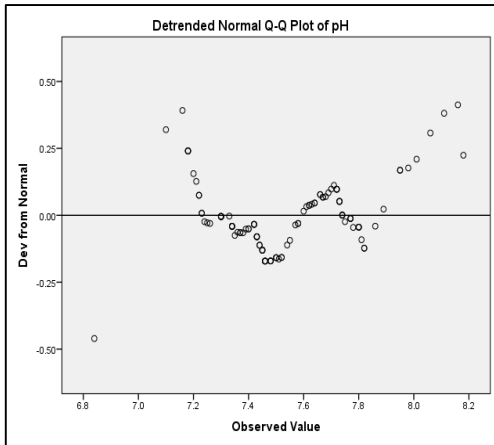
**Fig (b):**Normal Q-Q plot of ORP



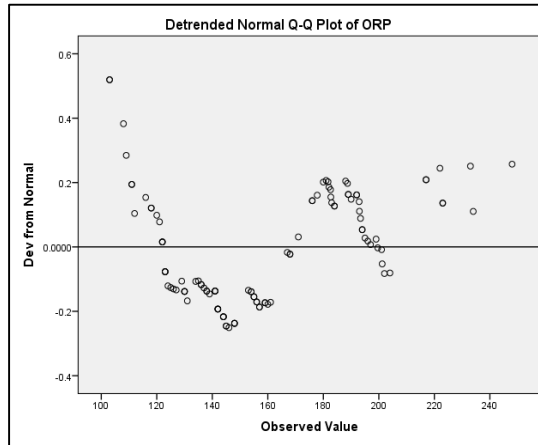
**Fig (c):**Normal Q-Q plot of TDS



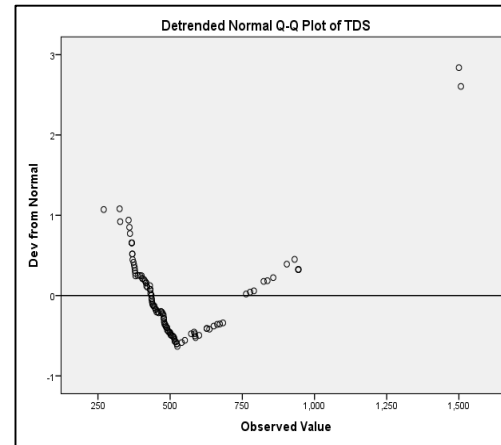
**Fig (d):**Normal Q-Q plot of Chloride



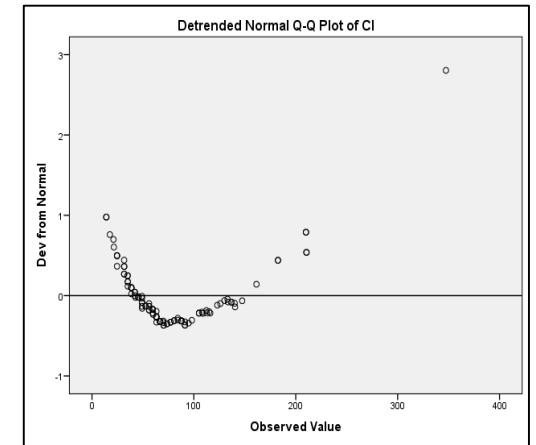
**Fig (e):**-Detrended Normal Q-Q plot of pH



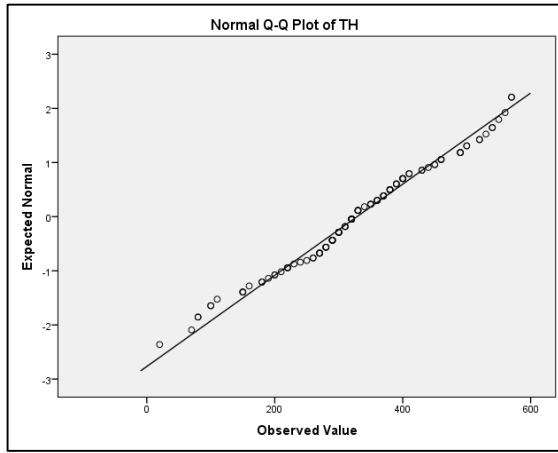
**Fig (f):**-Detrended Normal Q-Q plot of ORP



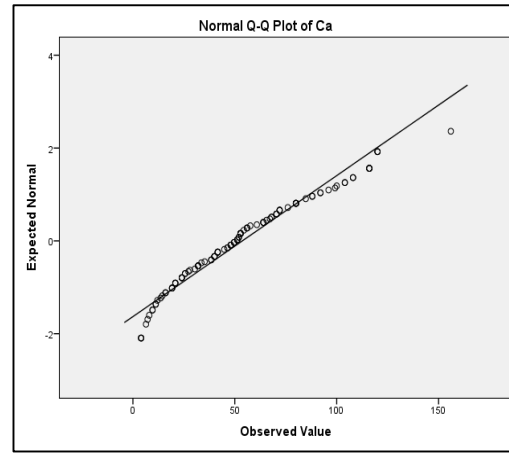
**Fig (g):**-Detrended Normal Q-Q plot of TDS



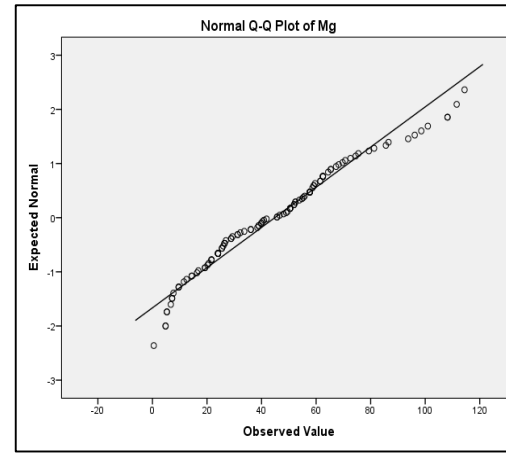
**Fig (h):**-Detrended Normal Q-Q plot of Chloride



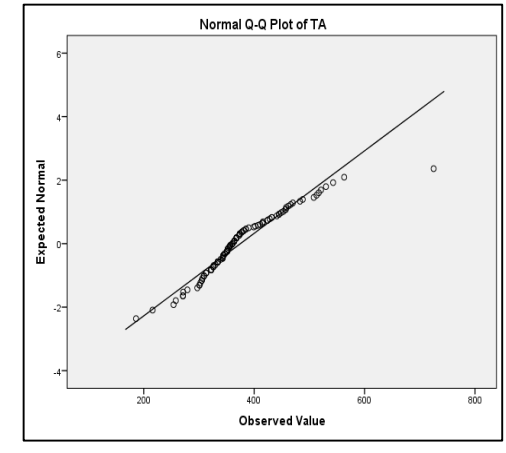
**Fig (i):-** Normal Q-Q plot of TH



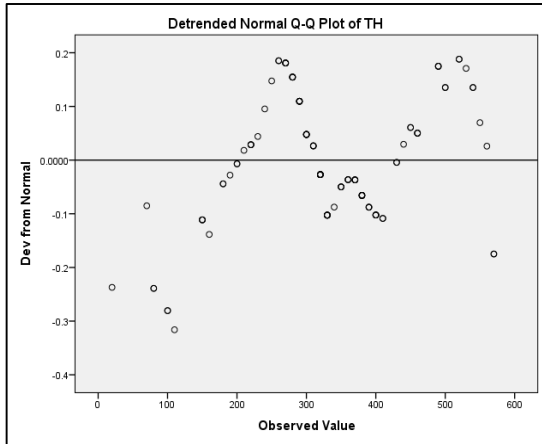
**Fig (j):-** Normal Q-Q plot of  $Ca^{+2}$



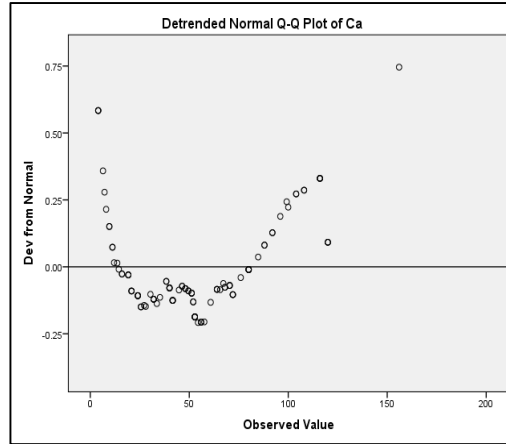
**Fig (k):-** Normal Q-Q plot of  $Mg^{+2}$



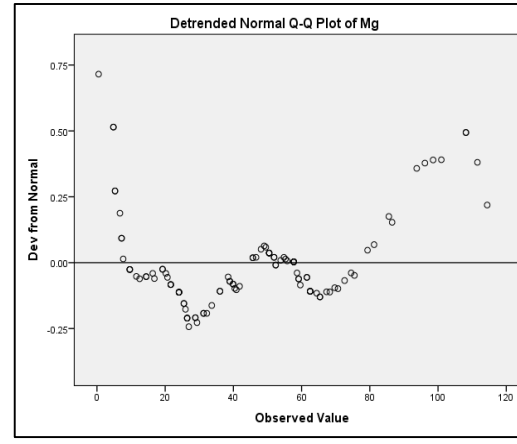
**Fig (l):-** Normal Q-Q plot of TA



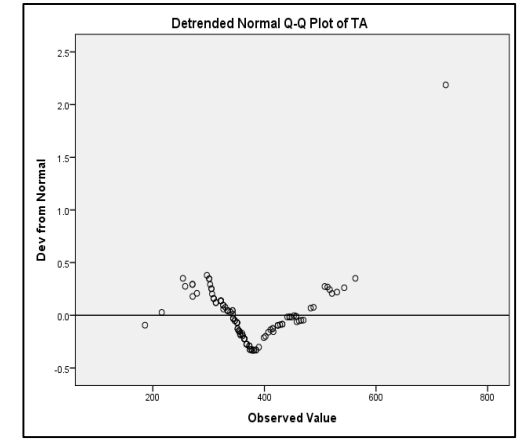
**Fig (m):-** Detrended Normal Q-Q plot of TH



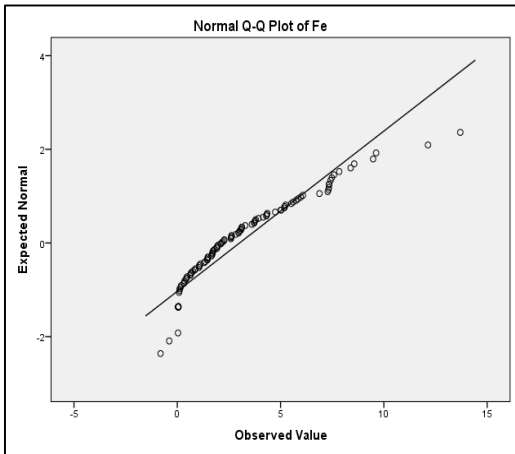
**Fig (n):-** Detrended Normal Q-Q plot of  $Ca^{+2}$



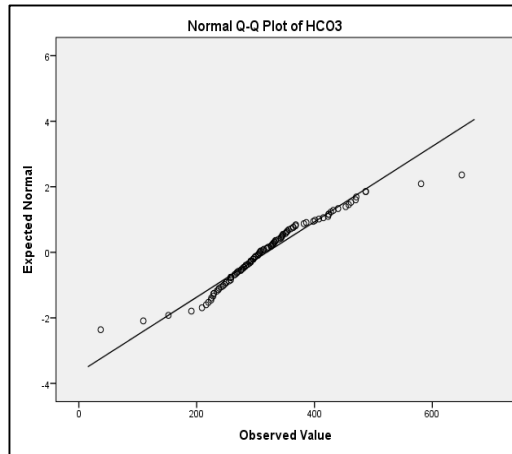
**Fig (o):-** Detrended Normal Q-Q plot of  $Mg^{+2}$



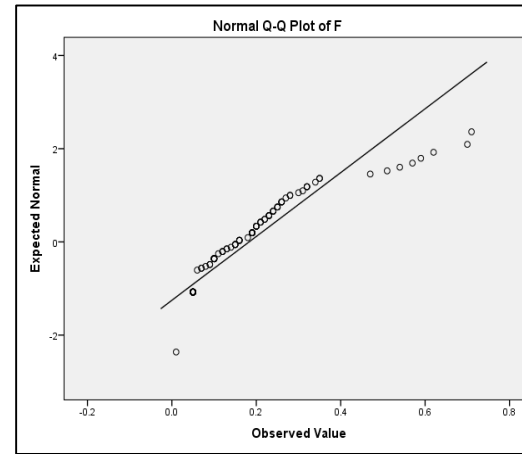
**Fig (p):-** Detrended Normal Q-Q plot of TA



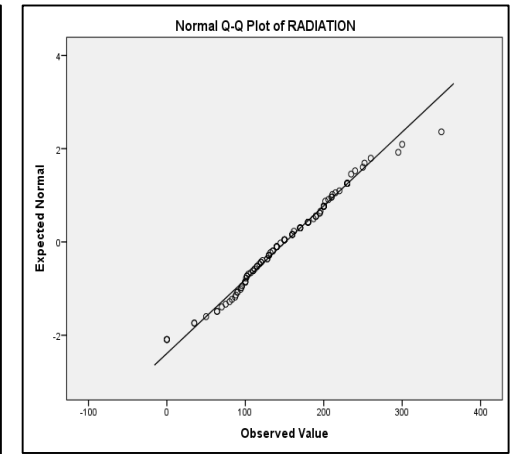
**Fig (q):-** Normal Q-Q plot of Fe



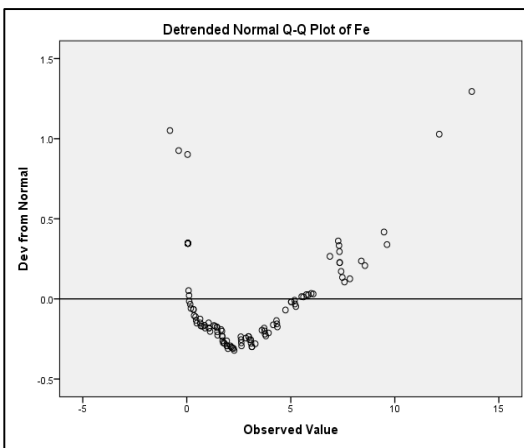
**Fig (r):-** Normal Q-Q plot of HCO<sub>3</sub><sup>-</sup>



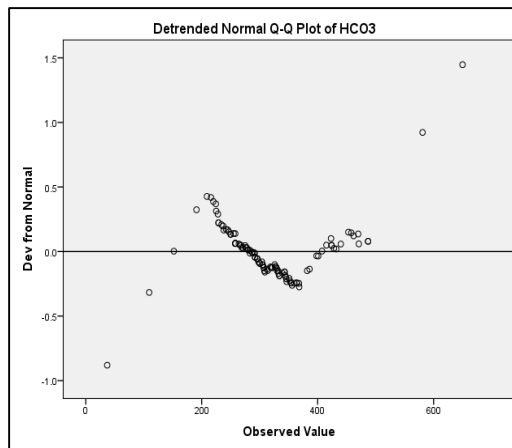
**Fig (s):-** Normal Q-Q plot of Fluoride



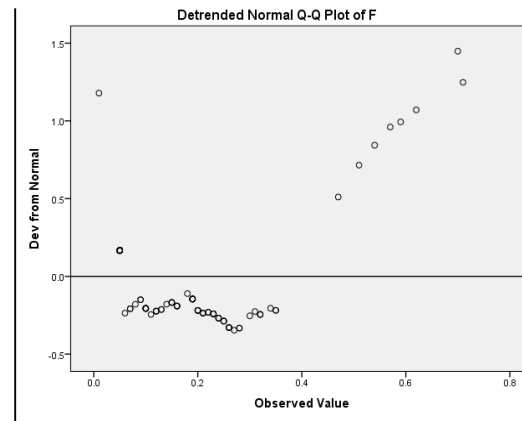
**Fig (t):-** Normal Q-Q plot of RADIATION



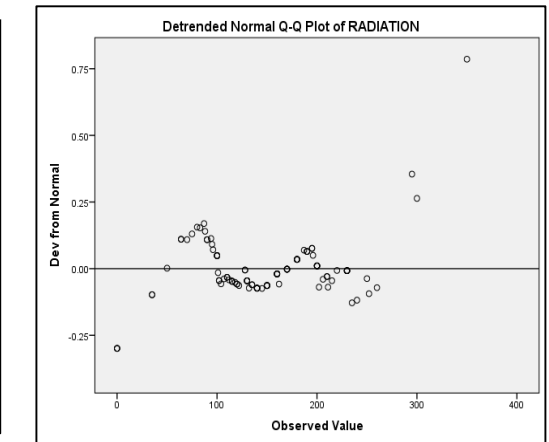
**Fig (u):-** Detrended Normal Q-Q plot of Fe



**Fig (v):-** Detrended Normal Q-Q plot of HCO<sub>3</sub><sup>-</sup>



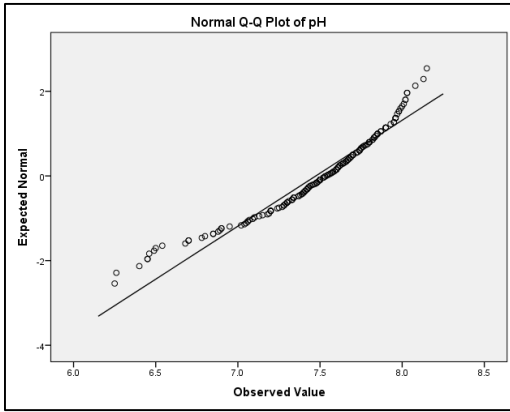
**Fig (w):-** Detrended Normal Q-Q plot of Fluoride



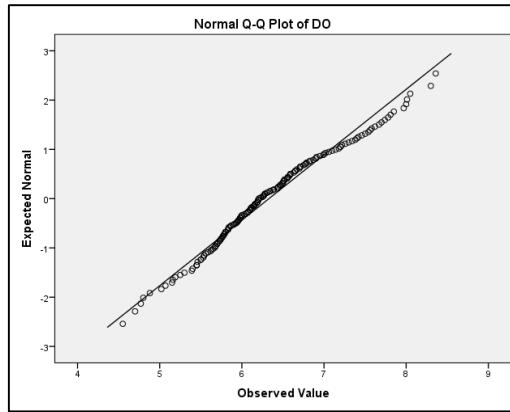
**Fig (x):-** Detrended Normal Q-Q plot of RADIATION

**Fig 6.4.1:** Normal and Detrended Normal Q-Q plot for NADIA

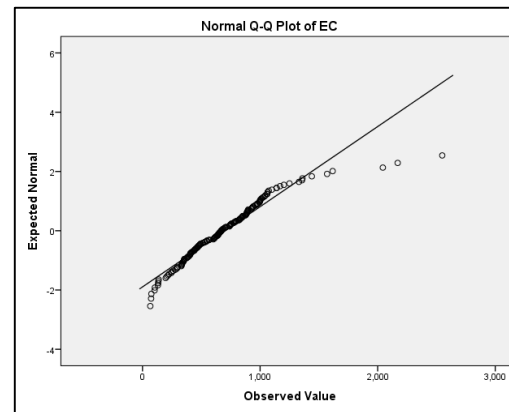
• Bardhaman



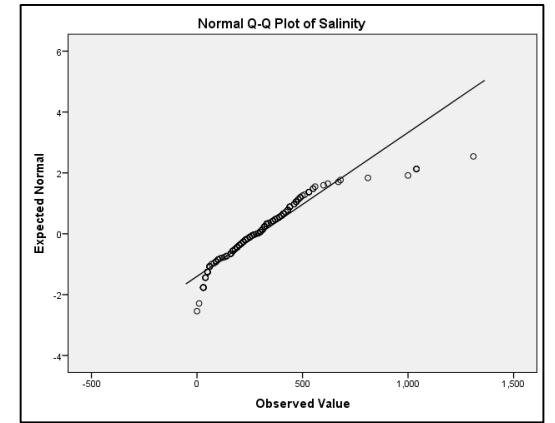
**Fig (a):-**Normal Q-Q plot of pH



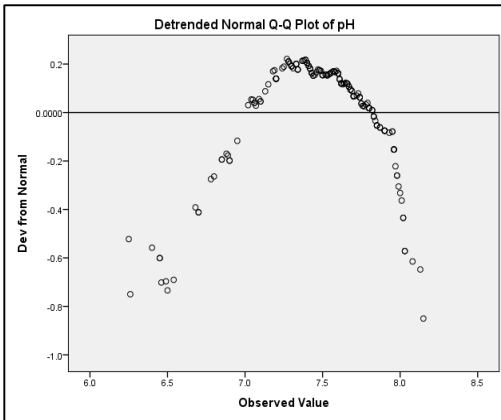
**Fig (b):-**Normal Q-Q plot of DO



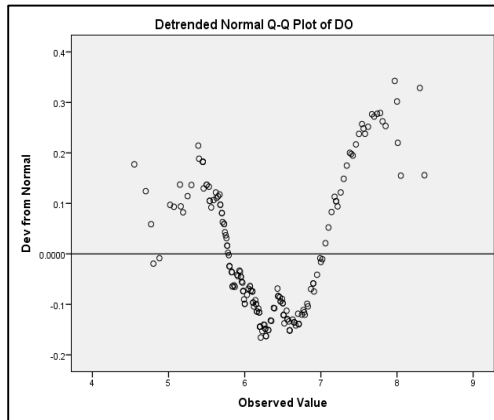
**Fig (c):-**Normal Q-Q plot of EC



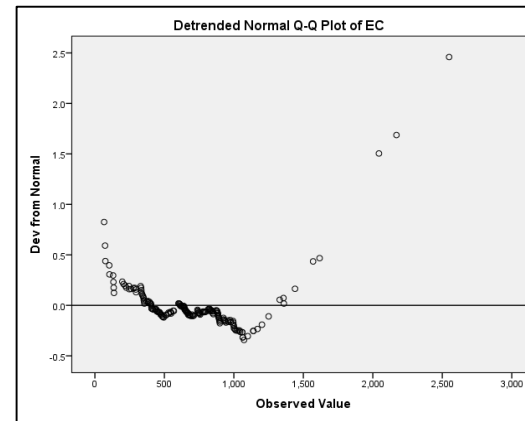
**Fig (d):-**Normal Q-Q plot of Salinity



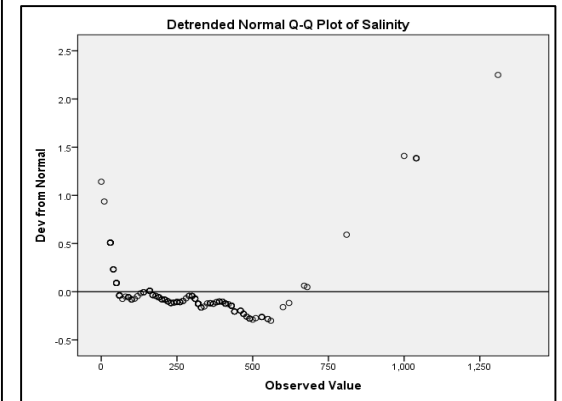
**Fig (e):-**Detrended Normal Q-Q plot of pH



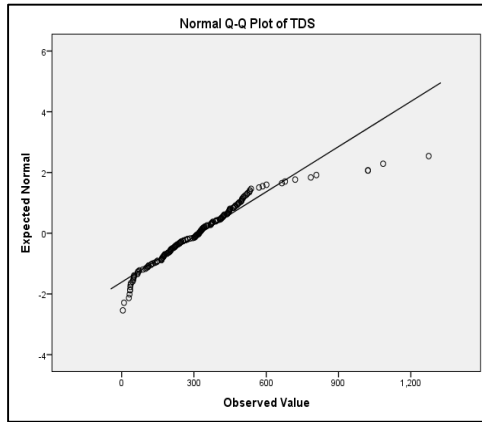
**Fig (f):-**Detrended Normal Q-Q plot of DO



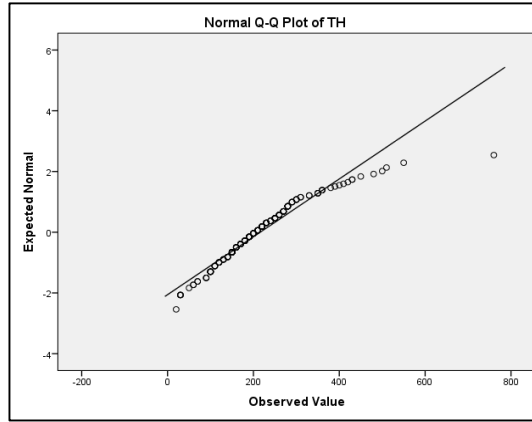
**Fig (g):-**Detrended Normal Q-Q plot of EC



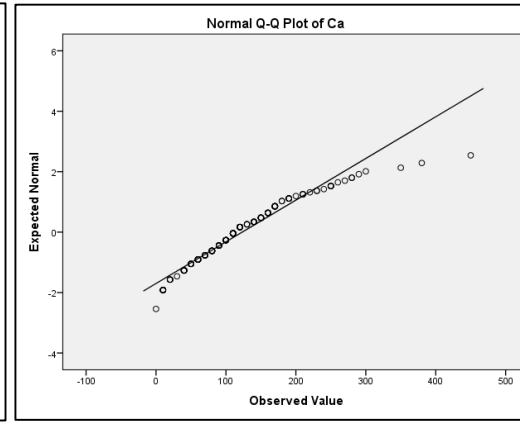
**Fig (h):-**Detrended Normal Q-Q plot of Salinity



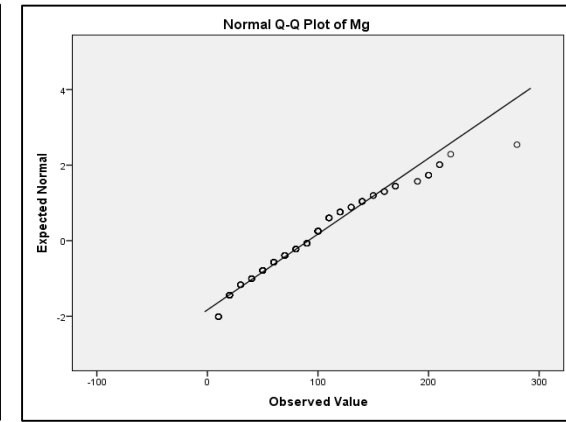
**Fig (i):**-Normal Q-Q plot of TDS



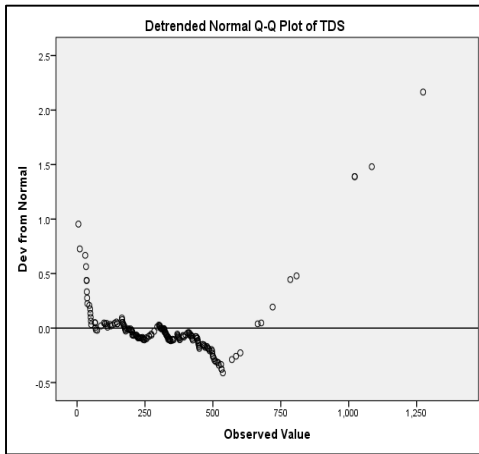
**Fig (j):**-Normal Q-Q plot of TH



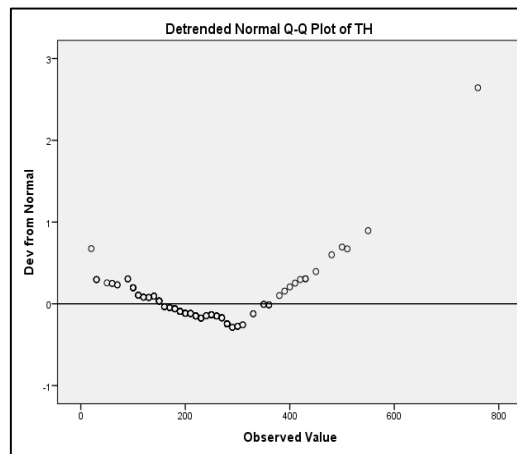
**Fig (k):**-Normal Q-Q plot of Ca<sup>+2</sup>



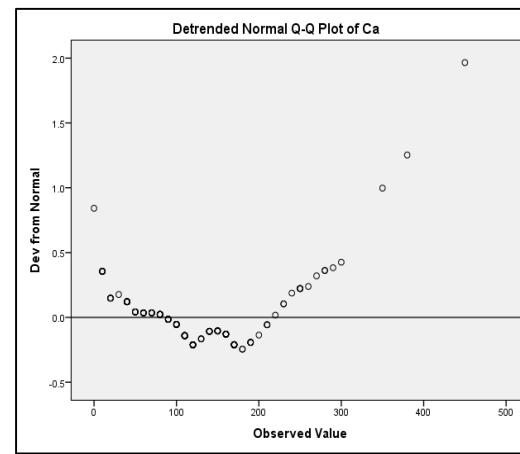
**Fig (l):**-Normal Q-Q plot of Mg<sup>+2</sup>



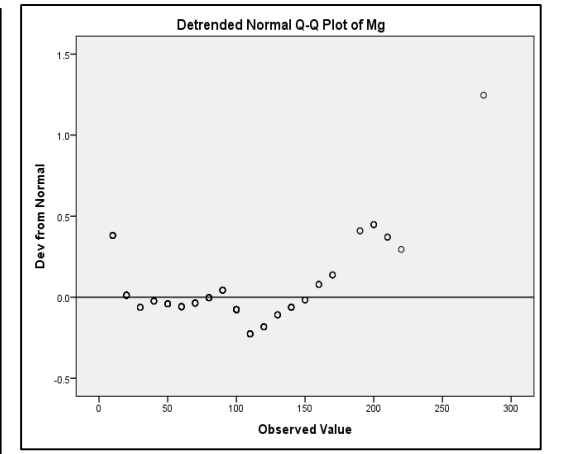
**Fig (m):**-Detrended Normal Q-Q plot of TDS



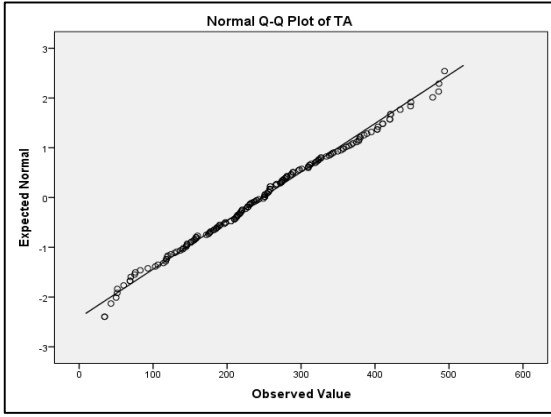
**Fig (n):**-Detrended Normal Q-Q plot of TH



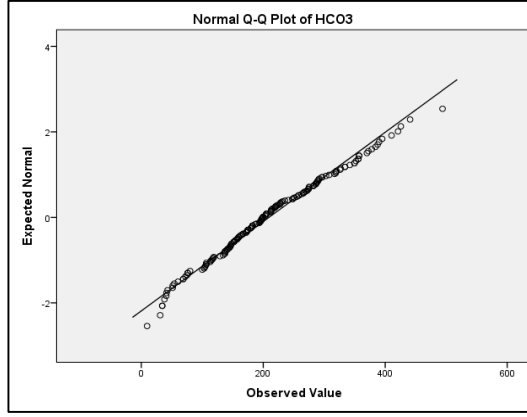
**Fig (o):**-Detrended Normal Q-Q plot of Ca<sup>+2</sup>



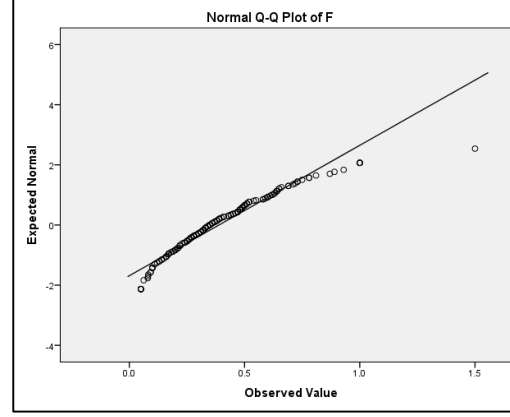
**Fig (p):**-Detrended Normal Q-Q plot of Mg<sup>+2</sup>



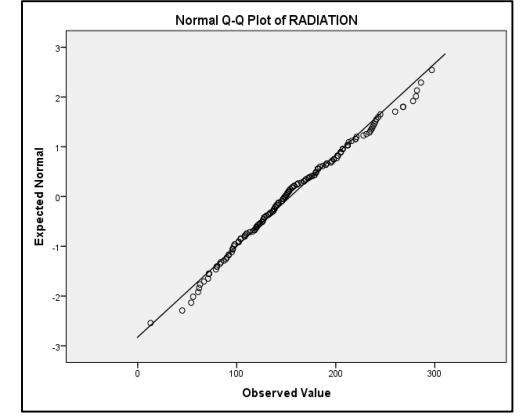
**Fig (q):**-Normal Q-Q plot of TA



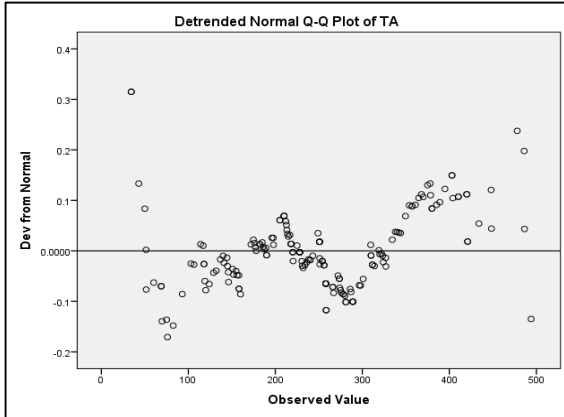
**Fig (r):**-Normal Q-Q plot of  $\text{HCO}_3^-$



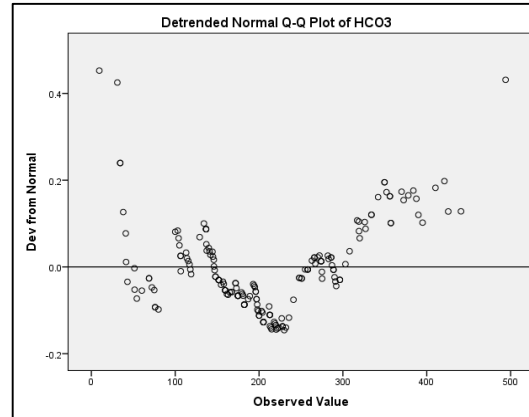
**Fig (s):**-Normal Q-Q plot of Fluoride



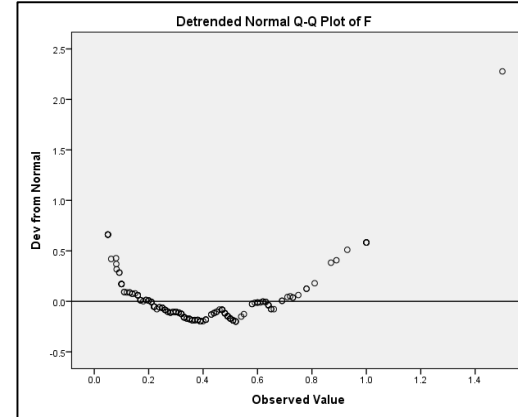
**Fig (t):**-Normal Q-Q plot of RADIATION



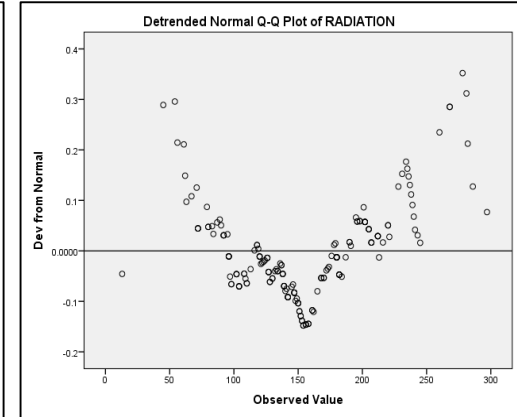
**Fig (u):**-Detrended Normal Q-Q plot of TA



**Fig (v):**-Detrended Normal Q-Q plot of  $\text{HCO}_3^-$



**Fig (w):**-Detrended Normal Q-Q plot of Fluoride



**Fig (x):**-Detrended Normal Q-Q plot of RADIATION

**Fig 6.4.2:** Normal and Detrended Normal Q-Q plot for BARDHAMAN



Q-Q plots for Nadia and Bardhaman satisfies the criteria of Skewness and Kurtosis. Yet there are some other Q-Q Plots whose structure, pattern and alignment seems to follow normal distribution.

[Fig 6.4.1 (c), Fig 6.4.1 (d), Fig 6.4.1 (i), Fig 6.4.1 (l), Fig 6.4.1 (q), Fig 6.4.1 (s), Fig 6.4.2 (a), Fig 6.4.2 (c), Fig 6.4.2 (d), Fig 6.4.2 (i), Fig 6.4.2 (j), Fig 6.4.2 (k), Fig 6.4.2 (l), Fig 6.4.2 (s)].

## 6.5 Descriptive Statistics: K-S Test and S-W Test

The results for both of the tests for the above individual parameters are discussed below.

**Table 6.5.1:** K-S and S-W Test results for Nadia

Water Parameter	Kolmogorov-Smirnov Test <sup>a</sup>					
	Statistic			Shapiro- Wilk Test		
As	0.224	df	Sig.	Statistic	df	Sig.
Ca	0.098	110	0	0.697	110	0
Cl <sup>-</sup>	0.156	109	0.012	0.957	109	0.001
CO <sub>3</sub> <sup>-2</sup>	0.145	109	0	0.834	109	0
DO	0.116	109	0	0.877	109	0
EC	0.239	109	0.001	0.886	109	0
F <sup>-</sup>	0.172	109	0	0.727	109	0
Fe	0.135	109	0	0.825	109	0
HCO <sub>3</sub> <sup>-</sup>	0.096	109	0	0.891	109	0
Mg <sup>+2</sup>	0.087	109	0.015	0.954	109	0.001
NO <sub>3</sub> <sup>-</sup>	0.238	109	0.043	0.961	109	0.003
ORP	0.105	109	0	0.745	109	0
pH	0.084	109	0.005	0.963	109	0.004
PO <sub>4</sub> <sup>-3</sup>	0.307	109	0.055	0.983	109	0.182
RADIATION	0.056	109	0	0.509	109	0
Salinity	0.215	109	.200*	0.989	109	0.487
SO <sub>4</sub> <sup>-2</sup>	0.176	109	0	0.728	109	0
TA	0.138	109	0	0.718	109	0
TDS	0.243	109	0	0.932	109	0
TH	0.081	109	0	0.721	109	0
U	0.259	109	0.072	0.983	109	0.165

- a – Lillifores correction for Kolmogorov-Smirnov test
- \* - Lower bound of true significance

### • K-S Test Discussion

The Kolmogorov-Smirnov Test result reveals that Calcium (Ca) has a significance of 0.012, Dissolved Oxygen (DO) has a significance level of 0.001, Bicarbonate (HCO<sub>3</sub><sup>-</sup>) has a significance level of 0.015, Magnesium (Mg<sup>+2</sup>) has a significance level of 0.043, and Oxidation Reduction Potential (ORP) has a significance level of 0.005 which are less than 0.05. Also Arsenic (As), Chloride (Cl<sup>-</sup>), Carbonate (CO<sub>3</sub><sup>-2</sup>), Electrical Conductivity (EC), Fluoride (F<sup>-</sup>), Iron (Fe), Nitrate (NO<sub>3</sub><sup>-</sup>), Phosphate (PO<sub>4</sub><sup>-3</sup>), Salinity, Sulphate (SO<sub>4</sub><sup>-2</sup>), Total Alkalinity (TA), Total Dissolved Solids (TDS) and Uranium (U) has a significance level of 0 (<0.05). All of them contributes to 85.71% of total dataset which fails to cross the chosen

alpha level of 0.05. Thus null hypothesis is rejected for these water quality parameters and normal distribution is impossible for them.

On the other hand, pH has a significance of 0.055, Radiation has a significance of 0.200 and Total Hardness (TH) has a significance of 0.072 which are higher than chosen alpha level of 0.05 and contributes to only 14.28% of the whole dataset. The alternative hypothesis is rejected for these water quality parameters and they succeed in following a normal distribution.

- **S-W Test Discussion**

The Shapiro-Wilk Test result reveals that Calcium (Ca) has a significance of 0.001, Bicarbonate ( $\text{HCO}_3^-$ ) has a significance level of 0.001, Magnesium ( $\text{Mg}^{+2}$ ) has a significance level of 0.003, and Oxidation Reduction Potential (ORP) has a significance level of 0.004 which are less than 0.05. Also Arsenic (As), Chloride ( $\text{Cl}^-$ ), Carbonate ( $\text{CO}_3^{-2}$ ), Dissolved Oxygen (DO), Electrical Conductivity (EC), Fluoride ( $\text{F}^-$ ), Iron (Fe), Nitrate ( $\text{NO}_3^-$ ), Phosphate ( $\text{PO}_4^{-3}$ ), Salinity, Sulphate ( $\text{SO}_4^{-2}$ ), Total Alkalinity (TA), Total Dissolved Solids (TDS) and Uranium (U) has a significance level of 0 ( $<0.05$ ). All of them contributes to 85.71% of total dataset which fails to cross the chosen alpha level of 0.05. Thus alternative hypothesis is accepted and normal distribution is impossible for these water quality parameters

On the other hand, pH has a significance of 0.182, Radiation has a significance of 0.487 and Total Hardness (TH) has a significance of 0.165 which are higher than chosen alpha level of 0.05 and contributes to only 14.28% of the whole dataset. The null hypothesis is accepted for these water quality parameters as they follow normal distribution.

**Table 6.5.2: K-S and S-W Test for Bardhhaman**

Water Parameter	Kolmogorov-Smirnov Test <sup>a</sup>					
	Statistic			Shapiro- Wilk Test		
As	0.273	df	Sig.	Statistic	df	Sig.
$\text{Ca}^{+2}$	0.112	181	0	0.393	181	0
$\text{Cl}^-$	0.215	180	0	0.934	180	0
$\text{CO}_3^{-2}$	0.17	180	0	0.733	180	0
DO	0.071	180	0	0.905	180	0

EC	0.074	180	0.029	0.981	180	0.016
F <sup>-</sup>	0.092	180	0.018	0.919	180	0
Fe	0.348	180	0.001	0.931	180	0
HCO <sub>3</sub> <sup>-</sup>	0.062	180	0	0.393	180	0
Mg <sup>+2</sup>	0.131	180	0.088	0.987	180	0.088
NO <sub>3</sub> <sup>-</sup>	0.374	180	0	0.957	180	0
ORP	0.121	180	0	0.366	180	0
pH	0.089	179	0	0.893	179	0
PO <sub>4</sub> <sup>-3</sup>	0.311	180	0.001	0.939	180	0
RADIATION	0.067	180	0	0.375	180	0
Salinity	0.093	181	0.049	0.989	181	0.203
SO <sub>4</sub> <sup>-2</sup>	0.235	180	0.001	0.887	180	0
TA	0.052	180	0	0.615	180	0
TDS	0.08	180	.200*	0.99	180	0.221
TH	0.104	180	0.007	0.913	180	0
U	0.148	180	0	0.927	180	0

- a – Lillifores correction for Kolmogorov-Smirnov test
- \* - Lower bound of true significance

- **K-S Test Discussion**

From the Kolmogorov-Smirnov test it is found that Dissolved Oxygen (DO) has a significance level of 0.029, Electrical Conductivity (EC) has a significance level of 0.018, Fluoride (F<sup>-</sup>), pH and Salinity has same significance level of 0.001, Total Dissolved Solids (TDS) has a significance level of 0.007, Radiation shows a significance level of 0.49 and Arsenic (As), Calcium ion (Ca<sup>+2</sup>), Chloride (Cl<sup>-</sup>), Carbonate (CO<sub>3</sub><sup>-2</sup>), Iron (Fe), Magnesium (Mg<sup>+2</sup>), Nitrate (NO<sub>3</sub><sup>-</sup>), Oxidation Reduction Potential (ORP), Phosphate (PO<sub>4</sub><sup>-3</sup>), Sulphate (SO<sub>4</sub><sup>-2</sup>), Total Hardness (TH) and Uranium (U) has equal significance level of 0 which are less than 0.05. All of these water quality parameters contribute to about 90.47% of the whole dataset and fails to satisfy the requirements of normal distribution criteria by rejecting the null hypothesis.

On the contrary to this Bicarbonate (HCO<sub>3</sub><sup>-</sup>) shows a significance level of 0.088 and Total Alkalinity (TA) shows a significance level of 0.2, both of which are greater than the chosen

alpha level of 0.05 but contributes to only 9.52% of the whole dataset. Thus only these two water parameter accepts the null hypothesis and follows the normal distribution.

- **S-W Test Discussion**

From the Shapiro-Wilk test it is found that Dissolved Oxygen (DO) has a significance level of 0.016, has a significance level of 0.018 and Arsenic (As), Calcium ion ( $\text{Ca}^{+2}$ ), Chloride ( $\text{Cl}^-$ ), Carbonate ( $\text{CO}_3^{-2}$ ), Electrical Conductivity (EC), Fluoride ( $\text{F}^-$ ), Iron (Fe), Magnesium ( $\text{Mg}^{+2}$ ), Nitrate ( $\text{NO}_3^-$ ), pH, Oxidation Reduction Potential (ORP), Phosphate ( $\text{PO}_4^{-3}$ ), Salinity, Sulphate ( $\text{SO}_4^{-2}$ ), Total Dissolved Solids (TDS), Total Hardness (TH) and Uranium (U) has equal significance level of 0 which are less than 0.05. All of these water quality parameters contribute to 85.71% of the whole dataset but do not follow normal distribution and accepts the alternative hypothesis.

On the contrary to this Bicarbonate ( $\text{HCO}_3^-$ ) shows a significance level of 0.088 which is same significance level as determined from Kolmogorov-Smirnov test. Radiation shows a significance level of 0.203 and Total Alkalinity (TA) shows a significance level of 0.221. These three water quality parameters shows a significance level greater than the chosen alpha level of 0.05 but contributes to only 14.28% of the whole dataset. Thus only these water parameters accept the null hypothesis and follows the normal distribution.

The K-S test and S-W test results for Nadia dataset concludes that less than 20% of the whole dataset follows normal distribution. Same can be concluded for Bardhaman dataset. So, it becomes well established that sampling locations' most groundwater quality parameters do not tend to follow normal distribution. The confirmation of K-S test and S-W test results should be done by performing other statistical tests.

## **6.6 KMO and Bertlett's Sphericity Test result**

The tests were run using SPSS. Following are the results and discussion of the tests.

**Table 6.6.1: KMO and Bartlett's Test for Nadia**

<b>KMO and Bartlett's Test</b>		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.595
Bartlett's Test of Sphericity	Approx. Chi-Square*	1442.899
	df	231
	Sig.	.000

- **KMO Test for Nadia**

KMO measure of sampling adequacy gives 0.595 (Which is  $KMO > 0.5$ ). As per the KMO index the value is miserable. But since it is more than 0.5 thus it can be used for Factor Analysis/Principal Component Analysis.

- **Bartlett's Test of Sphericity for Nadia**

Taking a 95% level of significance,  $\alpha = 0.05$  the  $p$ -value (sig.) of  $.000 < 0.05$ , therefore factor analysis is allowed for Nadia dataset.

**Table 6.6.2: KMO and Bartlett's Test for Bardhaman**

<b>KMO and Bartlett's Test</b>		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.512
Bartlett's Test of Sphericity	Approx. Chi-Square*	2497.692
	df	231
	Sig.	.000

- **KMO Test for Bardhaman**

KMO measure of sampling adequacy gives 0.512 (Which is  $KMO > 0.5$ ). As per the KMO index the value is miserable. But since it is more than 0.5 thus it can be used for Factor Analysis/Principal Component Analysis.

- **Bartlett's Test of Sphericity for Bardhaman**

Taking a 95% level of significance,  $\alpha = 0.05$  the  $p$ -value (sig.) of  $.000 < 0.05$ , therefore factor analysis is valid for Bardhaman dataset.

Now, for both of the cases, as  $p < \alpha$ , we therefore we reject the null hypothesis  $H_0$  and we accept the alternative hypothesis ( $H_a$ ) that there may be statistically significant interrelationship between variable.

\*Chi-square is a theoretical distribution which is generated from statistical tests. The value specifies the probability of obtaining the chi-square value from chance. If the probability is less than the significance level, the test is judged to be statistically significant. Based on degrees of freedom the chi-squared values differ.

## 6.7 Correlation Matrix

**Table 6.7.1:** Correlation Matrix for Nadia District

	pH	TDS	EC	ORP	Salinity	DO	F <sup>-</sup>	Cl <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	PO <sub>4</sub> <sup>3-</sup>	U	TH	Ca	Mg	TA	(CO <sub>3</sub> ) <sup>2-</sup>	(HCO <sub>3</sub> ) <sup>-</sup>	As	Fe	WQI	
<b>pH</b>	1																					
<b>TDS</b>	-0.16	1																				
<b>EC</b>	-0.16	<b>1.00</b>	1																			
<b>ORP</b>	-0.12	0.17	0.17	1																		
<b>Salinity</b>	-0.08	0.26	0.27	0.08	1																	
<b>DO</b>	-0.20	0.07	0.06	-0.01	-0.08	1																
<b>F<sup>-</sup></b>	0.33	0.09	0.08	-0.04	0.06	-0.13	1															
<b>Cl<sup>-</sup></b>	-0.10	<b>0.80</b>	<b>0.80</b>	0.23	0.28	0.13	0.06	1														
<b>NO<sub>3</sub><sup>-</sup></b>	-0.22	0.42	0.42	-0.05	0.16	0.01	-0.05	0.40	1													
<b>SO<sub>4</sub><sup>2-</sup></b>	-0.09	0.45	0.45	0.17	0.21	-0.13	0.00	0.44	0.29	1												
<b>PO<sub>4</sub><sup>3-</sup></b>	-0.09	0.09	0.09	-0.06	0.11	0.11	-0.07	0.09	0.11	0.02	1											
<b>U</b>	-0.09	0.42	0.43	-0.04	0.09	0.00	0.15	0.36	0.27	0.33	-0.02	1										
<b>TH</b>	-0.21	0.36	0.35	0.08	0.08	0.20	0.05	0.29	0.31	0.16	0.09	0.12	1									
<b>Ca</b>	-0.16	0.02	0.01	0.06	-0.09	-0.02	-0.16	-0.06	-0.07	-0.03	0.00	-0.15	0.30	1								
<b>Mg</b>	-0.08	0.33	0.33	0.06	0.12	0.17	0.21	0.33	0.21	0.18	0.09	0.21	0.73	-0.31	1							
<b>TA</b>	0.03	0.48	0.48	0.11	0.13	-0.21	0.14	0.42	0.09	0.15	0.00	0.20	0.09	-0.10	0.18	1						
<b>(CO<sub>3</sub>)<sup>2-</sup></b>	0.40	-0.09	-0.06	-0.01	0.14	-0.18	0.14	0.08	-0.15	0.13	-0.05	-0.07	-0.08	-0.22	0.14	0.29	1					
<b>(HCO<sub>3</sub>)<sup>-</sup></b>	-0.21	0.45	0.44	0.10	0.02	-0.11	0.07	0.31	0.15	0.07	0.03	0.22	0.15	0.08	0.08	0.75	-0.23	1				
<b>As</b>	0.08	-0.09	-0.09	0.05	-0.08	0.08	-0.14	-0.01	-0.07	0.00	-0.01	-0.13	-0.06	0.08	-0.14	-0.14	-0.06	-0.10	1			
<b>Fe</b>	-0.07	-0.02	-0.03	0.21	0.09	-0.03	-0.01	-0.02	-0.13	-0.06	-0.05	-0.06	0.14	0.01	0.06	0.01	-0.12	0.09	0.21	1		
<b>WQI</b>	-0.04	0.03	0.02	0.20	0.07	0.02	-0.06	0.05	-0.07	0.00	-0.03	-0.05	0.15	0.05	0.05	0.00	-0.12	0.08	0.59	<b>0.91</b>	1	

### 6.7.1. Correlation Matrix for Nadia District

Table 6.7.1 shows strong ( $r \geq \pm 0.8$ ) and good ( $\pm 0.4 \geq r \geq \pm 0.8$ ) correlation between various parameters.

1) Strong correlation between TDS with EC ( $r = 1$ ),  $\text{Cl}^-$  ( $r = 0.8$ ), EC with  $\text{Cl}^-$  ( $r = 0.8$ ), and Fe with WQI ( $r = 0.91$ ) are found.

2) Good correlation between TDS and EC with  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , U, TA,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$  with  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , TA, TH with  $\text{Mg}^{+2}$ ,  $\text{HCO}_3^-$  with TA and As with WQI are found.

Strong and good positive correlation indicates these parameters are linearly dependent on each other. It can be stated that all of them have originated from the same source. As Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are strongly correlated ( $r = 1$ ) and it can be said that concentrations of these ions increases with increase in conductivity. Total Hardness, Oxidation Reduction Potential, Salinity are positively correlated with conductivity and TDS but not with a good correlation. Yet from the linear positive relationship it can be said that most of the ions were involved in various physicochemical reactions, such as oxidation-reduction and ion exchange in the groundwater aquifer system (Subba Rao, 2002) Poor and negative correlation between pH and ORP indicates maybe there exists aquifers of both oxidizing and reducing types. The WQI was also incorporated into the correlation matrix to examine how individual elements govern the water quality index. It has been found that iron has a strong correlation ( $r = 0.91$ ) with WQI and arsenic has a good correlation ( $r = 0.59$ ) with WQI. Thus these two elements govern the Water Quality Index of the Nadia district. Though it is already reported that Nadia district is affected with arsenic contamination in groundwater (Rahman et al., 2014; Mandal et al., 1996; Ghosh et al., 2004). On the other hand, fluoride is not showing any good correlation with these ions, in fact it is negatively correlated with total hardness and zero correlation with sulphate. Also fluoride is positively correlated with uranium but not a good correlation and fluoride is negatively correlated with arsenic and nitrate. Thus it can be derived from this fact that origin of the fluoride is not local and may have generated from various anthropogenic activity. Uranium is positively correlated with calcium, magnesium, bicarbonate and negatively correlated with pH which indicates that they can influence uranium mobility into the groundwater. (Ho and Miller 1986). Correlation between nitrate and corresponding ions indicate that nitrate in the ground water is due to anthropogenic causes. Good correlation between Uranium and associated anions as well as TDS indicate the chemical reactions between them and TDS is



caused due to Uranium ions also in the study area. As far as the study is done it cannot be stated the occurrence of Uranium is due to anthropogenic or geogenic causes. But positive relation with Chloride may indicate the presence of uranium minerals in oxidizing state in the groundwater and strong negative correlation with Calcium ions and with iron may indicate reducing state of Uranium in the study area.

**Table 6.7.2: Correlation Matrix for Bardhaman**

	pH	TDS	EC	ORP	Salinity	DO	F <sup>-</sup>	Cl <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	PO <sub>4</sub> <sup>3-</sup>	U	TH	Ca	Mg	TA	(CO <sub>3</sub> ) <sup>2-</sup>	(HCO <sub>3</sub> ) <sup>-</sup>	As	Fe	WQI	
<b>pH</b>	1																					
<b>TDS</b>	0.06	1																				
<b>EC</b>	0.06	<b>0.84</b>	1																			
<b>ORP</b>	-0.47	0.05	0.16	1																		
<b>Salinity</b>	0.21	0.42	0.59	0.06	1																	
<b>DO</b>	0.23	-0.05	0.00	-0.31	0.06	1																
<b>F<sup>-</sup></b>	0.26	-0.03	0.08	-0.19	-0.05	0.23	1															
<b>Cl<sup>-</sup></b>	-0.19	0.48	0.61	0.17	0.29	0.02	0.06	1														
<b>NO<sub>3</sub><sup>-</sup></b>	-0.36	0.16	0.24	0.13	-0.14	-0.04	0.01	0.47	1													
<b>SO<sub>4</sub><sup>2-</sup></b>	-0.29	0.19	0.34	0.16	-0.11	-0.03	0.04	0.27	0.35	1												
<b>PO<sub>4</sub><sup>3-</sup></b>	0.09	0.09	0.04	-0.18	0.01	-0.03	0.02	-0.03	0.01	-0.07	1											
<b>U</b>	0.24	0.27	0.22	-0.15	0.20	0.16	0.37	0.22	0.04	0.00	-0.01	1										
<b>TH</b>	0.06	0.41	0.33	-0.16	-0.09	0.23	0.05	0.22	0.27	0.34	0.07	0.17	1									
<b>Ca</b>	0.10	0.37	0.29	-0.20	-0.09	0.26	0.10	0.21	0.26	0.28	0.05	0.20	<b>0.89</b>	1								
<b>Mg</b>	0.01	0.27	0.22	-0.05	-0.06	0.09	-0.07	0.15	0.17	0.24	0.09	0.08	0.74	0.37	1							
<b>TA</b>	0.32	0.21	0.28	-0.08	0.17	0.06	0.13	0.16	-0.05	-0.04	0.11	0.22	0.17	0.16	0.12	1						
<b>(CO<sub>3</sub>)<sup>2-</sup></b>	0.14	0.23	0.20	-0.07	-0.12	0.09	0.21	0.16	0.09	0.00	0.03	0.29	0.38	0.39	0.24	0.40	1					
<b>(HCO<sub>3</sub>)<sup>-</sup></b>	0.29	0.15	0.23	-0.05	0.23	0.03	0.05	0.11	-0.09	-0.05	0.10	0.15	0.05	0.03	0.05	<b>0.93</b>	0.07	1				
<b>As</b>	0.07	0.05	0.08	0.07	0.13	0.08	-0.03	-0.04	-0.05	-0.02	-0.07	-0.01	0.01	-0.02	0.03	0.06	0.04	0.05	1			
<b>Fe</b>	-0.25	-0.12	-0.17	-0.02	-0.11	-0.09	-0.11	-0.03	0.01	0.00	-0.06	-0.15	-0.05	-0.03	-0.05	-0.25	-0.16	-0.21	-0.02	1		
<b>WQI</b>	-0.26	-0.08	-0.13	-0.01	-0.11	-0.08	-0.10	0.02	0.07	0.04	-0.06	-0.13	0.00	0.01	-0.01	-0.22	-0.13	-0.19	0.03	<b>1.00</b>	1	

### 6.7.2 Correlation Matrix for Bardhaman

From Table 6.7.2 strong ( $r \geq \pm 0.8$ ) and good ( $\pm 0.4 \geq r \geq \pm 0.8$ ) correlation is observed between various parameters.

1) Strong correlation between TDS with EC ( $r = 0.84$ ), TH with Ca<sup>+2</sup> ( $r = 0.89$ ), TA with HCO<sub>3</sub><sup>-</sup> ( $r = 0.93$ ) and Fe with WQI ( $r = 1$ ) are found.

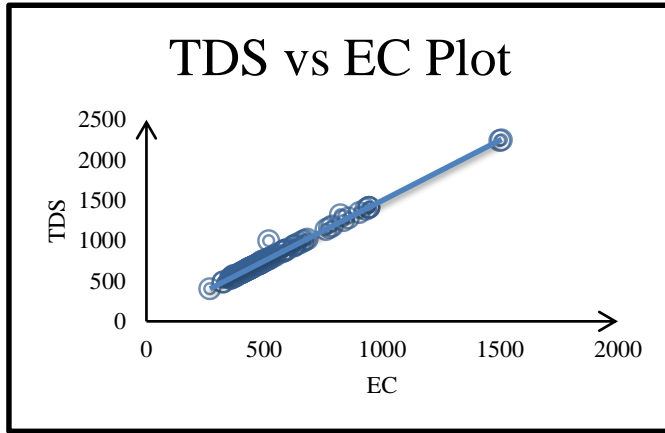
2) Good correlation between TDS with Salinity, Cl<sup>-</sup> and TH, EC with Salinity and Cl<sup>-</sup>, Cl<sup>-</sup> with NO<sub>3</sub><sup>-</sup>, TH with Mg<sup>+2</sup> and CO<sub>3</sub><sup>-2</sup> with TA are found.

Strong and good positive correlation indicates these parameters are linearly dependent on each other. It can be stated that all of them have originated from the same source. As Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are strongly correlated ( $r=0.84$ ) it can be said that as when conductivity increases concentrations of these ions increases. Total Dissolved Solids, Electrical Conductivity, Salinity, Chloride, Total Hardness, Uranium, Nitrate, Sulphate, Calcium, Magnesium, Total Alkalinity, Carbonate and Bicarbonate have a positive correlation but not with a good correlation. Yet from the linear positive relationship it can be said that most of the ions were involved in various physicochemical reactions, such as oxidation-reduction and ion exchange in the groundwater aquifer system (Subba Rao, 2002) Strong correlation between TDS and EC and good correlation with Salinity and Chloride indicates presence of brackish type groundwater in a lower groundwater table in the semi-arid climatic condition of the north-western part of the district. (Gupta et al., 2008) Strong ( $r=0.89$ ) and Good ( $r=0.74$ ) correlation of calcium and magnesium respectively with total hardness and positive correlation with carbonate and bicarbonate ions is an indication of the presence of carbonate hardness in the groundwater as well as the prevalence of Calcium hardness over Magnesium hardness. Lower positive correlation coefficient value of Calcium and Magnesium with Chloride, Sulphate and Nitrate indicates lesser chance of non-carbonate hardness. Very less correlation of calcium and magnesium with Total Alkalinity supports the above statement. On the other hand, strong correlation ( $r=0.93$ ) between Bicarbonate ions and good correlations with carbonate ions also indicate the presence of carbonate hardness in ground water. Good positive correlation between Nitrate and Chloride and positive correlation with sulphate as well as between both of them indicates presence of pollutants in groundwater caused by anthropogenic activities. The WQI was also incorporated into the correlation matrix to examine how individual elements govern the water quality index. It has been found that iron has a strong correlation ( $r=1$ ) with WQI. Thus only element that governs the whole Water Quality Index of the Bardhaman district is iron. Though it is found that no other parameters are not as strongly or goodly correlated with WQI (Nag et al., 1996). On the other hand fluoride is only showing a small positive correlation with Uranium but negative correlation with arsenic. Thus it can be derived from this fact that co-existence of arsenic and fluoride may not be possible and it may have generated from various anthropogenic or geogenic activities. Very little positive correlation between Uranium with pH, calcium, magnesium, carbonate and bicarbonate indicates that uranium mobility can be influenced by them (Ho and Miller 1986). As Uranium occurs in mineral forms in nature with Calcium and Chloride ions and since weak positive

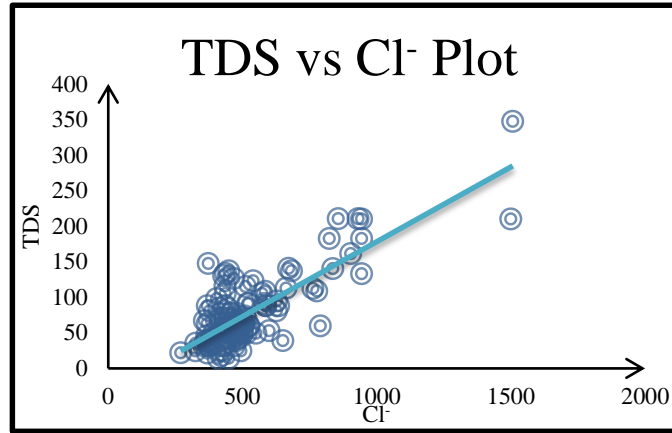
correlation is found with Uranium as well as these ions, thus there may be Uranium mobility in the groundwater due to presence of uranium minerals in the study area. Strong negative correlation with iron can indicate the reducing condition of uranium containing minerals in the study area. Negative correlation between pH and ORP indicates presence of reducing agent in the source of groundwater. As ORP is a measure of an element's oxidizing and reducing potential for another element (Van Loon et al., 2011) thus the negative correlation between arsenic, fluoride, iron and sulphate may indicate the presence of reducing type rock mineralogy and aquifer (Kim et al., 2012) as well as the poor correlations may support the lower chances of co-existence of these ions in ground water.

## 6.8 Graphical interpretation Scatter Diagram

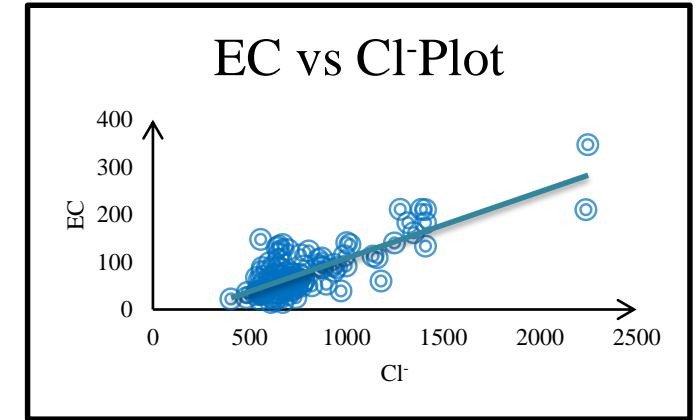
**Fig 6.8:** Scatter Plot of the elements which are showing good correlations in Correlation Matrix for the corresponding districts



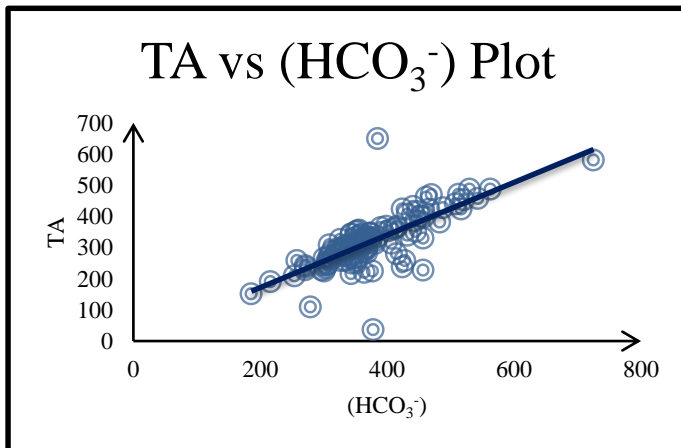
**Fig (a):-** TDS (Total Dissolved Solids) vs EC (Electrical Conductivity) scatterplot for Nadia District



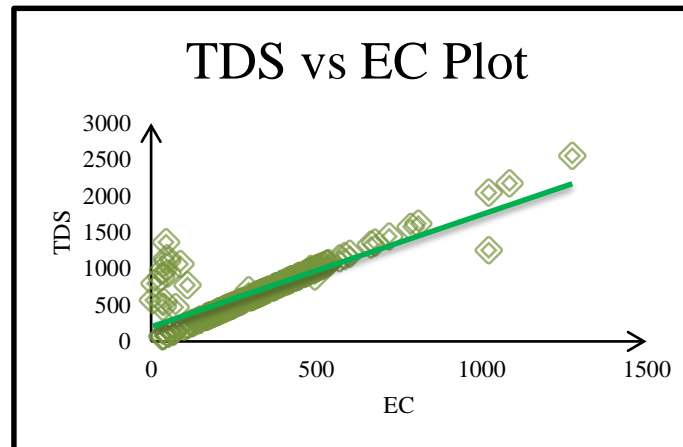
**Fig (b):-** TDS (Total Dissolved Solids) vs Cl<sup>-</sup> (Chloride) scatterplot for Nadia District



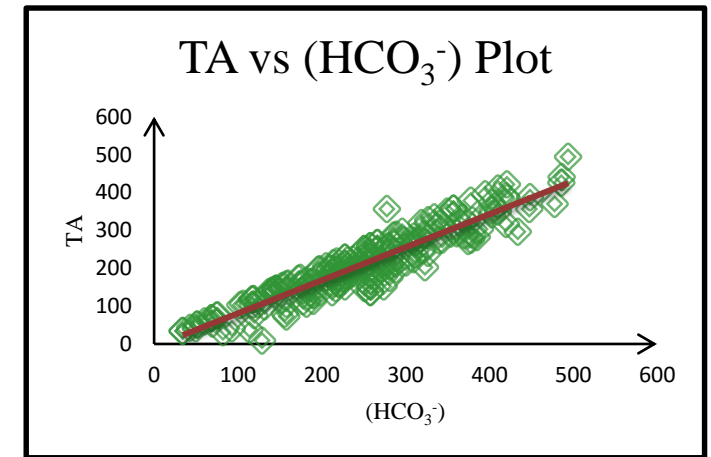
**Fig (c):** EC (Electrical Conductivity) vs Cl<sup>-</sup> (Chloride) scatterplot for Nadia District



**Fig (d):** TA (Total Alkalinity) vs HCO<sub>3</sub><sup>-</sup> (Bicarbonate) scatterplot for Nadia District



**Fig (e):** TDS (Total Dissolved Solids) vs EC (Electrical Conductivity) scatterplot for Bardhaman District



**Fig (f):** TA (Total Alkalinity) vs HCO<sub>3</sub><sup>-</sup> (Bicarbonate) scatterplot for Bardhaman district

**Table 6.8.1: Scatter Plot Derivations**

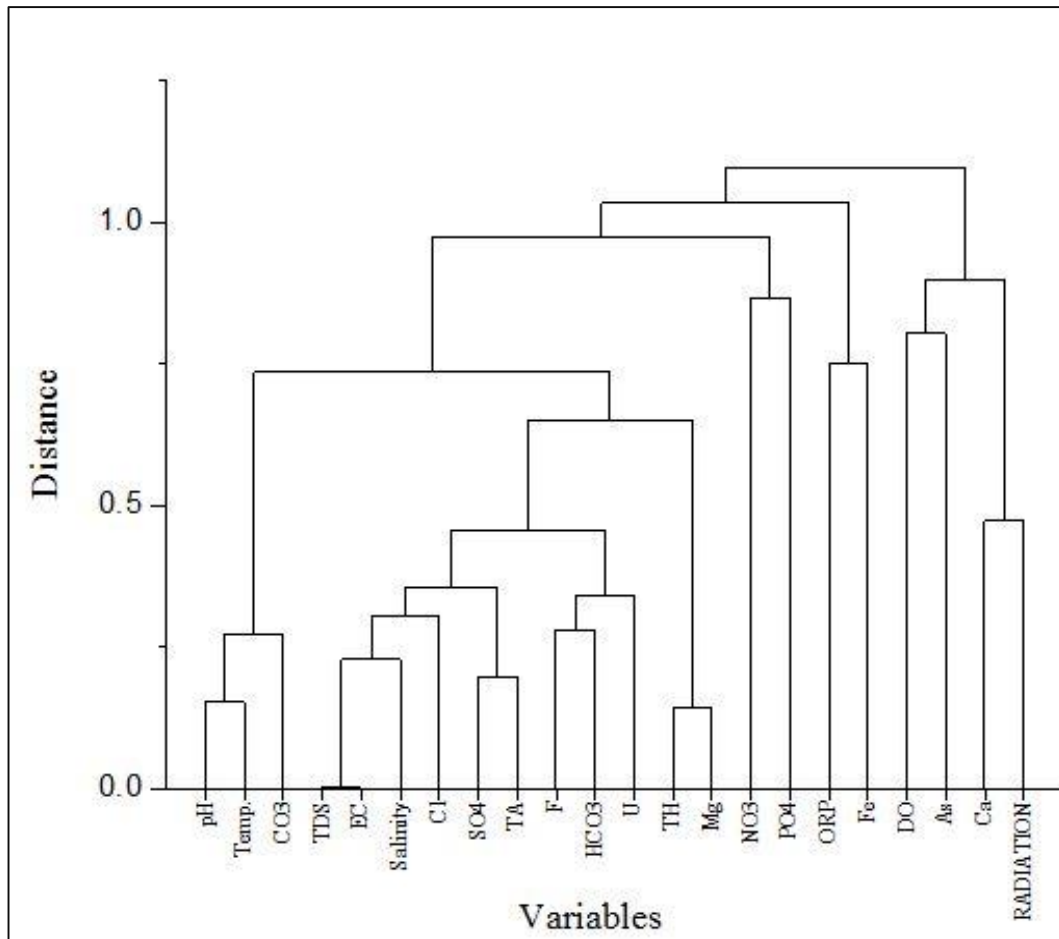
District	Fig	Linear Equation derived from plot	R <sup>2</sup> Value
Nadia	6.8 (a)	TDS= 1.4983EC + 0.94	0.994
	6.8 (b)	TDS= 0.2102(Cl <sup>-</sup> ) - 32.215	0.6355
	6.8 (c)	EC = 0.1402(Cl <sup>-</sup> ) - 32.297	0.6387
	6.8 (d)	TA = 0.8445 (HCO <sub>3</sub> <sup>-</sup> ) + 2.241	0.5588
Bardhaman	6.8 (e)	TDS = 1.5461EC + 197.94	0.7111
	6.8 (f)	TA = 0.8727(HCO <sub>3</sub> <sup>-</sup> ) - 6.6177	0.8717

### 6.9 Hierarchical Cluster Analysis

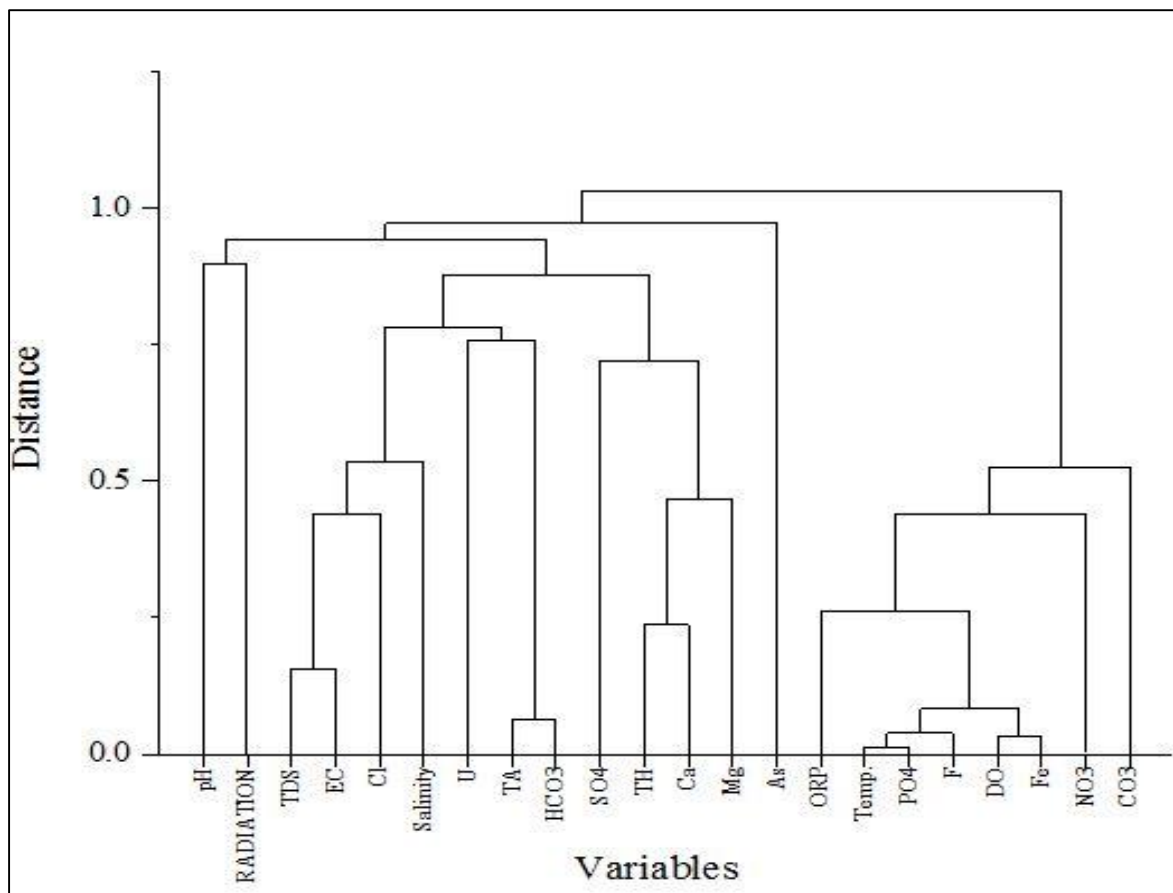
In our study, hierarchical agglomerative clustering analysis was performed on the normalized data set by means of Group Average method, also known as Unweighted Pair Group Average Method. In this method the distance between two groups is defined as the average distance between each of their members. Usually the hierarchical clustering is done taking considerations of Ward's method with Euclidean distance for the plotting of dendrogram. Previous works relating to Hierarchical Cluster Analysis reveals that (Shrestha & Kazama, 2007; Kazi et al., 2009; Singh et al., 2004; Alberto et al., 2001) spatial as well as temporal variation was calculated. In Shrestha & Kazama, 2007 and Singh et al., 2004 theoretical values were considered for calculation. In all of the above cases PCA/FA case scores were used with Ward's method with Euclidean Distance approach to determine and identify similarity between water quality parameters and a theoretical source of the WQPs. In their cases before analysing with PCA/FA the normality test scores from data treatment part were very convincing for null hypothesis of normal distribution. In our case K-S and S-W test results were not good enough for a convincing >90-95% normal distribution among the data. In our case KMO and Bartlett's test case scores were "miserable" for PCA/FA approach. In fact the PCA/FA analysis report was very convincing with 66.9% and 71.2% for each districts respectively. As we lack a large set of temporal variation data thus our approach is only towards spatial distribution analysis of the available data. Thus our approach towards Hierarchical Cluster Approach was to perform the analysis with Group Average method for the Correlation between the water quality parameters.

From the Hierarchical Cluster Analysis, it is found that a tree like structure or Dendrogram is created where the parameters cluster together based upon the average distance between them.

Any two parameters joined by an arm indicates a cluster. Later the two arms joined together with another one or two arms. In this way the overall correlation between all the parameters can be plotted. pH, Temp.,  $\text{CO}_3^{-2}$ , TH, EC, Salinity,  $\text{Cl}^-$ ,  $\text{SO}_4^{-2}$ , TA,  $\text{F}^-$ ,  $\text{HCO}_3^-$ , U, TH,  $\text{Mg}^{+2}$ ,  $\text{NO}_3^-$ , ORP and Fe falls in one cluster and DO, As,  $\text{Ca}^{+2}$  and RADIATION falls in another cluster. **(Fig: 6.9 (a))** The dendrogram structure thus formed has two large arms which shows the water quality parameters relation in Nadia. As the dendrogram of the Bardhaman district is formed **(Fig: 6.9 (b))** it is seen that at first pH and Radiation forms a cluster, then connects with the cluster formed by TDS, EC,  $\text{Cl}^-$ , Salinity, U, TA,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{-2}$ , TH,  $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$  and finally connects with As to form one arm of the dendrogram. On the other arm of the dendrogram there exists ORP only.



**Fig (a):- Dendrogram for WQP of Nadia**



**Fig (b):- Dendrogram for WQP of Bardhaman**

**Fig 6.9:** Hierarchical Cluster Analysis using Dendrogram showing correlation between the water quality parameters of both the districts.

## 6.10 Water Quality Index

The term "water quality" is defined as "those physical, chemical or biological characteristics of water by which the user evaluates the acceptability of water." (CPCB) The quality of drinking water can be characterised by water quality index. By preparing the Water Quality Index a quality rating scale is derived which reproduces a complete picture of the basic water quality of the study area. (Meng et al., 2016) WQI is commonly used for the detection and evaluation of water pollution and can be defined as a reflection of combined influence of different quality parameters on the overall quality of water. (Horton 1965)

For the calculation of WQI nineteen parameters have been selected for each of the study areas i.e. Nadia and Bardhaman. In the beginning, all parameters are assigned with weights (2 – 5) according to its significance according to the overall quality for drinking purpose. The selected weights are based upon the parameter's contribution in impairment to environment and human health. The maximum weight of 5 is assigned for arsenic and uranium due to their toxic and potent harmful nature. Fluoride and nitrate are assigned with a weight of 4 due to their contribution in groundwater pollution and level of impact on human health. pH, chloride and iron is assigned with a weight of 3 due to their correlation and passivity in the contribution towards the groundwater pollution. Total dissolved solids, total alkalinity, total hardness are assigned with a weight of 2 due to their impact on physical parameters of water. (See **Table 6.10**)

In the second step, Relative weight ( $W_i$ ) is determined using the following formula:

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i}$$

Where,  $W_i$  is the relative weight,  $w_i$  is the weight of each parameter and  $n$  is the number of parameters.



**Table 6.10.1:** Relative weight of chemical parameters

Parameters	Weight(wi)	Relative weight(Wi)	Indian Standards (mg/l; except pH)
pH	3	0.085714286	6.5-8.5
TDS	2	0.057142857	500-2000
Fluoride	4	0.114285714	1.0-1.5
Chloride	3	0.085714286	250-1000
Nitrate	4	0.114285714	45
Sulphate	2	0.057142857	200-400
Uranium	5	0.142857143	0.03*
Total hardness	2	0.057142857	200-600
Total Alkalinity	2	0.057142857	200-600
Arsenic	5	0.142857143	0.01
Iron	3	0.085714286	0.3
	$\Sigma = 35$	$\Sigma = 1$	

\*(WHO, 2004)

In the third step, a quality rating scale ( $q_i$ ) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines said in the BIS and the result multiplied by 100:

$$q_i = (C_i / S_i) \times 100$$

Where,  $q_i$  signifies the quality rating,  $C_i$  denotes the concentration of each chemical parameter in each water sample in mg/L, and  $S_i$  is the Indian drinking water standard for each chemical parameter in mg/L according to the guidelines of the BIS7 10500, 1991.

For computing the WQI, the *SI* is first calculated for each chemical parameter (only chemical parameters and pH are included), which is then used to determine the WQI as per the following equation,

$$SI_i = W_i \cdot q_i$$

$$WQI = \sum SI_i$$

$SI_i$  is the sub index of  $i^{th}$  parameter;  $q_i$  is the rating based on concentration of  $i^{th}$  parameter. At last, the computed WQI values are classified into five types of water quality “excellent” to “unsuitable for drinking”.( Ramakrishnaiah et al., 2009; Rajkumar 2015)

**Table 6.10.2:** Water quality categorisation based on WQI value for Nadia

WQI value	Water Quality	Percentage of Samples
<50	Excellent	4.55
50 - 100	Good	26.4
100 - 200	Poor	40.9
200 - 300	Very Poor	19.1
>300	Unsuitable for Drinking	9.1

In this study for the case of Nadia, the WQI value ranges between 36.8 to 555.1 and maximum water samples are classified as poor quality. About 9% water sample are absolutely inappropriate for drinking (Table 10.2).

**Table 6.10.3:** Water quality categorisation based on WQI value for Bardhaman

Range	Quality	Percentage of Samples
<50	Excellent	58.33
50 - 100	Good	24.44
100 - 200	Poor	11.67
200 - 300	Very Poor	3.33
>300	Unsuitable for Drinking	2.78

In this study for the case of Bardhaman, the WQI value ranges between 23.61 to 1019.91 and maximum water samples are classified as poor quality. About 3% water sample are absolutely inappropriate for drinking (**Table 6.10.3**).

## Chapter 7

# SPATIAL VARIABILITY

### 7.1 Contour Map

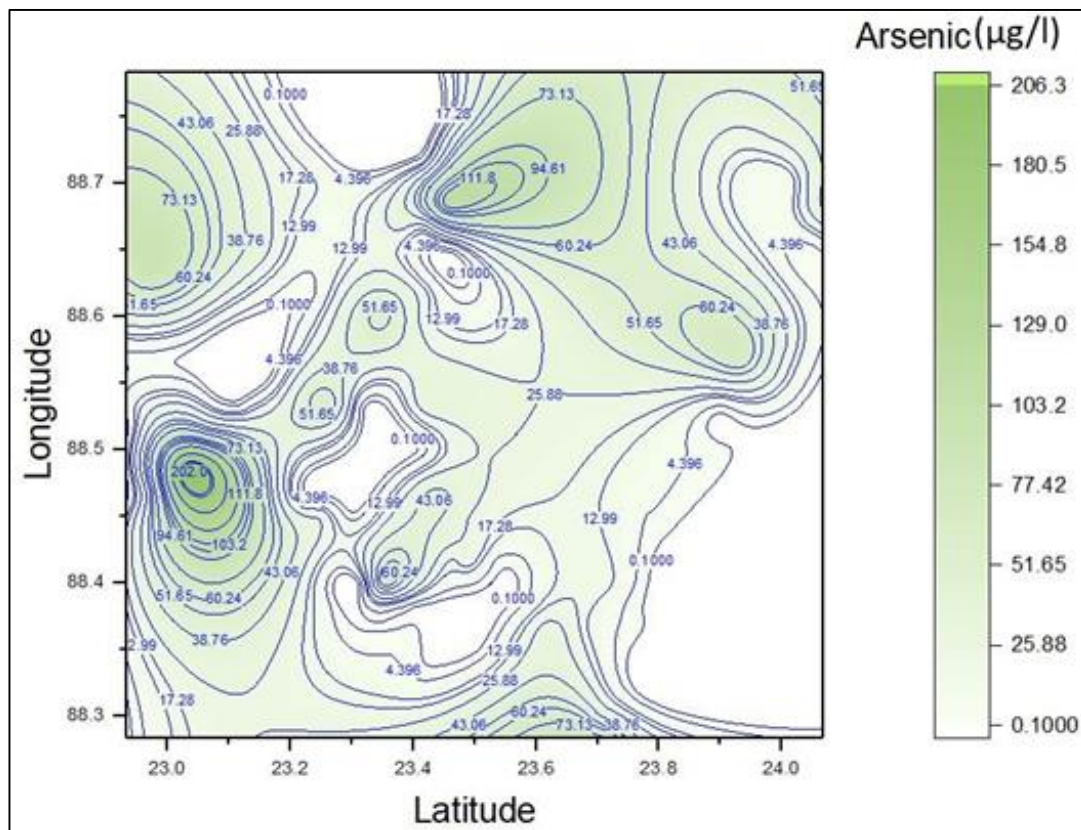
A Contour Line is derived when a function of two variables has a constant value connected through a curve (Hughes-Hallett et al., 2013). The representation of contour map is a plane section of the three-dimensional graph of the function parallel to the XY-plane. The gradient of the function should always be perpendicular to the contour lines. A steep variation is observed when the lines are close together and the gradient is large. A level set is a generalization of a contour line for functions of any number of variables. (Davis & Sampson, 1986) Contour lines can be curved, straight or a mixture of both lines on a map describing the intersection of a real or imaginary surface with one or more horizontal planes. The configuration of these contours allows map readers to gain knowledge of relative gradient of a parameter and estimate that parameter at specific places. Contour lines are interpolated from estimated surface elevations, using a computer program which threads contours through a network of observation points of area centroids. In this case, the method of interpolation affects the reliability of individual contours and their portrayal of slope, pits and peaks.

Based on the principle contour maps regarding water quality parameters are drawn on a hypothetical plane built on the geographical data of Nadia and Bardhaman district. Geographical datasets of a site were considered upon latitude and longitude of that particular place for water source. The purpose of making contour plots should be focused only upon the water quality parameters which imparts harm to human health depending upon exposure. Such water quality parameters are termed as toxic water quality parameters. Arsenic (As), Fluoride (F<sup>-</sup>), Nitrate (NO<sub>3</sub><sup>-</sup>) and Uranium (U) are characterized as toxic parameters.

The contour plot shown here are comprised of both real and interpolated values.

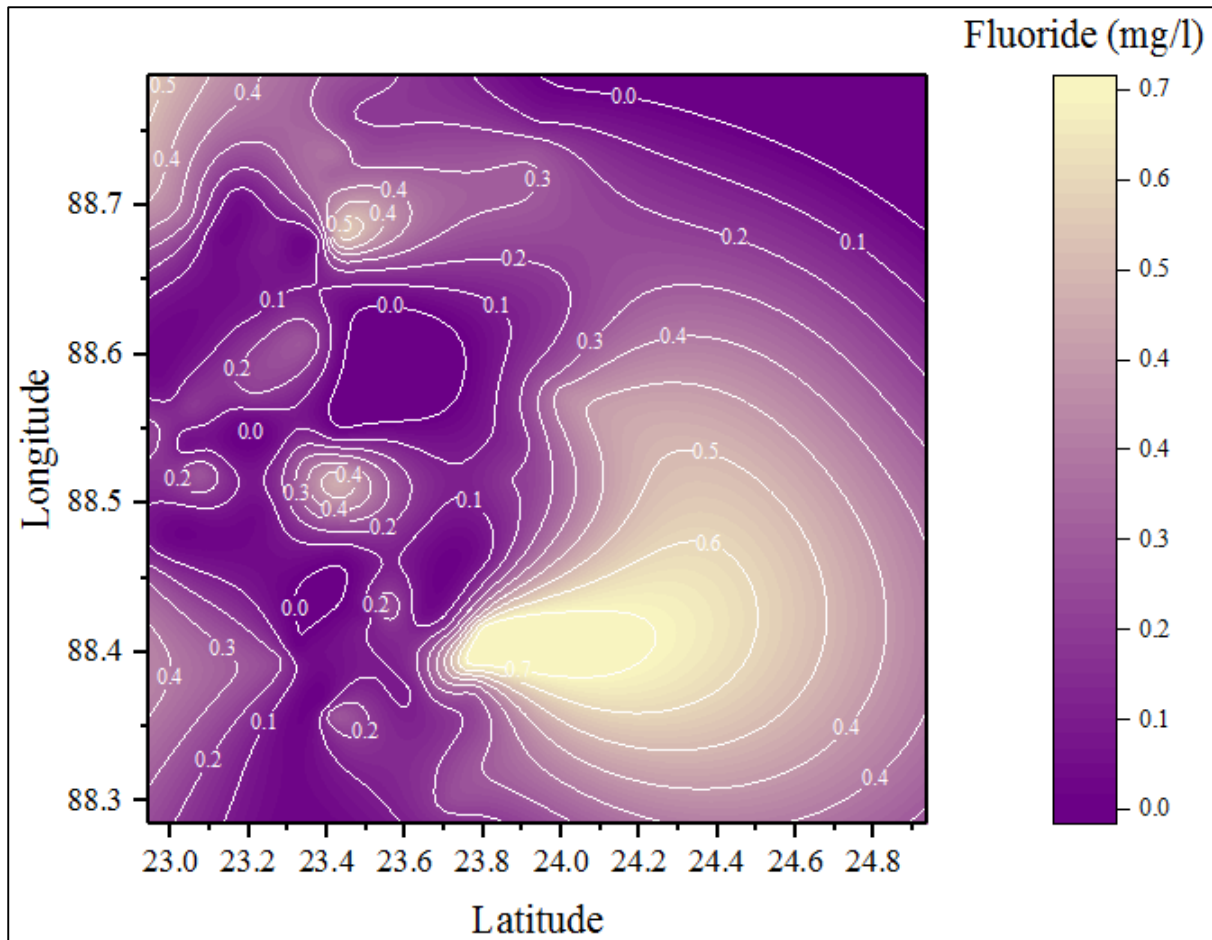
The contour plots are made using Origin 2017.

## 7.2 Nadia



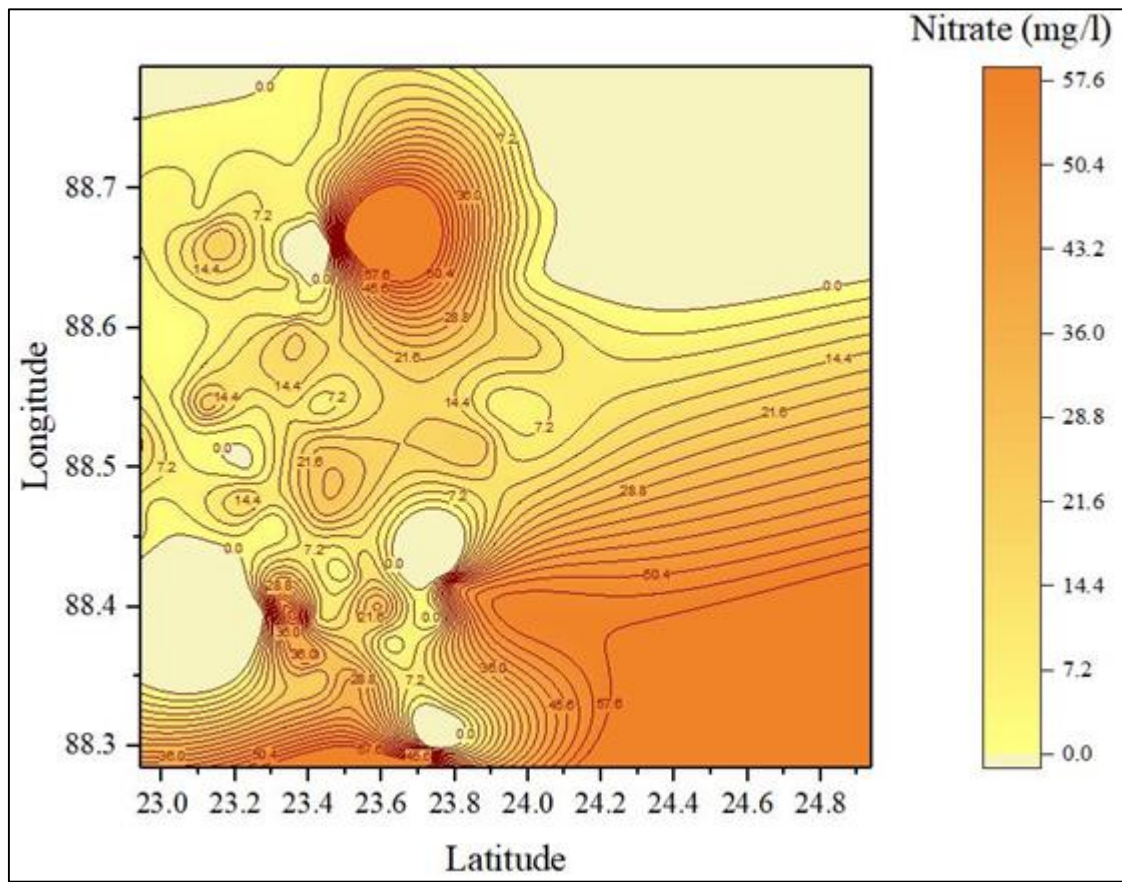
**Fig 7.2.1:** Contour Plot of arsenic

Hereby it is found that the highest magnitude is concentrated at 206.3 µg/l making a series a concentric circle towards the peak. Such peaks do exist at the magnitudes 111.8 µg/l, 73.13 µg/l and 60.24 µg/l. The peak of 206.3 µg/l has a steeper gradation and slope. The peak of 111.8 µg/l makes a lesser steep slope than the highest. The presence of high magnitudes of arsenic concentration throughout the district leads to the formation of more than one peak in the contour plot. The lowest concentration magnitude of <0.1 µg/l has enclosed areas of random shapes all over and beyond the contour plot. Apart from the highest and the lowest, other magnitudes in-between has used contour lines to form various random shapes and non-uniform slopes throughout the contour plot. As the spatial distribution of arsenic is studied, non-uniform distribution of the data is also observed. Irregularity on contour plot marks the uneven spatial distribution. Specific values determined from laboratory analysis often can show irregularity while contouring. Non-uniform and irregular contour lines can be a proof of uneven spatial distribution trend among the groundwater arsenic.



**Fig 7.2.2:** Contour Plot of fluoride

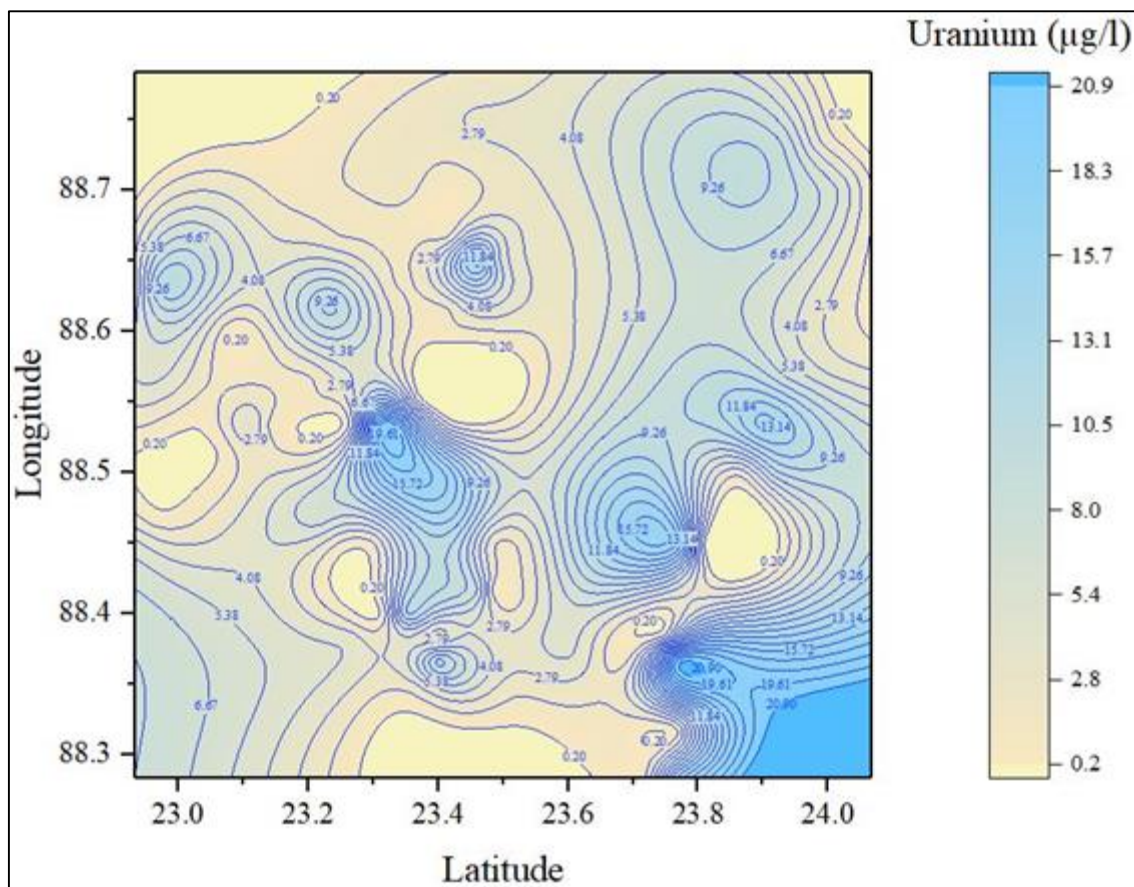
Hereby it is found that the highest magnitude is concentrated at 0.9 mg/l. The peak forms a series of uniformly spaced contour lines ranging towards the lowest concentration of 0 mg/l in a direction from the peak. In another side of the peak closely spaced contour lines form non-uniform slopes. There are two other peaks formed by other high magnitudes. At its lowest concentration fluoride of 0 mg/l has enclosed various areas over and beyond the contour plot making random pond like shapes. A blunt U-shaped convexity is spotted in the plot which confirms mostly uniform distribution for fluoride in Nadia. An imaginary ridge line can be drawn in the plot following the convex structure. Most of the contour plot indicates presence of the uniform distribution of fluoride but not confirms 100% uniform distribution. Unevenly distributed contour lines are also found in the plot which leads to the non-uniform distribution of contour lines and abrupt changes of slopes in the plot.



**Fig 7.2.3:** Contour Plot of nitrate

Hereby it is found that the highest magnitude is concentrated at 57.6 mg/l making a series a concentric circles towards the peak. Peaks as well as surfaces are also formed with the magnitude of 57.6 mg/l. The second largest value 53.4 mg/l is a contour line associated with the peak, while the magnitude of 38 mg/l builds another peak on the plot. The contour value beginning at 57.6 mg/l and spans up to 0 mg/l is uniform and well-spaced is a uniform slope. At its lowest concentration nitrate of 0 mg/l has made specific areas over the contour plot. Here a sharp V-shaped convexity is spotted in the plot which marks the presence of a valley line. As the spatial distribution of nitrate is studied, both uniform of abrupt presentation of the contours is observed. Presence of both uniform and irregular contour lines prove the uneven spatial distributional trend in the groundwater nitrate.



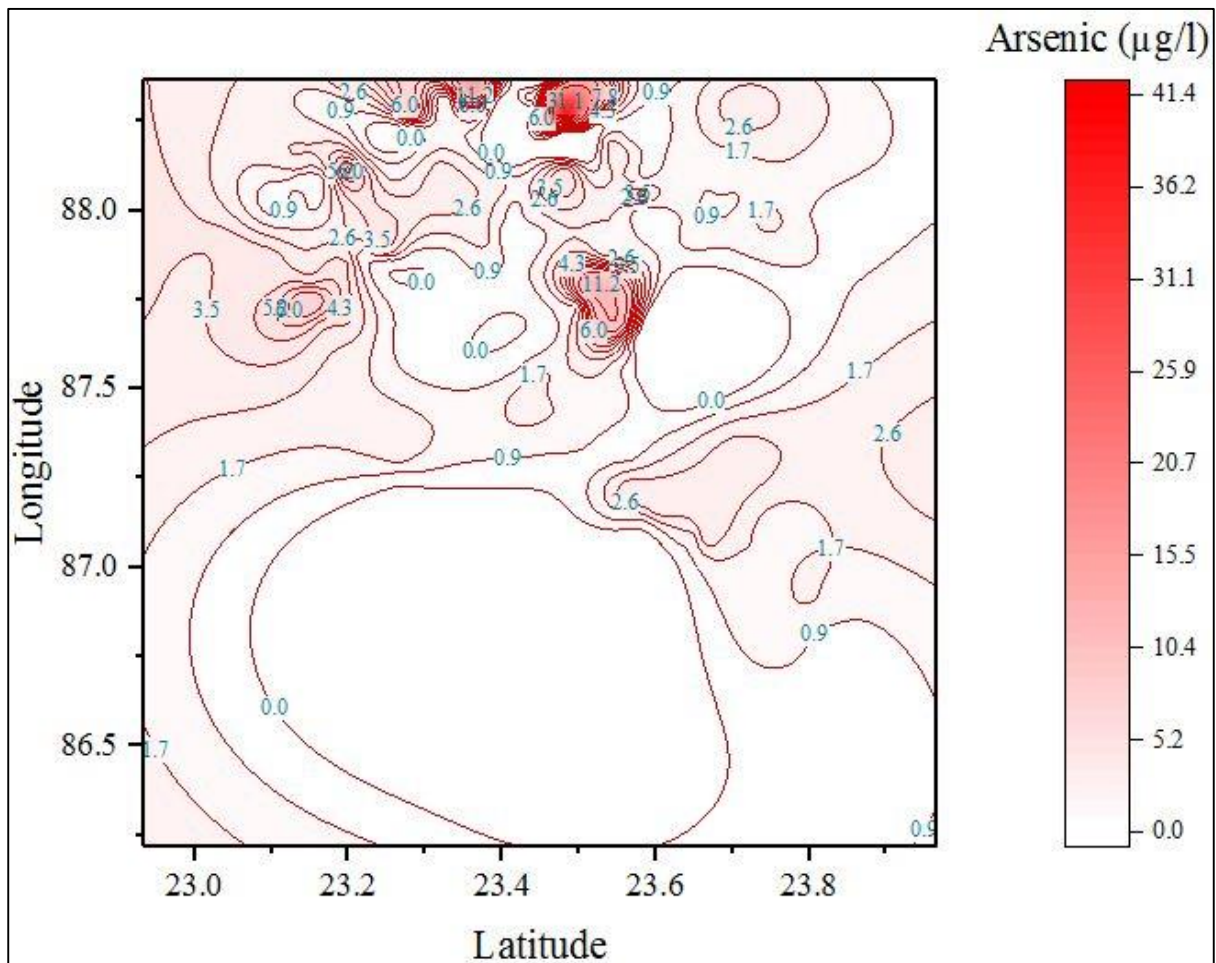


**Fig 7.2.4:** Contour plot of uranium

Hereby it is found that the highest magnitude is concentrated at 20.9  $\mu\text{g/l}$  making a series of enclosed areas towards the peak. Other than a peak the magnitude of 20.9  $\mu\text{g/l}$  makes a surface or plateau like structure in the lower right corner of the plot. The peak and the plateau of 20.9  $\mu\text{g/l}$  is joined by another surface made with 19.61  $\mu\text{g/l}$  contour line. At its lowest concentration uranium of 0.2  $\mu\text{g/l}$  has enclosed various areas over the contour plot making random pond like shapes. Many blunt U-shaped convexities are spotted in the plot which confirms uniform distribution mostly and the possibility of drawing many imaginary ridge lines throughout the plot. Congestion of contour lines are found in the plot which is due to the non-uniform distribution and abrupt changes of slopes in the plot. As the spatial distribution of uranium is studied, uniform as well as non-uniform distribution of the data is observed. Irregularity on contour plot marks the uneven spatial distribution. In this case abrupt change in values have had made sudden imaginary ridge lines all over the plot.

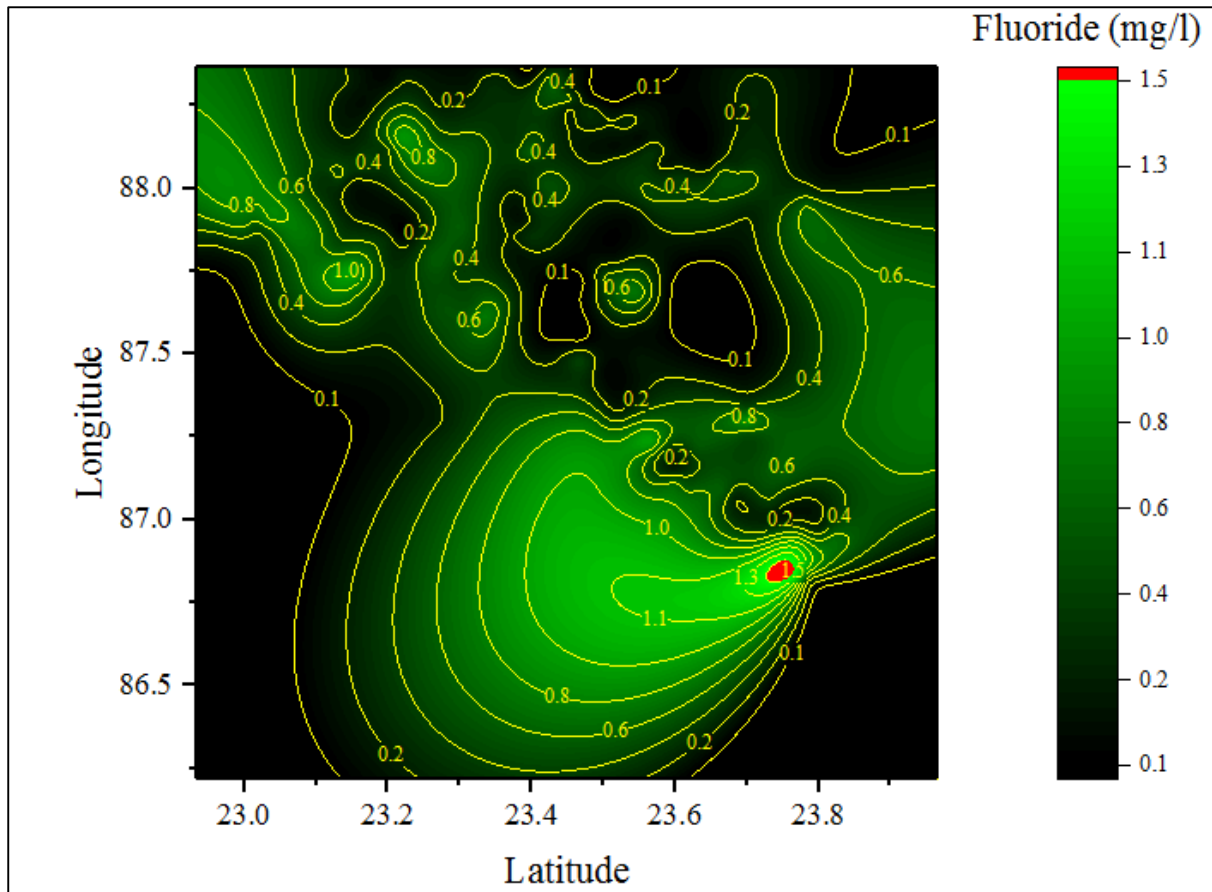


### 7.3 Bardhaman



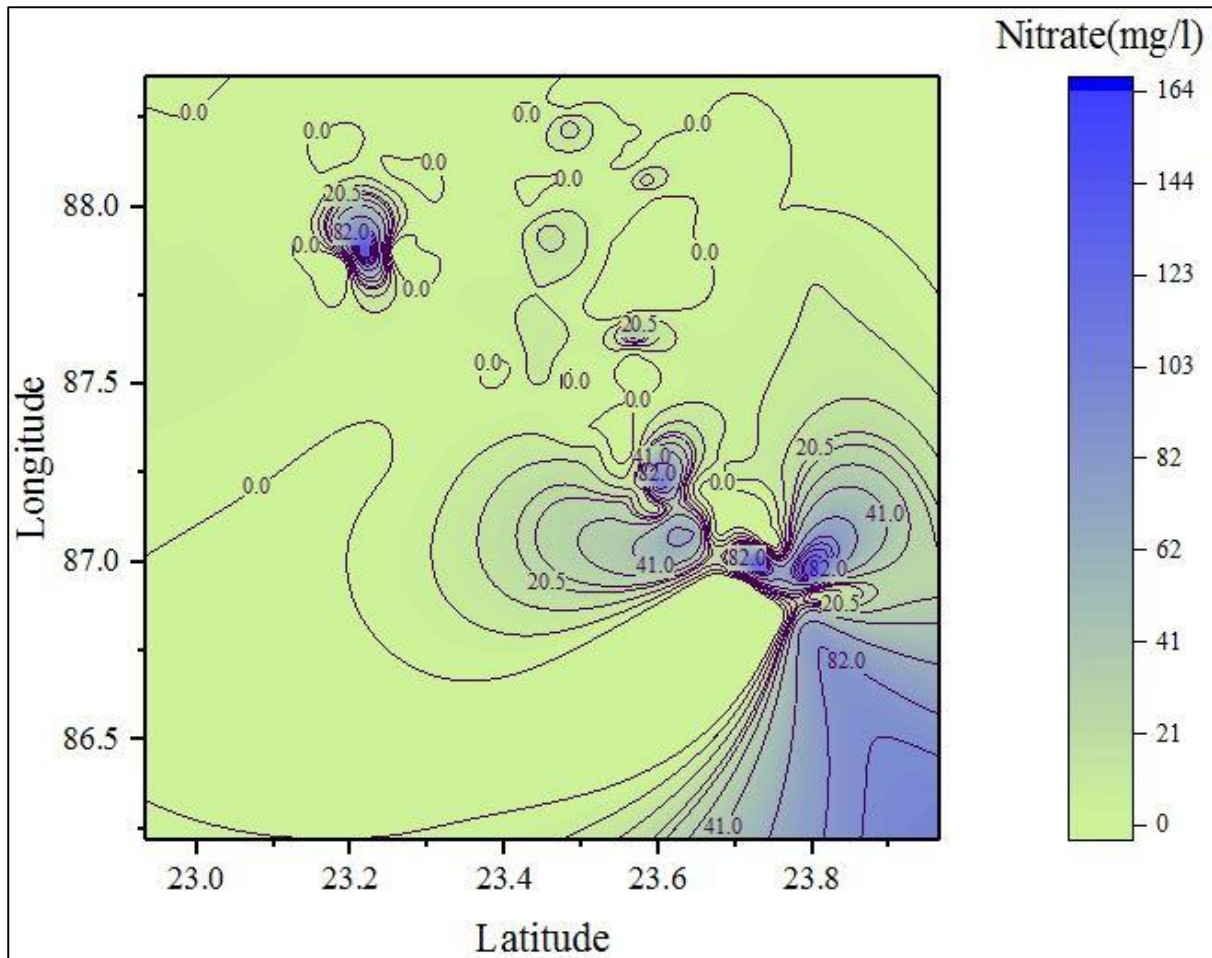
**Fig 7.3.1:** Contour Plot of arsenic

Hereby it is found that the highest magnitude is concentrated at 41.4  $\mu\text{g/l}$  (interpolated value; originally 41.28  $\mu\text{g/l}$ ) making only peak in the plot. A series of contour lines ranging from 0  $\mu\text{g/l}$  to 41.4  $\mu\text{g/l}$  forms this peak. As it covers very small amount of space in the plot for the formation of the peak thus the nature of peak becomes steep. A blunt U and a sharp V-shaped convexity are formed due to the elevation formed by associated contour lines. Uniform slopes of both shapes can be used to plot an imaginary ridge line and an imaginary valley line along the slopes of convex structures. Lower values  $>0$   $\text{mg/l}$  to 15.5  $\mu\text{g/l}$  are sparsely distributed throughout the plot, making random shapes of enclosed areas or spread beyond the plot. At its lowest concentration of 0  $\mu\text{g/l}$  two large pond like shape is formed within the contour plot. All other random distributions leads to formation of non-uniform slopes throughout the plot due to presence of lesser magnitude concentrations which ultimately leads to an uneven spatial distribution of irregularity nature as a whole.



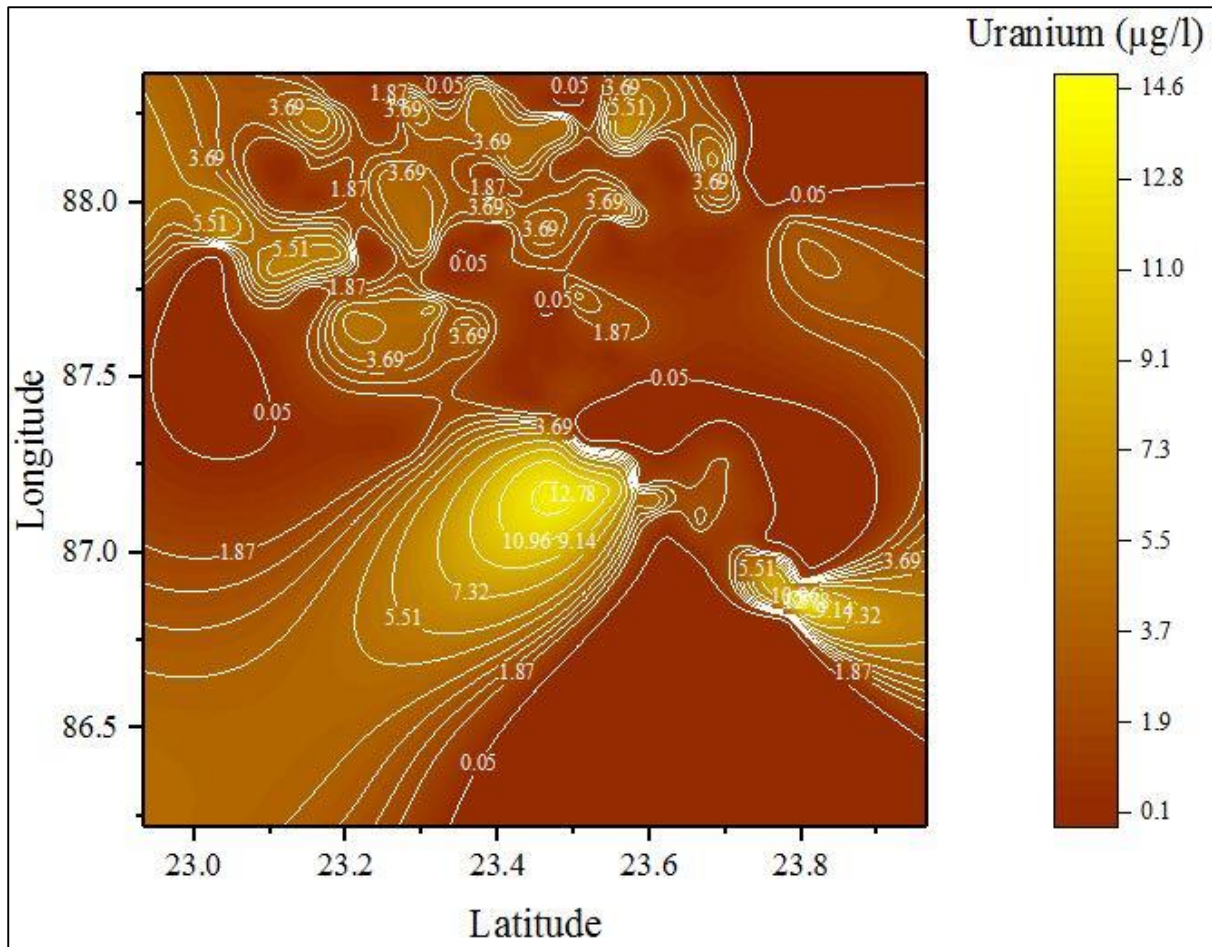
**Fig 7.3.2:** Contour Plot of fluoride

Hereby it is found that the highest magnitude is concentrated at 1.5 mg/l making only peak in the plot. A series of contour lines ranging from 1.0 mg/l to 1.5 mg/l gives a clear idea about the origin of the peak. A blunt U-shaped convexity is formed where concentrations of fluoride is decreasing towards 0.1 mg/l from the peak. Uniform slope of an imaginary ridge line can be plotted along the convex structure. Lower values ranging from <0.1 mg/l to 0.9 mg/l are dispersed throughout the plot, enclosing circles or spread beyond the plot. At its lowest concentration fluoride is spread beyond the limit of the contour plot. Random distribution and non-uniform slopes are formed throughout plot due to presence of random enclosed areas formed due to lesser magnitude of concentrations. The nature of this irregularity marks an uneven spatial distribution. The spatial distribution of fluoride is consisted of uniform as well as non-uniform distribution of the data is observed.



**Fig 7.3.3:** Contour Plot of nitrate

Hereby it is found that the three highest magnitudes of nitrate concentrates into three distinguished peaks. These three peaks have magnitudes of 164 mg/l, 160 mg/l and 149 mg/l. Closeness of the contour lines around these peaks enables to study the nature of the structure of these peaks. Two blunt U-shaped convexity and one sharp V-shaped convexity are formed in the plot. Two U-shaped convexities decrease into 0 mg/l in two opposite directions which ultimately leads to large plains of 0 mg/l. On the other hand the V-shaped convexity forms a plateau like structure in the plot. Uniform slopes of imaginary ridge lines and valley lines can be plotted along the U and V-shaped convex structures respectively. Lower values ranging from <0.1 mg/l to 20 mg/l are dispersed throughout the plot, enclosing different sizes of areas or spreading beyond the plot. Random distribution and non-uniform slopes are formed throughout plot due to presence of random enclosed areas which are formed due to lesser magnitude of concentrations. The nature of this irregularity marks an uneven spatial distribution of Nitrate in the district.



**Fig 7.3.4:** Contour Plot of uranium

Hereby it is found that the highest magnitude is concentrated into two peaks interpolated into the contour plot. The highest magnitude of Uranium found is 14.6  $\mu\text{g/l}$  which should logically make only one peak. But there are two distinguishable peak observed in the contour plot. This means one peak formed from the highest value is 14.6  $\mu\text{g/l}$  and another is for the next highest value of 9  $\mu\text{g/l}$ . Both of these peaks have blunt U-shaped convexities. The nature of convexities and the trend formed by contour lines shows the nature of imaginary ridge lines. Lower values ranging from  $<0.1 \mu\text{g/l}$  are dispersed throughout the plot, creates different shapes of enclosed areas or spread beyond the plot. At its lowest concentration uranium has made different pond like structures and is spread beyond the limit of the contour plot. The presence of random pond like structures are proof of random and non-uniform distributions throughout the plot. Thus the nature of this irregularity makes an uneven spatial distribution. As the spatial distribution of uranium is studied, uniform as well as non-uniform distribution of the data is observed.

The contour plots specify the accumulation of water quality parameters in groundwater. Peak values indicate higher accumulation and mark the presence of water quality parameter in a cluster form as well as with other parameters. Closely spaced contours with decreasing values at outward convexity from the peak describes uniform distribution in that direction. Widely but unevenly distributed contour lines may not be able to define the distribution pattern of selected parameter. Evenly distributed contours can be good indication of the nature of pollution in groundwater. Both even and uneven trends of distribution can be able to predict presence of both point and non-point pollution sources in the region depending on available data. Abrupt change without overlapping with other contour lines mark well distribution of uranium, mostly over the region. Pinpoint a sampling location with the co-ordinates derived from Latitude and Longitude is possible from the contour plot.

## CHAPTER 8

### FUTURE SCOPES

The present study has some limitations. Instead of the boundaries this work has some future prospects.

#### 8.1 Hydrogeochemical Aspects

It needs to focus on the estimation of sodium ( $\text{Na}^+$ ) in groundwater.

- 1) Hydro-geochemistry of the study areas could be observed more extensively with the help of available sodium concentration in groundwater.
- 2) Sodium ion concentration will be more accurate in the determination of the characterization of groundwater specifically for drinking and irrigation purpose.
- 3) The availability of Sodium concentration will help in the determination of Sodium Adsorption Ratio which could serve the above purpose.
- 4) Not only could these Sodium data predict the nature of alkalinity in groundwater more accurately but also their concentration variants could be identified.
- 5) Availability of Sodium ions will help in the determination of soil salts and their ionic behaviours.
- 6) Heavy metal concentration of the study areas could be determined to know their contribution in ground water pollution.
- 7) Geographic Information System can be used for a better approach towards the characterization and implementation of spatial data.
- 8) Leaching pattern of groundwater could be identified with the flow pattern studies.

#### 8.2 Statistical Aspects

- 1) Temporal data will help in the study of other linear and non-linear kind of distribution patterns.
- 2) Temporal analysis will also help the study of Euclidean distance in a broader aspect.
- 3) Factor analysis and Discriminant Analysis would be possible in order to determine correlation of the WQPs in a broader aspect for the study area.
- 4) To build a probability model for WQPs would be possible.

### **8.3 Other aspects**

- 1) The soil samples of study area can be collected for a broad aspect of studying the leaching and ground water flow pattern.
- 2) Mass Spectrometry could be done in the soil samples for more accurate information of the crystalline structures of the minerals.
- 3) Biology of the sampling sites can be studied for more accurate knowledge of ecology of microbes and their contribution towards determination of WQI of the sites.
- 4) Population forecasting and budget analysis could be done in order to pinpoint the application of water treatment systems.



## CHAPTER 9

### CONCLUSION

Consumption and usage of raw ground water in both study areas are in a questionable condition. The hydrochemical analysis of study area Nadia and Bardhaman reveals the maximum concentration of 206.3  $\mu\text{g/l}$  and 41.3  $\mu\text{g/l}$  of Arsenic, 0.71 mg/l and 1.5 mg/l of Fluoride in Tehatta II and Salanpur block, 57.6 mg/l and 164 mg/l of Nitrate concentration in Chapra and Burdwan I block. Uranium concentration is under safe limits for most parts of both study areas. The suitability of raw ground water for various purposes has been characterized in the study using water quality index method. For any unknown correlation between water quality parameters various statistical methods were applied. As the statistical tests reveal that a few parameters are normally distributed. Linear relationships between the parameters are established based on the corresponding correlation coefficients. These parameters are mostly of physical and physico-chemical types. Kolmogorov-Smirnov and Shapiro-Wilk statistical results show some conflicting estimates. KMO and Bartlett's tests have simplified the normal distribution and the result conflicts were resolved. Spatial analysis of the study area has clearly shown the distribution of elements.

#### **Suggestive options to make the water potable:**

The common and harmful groundwater toxic parameters are prime concern of our study. Thus primarily the ground water affected with Arsenic, Fluoride and Nitrate should be treated before consider them as potable. Some easy available and cheap methods are preferred for the treatment of ground water. Otherwise, rainwater harvesting as well as surface water treatment and use is always suggested for the study area.



**Table 9.1: Suggestive measures**

<b>Parameters</b>	<b>Suggestions</b>	<b>Reference</b>
Arsenic	Copper-impregnated coconut husk carbon as adsorbent	Manju et al, 1998
	Mosambi peel can be used as a biosorbent	Kamsonlian et al, 2013
	Banana peels can be used as an adsorbent	Memon et al, 2008
	Co-precipitation and filtration process using ferric hydrochloride	Bang et al, 2005
Fluoride	Montmorillonite can be used for defluoridation process	Ali Tor, 2008
	Tamarind fruits can be used for defluoridation purposes	Sivasankar et al, 2012
	Wheat straw raw, Sawdust raw and Activated bagasse carbon from sugarcane can be used as adsorbents	Yadav et al., 2013
	Solar water distiller unit	Antwi et al., 2011
Nitrate	Bamboo Powder Charcoal as adsorbents	Mizuta et al., 2004
	Sugar beet tailings and Peanut shells as adsorbents	Zhang et. al, 2012
TDS	Parthenium sp. dried biomass can be used as an adsorbent for Chloride removal	Apte Sagar et al., 2011

## CHAPTER – 10

### PUBLICATIONS

#### Seminar/Conference Proceedings:

1. Assessment of groundwater quality in an arsenic-affected district, Nadia of West Bengal with special reference to radioactive uranium. A. Das, **S. S. Das**, M. Joardar, N. Roy Chowdhury, S. Swain, A. De, T. Roychowdhury. Proceedings in Twentieth National Symposium on Environment (NSE-20), Focal Theme: Challenges in energy resource management & climate change. Eds. R. M. Tripathi, M. Kumar, S. K. Jha, V. Jain, A. v. Kumar, V. Pulhani, I. V. Saradhi, A. C. Patra, M. K. Mishra, S. K. Sahoo. Health, Safety & Environment Group, Bhabha Atomic Research Centre, Mumbai and Indian Institute of Technology, Ganghinagar, Board of Research in Nuclear Sciences, Department of Atomic Energy, Govt. of India, pp. 95-96.
2. Groundwater arsenic contamination with special reference to its entry in rice grain post-harvest in Bengal delta. T. Roychowdhury, N. Roy Chowdhury, M. Joardar, S. Swain, A. Das, M. Mukherjee, A. De, S. Ghosh, D. Saha, B. Ghosh, **S. S. Das**, S. Majumder. Proceedings in Twentieth National Symposium on Environment (NSE-20), Focal Theme: Challenges in energy resource management & climate change. Eds. R. M. Tripathi, M. Kumar, S. K. Jha, V. Jain, A. v. Kumar, V. Pulhani, I. V. Saradhi, A. C. Patra, M. K. Mishra, S. K. Sahoo. Health, Safety & Environment Group, Bhabha Atomic Research Centre, Mumbai and Indian Institute of Technology, Ganghinagar, Board of Research in Nuclear Sciences, Department of Atomic Energy, Govt. of India, pp. 101-102.
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