ADVANCED SPATIAL ANALYSIS AND HEALTH RISK ASSESSMENT OF GROUNDWATER ARSENIC CONTAMINATION IN NAGAON AND DARRANG DISTRICTS, ASSAM: AN INTEGRATED GIS AND HYDROLOGICAL MODELLING APPROACH

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CANDIDATE DECLARATION

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The matter embodied in this project has not been submitted by me for the award of any other degree.

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ABSTRACT

A study has been carried out on groundwater contamination of Arsenic in Darrang district and Nagaon district of Assam, India. Arsenic in groundwater is estimated by using Atomic Absorption Spectrometer, Perkin Elmer AA 200. Water sample analysis revealed that 27 out of 54 samples exceeded the WHO guideline of 0.01 ppm, with significant contamination particularly in Darrang. Elevated arsenic levels, often surpassing WHO and BIS standards, highlight a major public health concern, necessitating urgent remediation in both the districts. Elevation analysis using Arc-GIS showed an inverse relationship between surface elevation and arsenic concentration. Low-elevation areas in both districts had higher arsenic levels, with high-risk zones predominantly located at lower elevations. This spatial distribution using interpolation method Inverse Distance Weighing (IDW) underscores the need for targeted monitoring and remediation. Hazard and carcinogenic risk assessments using USEPA methods indicated significant non-carcinogenic and carcinogenic risks. Darrang exhibited higher average Hazard Index and Carcinogenic Index values compared to Nagaon, indicating greater health risks, particularly for children. Both districts showed elevated cancer risks, with critical areas identified for focused intervention. Hydro geological simulations with MODFLOW and MT3DMS provided insights into groundwater flow and arsenic transport, revealing a west-to-east flow gradient and significant dispersion of arsenic over time. These findings are crucial for managing water resources, predicting water availability, and planning effective remediation strategies.

Overall, the study emphasizes the need for immediate action to address arsenic contamination, protect public health, and ensure safe drinking water in both the districts.

Keywords: Arsenic, groundwater, Darrang, Nagaon, water quality, Arc-GIS, hazard index, carcinogenic risk, MODFLOW, MT3DMS, spatial distribution.

CHAPTER – 1

INTRODUCTION

1.1 Prologue –

Only 0.1% of the total water on our planet is pure drinking water (De Filippis et al. 2020). Most developing countries rely on groundwater as their principal supply of potable water, as well as water for agriculture and industry (Kadam et al. 2022). Despite meeting more than half of the world's drinking water requirement, rising population, growing urbanization, and mass industrialization have put a strain on groundwater resources (Amiri et al. 2021; Shukla & Saxena 2021). Additionally, depletion and deterioration of the available surface water supplies are also other contributing factors to increasing pressure on the groundwater (Singh et al. 2019). The chemical components of groundwater, which are primarily influenced by the underlying geological structures and activities caused by humans such as urbanization, wastewater discharges, and mining operations in the surrounding areas, determine its quality in most cases. Over the last few decades, growing anthropogenic interference has disrupted the chemical balance and resulted in a depletion of both the quality and quantity of groundwater (Devic et al. 2014; Selvakumar et al. 2017; Wang et al. 2020). In addition, the weathering and erosion of rocks, industrial discharges, agricultural practices, seepage of contaminated water, and the use of geothermal waters all contribute to the contamination of groundwater (Bodrud-Doza et al. 2020). When heavy metals are added to polluted groundwater, the contamination levels rise to even higher levels (Alsubih et al. 2021).

Groundwater contamination in India is a significant environmental and public health issue. It primarily stems from industrial effluents, agricultural runoff containing pesticides and fertilizers, untreated sewage, and improper disposal of solid waste. This contamination affects millions who depend on groundwater for drinking and irrigation, leading to health problems such as gastrointestinal diseases, kidney damage, and even cancer in severe cases. Mitigating this problem requires stringent regulatory measures, better waste management practices, and widespread awareness campaigns to promote sustainable water usage. The popularity of groundwater usage as compared to surface water is more due to its convenient availability and its excellent natural quality that can be adequately used for potable supplies with little or no treatment. In India, about 50 % of the urban population and 80 % of the rural population use groundwater for household purposes (Bhattacharya et al. 2014).

Contamination of inorganic arsenic in groundwater is considered among the most important public health issues. Arsenic is naturally occurring chemical element that found in the earth crust with symbol ‘As’ raised greatly concern from environment and health perspective. The toxicity of As(III) has been found to be the highest among other arsenic inorganic species such as As(V) and its organic forms such as dimethyl arsenic acid (DMA) and monomethyl arsenic acid (MMA) (Rathi & Kumar, 2021). Drinking water is one of the main sources of arsenic toxicity. In general, arsenic is distributed in various formations and can appear as an inorganic or organic compound in many oxidation states. Arsenic is a group ‘V’ heavy element with atomic number 33 and its atomic weight 74.9amu, specific gravity 5.73g/cm.

However, unlike its formidable presence in atmosphere, As asserts its characters when found in water sources and land. It is one of the ten chemicals in the list of ‘Chemicals of Public Health Concern’ by WHO and affects around 140 million people from around 50 countries across the world (WHO, 2018). Apart from developing countries like India, China, Argentina, Mexico, Bangladesh, etc., even developed countries like United States of America is suffering from As contamination. The most common medium by which As enters the human body is drinking water and its presence in soil, rocks and other formations is the leading cause of water contamination with As, be it groundwater or surface water. In this paper, we thus delve in the sources of As contaminations, its threat levels and impact in India and then look into the methods of mitigating and treating As contaminated water.

1.2 Geochemistry of Arsenic-

Arsenic, an element of the earth’s crust with an abundance of 1.8 ppm by weight, combines with oxygen, chlorine and sulphur to form inorganic arsenic compounds. Arsenic and its compounds are widely used in agriculture, livestock feed, medicine, electronics, metallurgy, chemical warfare agents etc. Arsenic is of interest in terms of environmental issues and health impacts. Rock-water interactions in aquifer systems are the major cause of release of arsenic and causes deterioration in groundwater quality. Arsenic is the 12th most common element in nature, and it usually appears in three allotropic forms, including black, yellow, and grey. If heated, it rapidly oxidizes to arsenic trioxide (As2O3) and has a garlic odour (Fendorf et al., 2010). Arsenic is also known as ‘king of poison’ as it is a highly toxic element ranking number one in the 2001 priority list of hazardous substances and disease registry defined by WHO. It is classified as carcinogen, mutagens, and teratogen. IARC (International Agency for Research on Cancer) has classified Arsenic is a class-1 human carcinogen. Also, organic forms of arsenic such as DMA and MMA have been considered by the IARC as potential carcinogens for humans (Yim et al., 2017). In natural water bodies arsenic mostly found in two states trivalent arsenic (As3+, Arsenite) and pentavalent arsenic (As5+) both forms are highly toxic inorganic species (Fendorf et al., 2010). The toxicity of arsenite is much higher than that of arsenate. Generally, in groundwater, natural occurrences of high arsenic levels were reported in aquifers- especially unconsolidated sediment aquifers throughout the world and have been connected to several adverse health effects (Smedley and Kinniburgh, 2013; Mozumder,2019).Arsenic contamination of groundwater is estimated to be affecting 500 million people around the globe. Continuous exposure to high arsenic water causes pigmentation, hyperkeratoses, ulceration, skin cancer and also affects liver, kidney, heart, and lungs (Sun et al., 2019 and references therein).

1.3 Permissible Limits of Arsenic for Human Body-

In 1963, the WHO established the limit for As in drinking water at 0.05 mg/L(50µg/L), but after some evidence of cancer at lower concentrations of arsenic, this threshold was reduced to 0.01 mg/L (10µg/L) in 1993 (Ahmad & Bhattacharya, 2019). Recent scientific findings show that consuming water with an arsenic concentration of even less than 0.01 mg/L during a long time can have health effects (Mochizuki et al., 2019).

According to United States Environmental Protection Agency (US EPA, 2015) the permissible limit of Arsenic is 0.01 mg/L (10µg/L).

In India, the permissible limit of arsenic in drinking water is regulated by the Bureau of Indian Standards (BIS). The permissible limit of arsenic in drinking water as per the BIS standard IS 10500:2012 is 0.05 mg/L (50µg/L). This standard is set to ensure that drinking water is safe for consumption and meets quality standards to protect public health.

1.4 Sources of Arsenic in Groundwater-

The main sources of arsenic contamination can be classified as natural and anthropogenic, and are evaluated below –

1.4.1 Natural sources-

There are several natural sources, as well as anthropogenic actions that may introduce arsenic into groundwater and drinking water. The major natural sources include geologic formations (e.g., sedimentary deposits/rocks, volcanic rocks and soils), geothermal activity, coal and volcanic activities. Geothermal water can be a source of inorganic arsenic in surface water and groundwater (Welchetal., 2000). Although concentrations of arsenic in the earth's crust fluctuate, the average levels are commonly reported to range from 1.5 to 5 mg/kg. Arsenic is a significant component of many mineral species in magmatic, hydro thermal and sedimentary rocks. It is widely present in sulphide ores of metals, including copper, lead, silver, and gold. There are over 100 arsenic-containing minerals, including arsenic pyrites (e.g., FeAsS), realgar (AsS), lollingite (FeAs2, Fe2As3,Fe2As5), and orpiment (As2S3).

1.4.2 Anthropogenic sources-

Anthropogenic related arsenic contamination in groundwater is reported in 54 countries and is largely created by human intervention, mining, coal and petroleum extraction. The source characterisation, continent wise, is given in Fig. 2. In Asia, sedimentary formations contribute 45%, followed by mining (30%), coal (10%), petroleum (10%) and volcanic rocks (5%). In Europe, sedimentary formations and mining activities contribute equally followed by volcanic rocks, coal and petroleum. In America, sedimentary formations, mining activities and volcanic rocks contribute equally followed by coal and petroleum. In Africa, mining and sedimentary formations are the major contributors with little addition from coal, petroleum and volcanic rocks. In Australia all sectors contribute equally. Anthropogenic related arsenic contamination may be categorised into different types such as mining-related, coal-related, or coal burning. Sulfides are frequently associated with goldores, and are a potential source of arsenic. Mining and smelting of these minerals create environ mental hazards of arsenic leaking into groundwater and surface water from slag pits, waste dumps, extraction basins, and mines. Mining related (coal mining) arsenic contamination is being affected in 74 countries across the world. Petroleum-related arsenic has affected 17 countries in the world. The main sources of As in the groundwater of India is alluvial sediments, and are mainly derived from Himalayan sediments due to erosion. Arsenic gets mobilized through the reductive dissolution of Fe3+- oxyhydroxides in a reducing environment (Kumar et al., 2016a).

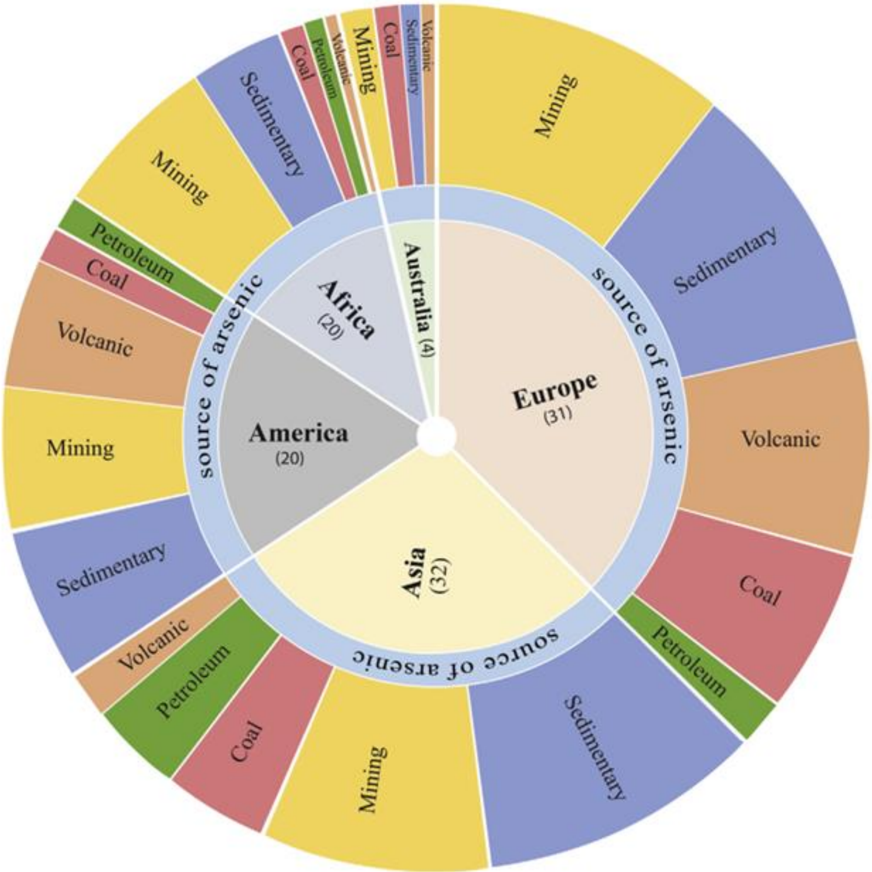

Fig-1.1. Pie-chart showing continent-wise arsenic source characterisation .It is clear that the major source of As on all continents is sedimentary formations followed by mining. (Source - E. Shaji et al., 2021)

1.5 World Scenario –

The various sources of arsenic that contaminate water across the subcontinent affect the lives of millions of people directly and indirectly. The natural contamination of As in groundwater has been reported worldwide, and the majority of these belong to South Asian and South American regions (Ravenscroft et al., 2009; Bundschuh et al., 2012; Hashimetal., 2019).

The severely affected countries include Bangladesh (Yangetal.,2014), India (Mukherjeeetal.,2009;Bhowmick et al., 2018; Chakraborti et al., 2018; Bindal and Singh, 2019; Dhillon, 2020), China (Guo et al., 2014), Nepal (Pokhrel et al., 2009), Cambodia (Polya et al., 2010), Vietnam (Winkel et al., 2011; Stopelli et al., 2020), Myanmar (Van Geen et al., 2014), Laos (Cho et al., 2011), Indonesia (Winkelet al., 2008), the USA(Gonget al., 2014). In addition, countries like Argentina, Chile, Hungary, Canada, Pakistan, Mexico, and South Africa are also affected (Ravenscroft et al., 2009). However, the South and Southeast

Asian Belt is considered as the most arsenic polluted areas including India, Bangladesh, Nepal, Vietnam and China (Ravenscroft et al., 2009; McArthur, 2019). The developed countries, like USA and Canada, also experience widespread levels of arsenic contamination in groundwater although the concentrations are characteristically lower in comparison with the Asian countries (Sorg et al., 2014).

In Latin America, the main sources of arsenic contamination in groundwater are geothermal fluids and volcanic activities (Morales Simfors et al., 2020).

In Mexico (North America), groundwater is the main source of drinking water (40%) and high As concentrations (>10 ppb) are reported in groundwater in different parts of Mexico (Bundschuh et al., 1997; Alarcón-Herrera et al., 2020). 1.5 million people in Mexico consume water with As above 25 μg/L, and about 150,000 people are exposed to As poisoning (Alarcón-Herrera et al., 2020).

Similarly, the North American regions like Guatemala El Salvador also have high As content in water resources (Armienta and Segovia, 2008; Libbey et al., 2015) and source is identified as volcanogenic.

In Bolivia, South America, high concentration of As (45.9 μg/L) in groundwater is recently reported (Alcaine et al., 2020) and the source is volcanic formations of the Neogene period. Similarly the groundwater's in the southern part of the Argentinean Chaco-Pampean plain are characterized by the elevated presence of arsenic (Smedley and Kinniburgh, 2002) and the Tertiary aeolian loess-type deposits in the Pampean plain and fluvial sediments of Tertiary and Quaternary age maybethesource (Alcaine et al., 2020).

In Europe, many countries report (especially Greece, Hungary, Romania, Croatia, Serbia, Turkey, and Spain) elevated arsenic content in groundwater resources (Katsoyiannis et al., 2015).

The worst affected African countries include Botswana,BurkinaFaso, Ethiopia, Ghana, Morocco, Nigeria, South Africa, Tanzania, Togo, and Zimbabwe(Medunićetal.,2020).In all these African countries both surface and groundwater resources are affected by arsenic contamination, however, the severity varies from region to region.

1.6 The scenario in Peninsular India –

Ground water plays a vital role in India to meet the water demands of various sectors, such as domestic, industrial and irrigational needs(Saha and Ray, 2019; Suhag, 2019). The alluvial tracts of Ganga and Brahmaputra rivers are the wealthiest groundwater province in the country.

High arsenic (>10 ppb) groundwater has been reported in shallow aquifers from 10 states in India (CGWB, 2018), however, the deeper aquifers of India (>100 m) are free from arsenic. The various sources of arsenic that contaminate water across the subcontinent affect the lives of millions of people directly and indirectly. India is badly affected by consumption of groundwater contaminated by arsenic. In response to a question in parliament, the Government of India acknowledged that 1.47 crore (14.7 million) people are at the frontlines of arsenic contamination of potable water across 16,889 areas (Hindustantimes, 2019). As per information entered by different States of India in the Integrated Management Information System (IMIS) of this Ministry as on 31.03.2019, there are 60,365 habitations affected by various chemical contaminants.

The first incidences of detection of As in groundwater in India can be traced back to the Bengal region in the last two-three decades of concluded millennia. Bengal Basin, which is formed by the delta of Ganga-Brahmputra rivers, is the hotbed of the As contamination of potable water. The reason for this has been attributed to the large volumes of the arsenic rich sediments brought down by these rivers during the Pleistocene and Holocene periods. Within India, west Bengal has 78 blocks in 9 districts with arsenic permissible limit of 0.05mg/lt. One of the flashiest areas of concern is the eastern side of Bhagirati River in Malda. Also the regions of north and south of Parganas are greatly affected. Some of the western side of Hooghly and Howrah are arsenic contaminated. Mainly arsenic is evident up to the depth of 80m. The deeper you go the lesser is water affected by arsenic. Arsenic has also been detected in the state of Uttar Pradesh, Bihar, Assam, Chhattisgarh, Jharkhand and Karnataka. In Bihar, West Bengal and Uttar Pradesh mostly it is seen in alluvial soil while in Chhattisgarh the arsenic contamination is mostly visible in volcanic rocks (Jalshkti, 2019).

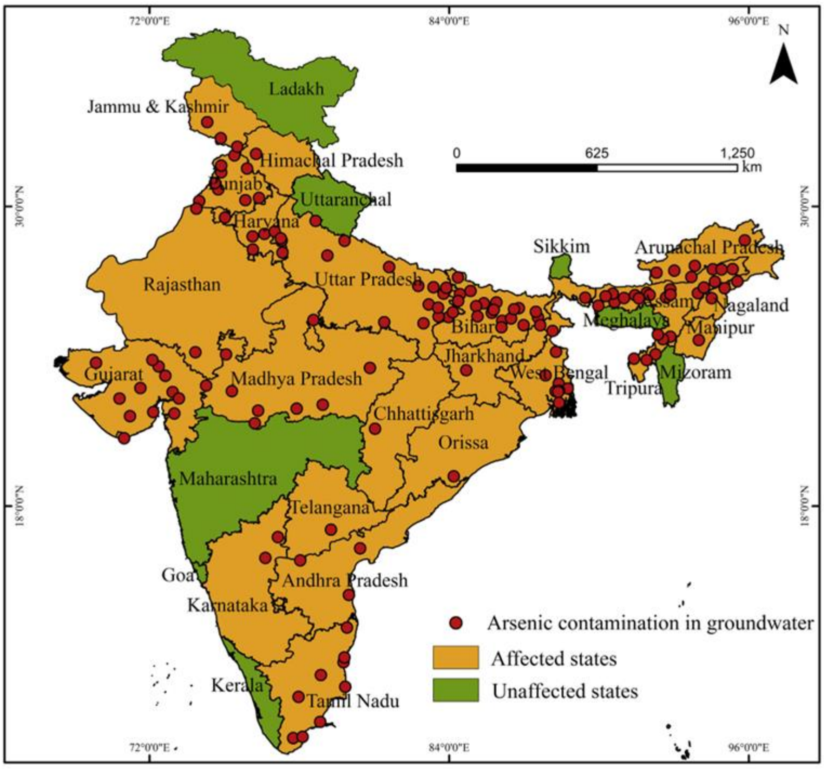

Fig – 1.2 Arsenic affected states in India. (Source: www.mapsofindia.com; Chakraborti etal., 2018 and references therein; CGWB, 2018).

1.7 Arsenic in Assam –

The occurrence of As in the groundwater of Assam in north-eastern India was first reported in 2004 following the studies of Singh (2004), Chakraborti et al. (2004) and later by Nickson et al. (2007) and Chetia et al. (2011). Attempts were made to evaluate the interrelationship between the major water quality parameters and As concentrations in groundwater to examine the probable mechanism that controls the mobility of As in groundwater (Choudhury et al. 2015; Mahantaet al. 2015). Another study by Goswami et al. (2014) has shown the magnitude of human As exposure in sporadic locations of Brahmaputra flood plain. Since the central Brahmaputra floodplain is a heavily populated area, so the health risk assessment is a matter of chief concern in this region.

Table – 1.1 Distribution of Arsenic in some districts of Assam

State	**District**	**Range of Concentration of Arsenic(g/L)**	**Probable Mechanism**	**References**
Assam	Sonitpur	0–11.15	Arsenic bearing minerals dissolution	Borah et al. (2010)
	Darrang	10.1–93.05	Transport after Kushiara river	Purkayastha et al. (2015)
	Karimganj	1.3–16.4	Dissolution of Arsenic-bearing Minerals	Buragohain et al. (2010)
	Dhemaji	0.1–569	Reductive dissolution of FeOOH faciliated in presence of high organic carbon	Jain et al. (2018)
	Barpeta	0–36.88	Reductive dissolution of FeOOH faciliated in presence of high organic carbon	Sridharan et al. (2018)

The concentration of arsenic in groundwater exceeds the permissible level (50 mg/l based on water consumption of 2 litre per day, WHO) in parts of Assam - 20 districts out of 24 districts. In Assam, the maximum arsenic was observed in Jorhat, Lakhimpur, Nalbari and Nagaon districts. In Jorhat district, the contamination of arsenic was highest in the range of 194-657 mg/l. Altogether 80 samples were collected and 21 percent of the samples were found contaminated with As. . In Lakhimpur district, total 76 samples analysed for As and 21 percent of the samples detected with As. The concentration of As in Lakhimpur district was in between 50-550 mg/l. In Nalbari district, 19 per cent samples (72 samples) contained arsenic with the value between 106 mg/l to 422 mg/l. In Nagaon district, 76 samples were collected and 13 percent of the samples were found contaminated with arsenic. The range of arsenic concentration was in between 112-601 mg/l. In flood plain area of Assam viz. Barpeta, Dhemaji, Dhubari, Darrang, and Golaghat, the arsenic was found in between 100-200 mg/l. Remaining 11 districts of Assam where As was detected contained arsenic in between 50-100 mg/l. Only three districts namely, Karbi Anglong, NC Hills and Morigaon were free from arsenic contamination. (A.K. Singh, 2022)

1.8 Techniques used for determining Arsenic content in Groundwater:-

The instrumental techniques generally used for arsenic determination are

- Hydride generation atomic absorption spectrometry (HGAAS),
- Graphite furnace atomic absorption spectrometry (GFAAS) and
- Inductively coupled plasma mass spectrometry (ICP-MS), can provide results only on the total amount of As and not on its chemical forms.

The atomic absorption spectrometry (AAS) has been widely used for arsenic determination at trace levels, in techniques such as electro thermal atomic absorption spectrometry (ETAAS) and hydride generation atomic absorption spectrometry (HGAAS).

1.9 Objectives of the study –

The present study attempts to find the arsenic contaminated aquifers in the Darrang and Nagaon districts of Asssam through the development of a hazard map using geographic information system (GIS) and the IDW interpolation method. GIS serves as a powerful tool for managing and interpreting geographical information about water resources, offering efficient means to analyze pollution pat terns and relationships (Selvam Manimaran & Sivasubramanian 2013). The resultant hazard map is critical for assessing groundwater contamination, which is vital for safe drinking water and agricultural use, as well as for mitigating serious environmental health issues. In addition, this study conducts a thorough risk evaluation of human health among the residents of Darrang and Nagaon districts, including both adults and children. This assessment focuses on the non-carcinogenic hazard and cancer risk (CR) associated with the presence of arsenic in groundwater. By doing so, it aims to provide a comprehensive understanding of the potential health impacts in the region.

Based on the background outlined above, the objectives for this paper are –

- To understand the level of arsenic contamination in groundwater of Darrang and Nagaon districts of Assam.
- To investigate the relation between elevation and arsenic contamination using Arc-GIS.
- To predict the spatial distribution of Arsenic contamination by Inverse Distance Weighing (IDW) method of interpolation using Arc-GIS.
- To estimate the carcinogenic and non-carcinogenic risks associated with chronic exposure to arsenic through oral and dermal according to the methods published by the U.S. Environmental Protection Agency (USEPA, 1989).
- To develop a groundwater flow model using MODFLOW to illustrate the distributional pattern of arsenic in Groundwater.

CHAPTER-2

LITERATURE REVIEW

2.1 Brief Review of Few References-

- *Peterson Hans et.al., (2006)* studies the ill effects of human exposure to arsenic (As) which have recently been re-evaluated by government agencies around the world. This has lead to a lowering of As guidelines in drinking water, with Canada decreasing the maximum allowable level from 50 to 25 μg/L and the U.S. from 50 to 10 μg/L. The reason for these regulatory changes is the realization that As can cause deleterious effects at lower concentrations than was previously thought. Exposure to As leads to an accumulation of As in tissues such as skin, hair and nails, resulting in various clinical symptoms such as hyper pigmentation and keratosis. There is also an increased risk of skin, internal organ, and lung cancers. Cardiovascular disease and neuropathy have also been linked to As consumption.
- *Bhatia Sidharth et al*., *(2014)* tests the drinking water supply of a marginalized village community of Khap Tola in the state of Bihar, a state in Northern India. Based on hand pump drinking water sample testing and analysis, it was found that there are high levels of arsenic (maximum value being 397 ppb), in excess of the WHO limits of 10ppb. Analysis showed 57% of the samples from private hand-pumps in the shallow aquifer zone of 15–35m have arsenic greater than 200 ppb. Using GIS overlay analysis technique it was calculated that 25% of the residential area in the village is under high risk of arsenic contamination. Further using USEPA guidelines, it was calculated that children age group 5–10 years are under high risk of getting cancer. The Hazard Quotient calculated for 21 children taken for study, indicated that children may have adverse non-carcinogenic health impacts, in the future, with continued exposure.

- *Shankar Shiv et.al., (2014)* studies the sources, speciation, and mobility of As and global overview of groundwater As contamination. The paper also critically reviews the As led human health risks, its uptake, metabolism, and toxicity mechanisms. The paper provides an overview of the state-of-the-art knowledge on the alternative As free drinking water and various technologies (oxidation, coagulation flocculation, adsorption, and microbial) for mitigation of the problem of As contamination of groundwater.

- *Edmunds W M et al., (2015)* studies Arsenic and Its Impacts in Groundwater of the Ganges-Brahmaputra-Meghna Delta, Bangladesh. The Arsenic problem arises from the move in the 1980s and 1990s by international agencies to construct tube wells as a source of water free of pathogens, groundwater usually considered a safe source. Since arsenic was not measured during routine chemical analysis and also is difficult to measure at low concentrations it was not until the late1990s that the widespread natural anomaly of high arsenic was discovered and confirmed. The problem arises in delta regions because of the young age of the sediments deposited by the Ganges-Brahmaputra-Meghna river system. The problem is most serious in a belt across southern Bangladesh, but within 50m of the coast the problem is only minor because of use of deep groundwater; salinity in shallow groundwater here is the main issue for drinking water. The Government of Bangladesh adopted a National Arsenic Policy and Mitigation Action Plan in 2004 for providing arsenic safe water to all the exposed population, to provide medical care for those who have visible symptoms of arsenicosis. The current statistics show that use of deep groundwater (below 150m) is the main source of arsenic mitigation over most of the arsenic affected areas as well as rainwater harvesting in certain location.
- *Kumar Manish et al., (2016)* studies the As contamination and factors governing its release in the Nagaon district in Brahmaputra floodplain, based on various water types, relation of As with other major ions and with various depth profiles. The origin of groundwater mineralization and the processes responsible for As enrichment in groundwater was determined by calculating saturation index using PHREEQC code. Multivariate statistical analysis was carried out for identification of As releasing mechanism based on rock–water interaction. Principle component analysis of physicochemical parameters revealed the association of As with SiO2 and Cl- in pre-monsoon and the fact that alkaline condition favours release of As. The relation between As and Fe shows that reductive dissolution of solid Fe oxide and hydroxide phases could be the source of As in Nagaon district. The result of hierarchical cluster analysis indicates that As release could also be associated with the agrochemicals application. Health risk assessment revealed that children are more susceptible to carcinogenic as well as non-carcinogenic health impact with consumption of As-contaminated drinking water.
- *Radhapyari Keisham et al., (2017)* determines the extent and severity of arsenic and other traces elements contamination in groundwater of Assam, India. Various physio-chemical parameters viz., pH, turbidity, total dissolved solids, electrical conductivity, alkalinity, hardness, nitrate, chloride, sulphate, fluoride, sodium, potassium and total iron content

were also analyzed along with arsenic. 319 groundwater samples were collected from 22 districts of Assam and analyzed for arsenic by AAS. It was found that 0.94% of the samples have arsenic above 0.050 mg L-1 and 4.39% of the samples have arsenic above 0.010 mg L-1. Hence 4.39% of the collected groundwater samples exceed the BIS guideline of 0.010 mg/L. Groundwater samples from 19 districts out of 22 districts of Assam were significantly contaminated with iron and 3 districts out of 22 districts, groundwater contaminated by fluoride was evaluated.

- *Kumari Aastha and Maurya N, (2019)* demonstrates the health risk assessment of residents consuming groundwater with high arsenic concentrations which has attracted widespread concern. This study therefore aimed at providing a framework to evaluate the risks imposed to local residents of Simaria Patti Ojha village of Bhojpur district, Bihar. Results showed that the mean values of ADD, HQ and CR were 5.1 μg/(Kg Day) (PTDI- 2.1 μg/(Kg Day), 5-17 (safe range <1) and 0.002-0.007(tolerable range,$10^{-6} to\ 10^{-4}$), respectively. Carcinogenic risk value was found as 4.7 × 10-3 around 100 times higher than safe range of$10^{-6} to\ 10^{-4}$, indicating high risks to the local residents.
- *Satyajit Kakati, (2020) aims* at the delineation of the aquifer zones in the interfluves of the rivers Brahmaputra and Kolong, Assam by studying the hydro-geological settings in the area, nature and areal extent of aquifers, subsurface disposition of aquifers through panel diagram, well inventory data, behaviour and direction of movement of groundwater with the help of water table contour mapping etc. Hydro-geological data such as depth to water level, seasonal fluctuations of groundwater level were collected from 61 key well locations from the study area in both pre- as well as post-monsoon seasons. The spatial and temporal variability of groundwater levels in the area were studied with depth to water level maps and the water level fluctuation maps of both pre- and post-monsoon seasons. In major part of the study area groundwater fluctuations remain within 1.5 m to 2 m. There are much lateral variations in the aquifer zones with lateral and vertical intercalations; however, the subsurface geology of the study area indicates the presence of very good aquifer zones. The water table conforms to the general topography of the area. The general direction of groundwater flow in the study area is towards the river Brahmaputra.
- *Patel Arbind et al., (2021)* investigates the arsenic related health risk through possible consumption of groundwater in the Ganga (GFP) and the Brahmaputra (BFP) floodplains. Through the integrated chemical analysis of 507 ground water samples, accounting all the possible dietary pathways of arsenic intake, it is revealed that GFP carries significantly higher risk in terms of cancer incidence as compared to BFP among different gender and

age groups. While spatially a greater number of wells have higher arsenic in BFP but significant concentration peaks were observed in GFP where concentration reached to 106.03 µg/L, almost 10 times higher than WHO limit. For both the floodplains, HQ remains above 1 for oral exposure ranging between 5.25 to 53.24 in the BFP and 5.6 to 57.6 in the GFP.

- *Chahal Kavita et.al (2022)* studies carcinogenic and non-carcinogenic toxic effects for inhabitants due to exposure to heavy metals through dermal and ingestion of drinking water. The maximum concentration of heavy metals was evaluated for Nickel and Arsenic metals, respectively. The average concentration values of heavy metals were found in increasing order as: Ni > As > Cr > Hg > Mn > Cu > Fe > Cd > Zn > Co = Pb 15.36 > 10.3 > 4.73 > 3.32 > 1.43 > 0.27 > 0.246 > 0.068 > 0.06 mg/l respectively. Also, the highest value of incremental lifetime cancer risk was evaluated due to chromium metal. The Hazard Index > 1 was recorded, concluding that non-carcinogenic health risk via ingestion of water, and the Hazard Index < 1 for dermal contact of water, concluded the low risk of non-carcinogenic health risk. These results disclose a new avenue for the removal of these hazardous metals from drinking water. Also, assist future researchers to plan for a healthy life for living things and the present work can be useful for the development of ideas for potential risk control and management.
- *Sarma Tirthankar et al., (2022)* investigate the elevation and groundwater arsenic contamination in Darang district of Assam. Primary data have been collected and tested in University laboratory to know the value of arsenic in groundwater. Many water samples were contaminated with arsenic. Arsenic affects a broad range of organs and system including skin, nervous system, respiration system, liver, kidney, immune system etc. Arsenic poisoning occurs due to the high level of arsenic in the body. Interpolation method has been use to show the vertical distribution pattern of groundwater arsenic contamination with the help of Arc GIS 10.2.1. Digital Elevation Model has been prepared with the help of satellite data to show the relation between elevation and arsenic in groundwater.
- *Islam Nazrul et al*., (2023) studies the present condition of arsenic concentration, its spatial pattern, and its relationship with tube well depth in the Gangni Union in the Chuadanga district of Bangladesh. Additionally, the study tried to assess the associated non-carcinogenic health risks imposed by oral ingestion of arsenic. Systematic sampling was used to collect water samples (n = 100) along with depth information from the sample tube wells. Both geostatistical (spatial autocorrelation, Hotspot analysis, and IDW) and

statistical (descriptive and correlation statistics) methods were used. The resultant arsenic content of the samples tested ranges from 0.0004 (mg/l) to 0.10 (mg/l). Arsenic levels in almost 42% of the samples exceeded the WHO standard, 21% exceeded the Bangladesh standard, and 37% were within the tolerable standard. Geostatistical analysis shows that approximately 63% of the total area is arsenic contaminated. Furthermore, hotspot analysis reveals that the north-eastern and south-eastern parts of the study area are more arsenic-contaminated than the other parts. Non-carcinogenic health risk assessment shows that children have a higher average daily dose (ADD) range (8.33E-06-0.00181) than adults (2.78E-06-0.0006). Similarly, the hazard quotient (HQ) value is also higher for children (0.0277–6.033) than for adults (0.0092–2.011). The result of Pearson's correlation coefficient, r (98) = − 0.7580, p = 0.000, shows a negative linear relationship between concentration values and depth, meaning that increasing depth will reduce arsenic contamination from tube well water.

- *Rahmani Alireza et al., (2023)* evaluated the occurrence and likelihood of health risks related to arsenic in drinking water of all counties of the Hamadan province in the northwest of Iran. In this work, 370 samples were collected from all of the water resources of urban and rural regions, during 5 years (2017 to 2021). Oracle Crystal Ball software was used to perform the Monte Carlo simulation and investigate the potential health risks. According to the results, the average values of arsenic in the nine counties were in the order Kabudarahang (40.1 ppb), Malayer (13.1 ppb), Nahavand (6.1 ppb), Bahar (2.05 ppb), Famenin (0.41 ppb), Asadabad (0.36 ppb), Tuyser kan (0.28 ppb), Razan (0.14 ppb), and Hamadan (< 0.1 ppb). The highest concentration of arsenic occurred in Kabudarahang with a maximum value of 185 ppb. In the spring season, the average concentration of the cations, including calcium, magnesium, sodium, lead, cadmium, and chromium, obtained 109.51 mg/l, 44.67 mg/l, 20.50 mg/l, 88.76 ppb, 0.31 ppb, and 0.02 ppb, respectively. Based on the Delphi classification, the P 90% of oral lifetime cancer risk, in Hamadan province, were within level II (low risk) to VII (extremely high risk). The risk analysis revealed there was a possible carcinogenic risk to humans from oral exposure to As-contaminated groundwater, especially in Kabudarahang country.
- *Borah Triptimoni and Bora Gyanashree, (2024)* emphasizes the overview of the present scenario of intensity of arsenic contamination in groundwater in different districts of Assam. This paper also critically reviews the sources of arsenic contamination and arsenic led human effects.

- *Chowdhury Tahmida et al., (2024)* studies groundwater contamination by arsenic and iron and its health implications within the Sylhet district in Bangladesh. Utilizing geographic information system (GIS) and inverse distance weighting (IDW) methods, hazard maps have been developed to evaluate contamination risk across various upazilas. The findings show significant arsenic and iron pollution, particularly in the northwestern part of the district. In about 50% of the area, especially in Jaintiapur, Zakiganj, Companiganj, and Kanaighat where arsenic levels surpass 0.05 mg/L which is the standard limit of Bangladesh. Iron levels peak at 13.83 mg/L, severely impacting 45% of the region, especially in Gowainghat, northeastern Jaintiapur, Zakigonj, and Golabganj. The study employs USEPA health risk assessment methods to calculate the hazard quotient (HQ) and hazard index (HI) for both elements via oral and dermal exposure. Results indicate that children face greater non-carcinogenic and carcinogenic risks than adults, with oral HI showing significant risk in Balagonj and Bishwanath. Dermal adsorption pathways exhibit comparatively lower risks. Cancer risk assessments demonstrate high carcinogenic risks from oral arsenic intake in all areas.
- *Foroughi Parvin et al., (2024)* studies the carcinogenic and Non-carcinogenic risks associated with occupational exposure to formaldehyde. This study was conducted in the pathology labs of four hospitals in Tehran. Cancer and Non-cancer risks were evaluated using the quantitative risk assessment method proposed by the United States environmental protection agency (USEPA), along with its provided database known as the integrated risk information system (IRIS). Respiratory symptoms were assessed using the American thoracic society (ATS) questionnaire. The results of this study indicated that 91.23% of exposure levels in occupational groups exceed the NIOSH standard of 0.016 ppm. Regarding carcinogenic risk, 41.03% of all the studied subjects were in the definite carcinogenic risk range (LCR > 10−4), 23.08% were in the possible carcinogenic risk range (10−5 < LCR < 10−4), and 35.90% were in the negligible risk range (LCR < 10−6). The highest index of occupational carcinogenesis was observed in the group of lab technicians with a risk number of 3.7 × 10−4, followed by pathologists with a risk number of 1.7 × 10−4. Furthermore, 23.08% of the studied subjects were within the permitted health risk range (HQ < 1.0), while 76.92% were within the unhealthy risk range (HQ > 1.0).

CHAPTER -3

DESCRIPTION OF THE STUDY AREA

The study area, encompassing Darrang and Nagaon districts, is situated in one of the eight north-eastern states of the country, which is Assam, as illustrated in the figure 3.1

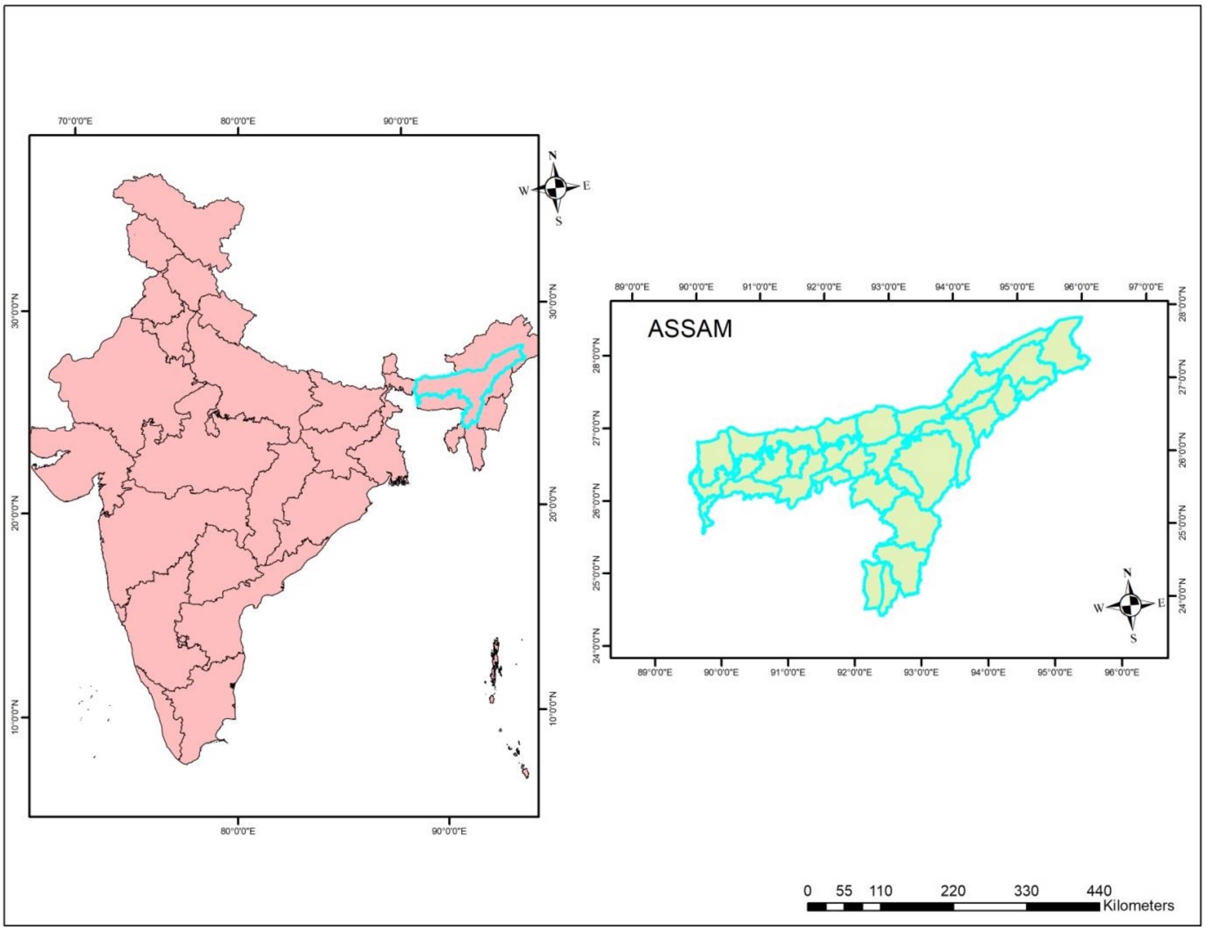

Fig - 3.1 Geographical Map of Assam

Hydro geologically the state can be divided into three units namely consolidated formation, semi consolidated formation and unconsolidated formation. More than 75% of the state is underlain by unconsolidated formation comprising of clay, silt, sand, gravel, pebble and boulders. The Bhabar belt is about 11 to 15 km wide. The Tarai zone follows immediately down slope of the Bhabar zone. The flood plains follow the Tarai in Brahmaputra valley. Geochemistry of ground water is mainly dependent upon several factors like, soil or rock through which rain water percolates, depositional history of the rock types, composition of the rock types, climate of the area, role of microorganisms, topography of the area and the role of human activities etc.

3.1 Darrang District –

3.1.1 Introduction-

The study area Darrang district in Assam as shown in fig-3.2 is situated in the eastern parts of India on the northeast corner of Assam. The district lies between longitudes 20°09'N to 26°95'N and latitudes 91°45'E to 92°22 E (approximately). The district is bounded by Arunachal Pradesh (State) and Bhutan (Country) and Udalguri district in the North, in the east Sonitpur District and in the west by Kamrup District. The mighty Brahmaputra flows along the southern boundary of the district. Sonitpur and Kamrup districts are in the East and West respectively. Located on the bank of mighty river Brahmaputra, the district is largely plain. Other important tributaries of the Brahmaputra are Barnadi, Nowanodi, Nanoi, Mangaldai, Saktola, Dhansiri, which are the main River flowing through the district and the rivers are perennial in nature. The total area is approximately 1585 km^2(612 sq mi), and the total population is 1,290,615 (estimates as per aadhar uidai.gov.in Dec 2023 data). Darrang district consist of six revenue circles. Name of the circles of Darrang district of Assam are Dalgaon (215 Villages), Mangaldoi (140 Villages), Sipajhar (93 Villages), Pathorighat (84), Kalaigaon (25) and Khoirabari (7).The administrative headquarters of the Darrang district is Mangaldai.

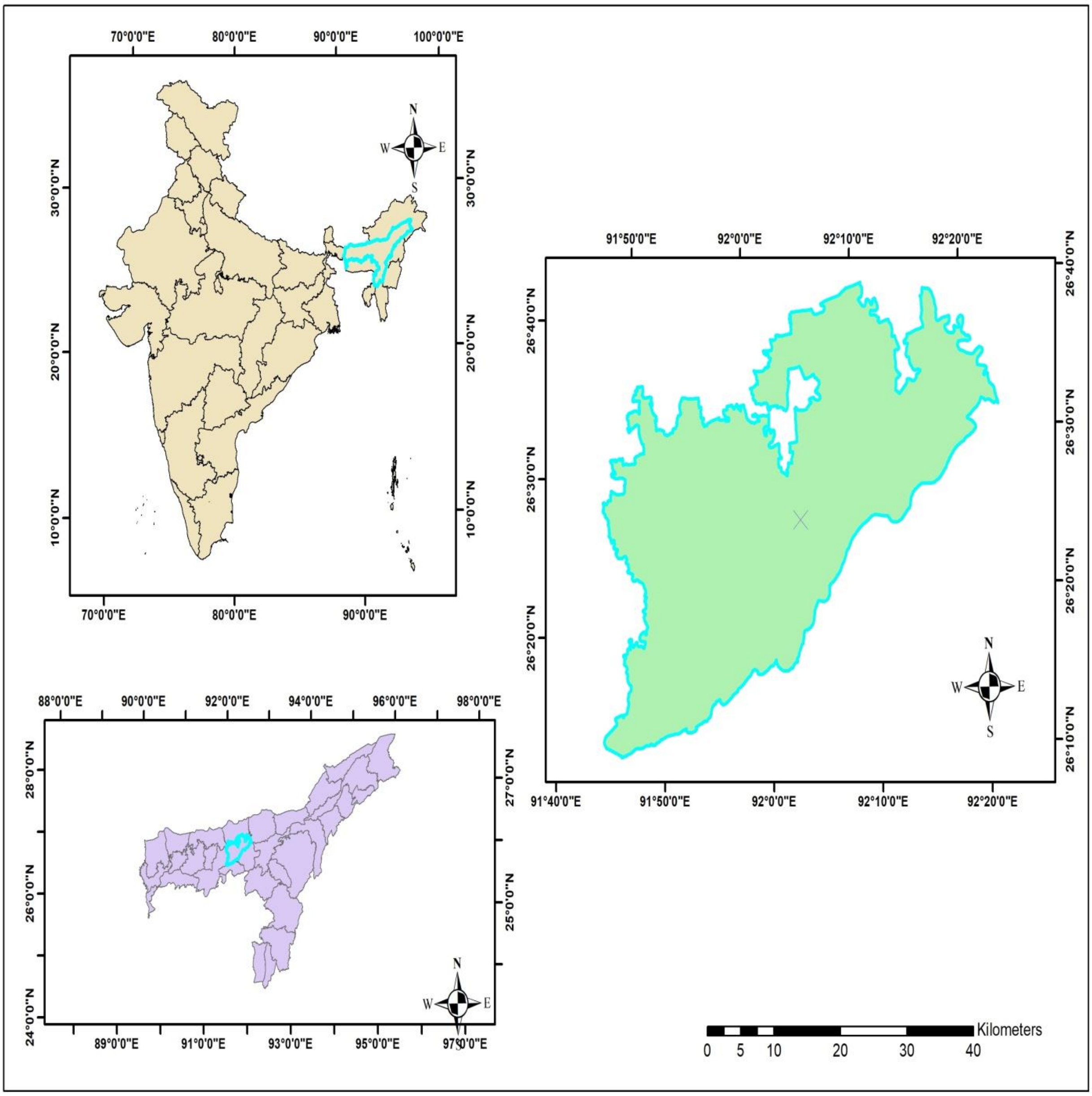

Fig- 3.2 Study area map of Darrang district, Assam

3.1.2 Climate and Rainfall -

The climate of the district is sub-tropical and humid. The winter season starts by November and continues till February. December/January is the coldest month and the temperature comes down to almost 150 C. The temperature starts rising from the month of February/March and July/August is the hottest month and it reaches up to about 400 C. The air is highly humid throughout the year and during rainy season; the relative humidity is about 90 percent (https://cgwb.gov.in)

The area receives heavy rainfall every year and out of 1,951 mm of annual normal rainfall, 60 to 65% is received during June to September from south-west monsoon.

The district also receives about 501 mm of rainfall during pre-monsoon period from March to May in the form of thunder showers and hail storms. (https://cgwb.gov.in)

3.2.3 Geology –

Darrang district in Assam, India, is characterized by its diverse geological features. It primarily lies within the Brahmaputra Valley, which is known for its fertile alluvial plains. Here are some key geological aspects:

1. Alluvial Plains - The district is predominantly covered by fertile alluvial plains formed by the Brahmaputra River and its tributaries. These plains are composed of rich sedimentary deposits brought down by the rivers over time.

2. Riverine Deposits - The Brahmaputra River and its tributaries, such as the Manas River, deposit a variety of sediments including sand, silt, and clay. These deposits contribute to the fertility of the soil in the region.

3. Hill Ranges - While the district is primarily flat, it does have some hilly areas towards its northern and eastern borders. These hills are part of the foothills of the Himalayas and are composed of older sedimentary rocks and occasional igneous intrusions.

4. Geological History - The geological history of the region dates back to the Paleogene and Neogene periods when the Brahmaputra River system began to form. The deposition of sediments continued through the Quaternary period, shaping the current landscape.

5. Natural Hazards- The area is prone to natural hazards such as floods and erosion due to the dynamic nature of the Brahmaputra River. Erosion and sediment deposition continually reshape the landscape.

3.2 Nagaon District –

3.2.1 Introduction -

Nagaon district as shown in Fig. 3.3 is located in central Brahmaputra valley zone. The area of the district spans 2287 km^2(https://nagaon.assam.gov.in). The district of Nagaon is located on the south bank of the Brahmaputra river at a central geographical position in the state of Assam. The district lies between 25°45' and 26°44'North latitudes and 91°50' and 93°20' East longitudes. On the north the district is bounded by the river Brahmaputra, on the south by

Karbi Anglong and Dima Hasao districts, on the east by Golaghat and Karbi-Anglong districts, and on the west by the Morigaon district which was originally a part of the erstwhile Nagaon District (http://nagaonmunix.in). The average altitude of the district is 60.6 masl. Its major rivers include the Brahmaputra, Kalong, Sonai, Nanoi, Jamuna, Kopili and Barpani. Geomorphologically the study area belongs to the south bank of Brahmaputra Plain of central Assam, the landmass of which is build up largely by fluvial aggradation of a geological trough.

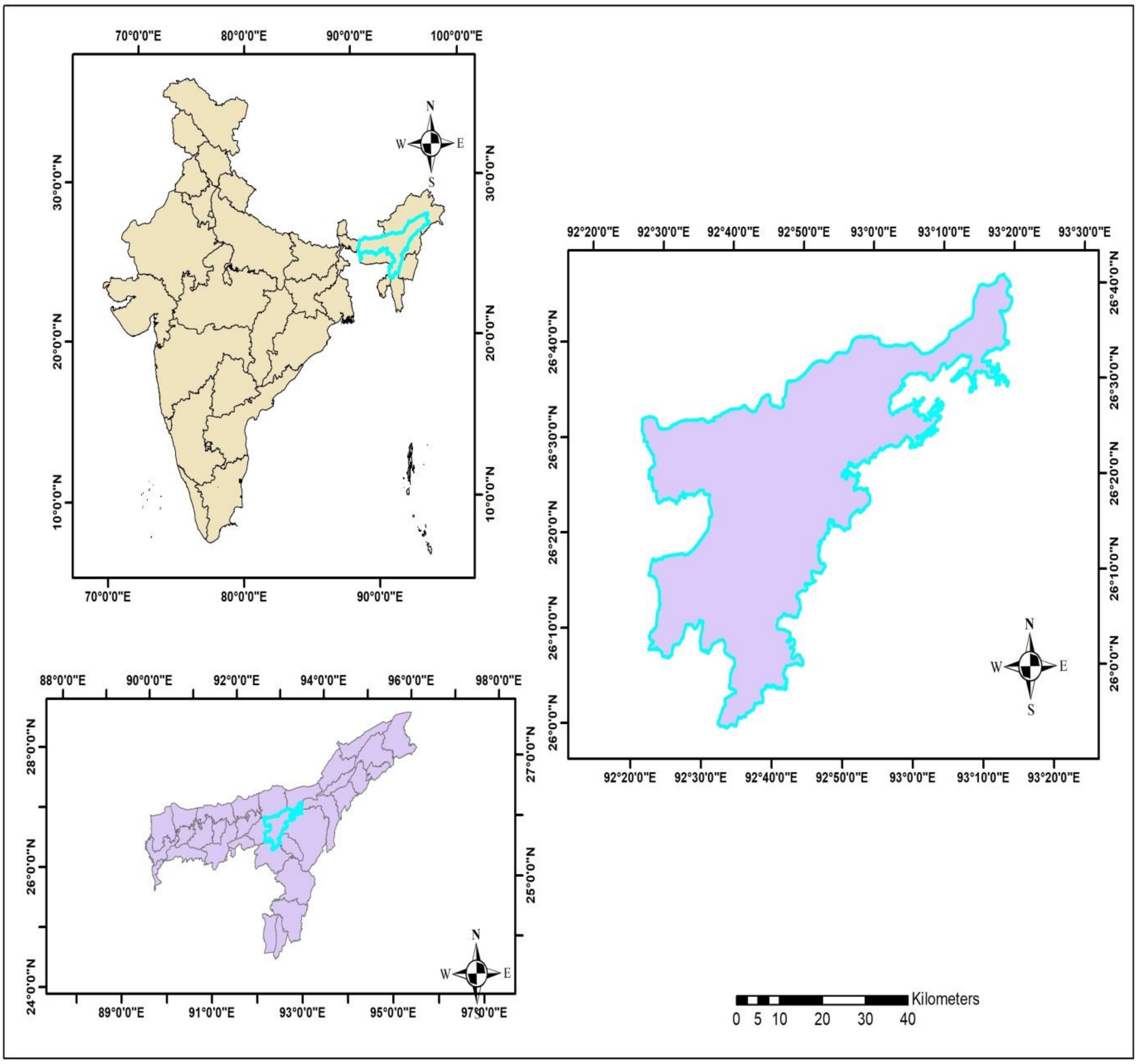

Fig-3.3 Study area map of Nagaon district, Assam

3.2.2 Climate and Rainfall –

Nagaon district is located at an elevation of 72.22 meters (236.94 feet) above sea level, Nagaon has a Humid subtropical, dry winter climate (Classification: Cwa). The district's yearly temperature is 27.01ºC (80.62ºF) and it is 1.04% higher than India's averages. Nagaon typically receives about 81.2 millimeters (3.2 inches) of precipitation and has 62.55 rainy days (17.14% of the time) annually (https://weatherandclimate.com/india/assam/nagaon). Average rainfall distribution throughout the year shows the following trend: southwest monsoon (June–September) 1231.0 mm, northeast monsoon (October–December) 139.6 mm, winter (January–February) 31.9 mm and summer (March–May) 633.8 mm (Agriculture Contingency Plan for District, Nagaon 2012). Rainfall increases toward the east and the west of Assam from this district. The pattern of rainfall is such that the south is usually dry and the north is relatively rainy (Kumar Manish et al., 2015) The warmest in the district is April with temperature of 33.67ºC / 92.61ºF) and the coldest month is January with temperature of 14.18ºC / 57.52ºF. The humidity is 71.92% (https://weatherandclimate.com/india/assam/nagaon).

3.2.3 Geology-

Nagaon district in Assam, India, displays a varied geological profile influenced by its location within the Brahmaputra Valley and the eastern Himalayan foothills. Here are the key geological features:

1. Alluvial Plains - Similar to other parts of the Brahmaputra Valley, Nagaon district is characterized by extensive alluvial plains. These plains are formed by the deposition of sediments carried by the Brahmaputra River and its tributaries over thousands of years. The soil here is highly fertile, making it suitable for agriculture.

2. Riverine Systems - The Brahmaputra River flows through the district, shaping its landscape through erosion and deposition. Tributaries like the Kopili River also contribute to the geological dynamics of the area, depositing sediments and influencing local hydrology.

3. Himalayan Foothills - The northern part of Nagaon district extends into the foothills of the eastern Himalayas. These hills are characterized by sedimentary rocks and occasional intrusions of igneous rocks. The geological formation here includes older rocks compared to the alluvial plains.

4. Geological History - The geological history of Nagaon district spans millions of years, starting from the Paleogene period when the Brahmaputra River system began to take shape. The region has been shaped by tectonic activities, erosion, and sedimentation processes over time.

5. Natural Hazards - The district is prone to natural hazards such as floods and landslides, particularly during the monsoon season. The Brahmaputra River, known for its seasonal changes in flow and sediment load, plays a significant role in these hazards.

CHAPTER – 4

ASSESSMENT OF GROUNDWATER ARSENIC CONTAMINATION IN DARRANG AND NAGAON DISTRICTS OF ASSAM

4.1 Introduction –

With the escalation in world population and the intensification of development initiatives, there is a corresponding escalation in the need for dependable and uncontaminated water resources. To make up for the disparity between water demand and available surface water in the 21st century, there has been a growing trend towards the utilization of ground water. However, this increased reliance on groundwater has led to a decline in its quality. The introduction of human-made substances into groundwater and the amplification of geochemical reactions resulting from aquifer recharge contribute to the deterioration of groundwater quality (Q Li et al., 2022). According to Li, 2015 Arsenic (As) has been widely used in medicinal and industrial applications. Yet, the health risks associated with arsenic exposure have not been recognized until the 20thcentury. Arsenic is a geogenic, insipid, transparent, and odourless toxic metalloid. In recent decades, arsenic contamination has garnered significant scientific interest owing to its adverse effects on the well-being of individuals, ecological systems, and socio-economic progress. This challenge is particularly noteworthy due to the widespread distribution of high arsenic content in over 70 nations worldwide. As per the World Water Report by the United Nations, there is a correlation between declining groundwater levels and the degradation of global water quality. Approximately 66% of the global extracted groundwater is concentrated on the severity of arsenic poisoning in Asia, particularly in South and Southeast Asia (UNESCO World Water Assessment Programme, 2022). According to Singh, 2004 Groundwater arsenic contamination and sufferings of people have been reported in 20 countries in different parts of the world. The magnitude is considered highest in five Asian countries and the severity is in order of Bangladesh>India>Mangolia>China>Taiwan. In all these countries, more and more groundwater withdrawal is taking place because of increase in agricultural irrigation. In India after West Bengal and the bordering districts of Bangladesh, arsenic in groundwater was detected in part of Assam, Arunachal Pradesh, Manipur, Nagaland and Tripura. To protect human health, the World Health Organization (WHO) and the U.S.EPA have set a maximum contaminant level (MCL) of 10 μg/L for inorganic arsenic in drinking water. To date, elevated arsenic levels in drinking water sources have been reported in more than 50 countries, affecting well over 200 million people. In many of these countries, groundwater was promoted as safe for drinking given the reduced likelihood of microbial contamination. Even though microbial contamination was not present, groundwater sources in these countries were contaminated with naturally occurring subsurface arsenic. Further, arsenic is odourless, tasteless, and colourless, making arsenic detection in contaminated water a challenge even when present at high concentrations is studied by Smith et al. (2009). Another study by Sarkar et al. (2016) proposed several techniques to remove arsenic from groundwater including precipitation, coagulation/filtration, adsorption, ion exchange, lime treatment, oxidation, and membrane filtration. However, the broader implementation of these technologies is challenged by cost and complex operation and maintenance, making them less desirable for remote and challenged communities. Yet, significant research efforts have been spent on identifying appropriate aqueous arsenic removal technologies that are cost-effective, easily operated, and require minimal experience, while having high arsenic removal rates.

The problem of arsenic in groundwater in Assam is also a matter of great concerned. The presence of groundwater arsenic in the state of Assam was first reported by Singh (2004), NERIWALM. His study revealed that 20 of the 30 districts of Assam have arsenic concentration exceeding 0.050 mg/l. Another study by Chakraborty et al. (2004) revealed that several underground water sources in India's northeast are unfit for consumption due to highly toxic contamination of arsenic. In 2005, Public Health Engineering Department (PHED), Assam carried out a state wide blanket survey for arsenic contamination in drinking water. In total 5729 water samples collected from 22 of the 30 districts in Assam, where the water samples collected from 18 districts had arsenic concentration greater than 0.05 mg/l. Brammer and Ravenscroft (2009) have reviewed the nature of the threats, taking into account the natural sources of arsenic pollution, areas affected, factors influencing arsenic uptake by soils and plants, toxicity levels and the dietary risk to people consuming arsenic-contaminated rice. Chetia et al. (2010) have studied about Groundwater arsenic contamination in Brahmaputra River basin of Golaghat district (Assam). They observed a very significant correlation between arsenic and iron and suggested that the mobilisation of arsenic in the groundwater of that region may have been caused by the reductive breakdown of arsenic-iron featuring minerals. Bhuyan et al. (2010) studied about arsenic and iron contamination of ground water in three development blocks of Lakhimpur district, Assam. His study shows the naturally occurring arsenic in ground water is more widespread than generally recognised. Ali Shah (2012) has studied on the Role of Quaternary stratigraphy on arsenic-contaminated groundwater from parts of Barak Valley, Assam, North–East India'. He suggested deeper tube wells (>60 m) in PlioPleistocene Older Alluvium aquifers would be a better option for arsenic-safe groundwater. Chandrasekhar et al. (2013) have reviewed a geotechnical signature of arsenic contaminated ground water in Barak Valley (Assam) and surrounding areas of north eastern India. In their observations, Arsenic is detected at levels above the maximum permissible limit of WHO guidelines concentration which contributes to the observed adverse toxicological effects to humans. The contaminated aquifers of their study area are likely to be confined to the Holocene alluvial terrain and Tipam formation. Elevated levels of Arsenic in the bedrock and soil of study area suggest that the source of Arsenic contamination is geogenic. Das Saurav et al. (2015) emphasized on the occurrence and distribution process of arsenic in ground-water sources as well as associated health risks in North-eastern Region (NER) of India. Mahanta et al. (2016) have studied about health costs of arsenic contamination of drinking water in Assam. They estimated three structural equations to determine health costs due to arsenic contamination and showed that the annual household health cost of a 1µg increase in arsenic concentration per liter is about INR 4. This study draws a policy implication for providing safe drinking water in Assam.

The goal of this paper is to investigate arsenic contamination in groundwater of Darrang and Nagaon districts of Assam. A study by Borah et al, (2018) the groundwater of Darrang district is highly contaminated with Arsenic and Iron. Keeping in view of the high concentrations of Arsenic, it is suggested to test the portability of groundwater of the area before using it for drinking.

4.2 Study Area –

The present study was conducted in Assam's two major districts – Darrang and Nagaon.

(Refer to chapter -3, page 18-24)

In the study area, groundwater is the main source of water for drinking and agricultural purposes. According Tiwari et al., (2021) the arsenic sources were related to specific geological conditions, volcanic rocks, and sulfide compounds in the flood plains of Brahmaputra and Ganga. Information on groundwater quality of North Eastern India is scanty. Available literature shows that groundwater of Assam valleys are highly ferruginous (Aowal 1981).

From the works of the different study in arsenic it is known that the arsenic originates in the Himalayan head waters of the Ganga and Brahmaputra rivers and has lain undisturbed beneath the surface of the region's deltas for thousands of years in thick layers of fine alluvial mud smeared across the area by the rivers. It also appears from analytical results for arsenic in Assam that groundwater adjacent to foothills is highly arsenic contaminated. This area lies within an alluvial basin bounded by Himalayan Mountains. The alluvial sediments are composed of a mixed sequence of sands, silts and clay deposits eroded from the surrounding mountains. Another study by A.K Singh states the probable reason of arsenic contamination in those areas might be heavy deposition of sediments due to surface erosion from surrounding hills and creating aquifers. Several other studies have shown that the ground water in the region is generally in a reducing state (presence of relatively high concentration of sedimentary organic matter) and suggest that arsenic is being released when arsenic – iron bearing minerals in the sediments are reduced by oxygen deficient ground water. Although, arsenic contents beyond the guideline values of WHO (World Health Organisation) have been found in a large number of samples.

4.3 Sampling Methodology -

Water samples collected in this work were of the nature of integrated samples. Necessary precautions were taken to collect sample from a well mixed zone avoiding floating materials. Samples were collected mainly from tube wells or hand pumps. Samples were collected by grab method and random selection. Before the samples were taken, the water was pumped out 5–10 min depending upon the depth of the aquifer (more pumping for deeper aquifers in order to empty the volume of standing water from the underground pipes of the tube well and to collect flowing water from aquifers directly) until fresh water comes from deep in the well. Water samples were collected in 500 mL high-density polyethylene (HDPE) bottles and were washed out with filtered water to be sampled. The sampled water was acidified immediately with 5 ml of nitric acid (HNO3) for preservation and storage of samples, until the ph paper turns lemon juice in colour. Samples were protected from direct sun light during transportation to the laboratory. All probable safety measures were taken at every stage, starting from sample collection, storage, transportation and final analysis of the samples to avoid or minimize contamination. The collected samples should be tested in laboratory immediately.

4.4 Sampling Collections -

Total 54 groundwater samples were collected from 2 districts namely Darrang and Nagaon of Assam. Out of 54 samples, 25 samples were collected from Darrang district in January 2023 during winter season.

Fig 4.1 Water Sample Collection from Chamuapara and Ramraipara, Darrang District, Assam on January 6

Further, 29 samples have been collected from Nagaon district in April 2024 during pre-monsoon season. The water samples so collected were labelled describing the sampling locations.

Fig-4.2 Water Samples Collected from Nartum Gaon and Gomuthagaon, Nagaon District, Assam on April 1

Fig- 4 Water Samples Collected from Kondoli Road and Nam Gumutha, Nagaon District, Assam on April 24

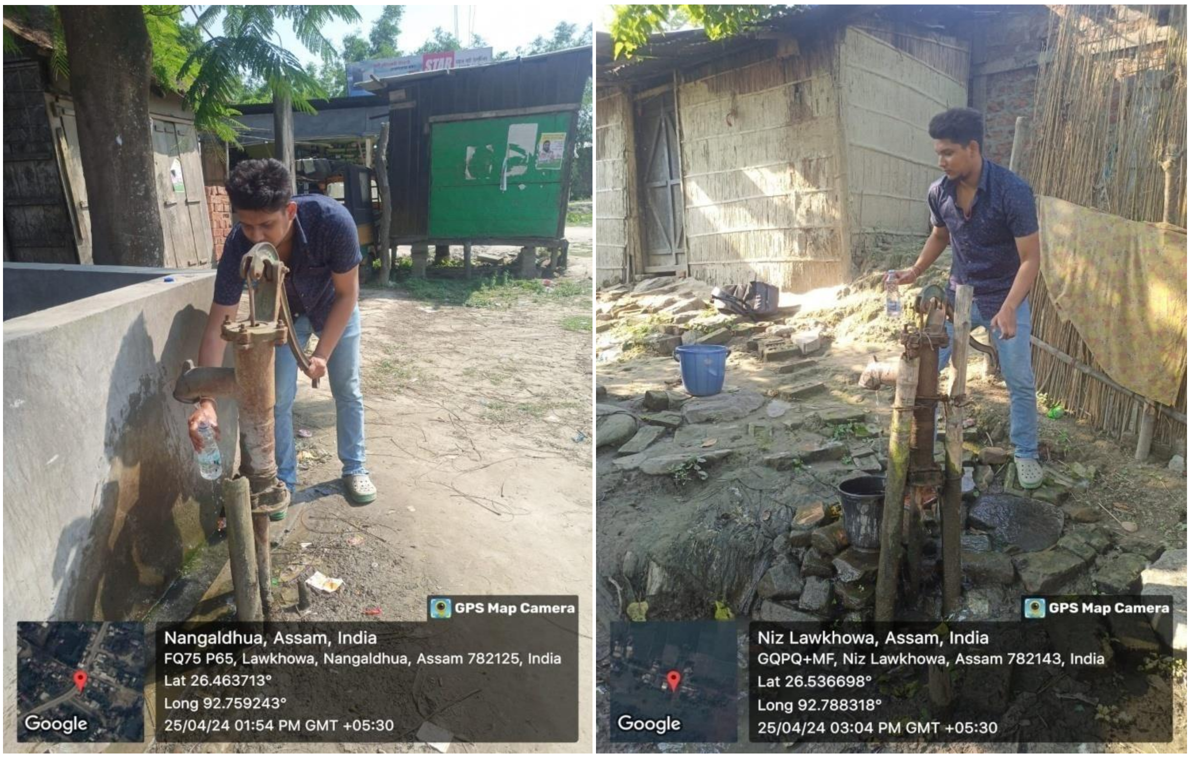

Fig- 4.4 Water Samples Collected from Nangaldhua and Niz Laokhua, Nagaon District, Assam on April 25

4.4 Sample verification and analysis –

The locations of the groundwater samples were verified using a handheld GPS receiver and arsenic concentrations were measured in the Public Health Laboratory Betkuchi and Public Health Laboratory, Mangaldoi and the technique used for determining arsenic contamination in ground water is Atomic Absorption Spectrometry (AAS). Standard safety precautions and protocols were used to examine the sample.

4.5 Sampling Locations –

Water samples were collected from twenty five (25) sampling stations distributed over Darrang district of the study area in January, 2024 as shown in Table 4.1

Table 4.1 Sampling locations along with their sampling source from Darrang district.

SAMPLE ID	LATITUDE	LONGITUDE	SOURCE	VILLAGE
D1	26.4722	92.0644	Hand Tube Well (HTW)	Hati bakar
D2	26.4934	92.0171	-do-	Chaporiyal para
D3	26.4338	92.0113	HTW	Konwarpara
D4	26.4632	91.9159	HTW	Major chuba
D5	26.7024	91.7096	HTW	Ramgaon
D6	26.4221	91.9309	HTW	Satghoria
D7	26.268	91.811	HTW	Suktaguri no 1
D8	26.326	91.825	HTW	Chamuapara
D9	26.353	91.851	HTW	Dumuni chowki
D10	26.423	91.835	HTW	Naodingerdal
D11	26.308	91.863	HTW	Kholihoi gaon
D12	26.375	91.877	HTW	Dheki para
D13	26.425	91.884	HTW	Ghurachal
D14	26.422	91.918	HTW	Muslim ghopa
D15	26.372	91.901	HTW	Bijulibari
D16	26.4464	91.916	HTW	Kumarpara
D17	26.4868	91.9323	HTW	Borigaon
D18	26.502832	91.892808	HTW	Laltupara
D19	26.490848	91.922599	HTW	Hirapara
D20	26.481103	91.950318	HTW	Lozora
D21	26.534	91.8973	HTW	Lakhimpur(pub)
D22	26.542685	91.844025	HTW	Pachim chuba
D23	26.4695143	91.8440159	HTW	Nadirtari chuba
D24	26.484	91.8324	HTW	Uttar bherua
D25	26.5689	91.9124	HTW	Kawaimari

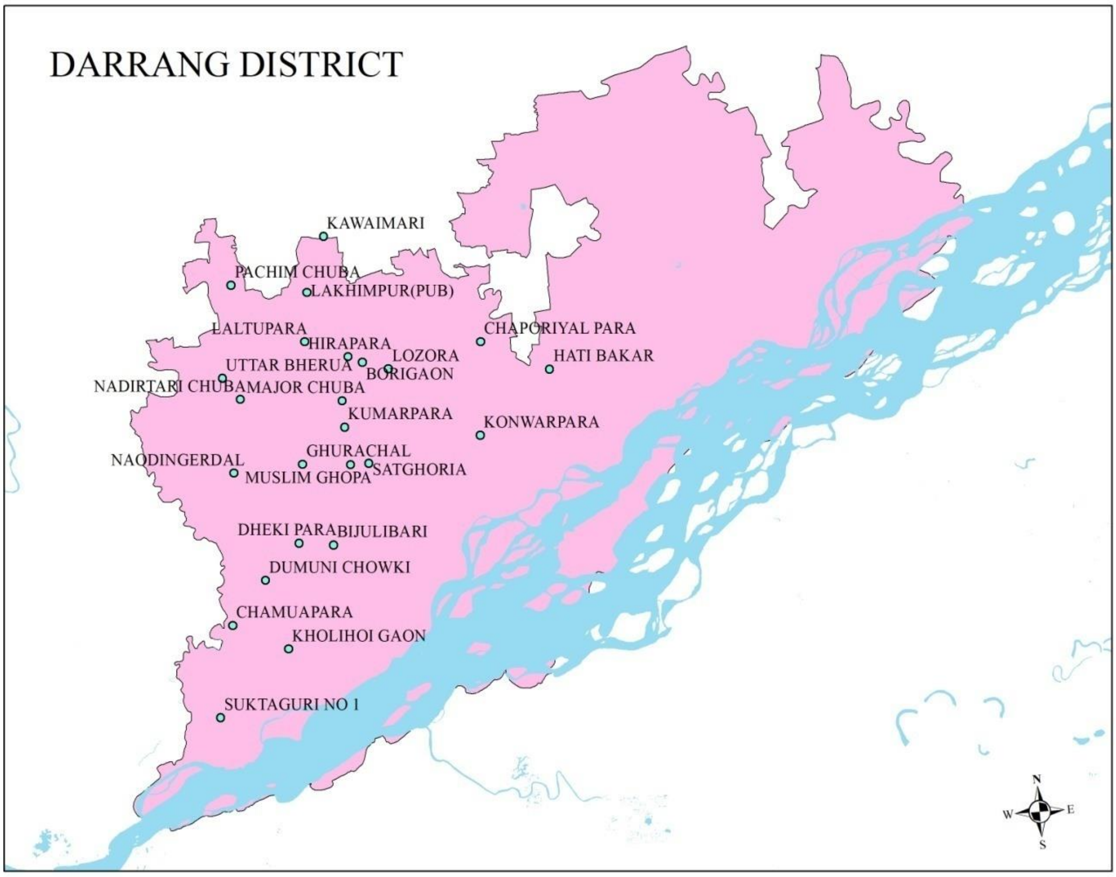

Fig - 4.5 Map of Darrang district showing the location with drinking water sample locations.

In Nagaon district, 29 samples were collected in month of April, 2024 which are tabulated below-

Table 4.2 Sampling locations along with their sampling source from Nagaon district.

SAMPLE ID	LATITUDE	LONGITUDE	SOURCE	VILLAGE
N1	26.272181	92.739255	Hand Tube Well (HTW)	Kondoli Rd, Nonoi
N2	26.272967	92.756048	-do-	Kondoli Rd, Teliagaon
N3	26.266495	92.72953	HTW	Nonoi Bhelaigaon
N4	26.262592	92.716361	HTW	Nam Gumutha
N5	26.276765	92.705246	HTW	Nonoi Namkuri

N6	26.332723	92.698434	HTW	Nagaon-Lumding Rd
N7	26.378504	92.739213	HTW	Lawkhowa
N8	26.463712	92.759242	HTW	Lawkhowa Nangaldhua
N9	26.536911	92.791831	HTW	Bongaon, Niz Laukhowa
N10	26.556698	92.788318	HTW	Niz Laukhowa
N11	26.502222	92.783989	HTW	Pub Salpara
N12	26.501347	92.783116	HTW	Salpara
N13	26.366522	92.702891	HTW	Diphalu
N14	26.343089	92.733348	HTW	Chakarigaon
N15	26.348888	92.757914	HTW	Niz Gumuthagaon
N16	26.365757	92.763978	HTW	Nartum Gaon
N17	26.349394	92.80802	HTW	Chalchali Jalah
N18	26.343797	92.86753	HTW	Chapanal Grant
N19	26.342008	92.868683	HTW	Chapanala
N20	26.327982	92.841075	HTW	Killing Nepali Gaon
N21	26.327982	92.841075	HTW	Kaziranga road
N22	26.343055	92.754493	HTW	Gomothagaon
N23	26.398157	92.461814	HTW	Bichamari
N24	26.247	92.431	HTW	Ghasibari
N25	26.554161	92.93928	HTW	Gomotha
N26	26.203	92.448	HTW	Chaobori
N27	26.220045	92.485975	HTW	Duboritoli Kolongpar
N28	26.46623	92.491669	HTW	Bilatia
N29	26.543003	92.988402	HTW	Bamunigaon

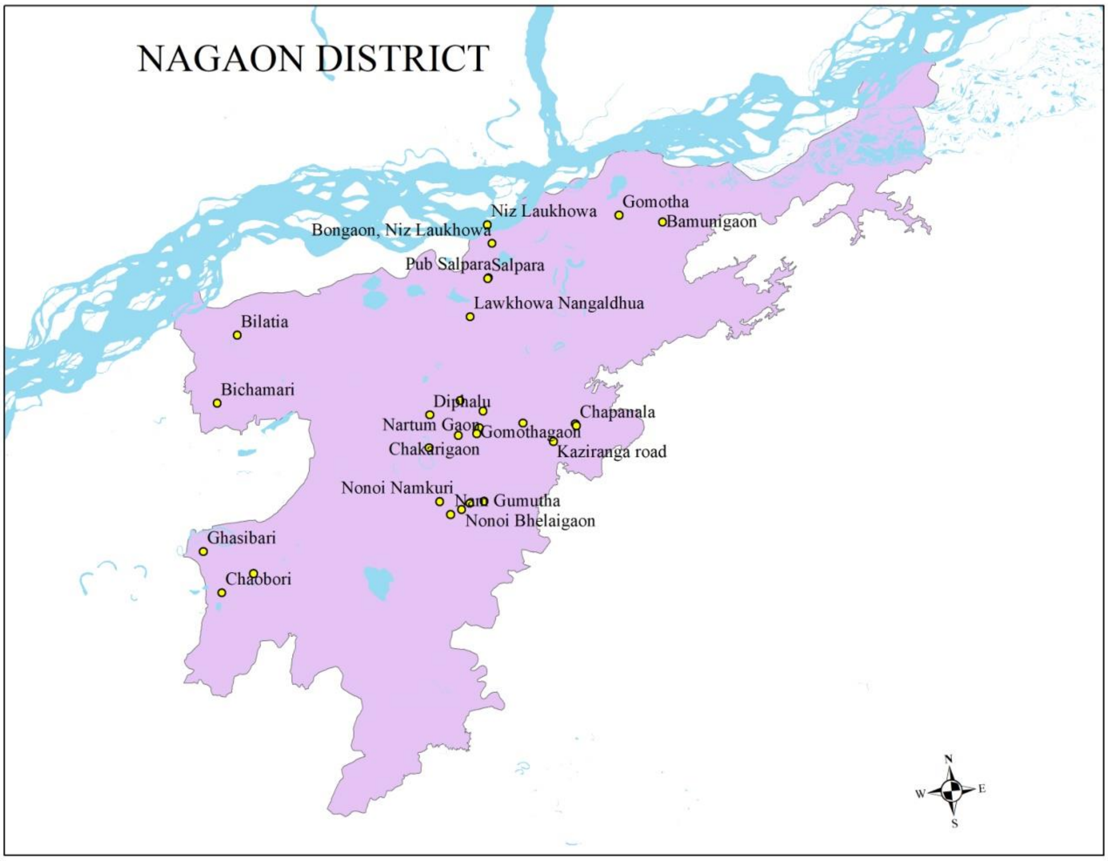

Fig – 4.6 Map of Nagaon district showing the location with drinking water sample locations.

4.6 Experimental Analysis -

The collected Groundwater samples from Darrang and Nagaon district of Assam are further then tested in public health laboratory, Betkuchi using the technique used for determining arsenic contamination in ground water is Atomic absorption spectrometry (AAS).

4.6.1 Apparatus used –

a) Arsenic Generator, Scrubber, Absorption tube

b) Fume hood

c) Photometric equipment

1) Spectrophotometer

2) Filter Photometer

3) Cells – to prevent chloroform evaporation

4.6.2 Reagents Used –

a. Reagent water

b. Acetate buffer, pH 5.5

c. Sodium acetate, 0.2 M

d. Acetic acid (CH3COOH), 0.2 M

e. Sodium borohydride solution, 1%.

f. Hydrochloric acid (HCl), 2 M

g. Lead acetate solution

h. Silver diethyldithiocarbamate solution

4.6.3 Procedure –

For Arsenic test, Silver diethyldithiocarbamate (SDDC) method is used.

a. Firstly 35 ml of collected water sample is taken in a 100 ml conical flask.

Fig - 4.7 35ml of water sample in 100ml of conical flask.

b. Then 5 ml of concentrated Hydrochloric Acid (HCI) and 2 ml of 15% KI (Potassium iodide) solution is added to it.

c. 8 drops of 40% stannous chloride (SnCl) solution is added and the reaction is allowed to proceed for 15-20 minutes for the reduction of As (V) to As (111).

d. Meanwhile Scrubber tube and Absorber tube is prepared and glass wool is impregnated with 3-4 drops of lead acetate (10%solution) in the scrubber tube.

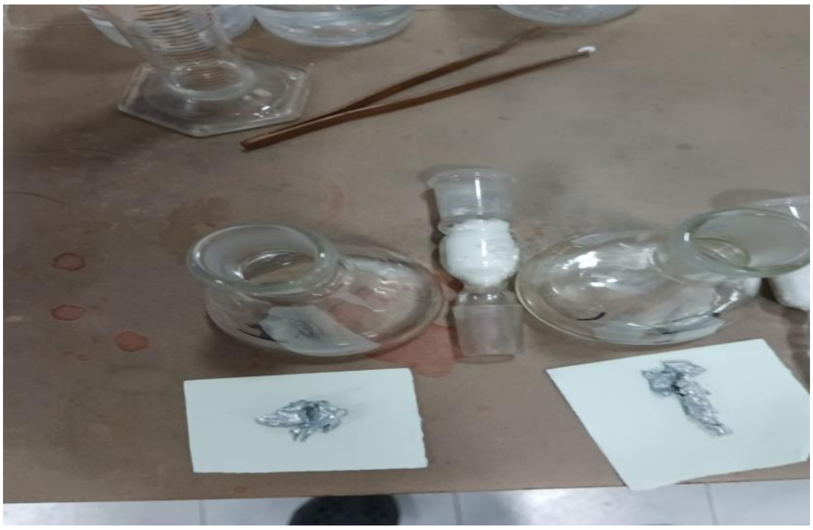

Fig -4.8 Scrubber tube and Absorber tube is prepared and glass wool is impregnated.

e. Then 4 ml of SDDC solution is taken in the absorber tube in Gutzeit apparatus.

f. 3 grams of zinc (Zn) granules is added to the generator and it is immediately connected to the scrubber-absorber assembly so that the gas does not escape.

g. Now Arsine gas will pass through glass wool impregnated with lead acetate.

h. SDDC solution in the absorber tube will absorbs the arsine gas giving a reddish coloration and the reaction is allowed to proceed for 30 min at room temperature.

i. After that the generator on the hot plate is warmed slightly to ensure that all arsine is released and then the solution is transferred from absorber to cuvette and measure concentration against blank at 535 nm.

Fig-4.9 Performing Arsenic test in Public Health Laboratory, Betkuchi.

4.7 Results and Discussion –

The results of analysis of Arsenic in groundwater samples of Darrang and Nagaon district, Assam are given in Table 4.3 and 4.4. To look into the trend and distribution patterns of As in groundwater of the study area, data obtained from 44 sampling stations were exposed to several statistical treatments.

Table 4.3 Sampling locations along with their concentrations in PPM in Darrang district, Assam

SAMPLE ID	LATITUDE	LONGITUDE	CONCENTRATION (PPM)	VILLAGE
D1	26.4722	92.0644	**0.055**	Hati bakar
D2	26.4934	92.0171	0.005	Chaporiyal para
D3	26.4338	92.0113	**0.011**	Konwarpara
D4	26.4632	91.9159	**0.0149**	Major chuba
D5	26.7024	91.7096	BDL	Ramgaon
D6	26.4221	91.9309	BDL	Satghoria
D7	26.268	91.811	**0.038**	Suktaguri no 1

D8	26.326	91.825	**0.02**	Chamuapara
D9	26.353	91.851	**0.051**	Dumuni chowki
D10	26.423	91.835	**0.052**	Naodingerdal
D11	26.308	91.863	**0.011**	Kholihoi gaon
D12	26.375	91.877	0.008	Dheki para
D13	26.425	91.884	0.007	Ghurachal
D14	26.422	91.918	0.004	Muslim ghopa
D15	26.372	91.901	0.002	Bijulibari
D16	26.4464	91.916	**0.029**	Kumarpara
D17	26.4868	91.9323	**0.025**	Borigaon
D18	26.502832	91.892808	0.007	Laltupara
D19	26.490848	91.922599	0.004	Hirapara
D20	26.481103	91.950318	0.009	Lozora
D21	26.534	91.8973	0.006	Lakhimpur(pub)
D22	26.542685	91.844025	0.009	Pachim chuba
D23	26.4695143	91.8440159	**0.03**	Nadirtari chuba
D24	26.484	91.8324	**0.04**	Uttar bherua
D25	26.5689	91.9124	0.008	Kawaimari

Table 4.4 Sampling locations along with their concentrations in PPM in Nagaon district, Assam

SAMPLE ID	**LATITUDE**	**LONGITUDE**	**CONCENTRATION (PPM)**	**VILLAGE**
N1	26.272181	92.739255	0.002	Kondoli Rd, Nonoi
N2	26.272967	92.756048	BDL	Kondoli Rd, Teliagaon
N3	26.266495	92.72953	0.005	Nonoi Bhelaigaon
N4	26.262592	92.716361	0.002	Nam Gumutha
N5	26.276765	92.705246	**0.013**	Nonoi Namkuri
N6	26.332723	92.698434	**0.014**	Nagaon-

				Lumding Rd
N7	26.378504	92.739213	0.005	Lawkhowa
N8	26.463712	92.759242	**0.03**	Lawkhowa Nangaldhua
N9	26.536911	92.791831	0.001	Bongaon, Niz Laukhowa
N10	26.556698	92.788318	**0.051**	Niz Laukhowa
N11	26.502222	92.783989	BDL	Pub Salpara
N12	26.501347	92.783116	0.006	Salpara
N13	26.366522	92.702891	0.005	Diphalu
N14	26.343089	92.733348	**0.016**	Chakarigaon
N15	26.348888	92.757914	BDL	Niz Gumuthagaon
N16	26.365757	92.763978	**0.012**	Nartum Gaon
N17	26.349394	92.80802	0.001	Chalchali Jalah
N18	26.343797	92.86753	**0.037**	Chapanal Grant
N19	26.342008	92.868683	0.001	Chapanala
N20	26.327982	92.841075	0.006	Killing Nepali Gaon
N21	26.327982	92.841075	**0.022**	Kaziranga road
N22	26.343055	92.754493	0.01	Gomothagaon
N23	26.398157	92.461814	**0.016**	Bichamari
N24	26.247	92.431	**0.011**	Ghasibari
N25	26.554161	92.93928	**0.055**	Gomotha
N26	26.203	92.448	**0.012**	Chaobori
N27	26.220045	92.485975	**0.011**	Duboritoli Kolongpar
N28	26.46623	92.491669	**0.015**	Bilatia
N29	26.543003	92.988402	**0.053**	Bamunigaon

In 27 samples out of 54 in both Darrang and Nagaon of Assam under investigation, the Arsenic contents were above the guideline value of 0.01ppm as set by WHO (WHO, 2011), EPA and ISI. However, the possibility of distribution of the Arsenic to the toxic level to more water sources cannot be ruled out in the area. Moreover, in 5 samples the Arsenic contents were predominantly high above the guideline value of 0.05ppm as set by Bureau of Indian Standards (BIS).

According to Singh (2004), high concentration of arsenic in groundwater of North eastern states of India viz. Assam, Manipur, Mizoram etc. has become a major cause of concern in recent years. The problem of arsenic in groundwater in Assam is also a matter of great concerned. The presence of groundwater arsenic in the state of Assam was first reported by Singh (2004), NERIWALM. His study revealed that 20 of the 30 districts of Assam have arsenic concentration exceeding 0.050 mg/l. Another study by Chakraborty et al. (2004) revealed that several underground water sources in India's northeast are unfit for consumption due to highly toxic contamination of arsenic. In 2005, Public Health Engineering Department (PHED), Assam carried out a state wide blanket survey for arsenic contamination in drinking water. In total 5729 water samples collected from 22 of the 30 districts in Assam, where the water samples collected from 18 districts had arsenic concentration greater than 0.05 mg/l. Chetia et al. (2010) have studied about Groundwater arsenic contamination in Brahmaputra River basin of Golaghat district (Assam). They observed a very significant correlation between arsenic and iron and suggested that the mobilisation of arsenic in the groundwater of that region may have been caused by the reductive breakdown of arsenic-iron featuring minerals. Ali Shah (2012) have studied on the Role of Quaternary stratigraphy on arsenic-contaminated groundwater from parts of Barak Valley, Assam, North–East India'. He suggested deeper tubewells (>60 m) in Plio Pleistocene Older Alluvium aquifers would be a better option for arsenic-safe groundwater. Mahanta et al. (2016) have studied about health costs of arsenic contamination of drinking water in Assam. They estimated three structural equations to determine health costs due to arsenic contamination and showed that the annual household health cost of a 1µg increase in arsenic concentration per litre is about INR 4. This study draws a policy implication for providing safe drinking water in Assam. Jain et al. (2018) reported on Physio-chemical characteristics and hydro geological mechanisms in groundwater with special reference to arsenic contamination in Barpeta District, Assam (India). From their study it is found that the groundwater samples are contaminated with high amount of arsenic, which refers that water is unfit for consumption as well as agricultural activities. Hydrogeological studies revealed that regional geological factors might be responsible for excess arsenic concentration in the region. Sathe et al. (2020) have suggested that Arsenic enrichment in the shallow aquifer, contaminating groundwater source, has been envisaged as a serious health concern in parts of the Brahmaputra floodplains (BFP), Assam, India. It is observed that in some of the district such as Morangi, Golaghat South, Kaliapani, and Majuli, where the data are almost absent. Fatoki et al. (2022) revealed the significance of arsenic toxicity and its contribution to health related challenges. S. Sathe et al. (2020) have suggested that Arsenic enrichment in the shallow aquifer, contaminating groundwater source, has been envisaged as a serious health concern in parts of the Brahmaputra floodplains (BFP), Assam, India. Nath et al. (2022) presented the high- and low-risk areas in the two most affected districts of Assam, as well as the moderate-risk areas in the district of Majuli, whose inhabitants are relatively poor Darrang district in Assam, India, has faced issues related to arsenic contamination in groundwater.

In our study, a total of 25 water samples were collected from various Gaon-Panchayats (GPs) and villages in Darrang district. Analysis conducted at the Public Health Laboratory in Betkuchi revealed that 12 of these samples exceeded the WHO's permissible limit of 0.01 ppm for arsenic, highlighting significant contamination. Similarly, Nagaon district also faces issues with arsenic contamination. Out of 29 samples collected in April, 15 samples were found to have arsenic concentrations exceeding the WHO guideline value of 0.01 ppm. These findings underscore the widespread presence of arsenic in both districts and the urgent need for effective monitoring and remediation strategies to address the contamination.

4.7.1 Statistical Analysis of Arsenic contaminations –

Microsoft Excel version 2007 is used for descriptive statistical analysis.

Table- 4.5 Statistical Analysis of Arsenic contaminations in Darrang district.

SAMPLE ID	CONCENTRATION (PPM)	VILLAGE
D1	**0.055**	Hati bakar
D3	**0.011**	Konwarpara
D4	**0.0149**	Major chuba
D7	**0.038**	Suktaguri no 1
D8	**0.02**	Chamuapara
D9	**0.051**	Dumuni chowki
D10	**0.052**	Naodingerdal

D11	**0.011**	Kholihoi gaon
D16	**0.029**	Kumarpara
D17	**0.025**	Borigaon
D23	**0.03**	Nadirtari chuba
D24	**0.04**	Uttar bherua
STATISTICS		
MAXIMUM	0.055	
MINIMUM	0.011	
AVERAGE	0.031408333	
STD DEV	0.015857918	

The maximum arsenic concentration in Darrang district is found in Hati Bakar of 0.055ppm or 55ppb indicating high presence of arsenic in drinking water hand-pumps in Hati Bakar.

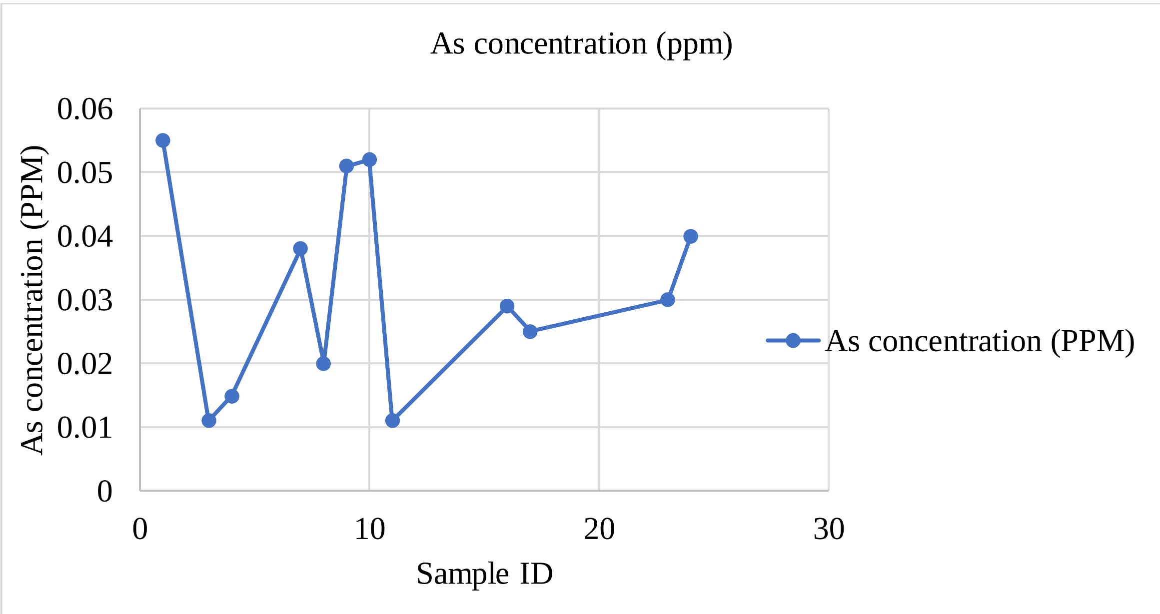

Fig- 4.10 Variation of Arsenic in Darrang district.

Table- 4.6 Statistical Analysis of Arsenic contaminations in Nagaon district.

SAMPLE ID	As CONCENTRATION (PPM)	VILLAGE
N5	**0.013**	Nonoi Namkuri
N6	**0.014**	Nagaon-Lumding Rd

N8	**0.03**	Lawkhowa Nangaldhua
N10	**0.051**	Niz Laukhowa
N14	**0.016**	Chakarigaon
N16	**0.012**	Nartum Gaon
N18	**0.037**	Chapanal Grant
N21	**0.022**	Kaziranga road
N23	**0.016**	Bichamari
N24	**0.011**	Ghasibari
N25	**0.055**	Gomotha
N26	**0.012**	Chaobori
N27	**0.011**	Duboritoli Kolongpar
N28	**0.015**	Bilatia
N29	**0.053**	Bamunigaon
STATISTICS		
MAXIMUM =	**0.055**	
MINIMUM =	**0.011**	
AVERAGE =	**0.024533333**	
STD DEV =	**0.016457159**	

The maximum Arsenic concentration of 0.055ppm or 55ppb in Nagaon district is found in Gomotha village which is located near River Brahmaputra.

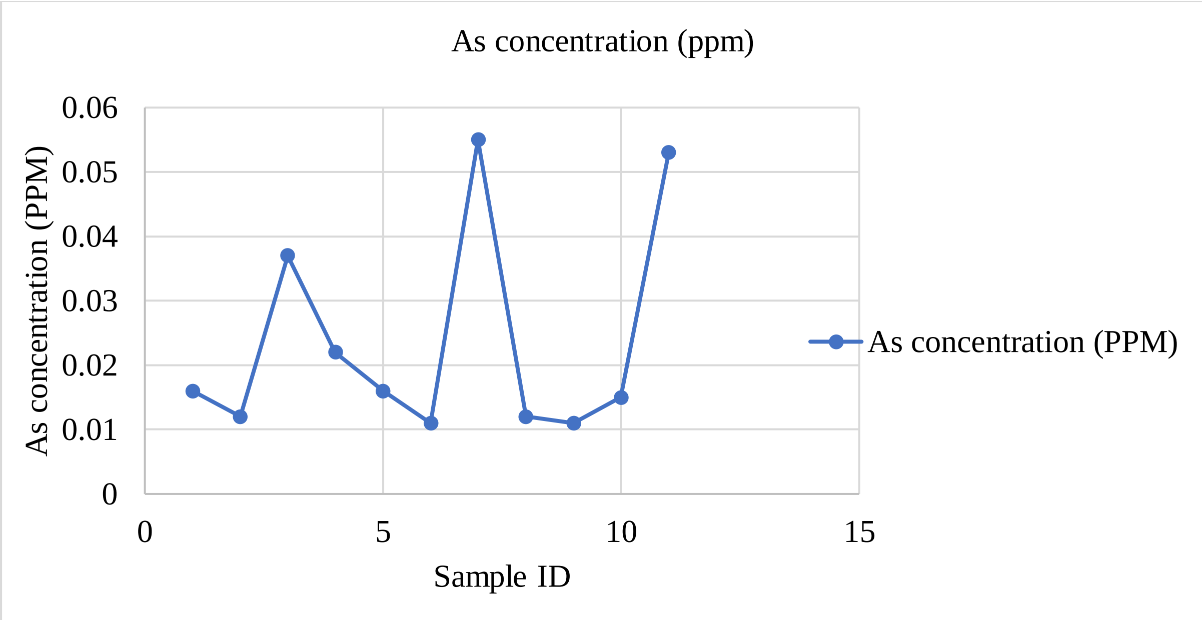

Fig 4.11 – Variation of Arsenic in Nagaon district.

Comparing the Statistical Analysis of Arsenic contaminations in Darrang and Nagaon district of Assam is tabulated below-

Table- 4.7 Statistical Analysis of Arsenic contaminations in Darrang and Nagaon district.

Statistics	**Arsenic in Darrang**	**Arsenic in Nagaon**
Maximum	0.055	0.055
Minimum	0.011	0.011
Average	0.031408333	0.024533333
Std Dev	0.015857918	0.016457159

The average values of Arsenic ranges from 0.03 in Darrang to 0.02 in Nagaon district of Assam.

The assessment of arsenic concentrations in groundwater across Darrang and Nagaon districts reveals notable differences in contamination levels. In both districts, arsenic concentrations ranged from 0 to over 50 ppb, indicating a significant variability in water quality. Notably, 52% of samples from Darrang district and 48.28% of samples from Nagaon district recorded arsenic levels below 10 µg/L or below the detection limit. However, a substantial portion of the water samples exceeded the WHO permissible limit, with 51.72% of samples in Nagaon and 48% in Darrang district showing concentrations above this threshold.

The data highlights that groundwater in Darrang district exhibits higher levels of arsenic contamination compared to Nagaon district. Specifically, 12% of samples in Darrang district and 6.89% in Nagaon district had arsenic concentrations surpassing both WHO and BIS permissible limits. These findings suggest that Darrang district is more heavily impacted by arsenic contamination than Nagaon, emphasizing the need for targeted interventions and remediation efforts. The elevated levels in Darrang district warrant immediate action to address and mitigate arsenic pollution to protect public health and ensure safe drinking water.

CHAPTER -5

Elevation and Arsenic Contamination Analysis Using Arc-GIS

5.1 Introduction –

Groundwater occurs almost everywhere beneath the land surface. Arsenic contamination in groundwater is a form of groundwater pollution. Arsenic is a chemical element with the symbol 'As' and atomic number 33. Arsenic in water is a vital problem in many countries around the world including Bangladesh, India and China etc.

5.1.1 Geographical Information System - GIS (geographic information system) is a computer-based information system used to digitally represent and analyse geographic data. Also, it is a system designed to capture, store, analyse, manage, and present all types of spatial or geographical data. The GIS uses layers, called 'themes', to overlay different types of information to a geographic background. GIS has emerged as an effective tool for handling spatial data and decision making in several areas including engineering and environmental fields (Stafford, 1991; Goodchild, 1993). GIS provides a means of representing the real world through integrated layers of constituent spatial information (Corwin, 1996).

5.1.2 Arc GIS – Arc GIS is an online geographic information system (GIS) software developed and maintained by ESRI. ArcGIS is a geographical information system (GIS) software that allows handling and analyzing geographic information by visualizing geographical statistics through layer building maps like climate data or trade flows. It's used by a whole host of academic institutions and departments, both in the humanities and sciences, to develop and illustrate groundbreaking research. Further, it is used by several governments and private/commercial institutions worldwide. The system has the capacity to create geographical information accessible throughout a company, institution, privately or publicly on the internet. Therefore, the software essentially works as a platform whereby geographical information can be linked, shared and analyzed (https://www.geospatialworld.net). ArcGIS creates maps that require categories organized as layers. Each layer is registered spatially so that when they're overlaid one on top of another, the program lines them up properly to create a complex data map. The base layer is almost always a geographical map, pulled out of a range of sources depending upon the visualization needed (satellite, road map, etc). This program has a lot of them available to users and also contains live feed layers including traffic details.

The first three layers are called feature or vector layers, each containing individual functions distinguished through the platform. These are:

- **points** (like landmarks, buildings)
- **lines** (like roads and other 1D schemata)
- **polygons** (like political information and geographical census, called 2D data)
- **raster images** (a base vector layer like an aerial picture)

5.1.3 Digital Elevation Model - A Digital Elevation Model (DEM) is a representation of the bare ground (bare earth) topographic surface of the Earth excluding trees, buildings, and any other surface objects (https://www.usgs.gov). Digital Elevation Modeling (DEM) is not only an important basic geographic information data of the city, but also an important element to describe and express the topography. A detail and high-resolution terrain are essential for management in various domains (Zhang Longqi et al., 2023). DEMs are created from a variety of sources. USGS DEMs used to be derived primarily from topographic maps. Those are being systematically replaced with DEMs derived from high-resolution lidar and IfSAR (Alaska only) data.

A Digital Elevation Model is a type of raster GIS layer. They are raster grids of the Earth's surface referenced to the vertical datum—the surface of zero elevation to which heights are referred to by scientists, insurers, and geodesists (https://up42.com).

It is a digital cartographic dataset that represents a continuous topographic elevation surface through a series of cells. Each cell represents the elevation (Z) of a feature at its location (X and Y). Digital Elevation Models are a "bare earth" representation because they only contain information about the elevation of geological (ground) features, such as valleys, mountains, and landslides, to name a few. They do not include any elevation data concerning non-ground features, such as vegetation or buildings (https://equatorstudios.com).

Digital Elevation Models come in several different file formats, such as GeoTIFF, IMG, Gridfloat (.flt), and ArcGRID. However, the GeoTIFF file format is most commonly used throughout the geospatial community worldwide because of its interoperability among computer systems and many commercial GIS and spatial data analysis software products (https://equatorstudios.com)

5.2 Study Area –

Here in our study, Darrang and Nagaon districts in Assam has been selected for the evaluation of the dissertation. The Geographical description, Geological features and topography has been discussed in Chapter – 3 page no 18-24 for both the districts, respectively.

5.3 Methodology -

5.3.1 Data collection and Analysis –

Standard protocol was used for sample collection and analysis in this study. Twenty five (25) and twenty nine (29) water samples were taken from Darrang and Nagaon districts of Assam and the source was Hand pump or Tube wells. The collected water was intended to be used for human consumption and agricultural purposes. Further the collection. the samples were tested in Public Health Laboratory, Betkuchi, Guwahati and Public Health Laboratory, Mangaldoi Division. The detailed description of the collection procedure and analysis is discussed in Chapter 4 (4.3 – 4.6) page no 28-38 of this paper.

The shape files (.shp format) of Administrative Database were downloaded from https://onlinemaps.surveyofindia.gov.in for computing the Digital Elevation Model.

The Digital Elevation data were downloaded from https://earthexplorer.usgs.gov by creating polygons along the boundaries of respective districts, and setting data in SRTM 1 Arc-Second Global. The tiles were downloaded in GeoTiFF format.

5.3.2 Software used –

The Digital elevation modelling of contamination of Arsenic in ground water of the study area is performed in Arc-GIS software Desktop version 10.4.

5.4 Results and Discussion –

5.4.1 Mosaic or combine or Merge Raster datasets using Arc-GIS –

The downloaded Digital Elevation Data from https://earthexplorer.usgs.gov for both Darrang and Nagaon district is added in Arc-GIS to perform Raster dataset respectively.

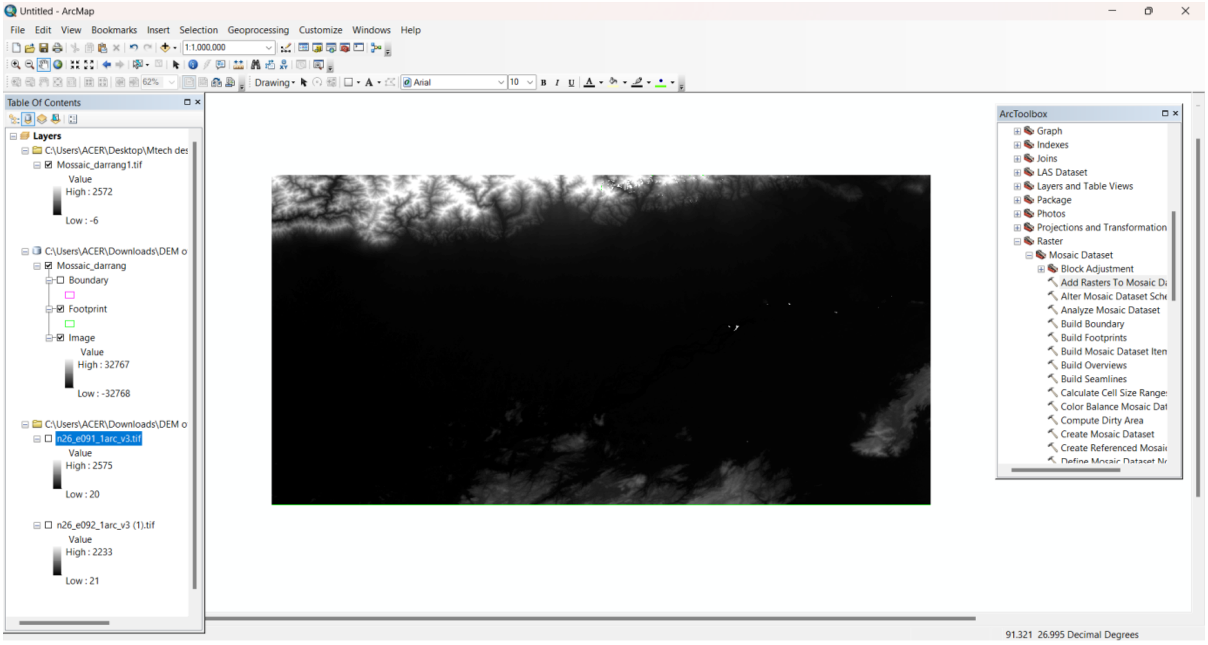

Fig 5.1 Mosaic dataset using Arc-GIS for Darrang district.

In fig 5.1 the elevation is high at 2572 and low elevation is at -6 in metres.

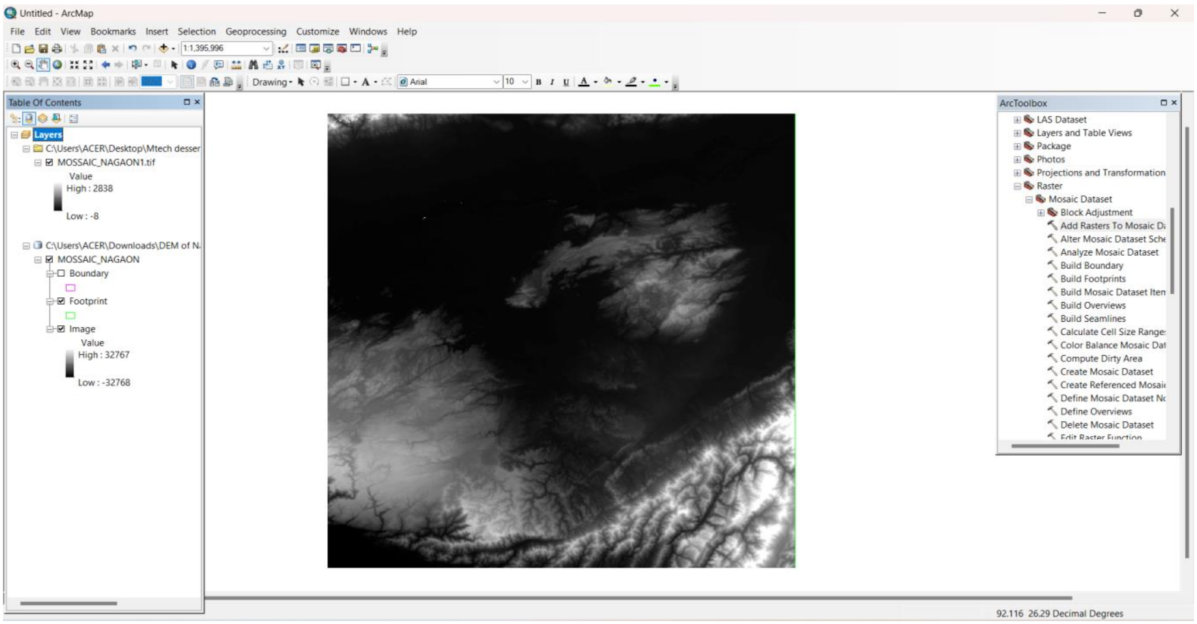

Fig - 5.2. Mosaic dataset using Arc-GIS for Nagaon district.

In fig 5.2 the high elevation is at 2838 and the low elevation is at -8 in metres.

The coordinate is set to GCS WGC 1984 according to geographical location of tiles downloaded.

5.4. The DEM is clipped using Arc GIS –

The shape file is added to Mosaic dataset and DEM is clip for both the districts respectively in Arc GIS software.

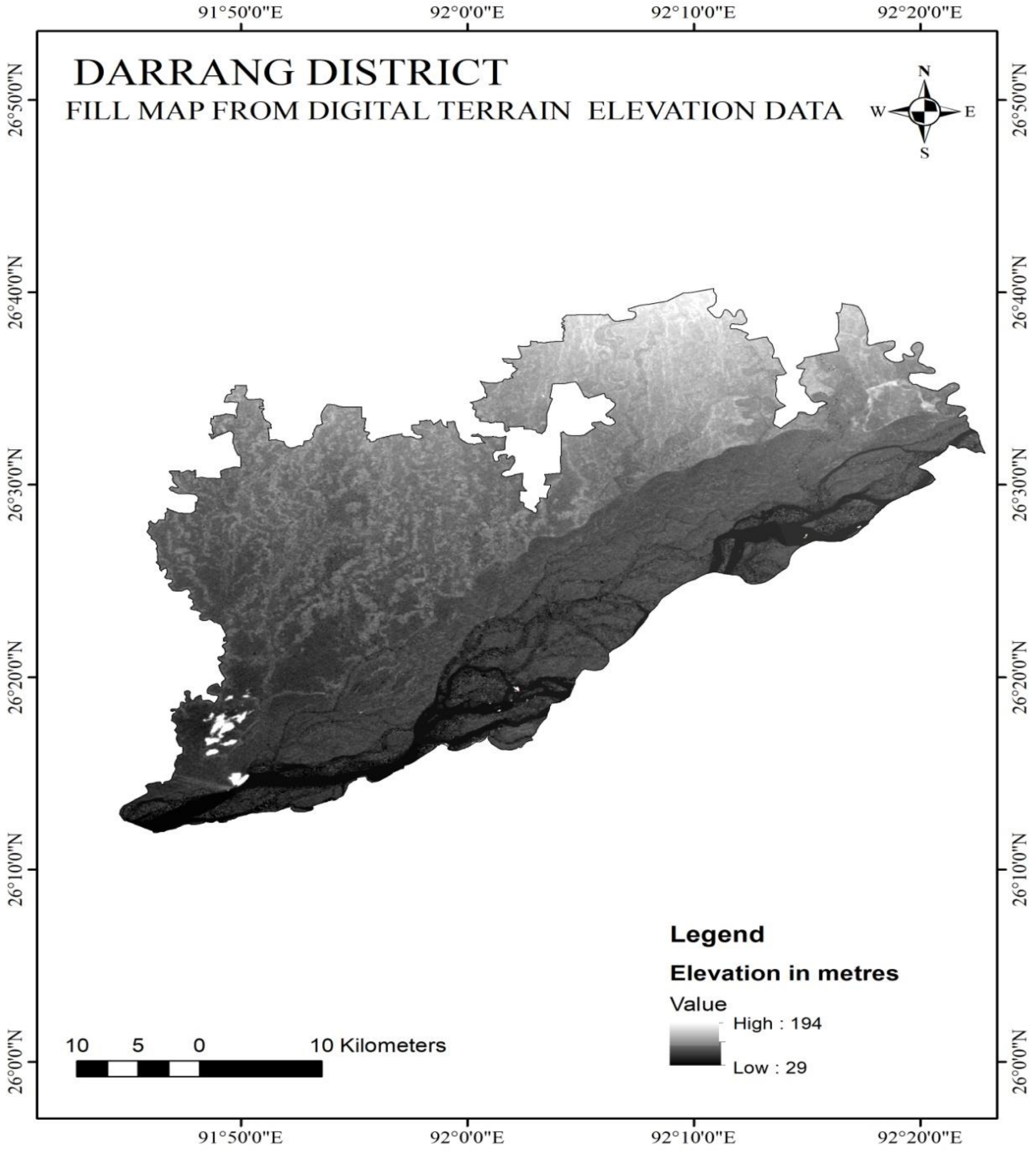

Fig-5.3 Digital Elevation Model of Darrang district.

In Darrang district, Elevation is high at 194m and low at 29m from mean sea level (MSL).

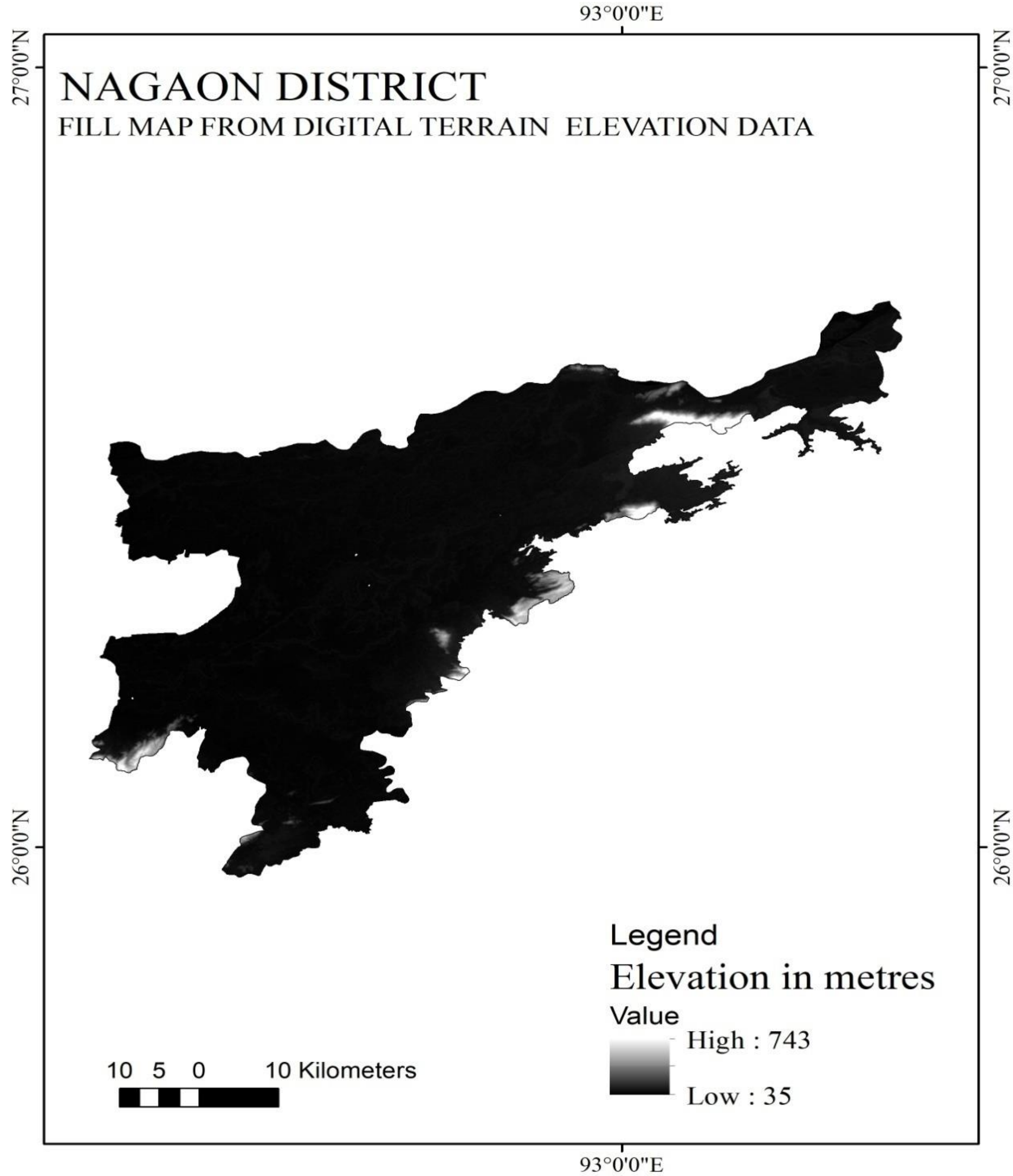

Fig 5.4 Digital Elevation Model of Nagaon district.

The elevation in Nagaon, as computed from the digital elevation model, peaks at 743 meters and reaches a minimum of 35 meters above sea level.

5.4.3 Reclassify and covert Raster to Polygon (shape file) and calculation of area using Arc GIS -

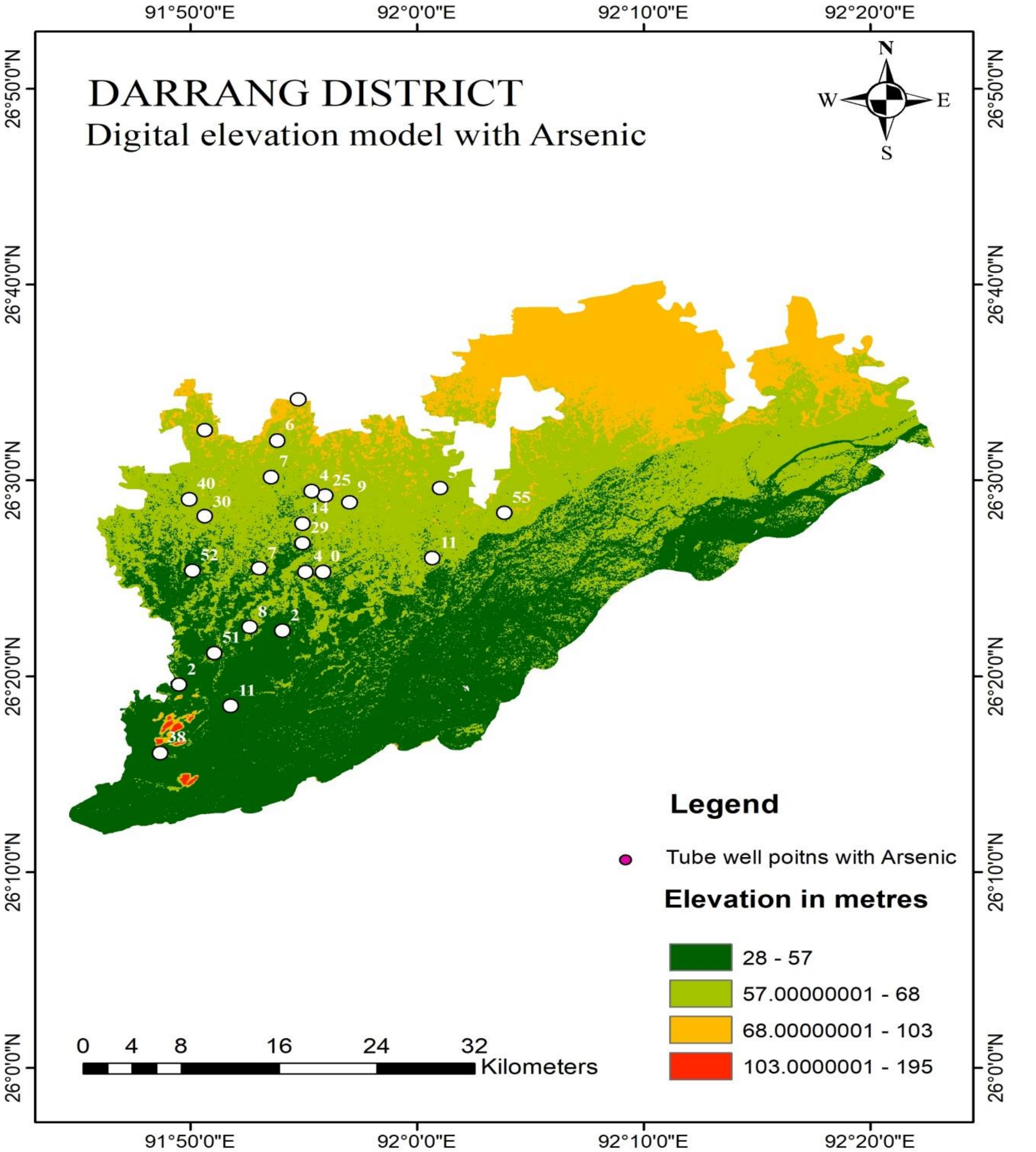

Fig 5.5 Elevation and groundwater arsenic contamination in Darrang district of Assam

Elevation of the study area Darrang district has been classified in four categories. Elevation between 28 -57 meters from mean sea level is classified as first category. Elevation between 57 to 68 meters of the study area has been classified as second class. Elevation between 68 to 103 meters classified as third category. 103 to 195 metres has classified as fourth category.

Surface elevation of the study area ranges from 28 meters to 195 meters above mean sea level. About 664 sq km of the study area is between 28 -57 meters elevation (41.6 per cent). Average groundwater arsenic contamination on that area is 21 ppb. Six hundred forty two sq km (40.6 per cent) area of Darrang district is under 57 to 68 meters elevation. Average groundwater arsenic contamination on that area is 19ppb. In Darrang district 273 sq km area (17.6 per cent) has elevation between 68 to 103 meters. Average groundwater arsenic contamination on that area is 7.5 ppb. About 3 sq km area (0.2 per cent) of the study area has elevation between 103 to 195 meters. There is no Average groundwater arsenic on that elevation topography. In Darrang district Average groundwater arsenic concentration is high in low elevation area. In high elevation area groundwater arsenic contamination is very low or no arsenic can be detected. Generally, higher elevations tend to have lower arsenic levels compared to lower elevations. This is because arsenic tends to accumulate in certain geological formations and can be more concentrated in groundwater or soil at lower elevations. Factors such as geology, groundwater flow patterns, and human activities can also influence arsenic levels in specific locations. Therefore, elevation can be a significant factor in understanding and predicting arsenic concentrations in the environment.

Table 5.1 Digital elevation model and arsenic in Darrang district.

Sl no.	Elevation in metre	Area in sq km	Area in Percentage	Average Arsenic (ppb)
1	28-57	664	41.6	21
2	57-68	642	40.6	19
3	68-103	273	17.6	7.5
4	103-195	3	0.2	0
Total		1582	100	

According to official government records, the area of Darrang is documented as 1585 square units. In contrast, data obtained from Arc GIS reports the area of Darrang as 1582 square units. This small difference in area measurements between Arc GIS and government website are typically may be due to variations in coordinate systems, data accuracy, rounding methods, boundary definitions, updates, and calculation methodologies.

Mukherjee et al. (2020) found that arsenic (As) contamination in Ladakh's groundwater is primarily sourced from volcanic rocks and ophiolitic mélange. In the region, 70% of groundwater samples from complex bedrock aquifers exceed the WHO limit of 10 µg/L. Hot springs also show higher arsenic levels compared to regional groundwater. The study highlights that arsenic enrichment is associated with increased temperature and depth, with volcanic and ophiolitic melange aquifers identified as major sources.

Another study by Sarmah et al. (2023) investigated the relationship between surface elevation and groundwater arsenic contamination in Darrang district, Assam. Their study revealed that arsenic levels are highest in areas up to 100 meters above sea level, with an average concentration of 28 ppb over 435 sq km (27.45% of the district). In areas with elevations between 100 and 200 meters, the average arsenic concentration is 9 ppb across 423 sq km (26.69%). For elevations between 200 and 300 meters, the average drops to 3 ppb over 403 sq km (25.42%). At 300 to 400 meters, the average concentration is 2 ppb across 32 sq km (20.32%), and above 400 meters, where only 2 sq km (0.12%) is affected, no arsenic contamination is detected. This indicates that arsenic contamination in groundwater is significantly higher at lower elevations and markedly lower at higher elevations.

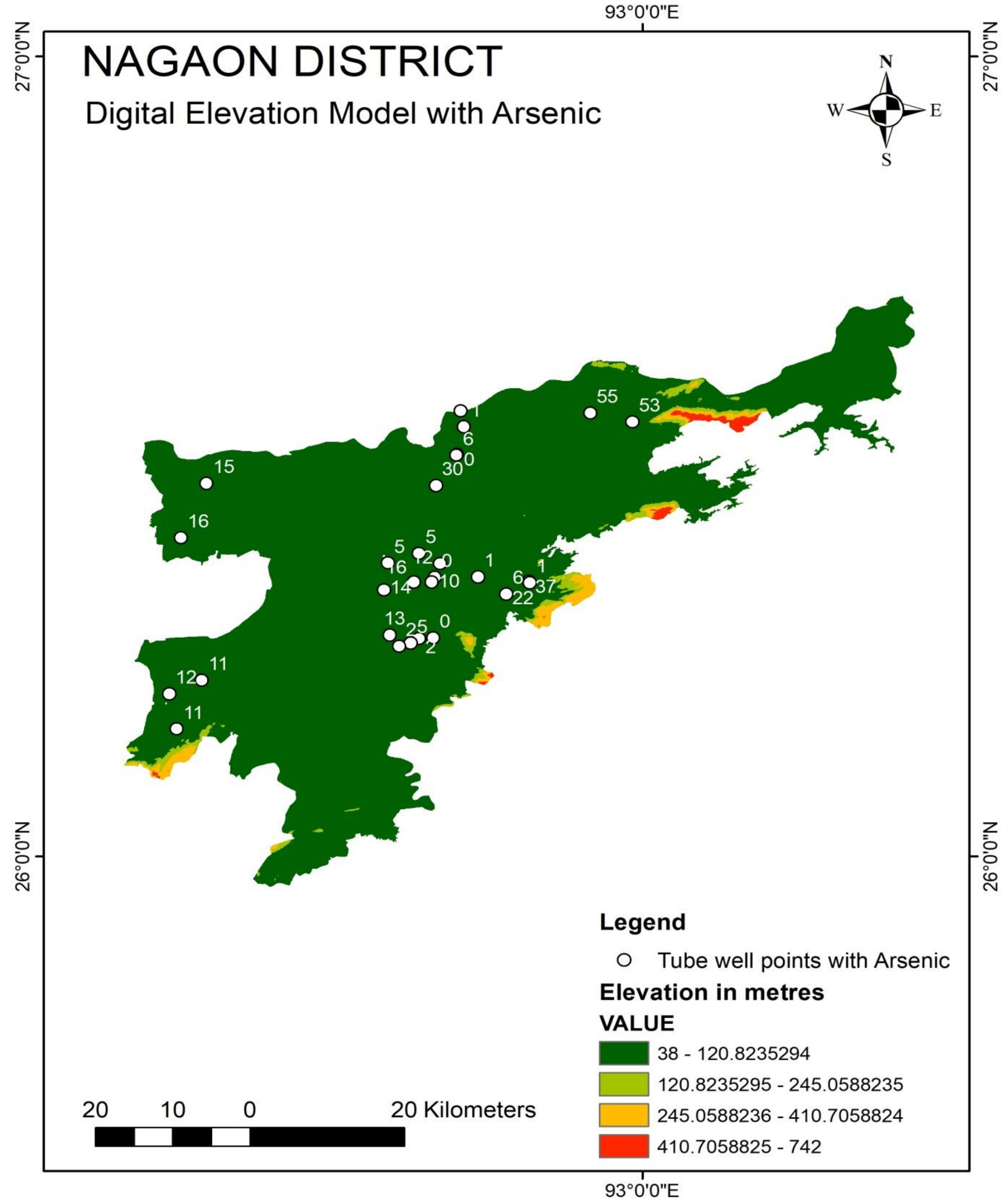

Fig 5.6 Elevation and groundwater arsenic contamination in Nagaon district of Assam

Elevation of the study area Nagaon district has also been classified in four categories. Elevation between 38 -120 meters from mean sea level is classified as first category. Elevation between 120 to 245 meters of the study area has been classified as second class. Elevation between 245 to 410 meters classified as third category. 410 to 742 metres has classified as fourth category. Surface elevation of the study area ranges from 38 meters to 742 meters above mean sea level. About 2278 sq km of the study area is under 38 -120 meters from mean sea level elevation (96 percent). Average groundwater arsenic contamination on that area is 15.8 ppb. Forty five sq km (2 per cent) area of Nagaon district is under 120 to 245 meters elevation. In Nagaon district 37 sq km area (1.5 per cent) has elevation between 245 to 410 meters. About 13 sq km area (0.5 per cent) of the study area has elevation between 410 to 742 meters. Average groundwater arsenic on elevation second, third and fourth category is 0 ppb as 96 percent of area of Nagaon district is covered with elevation in first category of 38 – 120 metres above Mean sea level. In Nagaon district Average groundwater arsenic concentration is high in low elevation area. In high elevation area groundwater arsenic contamination is very low and cannot be detected.

Since 96% of the total land area or geographical extent being considered falls within this lowest elevation range of 38 to 120 metres above mean sea level, this would imply that higher elevations (such as upland, mountain, or alpine areas) cover only a small percentage (4%) of the total area. This interpretation would indicate a distribution where the majority of the area considered is at lower elevations; the contamination of arsenic is more in that elevation. As higher elevations covering a smaller fraction, so no contamination of arsenic can be found in those regions having high elevation.

Table 5.2 Digital elevation model and arsenic in Nagaon district.

Sl no.	Elevation in metre	Area in sq km	Area in Percentage	Average Arsenic (ppb)
1	38-120	2278	96	15.8
2	120-245	45	2	0
3	245-410	37	1.5	0
4	410-742	13	0.5	0
Total		2373	100	

There appears to be a discrepancy between the reported area (sq km) of Nagaon. Officially, it is documented as 2,287 square kilometres (https://nagaon.assam.gov.in) , whereas in our study, it is recorded as 2,373 square kilometres. Potential reasons for this difference include:

1. Data Sources: Different studies may use data from varying sources or different versions of geographic datasets, leading to discrepancies in area calculations. In our study the shape files

(.shp format) of Administrative Database were downloaded from https://onlinemaps.surveyofindia.gov.in and the Digital Elevation data were downloaded from https://earthexplorer.usgs.gov by creating polygons along the boundaries of respective districts, and setting data in SRTM 1 Arc-Second Global.

2. Methodology: Studies may employ different methodologies for measuring and calculating geographic areas, such as different map projections or approaches to handling boundaries.

3. Updates and Revisions: Geographic boundaries and area calculations can be updated over time due to new surveys, satellite imagery, or administrative changes, which may result in updated figures.

4. Accuracy and Precision: Differences in the precision of measurements and the resolution of geographic data used in the studies can also contribute to discrepancies in reported area values.

A study by Rahman et al. (2016) found that in Ballia district, India, only 6% of the area (175 sq km) with a surface elevation of 72–73 meters has arsenic (As) within the permissible limit of 10 ppb. Conversely, 94% of the area (2806 sq km) with elevations between 56 and 73 meters has arsenic levels exceeding 15 ppb. The scatter plots indicate a strong non-linear positive correlation between arsenic concentration and surface elevation, with correlation coefficients of 0.89 and 0.76 for pre-monsoon and post-monsoon seasons, respectively. This suggests that lower elevations are associated with higher arsenic concentrations, while higher elevations have lower arsenic levels.

The analysis of elevation and arsenic contamination using ArcGIS has provided significant insights into the spatial distribution of arsenic in groundwater. The study reveals a clear inverse relationship between surface elevation and arsenic concentration. Specifically, areas at lower elevations consistently show higher levels of arsenic contamination compared to higher elevation regions. This pattern is evident across various study areas, including Darrang district and Nagaon district, where lower elevation zones exhibit elevated arsenic levels, while higher elevations have lower concentrations.

These findings underscore the importance of incorporating elevation data into groundwater quality assessments and management strategies. The inverse relationship between elevation and arsenic concentration highlights the need for targeted monitoring and remediation efforts in low-lying areas. Additionally, the use of ArcGIS for spatial analysis has proven to be a valuable tool in understanding and visualizing the distribution patterns of arsenic contamination, facilitating more informed decision-making and effective intervention strategies to ensure safe drinking water.

CHAPTER – 6

SPATIAL DISTRIBUTION OF ARSENIC CONTAMINATION USING IDW INTERPOLATION IN ARC-GIS

6.1 Introduction –

Interpolation is the process of estimating unknown values that fall between known values. A few studies have used methods of Interpolation such as Thiessen polygon, inverse distance weighing (IDW) (Gong et al., 2014), global polynomial interpolation (Bhunia et al., 2016), and kriging (Gong et al., 2014; Sovann and Polya, 2014) to predict the spatial variation of contaminants in groundwater from different aquifers of the world. Although these methods are effective, non-availability of accurate spatial data points is the hurdle to produce meaningful outcomes. However, these methods do not account for spatial dependency of the data to predict the occurrence of the contaminants.

6.1.1 Spatial interpolation –

The continuous data for the unsampled areas in the study area can be identified with the help of spatial interpolation method based on the actual results (Hossain et al. 2023). It is an essential tool for spatial analysis and modelling, and a wide range of interpolation techniques are available depending on the characteristics of the data and the research question (Liang et al. 2017). The two primary kinds of spatial interpolation techniques are deterministic and stochastic. Deterministic methods rely on mathematical formulas that estimate values at unsampled sites using measured values at nearby places. Inverse Distance Weighing IDW, kriging, and spline interpolation are a few examples of deterministic interpolation methods (Taheri and Mohamadi 2019). A well-liked technique for spatial interpolation is inverse distance weighting (IDW), which estimates values at unmeasured places from measured values at nearby locations. The interpolation calculation gives a known location more weight the closer it is to the unknown place (Gong et al. 2014). To illustrate the spatial distribution, IDW was used in this paper to predict the location's concentration using Arc GIS 10.4.

6.1.2 Inverse Distance Weighing IDW –

Inverse Distance Weighting (IDW) is one of the interpolation techniques. It explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted.

6.2 Study Area –

This study was conducted in Darrang and Nagaon district of Assam, located in the north-eastern of India, covering an area of 1585 km^2 (Sarma et al. 2023) and 2287 km^2 (https://nagaon.assam.gov.in) in Darrang and Nagaon district respectively.

(Refer to Chapter – 3 page no18-24 for detailed description of the study area).

6.3 Methodology –

6.3.1 Data collection and laboratory analysis –

Groundwater samples were collected from Darrang and Nagaon districts of Assam in winter and summer to avoid monsoon dilution. Samples were randomly chosen across different administrative units. Twenty-five (25) and Twenty-nine (29) samples were collected in 500 ml pre-washed high-density polyethylene bottles from Darrang and Nagaon district respectively. The sampling sites were geographically pinpointed using GPS, and the water was collected from deep tube wells or hand pumps.

As levels were measured using a UV-spectrophotometer (DR 6000) in Public Health Laboratory, Betkuchi and Public Health Laboratory, Mangaldoi division.

6.3.1. Hazard map generation -

Hazard maps for As were created using inverse distance weighted (IDW) interpolation in Arc-Map (Version 10.4) for both Darrang and Nagaon districts. This non-geostatistical tool averages values from neighbouring areas, weighted by distance. The IDW power coefficient, a key accuracy factor, determines the influence of adjacent points (Li & Heap 2008). Other techniques like Thiessen polygon, kriging can be considered based on sample distribution and phenomena studied. The UTM projection system within zone 46 N-Datum Geodetic System (WGS) 1984 was used for spatial distribution maps, categorized into five classes (Mosaferi et al. 2014) as No risk, Medium risk, High risk, Very high risk.

6.4 Results and Discussion –

Arsenic concentrations in the study area are categorized into five classes according to safety thresholds. Category 'No Risk' ranges below 10 ppb or 0.01ppm and it indicates that there is an absence or negligible possibility of harm, danger, or adverse consequences.

Category 'Low Risk' ranges between 0.01 – 0.02ppm and it implies that the probability of encountering adverse effects or consequences is significantly low compared to higher risk zones.

Category 'Moderate Risk' ranges between 0.02 - 0.027ppm and it refers to a level of risk that is neither very low nor very high, indicating a medium level of potential harm or adverse consequences.

Category 'High Risk' ranges between 0.027 – 0.037ppm refers to a situation where there is a significant probability of encountering adverse effects or consequences that could cause considerable harm or damage.

Category 'Very High Risk' ranges between 0.037 – 0.54ppm 2 indicates an even greater level of potential harm or danger, often implying a critical or urgent need for mitigation measures to reduce the likelihood of severe consequences.

Hussain et al. (2016) analyzed the spatial distribution of arsenic in groundwater and its link to major human diseases in District Layyah. Using the Inverse Distance Weight (IDW) technique, they mapped arsenic concentrations and developed an Arsenic Risk Index (ARI) based on WHO standards. The study classified the area into two risk zones: no risk (≤10 ng/ml) and high risk (>10 ng/ml). The results indicate high arsenic levels near the Indus River, with concentrations decreasing towards the central and eastern parts near the Chenab River. Another study by Ghosh et al. (2020) utilized spatial interpolation techniques, specifically Thiessen polygon and Kriging, to map arsenic contamination in groundwater across North 24 Parganas, West Bengal. This area, known for severe arsenic pollution, was classified into seven zones based on arsenic levels. The study analyzed six seasonal datasets from 2006 to 2008 to observe temporal changes and project future trends in arsenic concentration.

6.4.1. Hazard map of arsenic in Darrang district –

The Hazard Map of Darrang district was created using the Inverse Distance Weighting interpolation technique in Arc GIS 10.4 and categorizes arsenic concentrations into five distinct levels. These categories align with international and national standards:

- The 'No Risk' category adheres to the World Health Organization's recommended limit of 0.01 mg/L.
- The 'Very High Risk' category denotes concentrations exceeding the Bureau of Indian Standard limit of 0.05 mg/L (WHO 2008; Department of Environment 2023).

Chowdhury et al. (2024) employed Geographic Information Systems (GIS) and Inverse Distance Weighting (IDW) methods to create hazard maps for assessing arsenic contamination across various upazilas in the Sylhet district. The study classified arsenic concentrations into five categories based on safety thresholds: 'Excellent' (WHO recommended limit of 0.01 mg/L) and 'No Risk' (Bangladesh National Standard of 0.05 mg/L), which together cover 1,762 km² or 51% of the study area. The remaining regions are categorized into medium, high, or extremely high-risk zones, comprising 29%, 17%, and 3% of the area, respectively. The results highlight significant spatial variability in arsenic levels: Jaintia Pur, Zakiganj, Companiganj, Gowainghat, and Kanaighat have concentrations between 0.1 and 0.15 mg/L, indicating substantial risk, while northwestern and northeastern regions show levels of 0.06 to 0.09 mg/L. Central Sylhet remains within the safe range of 0–0.05 mg/L.

According to Table 6.1, the combined area of the 'No Risk' and 'Very High Risk' categories spans 462 km², which accounts for 29% of the study region. The remaining areas are classified as low-risk (43%), moderate-risk (17%), and high-risk (10.7%) zones based on their respective arsenic concentration ranges.

This classification provides a comprehensive overview of arsenic contamination levels across Darrang district, facilitating targeted interventions and regulatory measures to manage health and environmental risks associated with arsenic exposure.

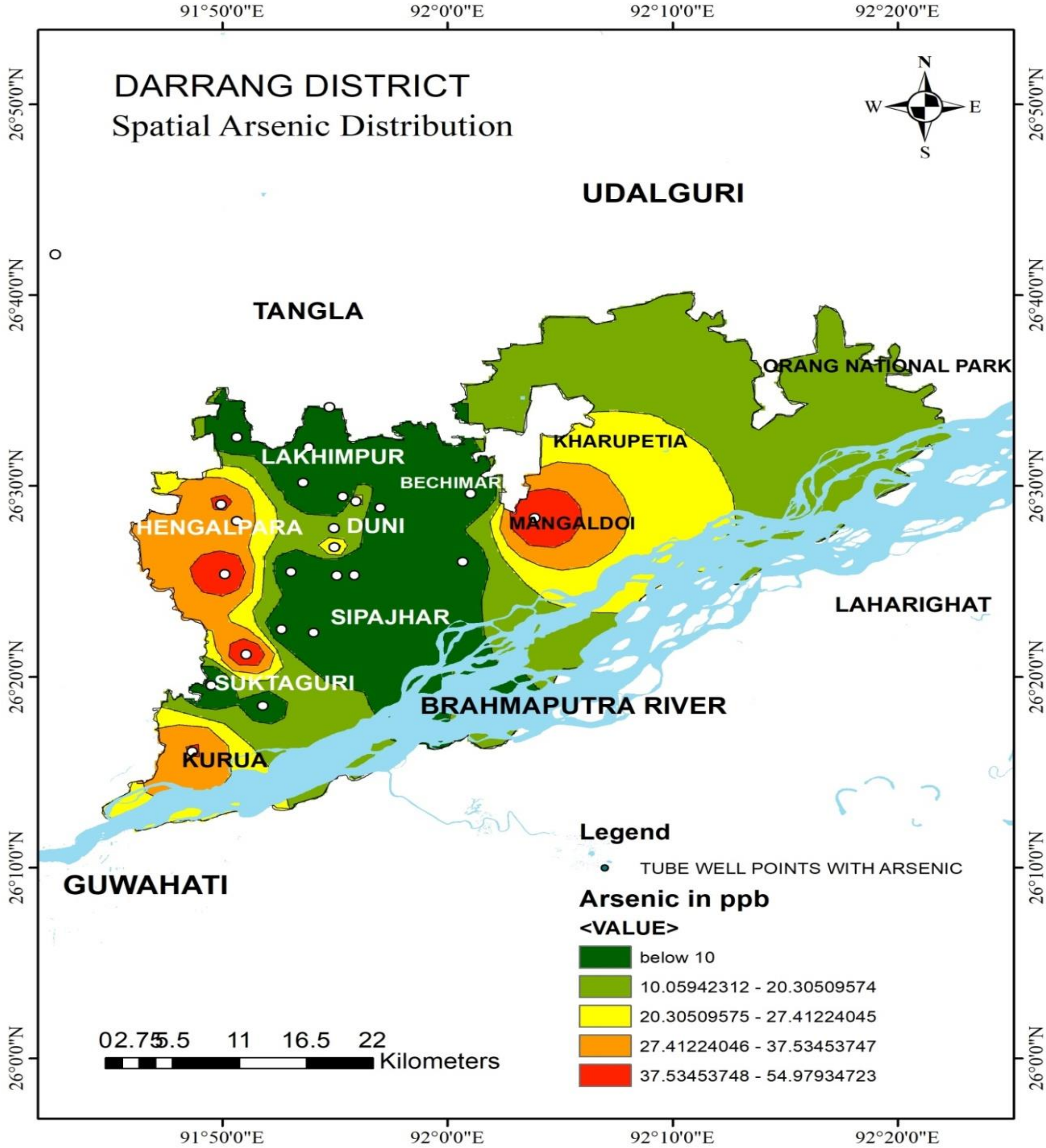

Figure 6.1 Hazard map for arsenic (As) in study area Darrang.

Figure 6.1 displays the spatial distribution of groundwater arsenic concentrations across 25 regions within Darrang district. It highlights significant variations in arsenic levels:

- Hati Bakar, Sukataguri No.1, Dumunichowki, Naodengerdal, and Uttar Bherua exhibit arsenic concentrations ranging from 0.037 to 0.054 mg/L, categorized as Very High Risk zones, indicating substantial health risks associated with arsenic contamination.
- Konwarpara, Major Chuba, and Kholihoi Gaon are categorized under the Low Risk zone, suggesting comparatively lower arsenic concentrations.
- Nadirtari Chuba falls within the High Risk zone, indicating elevated arsenic levels but not as severe as those in the Very High Risk zones.

This spatial representation helps in identifying areas of heightened arsenic contamination within Darrang district, guiding targeted mitigation efforts and public health interventions to address arsenic exposure risks effectively.

Table 6.1 Range of arsenic concentration and covered area for each range.

Range of Concentration (ppm)	< 0.01	0.01 - 0.02	0.02 - 0.27	0.027 - 0.037	0.037 - 0.054
Reclassified Range	No Risk	Low Risk	Moderate Risk	High Risk	Very High Risk
Area (km^2)	418	681	272	171	44
Percentage of Area	26.5	43	17	10.7	2.7
Average Arsenic in ppm	0.006	0.014	0.025	0.03	0.047

According to Table 6.1, the distribution of areas categorized by arsenic risk levels in Darrang district is as follows:

- The Low Risk range covers 681 sq km, which represents 43% of the total area.
- The Very High Risk range has the smallest coverage, accounting for 2.7% or 44 sq km of the district's total area.

This table provides a clear overview of the spatial distribution of arsenic contamination levels across Darrang district, highlighting the significant extent of areas categorized under Low Risk and the smaller but notable area under Very High Risk.

Table 6.2 Reclassified range of values alongside their corresponding villages.

SAMPLE NO.	**CONCENTRATION (PPM)**	**VILLAGE**	**RECLASSIFIED RANGE**
D1	0.055	Hati bakar	Very High Risk
D2	0.005	Chaporiyal para	No Risk
D3	0.011	Konwarpara	Low Risk
D4	0.0149	Major chuba	Low Risk
D5	BDL	Ramgaon	No Risk
D6	BDL	Satghoria	No Risk

D7	0.038	Suktaguri no 1	Very High Risk
D8	0.02	Chamuapara	Moderate Risk
D9	0.051	Dumuni chowki	Very High Risk
D10	0.052	Naodingerdal	Very High Risk
D11	0.011	Kholihoi gaon	Low Risk
D12	0.008	Dheki para	No Risk
D13	0.007	Ghurachal	No Risk
D14	0.004	Muslim ghopa	No Risk
D15	0.002	Bijulibari	No Risk
D16	0.029	Kumarpara	Moderate Risk
D17	0.025	Borigaon	Moderate Risk
D18	0.007	Laltupara	No Risk
D19	0.004	Hirapara	No Risk
D20	0.009	Lozora	No Risk
D21	0.006	Lakhimpur(pub)	No Risk
D22	0.009	Pachim chuba	No Risk
D23	0.03	Nadirtari chuba	High Risk
D24	0.04	Uttar bherua	Very High Risk
D25	0.008	Kawaimari	No Risk

Table 6.2 categorizes locations/villages based on reclassified ranges of arsenic concentration as follows:

- The No Risk category, which ranges below 0.01 mg/l, includes 13 locations/villages.
- The Low Risk category, ranging between 0.011 and 0.02 mg/l, comprises 3 regions.
- In the Moderate Risk category, spanning from 0.02 to 0.027 mg/l, there are 3 locations/villages.
- The High Risk category, with a range between 0.027 and 0.037 mg/l, encompasses 1 village.
- The Very High Risk category, covering the range from 0.037 to 0.054 mg/l, includes the remaining 5 sampling locations or villages.

This classification provides a clear breakdown of arsenic contamination levels across different areas, aiding in targeted interventions and risk management strategies.

6.4.2. Hazard map of arsenic in Nagaon district –

The Hazard Map of Nagaon district was generated using data from Twenty-nine (29) samples collected across various regions within the district. Arsenic concentration was interpolated using the Inverse Distance Weighting technique in Arc GIS 10.4. The map classifies areas into five distinct risk categories based on arsenic concentration levels:

- No Risk Category: Arsenic concentration below 0.01 mg/l
- Low Risk Category: Arsenic concentration between 0.01 and 0.021 mg/l
- Moderate Risk Category: Arsenic concentration between 0.021 and 0.031 mg/l
- High Risk Category: Arsenic concentration between 0.032 and 0.042 mg/l
- Very High Risk Category: Arsenic concentration between 0.042 and 0.054 mg/l

This classification scheme provides a spatial representation of arsenic contamination levels across Nagaon district, facilitating targeted planning and intervention strategies to mitigate health and environmental risks associated with arsenic exposure.

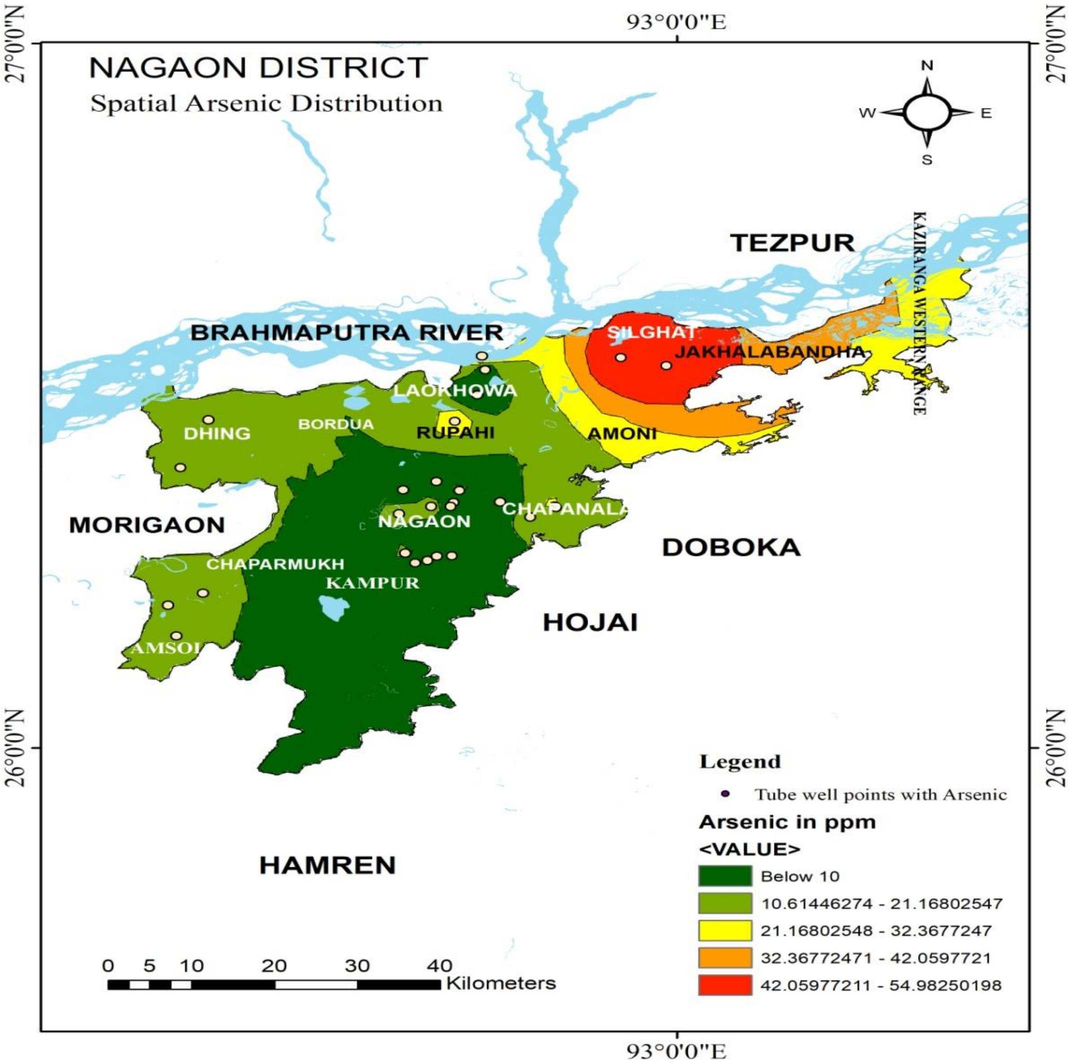

Figure 6.2 Hazard map for arsenic (As) in study area Nagaon.

Figure 6.2 illustrates the spatial distribution of groundwater arsenic concentrations across 29 regions within Nagaon district. It highlights significant variations in arsenic levels, specifically:

- Niz Laokhowa, Gomotha, and Bamunigaon exhibit arsenic concentrations ranging from 0.042 to 0.054 mg/L.

These regions are categorized as experiencing substantial risk due to elevated arsenic levels in their groundwater. This spatial depiction aids in identifying areas requiring urgent attention and targeted interventions to mitigate health risks associated with arsenic contamination in Nagaon district

Table 6.3 Range of arsenic concentration and covered area for each range.

Range of Concentration (ppb)	0 - 0.01	0.01 - 0.021	0.021 - 0.032	0.032 - 0.042	0.042 - 0.054
Reclassified Range	No Risk	Low Risk	Moderate Risk	High Risk	Very High Risk
Area (km^2)	957	781	220	172	158
Percentage of Area	41.8	34.1	9.6	7.5	7
Average Arsenic in ppm	0.003	0.013	0.021	0.037	0.054

Table 6.3 illustrates that the combined area of the 'No Risk' and 'Very High Risk' categories totals 1115 km², representing 48.8% of the study region. Conversely, the low-risk, moderate-risk, and high-risk zones constitute 34.1%, 9.6%, and 7.5% of the study area, respectively.

Table 6.4 Reclassified range of values alongside their corresponding villages

SAMPLE NO.	CONCENTRATION (PPM)	VILLAGE	RECLASSIFIED RANGE
N1	0.002	Kondoli Rd, Nonoi	No Risk
N2	BDL	Kondoli Rd, Teliagaon	No Risk
N3	0.005	Nonoi Bhelaigaon	No Risk

N4	0.002	Nam Gumutha	No Risk
N5	0.013	Nonoi Namkuri	Low Risk
N6	0.014	Nagaon-Lumding Rd	Low Risk
N7	0.005	Lawkhowa	No Risk
N8	0.03	Lawkhowa Nangaldhua	High Risk
N9	0.001	Bongaon, Niz Laukhowa	No Risk
N10	0.051	Niz Laukhowa	Very High Risk
N11	BDL	Pub Salpara	No Risk
N12	0.006	Salpara	No Risk
N13	0.005	Diphalu	No Risk
N14	0.016	Chakarigaon	Low Risk
N15	BDL	Niz Gumuthagaon	No Risk
N16	0.012	Nartum Gaon	Low Risk
N17	0.001	Chalchali Jalah	No Risk
N18	0.037	Chapanal Grant	High Risk
N19	0.001	Chapanala	No Risk
N20	0.006	Killing Nepali Gaon	No Risk
N21	0.022	Kaziranga road	Moderate Risk
N22	0.01	Gomothagaon	No Risk
N23	0.016	Bichamari	Low Risk
N24	0.011	Ghasibari	Low Risk
N25	0.055	Gomotha	Very High Risk
N26	0.012	Chaobori	Low Risk
N27	0.011	Duboritoli Kolongpar	Low Risk
N28	0.015	Bilatia	Low Risk
N29	0.053	Bamunigaon	Very High Risk

Table 6.4 categorizes locations based on arsenic risk levels as follows:

- The No Risk category encompasses 14 locations.

- Low Risk includes 9 locations.

- Moderate Risk includes 1 location.
- High Risk covers 2 locations.
- Very High Risk covers 3 locations.

In Darrang district, an area totalling 418 sq km, representing 26.5% of the district, falls under the No Risk category for arsenic contamination, with an average arsenic concentration of 0.003 ppm. Conversely, in Nagaon district, 957 sq km, accounting for 41.8% of its area, is categorized as No Risk, with an average arsenic level of 0.006 mg/l.

The Very High Risk category in Darrang covers 44 sq km, equivalent to 2.7% of the district, where the average arsenic contamination measures 0.047 mg/l.

. In Nagaon, this category extends over 158 sq km, comprising 7% of the district area, with an average arsenic concentration of 0.054 mg/l.

The highest recorded arsenic concentration in our study in both Darrang and Nagaon districts is 0.055 mg/l. However, the number of concentrations categorized as Very High Risk in Darrang district exceeds that in Nagaon district by 5, where the latter has 3 such concentrations fewer.

Buragohain et al. (2011) investigated groundwater arsenic contamination in Dhemaji district, analyzing forty water samples from five development blocks over three years (2007-2010) using Atomic Absorption Spectroscopy (AAS). Spatial distribution maps created with Arc View GIS revealed that most groundwater samples in the area were unsafe due to high arsenic levels. Another study by Khirod Shankar (2015) mapped the spatial distribution of arsenic in groundwater across Assam's districts: Sonitpur, Nagaon, Kamrup, Nalbari, and Darrang. The study found that Nagaon, Nalbari, and Kamrup had higher arsenic levels compared to Sonitpur and Darrang. While arsenic concentrations in Sonitpur and Darrang were within safe drinking water limits, Nagaon, Kamrup, and Nalbari had levels exceeding the WHO limit of 10 ppb, although they remained below the national standard of 50 ppb. Sharma et al. (2021) studied groundwater arsenic contamination in Hajo Circle, Assam, using primary data collected from 18 tube wells and analyzed at Tezpur University. Spatial distribution was mapped using ArcGIS 10.2.1. The results revealed that 50.73% of the area (210 sq km) had arsenic levels below 10.40 ppb. Approximately 27.05% of the area (112 sq km) had arsenic concentrations between 10.41 and 20.80 ppb, while 4.83% (20 sq km) had levels between 20.81 and 31.20 ppb. About 9.90% of the area (41 sq km) showed arsenic contamination between 31.21 and 41.60 ppb, and 7.49% (31 sq km) had levels exceeding 41.60 ppb. The findings indicate that Hajo Tehsil has significant arsenic contamination exceeding the WHO maximum limit of 10 ppb.

The comprehensive study conducted in the Darrang and Nagaon district of Assam provides an insightful analysis of groundwater contamination by arsenic. By constructing hazard maps for arsenic contamination, the research identifies the most polluted regions in the study area by the process of interpolation through IDW. The spatial analysis not only delineates the zones of significant contamination but also serves as a vital tool for legislative authorities and policymakers in strategizing tube well placements and enacting legislation to combat groundwater pollution. The acknowledgment of arsenic as prevalent contaminants sets a precedent for future research to explore other heavy metals present in the groundwater of Darrang and Nagaon district of Assam, aiming to devise comprehensive mitigation strategies against the adverse health effects posed by these pollutants. In conclusion, this study effectively maps out the hazardous landscapes of arsenic contamination within the districts, offering a foundational understanding of the health risks involved and proposing a pathway for enhancing water quality management and public health initiatives. By doing so, it not only contributes to the immediate need for safe drinking water but also emboldens the broader objective of sustaining environmental health and well-being, encapsulating a vital step forward in the global endeavour to mitigate water-related diseases and ensure environmental sustainability.

CHAPTER 7

HEALTH RISKS ESTIMATION FROM CHRONIC ARSENIC EXPOSURE VIA INGESTION AND DERMAL ROUTES: USEPA METHODS

7.1 Introduction –

Arsenic has been naturally present in groundwater for thousands of years; the kinetics of release from sediments and the residence time plays an important role increasing the arsenic concentrations in certain aquifers, especially in the younger alluvium flood plains of the Ganges and Brahmaputra (Stute et al., 2007). WHO has classified arsenic as one of 10 chemicals of public health concern (WHO, 2010). A number of health effects, like skin lesions, peripheral neuropathy, gastrointestinal symptoms, diabetes, renal system effects, cardiovascular disease, and cancer have been linked to arsenic contamination. However, the signs and symptoms can take years to develop depending on the level of exposure (Hindmarsh et al., 2002; WHO, 2010). The vulnerable groups are pregnant women and infants, who are at higher risk of arsenic exposure, as arsenic is known to pass through the placenta (U.S. EPA, 2007). Children are at higher risk of arsenic poisoning, as the symptoms are usually undetectable in the early stages (Singh and Ghosh, 2012). The early symptoms go unnoticed or are ignored, due to lack of education and awareness in the context of low socio-economic status and poor medical facilities (Safiuddin and Karim, 2001). Further, the high prevalence of malnutrition and protein deficiency among children makes them more vulnerable to arsenic poisoning (WHO, 2010). The International Agency for Research and Cancer (IARC) first evaluated the health effects of arsenic in 1973 and concluded that it causes cancer through drinking water (IARC, 1973). In the recent studies conducted by IARC, inorganic arsenic was classified as Group A human carcinogen which can cause cancer of the urinary bladder, lung, skin and possibly also kidney and liver (IARC, 2004). The earliest signs of toxicity from chronic exposure to arsenic in drinking water in humans are pigmentation changes, which are known as arsenicosis (IARC, 2004).

Based on this evidence and the widespread arsenic cases around the world, WHO revised the drinking water guidelines in 1993, with safe limits for arsenic in drinking water was reduced from 50to10ppb,making more stringent acceptable limits in the drinking water standards. However, in India the old acceptable limits of 50ppb are being followed by Bureau of Indian Standards (BIS) (Smedley and Kinniburgh, 2002).

According to Patel Arbind et al., (2021) the vast alluvial floodplains of Ganga and Brahmaputra have significantly higher geogenic exposure of arsenic as reported by various previous studies; covering hazard zones extending from state of Uttar Pradesh in the north to Assam in the east of India.

Based on this hypothesis we have selected the two districts of BFP namely Darrang and Nagaon from Assam, India to understand the mediated response of arsenic and its associated health risk among different gender and age groups. This research aims to find the arsenic contaminated aquifers in Darrang and Nagaon district of Assam and to estimate the carcinogenic and non-carcinogenic risks associated with chronic exposure to ground water arsenic through oral and dermal according to the methods published by the U.S. Environmental Protection Agency (USEPA, 1989). However, the risk assessment of arsenic is a tricky and challenging task despite identifying the hazard zones and the underlying operative processes. Our study has quantified the arsenic hazard from groundwater in terms of non-carcinogenic risk by using the Health Risk Index (HRI) indicator. The main objective of the study behind using HRI as an active indicator of health risk on the people is driven by the display of non-carcinogenic symptoms in people including respiratory disease, liver dysfunction, gastrointestinal dysfunction, cardiovascular disease, hematological, neurotoxicity and diabetes studied by Mazumdar et al., (2011). The critical factor is the concentration of the population within the periphery of these two districts, which have reported arsenic concentration above the permissible limit of WHO 2004 (greater than 10ppb), enough to manifest carcinogenic risk later in the life of the exposed population. In our targeted review of literature we have observed several health related issues from the region especially where the meandering and braided patterns of Brahmaputra flood plains and its tributaries expands. The long-term exposure of As-contaminated groundwater through oral and dermal exposure can be a high risk for the people in the contaminated areas. However, very less work has been done on the dermal exposure due to ground water arsenic contamination in Assam with almost no reporting done in this regard in the Brahmaputra floodplain. Though our study, an attempt has been made to identify the extent of dermal and oral exposure due to the As-contaminated groundwater in the two districts of Assam in Brahmaputra Flood Plain by calculating oral and dermal hazard index among the different age and gender group.

7.2 Study Area –

The study area Darrang district is situated in the eastern parts of India on the northeast corner of Assam. Located on the bank of mighty river Brahmaputra, the district is largely plain.

(Refer to chapter- 3, page 18-24)

Another study area of this paper is Nagaon district which is situated in the central part of Assam. It lies between the Brahmaputra River to the north and the Barak River to the south. The district has a varied topography ranging from plains to hilly terrain. The Kopili River and its tributaries flow through parts of the district, contributing to its geography.The River Kolong flows centrally through the district.

(Refer to chapter- 3, page 18-24)

7.3 Collection and Analysis of Samples –

A total of n = 54 samples were collected from Ground water source including hand pumps and tube wells to access the groundwater quality of Darrang and Nagaon district, Assam, India. 25 samples and 29 samples were randomly collected from different regions of Darrang and Nagaon district respectively. Groundwater samples were collected in polyethylene contamination-free bottles having a capacity of 500 ml. Prior to sampling, the wells were pumped to avoid the effects of stagnant water. Preservative (1:1 HNO3 solution, pH <2, approx. 5 ml L-1 sample) were added to each water samples collected for Arsenic analysis at the time of sampling and the containers were sealed. All probable safety measures were taken at every stage, starting from sample collection, storage, transportation and final analysis of the samples to avoid or minimize contamination. A global positioning system was employed to record the sample sites' geographic positions and ground elevation (GPS). Groundwater samples were analyzed in Public Health Laboratory, Betkuchi and Public Health Laboratory, Mangaldoi division using Atomic Absorption Spectrometry (AAS).

7.4 Statistical Analysis –

Descriptive statistics such as mean, standard deviation graphs, trends, bar charts, along with percentages, were used to represent the data of Arsenic contamination in the study area which is tabulated using MS Excel 2007. The health risks estimation from chronic arsenic exposure via ingestion and dermal routes using USEPA methods of statistical formulas are also calculated in MS Excel.

7.5 Assessment of health risk –

This study estimated the risk associated with chronic consumption of water via oral and dermal with high concentrations of arsenic in children and adults in Darrang and Nagaon districts of Assam, India.

Chronic daily arsenic intake was estimated, and systemic Hazard Quotient (HQ) and deterministic Lifetime Cancer Risk (LCR) were calculated using U.S. Environmental Protection Agency methodology. The locations studied have a high risk of adverse health effects from exposure to arsenic.

7.5.1 Assessment of Chronic daily intake –

The Chronic Daily Intake (CDI) of pollutants by oral ingestion and skin absorption was determined using Equations (1) and (2) developed by the USEPA to quantify the ingestion and dermal absorption of pollutants in a human body via water consumption (USEPA 2004; Agyeman et al. 2021).

$$CDI_{oral} = \frac{C \times EF \times ED \times IR}{BW \times AT} \quad (1)$$

$$CDI_{dermal} = \frac{C \times KP \times SA \times ET \times EF \times ED \times CF}{BW \times AT}$$

(2)

Where,

CDI_{oral} = Chronic daily intake (CDI) for oral,

CDI_{dermal} = Chronic daily intake (CDI) for dermal,

C = Concentration of heavy metal in mg/L for the water sample,

BW = Body Weight of the exposed individual in kg,

ED = Exposure Duration in years,

EF = Exposure Factor, or frequency of daily exposure (days/year),

IR = Intake Rate of the contaminated medium (in this case, average daily water Consumption) in L/day,

AT = Averaging Time, or period over which exposure is averaged in days,

SA = Skin Surface Area Available for Contact (cm^2),

KP = Chemical-specific Dermal Permeability Constant (cm/hr),

ET = Exposure Time (hours/day),

CF = Volumetric Conversion Factor for Water (1 liter/1000 cm^3).

7.5.2 Assessment of Non-Carcinogenic risk –

To the assessment of the non-carcinogenic risk, the total Hazard Index (HI) for Arsenic through dermal and oral exposures is calculated by Eqs. (3) – (6) using Average Chronic daily intake (CDI) and ingestion reference dose RfDing (mg/kg-day).

$$HQ_{oral} = \frac{CDI_{oral}}{RfD_{oral}} \quad (3)$$

$$HQ_{dermal} = \frac{CDI_{dermal}}{RfD_{dermal}} \quad (4)$$

$$HI = \sum HQ$$

$$HI = HQ_{oral} + HQ_{dermal}$$

$$= \frac{CDI_{oral}}{RfD_{oral}} + \frac{CDI_{dermal}}{RfD_{dermal}} \quad (5)$$

Where,

HQ_{oral} is hazard index for oral contact and

HQ_{dermal} is hazard index through dermal contact.

Both of them are dimensionless. RfD_{dermal} and RfD_{oral} are reference doses for dermal and oral exposure, respectively (mg/kg/day), which are accepted as 0.000123 mg/kg/day and 0.0003 mg/kg/day by Schuhmacherwolz et al.,(2009), respectively.

7.5.3 Assessment of carcinogenic risk -

The values of Lifetime Cancer Risk (LCR) for carcinogenic risk of arsenic through oral and dermal exposure were determined by using Equations (6)–(8)

$$LCR_{oral} = CDI_{oral} \times CSF_{oral} \quad (6)$$

$$LCR_{dermal} = CDI_{dermal} \times CSF_{dermal} \quad (7)$$

$$\text{CI} = LCR_{oral} + LCR_{dermal} \quad (8)$$

Where,

CI is Carcinogenic Indices for both oral and dermal,

CSF_{dermal} and CSF_{oral} (mg/kg/day) are carcinogenic slope factors, which recommended to be 3.66 and 1.5 mg/kg/day by USEPA, respectively.

In this study we have considered children, female and male for statistical computations of health risks estimation from chronic arsenic exposure via ingestion and dermal routes using the above equations (1) – (8)

The values of parameters for the risk assessment for carcinogenic and non-carcinogenic factors are shown in Table 7.1 and 7.2.

Table – 7.1 The values of parameters for carcinogenic and non-carcinogenic risk assessment through oral

Parameters	**Measurement Unit**	**Values**			**References**
		Children	**Adults**		
			Female	**Male**	
Concentration of arsenic in sampled drinking water (CW)	mg/L	-	-	-	-

Body Weight (BW)	kg	10	58	70	Das et al.,2018; Kumar et al.,2017b; USEPA, 1989
Exposure Duration (ED)	years	8	70	70	Kumar et al., 2017b; USEPA, 1989
Exposure Frequency (EF)	Day/year	365	365	365	USEPA, 1989
Averaging Time (AT)	Days	2920	25550	25550	USEPA, 1989
Ingestion Rate (IR)	L/day	1.7	2.7	3.7	Das et al., 2018; Kumar et al.,2017b
Reference dose (RfD)	mg/kg/day	0.0003			Schuhmacherwolz et al.,2009
Cancer Slope Factor (CSF)	mg/kg/day	1.5			USEPA, 2004

Table – 7.2 The values of parameters for carcinogenic and non-carcinogenic risk assessment through dermal

Parameters	**Measurement Unit**	**Values**			**Reference**
		Children	**Adult**		
			Female	**Male**	
Concentration of arsenic in	**mg/L**	-	-	-	-

sampled drinking water (CW					
Body Weight (BW)	kg	10	58	70	Das et al.,2018; Kumar et al.,2017b; USEPA,1989
Exposure Duration (ED)	years	8	30	30	Kumar et al., 2011; USEPA, 2004
Exposure Frequency (EF)	Day/year	350	350	350	USEPA, 2004
Averaging Time (AT)	Days	2920	10950	10950	Dawoud and Purucker, 1996
Exposure Time (ET)	h/day	0.25	0.33		Dawoud and Purucker, 1996
Unit Conversion Factor	L/cm^3	0.001			Dawoud and Purucker, 1996
Skin Permeability coefficient, K_P	cm/h	0.001			Means, 1989
Skin Area (SA)	cm^2	4900	16000	18000	USEPA, 2004
Reference dose (RfD)	mg/kg/day	0.000123			Schuhmacherwolz et al.,2009
Cancer Slope Factor (CSF)	mg/kg/day	3.66			USEPA, 2004

7.5.4 Interpretation of Hazard Quotient (HQ) and Lifetime Cancer Risk (LCR) –

An HQ value >1 indicates a high probability of adverse systemic effects from chronic ingestion of water contaminated by As, and a value below the threshold indicates a low probability of such effects. There is no safe level of exposure for carcinogenic agents. Instead, the EPA has established "tolerable" or "acceptable" risk levels of 10-4 or 10-6; that is, lifetime exposure will not produce more than 1 cancer case per 10,000 inhabitants or 1 case per 1,000,000 inhabitants in the population (Asante-Duah, 2017). Values above these limits represent an increased risk of cancer as compared to expected rates.

Table – 7.3 Levels and values of assessment standards based on the Delphi method.

The levels	**The values**	**Acceptability**
I	$< 10^{-6}$	Completely accept
II	10^{-6} to 10^{-5}	Not eager to care about the probable risk
III	10^{-5} to 5×10^{-5}	Not to be mindful about the risk
IV	5×10^{-5} to 10^{-4}	Worry about the probable risk
V	10^{-4} to 5×10^{-4}	Care about the risk and willing to invest
VI	5×10^{-4} to 10^{-3}	Pay attention and take action to solve it
VII	$> 10^{-3}$	Must solve it

7.6 Results and Discussion –

The Chronic Daily Intake (CDI), HQ (Hazard Quotient), HI (Hazard Indices), Carcinogenic Risk (CR) and Cancer Indices (CI) values for dermal absorption and oral ingestion exposure due to As-contaminated groundwater in Darrang and Nagaon district is shown in table 7.1 and table 7.2 (Page). If HI or HQ > 1 as per the human health risk assessment, there is a chance of chronic (non-carcinogenic) health risk due to the consumption of As-contaminated drinking water (USEPA 2004). However, the carcinogenic effect can also be reflected, even at a low level of As being present in the potable drinking water signifying a potential sign for LCR. Arsenic contaminated water having LCR value > $10^{-6}$is a clear indication of the population exposed to As-contaminated drinking water (USEPA, 2004).

7.6.1. Non-carcinogenic risk assessment-

In evaluating the non-carcinogenic health risks associated with drinking water in Darrang and Nagaon districts, the USEPA methods for calculating chronic health risk exposure are employed, focusing on both oral and dermal intake pathways. The hazard index (HI) for non-carcinogenic effects is derived using these methods to assess potential adverse health impacts across different demographic groups, specifically children, females, and males. The results are illustrated through bar-line graphs that visually represent the comparative risks across these populations and districts. Statistical analysis accompanies these graphs, providing detailed insights into the variations in risk levels based on different intake routes and demographic characteristics. This comprehensive approach ensures that the hazard index is accurately reflective of the potential non-carcinogenic health risks posed by contaminants in drinking water, highlighting any significant disparities in risk exposure among the different groups studied.

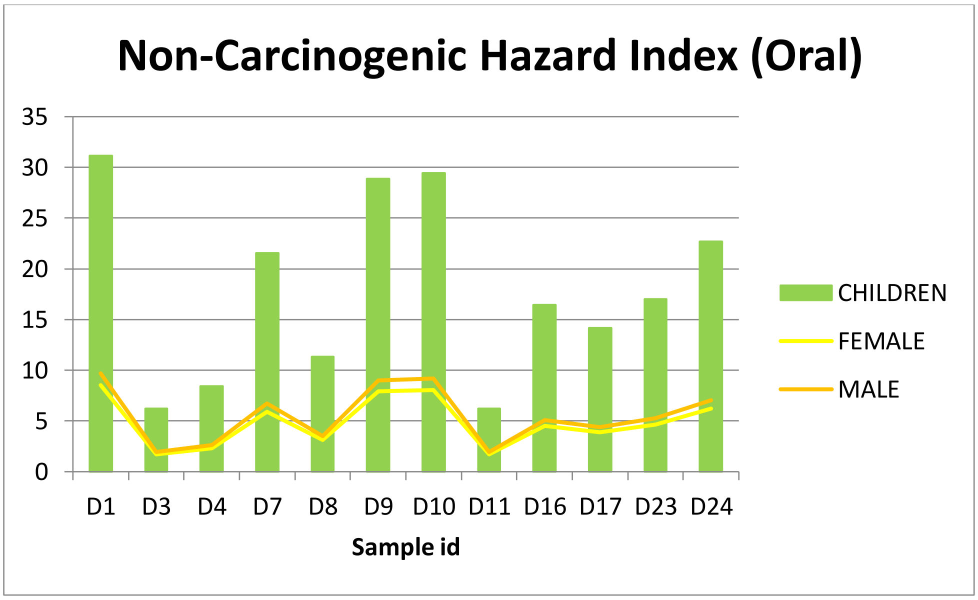

Fig - 7.1 Non carcinogenic Hazard Index in Darrang district through oral intake of arsenic (D - Darrang).

In our study, the maximum non-carcinogenic hazard index for sample id D1, which is sourced from Hati Bakar in the Darrang district of Assam, is depicted in Figure 7.1. This figure illustrates the highest hazard index value observed in the study, highlighting the level of risk associated with non-carcinogenic effects for this particular water sample. The data represented in this figure provides critical insight into the potential health impacts of the water quality in this area, emphasizing the need for targeted interventions to address any significant health risks identified.

Patel et al. (2021) investigated arsenic-related health risks in the Ganga (GFP) and Brahmaputra (BFP) floodplains by analyzing 507 groundwater samples and considering all potential dietary arsenic intake pathways. The study revealed that the GFP poses a significantly higher cancer risk compared to the BFP across various gender and age groups. Although the BFP has more wells with elevated arsenic levels, the GFP exhibited extreme concentration peaks, with levels reaching up to 106.03 µg/L—nearly ten times the WHO limit. In both floodplains, the hazard quotient (HQ) for oral exposure exceeded 1, ranging from 5.25 to 53.24 in the BFP and from 5.6 to 57.6 in the GFP.

Table – 7.4 Statistical Analysis of Non carcinogenic Hazard Index in Darrang district through oral intake of arsenic

STATISTICS	CHILDREN	FEMALE	MALE
MAX	31.16666667	8.53448276	9.690476
MIN	6.233333333	1.70689655	1.938095
AVG.	17.92690476	4.8737069	5.533849
STD DEV.	8.986153485	2.4607114	2.794014

Table 7.4 reveals that children experience higher exposure to arsenic through the oral intake of contaminated drinking water compared to adults. This increased exposure for children can be attributed to their higher water consumption relative to their body weight and their potentially greater sensitivity to contaminants. The data underscores the elevated health risks faced by children in areas with arsenic-contaminated water and highlights the importance of prioritizing protective measures and interventions to safeguard their health.

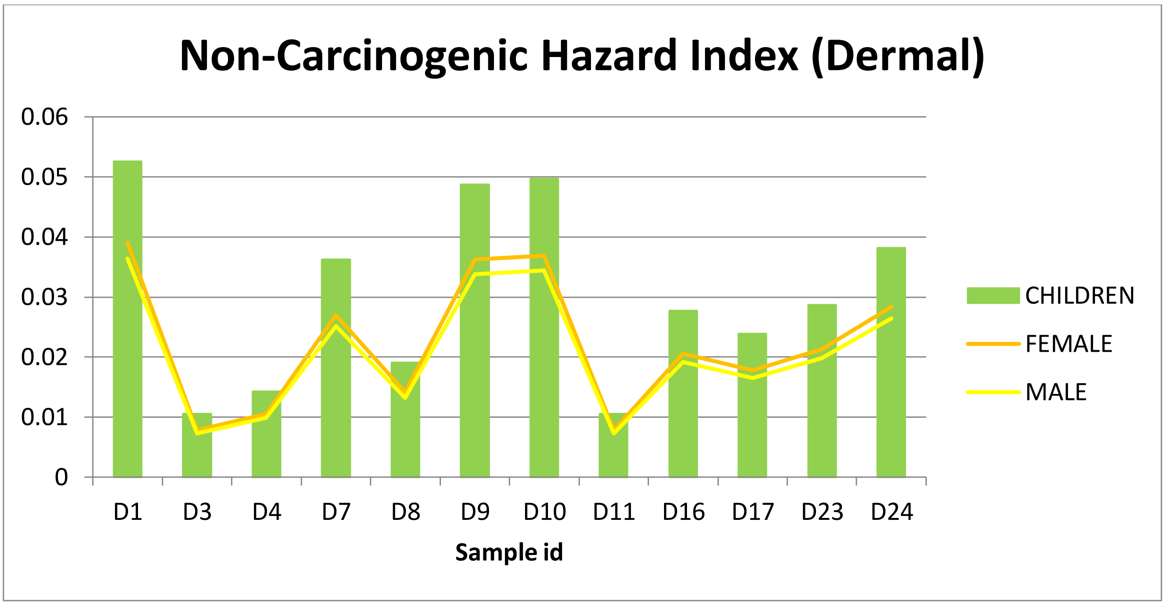

Fig - 7.2 Non carcinogenic Hazard Index in Darrang district through dermal intake of arsenic (D- Darrang).

Figure 7.2 indicates that the highest hazard index is observed in sample id D1, which corresponds to Hati Bakar Village in Darrang District. Despite this, the hazard index values for all sampled locations remain below one. Consequently, this suggests that there is no significant risk of arsenic exposure to humans through dermal contact in these areas.

Table – 7.5 Statistical Analysis of Non carcinogenic Hazard Index in Darrang district through dermal intake of arsenic.

STATISTICS	CHILDREN	FEMALE	MALE
MAX	0.052525337	0.039033607	0.036384898
MIN	0.010505067	0.007806721	0.00727698
AVG.	0.029995151	0.022290555	0.020777982
STD DEV.	0.015144409	0.011254395	0.010490704

Table 7.5 indicates that the dermal absorbed dose of arsenic from contaminated water does not pose a significant health risk, as the Hazard Quotient (HQ) values are below 1. According to the USEPA 2004 guidelines, an HQ greater than 1 would suggest a potential health risk, but in this scenario, the HQ values for dermal exposure to arsenic are not considerable. This means that while oral intake of arsenic-contaminated water might be a concern, the risk associated with dermal absorption is not substantial.

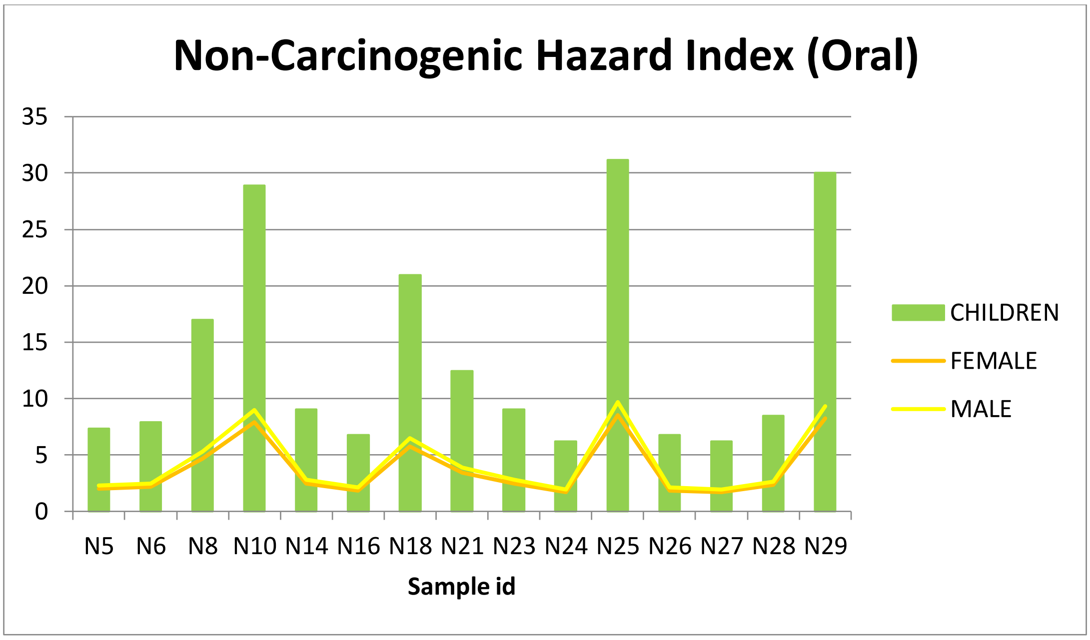

Fig - 7.3 Non carcinogenic Hazard Index in Nagaon district through oral intake of arsenic (N– Nagaon).

Figure 7.3 illustrates the maximum hazard index for sample N25, which is from the Gomotha habitation in the Nagaon district. This figure highlights the highest recorded hazard index value for this particular location, providing a visual representation of the non-carcinogenic health risks associated with the contaminated drinking water in Gomotha. The data in this figure underscores the extent of potential health risks present in this area, emphasizing the need for focused assessment and remediation efforts.

Table – 7.6 Statistical Analysis of Non-carcinogenic Hazard Index in Nagaon district through oral intake of arsenic.

STATISTICS	CHILDREN	FEMALE	MALE
MAX	31.166667	8.534483	9.690476
MIN	6.2333333	1.706897	1.938095
AVG.	13.902222	3.806897	4.32254
STD DEV.	9.3257237	2.553697	2.899595

Table 7.6 illustrates that the hazard indices for chronic exposure to pollutants in Nagaon district vary significantly, with children exhibiting a range from 31.66 to 6.233, females from

8.53 to 1.70, and males from 9.69 to 1.93. These figures indicate that children are at a higher risk of chronic exposure compared to adults in the region. This pronounced disparity underscores the need for targeted interventions to mitigate health risks for the pediatric population.

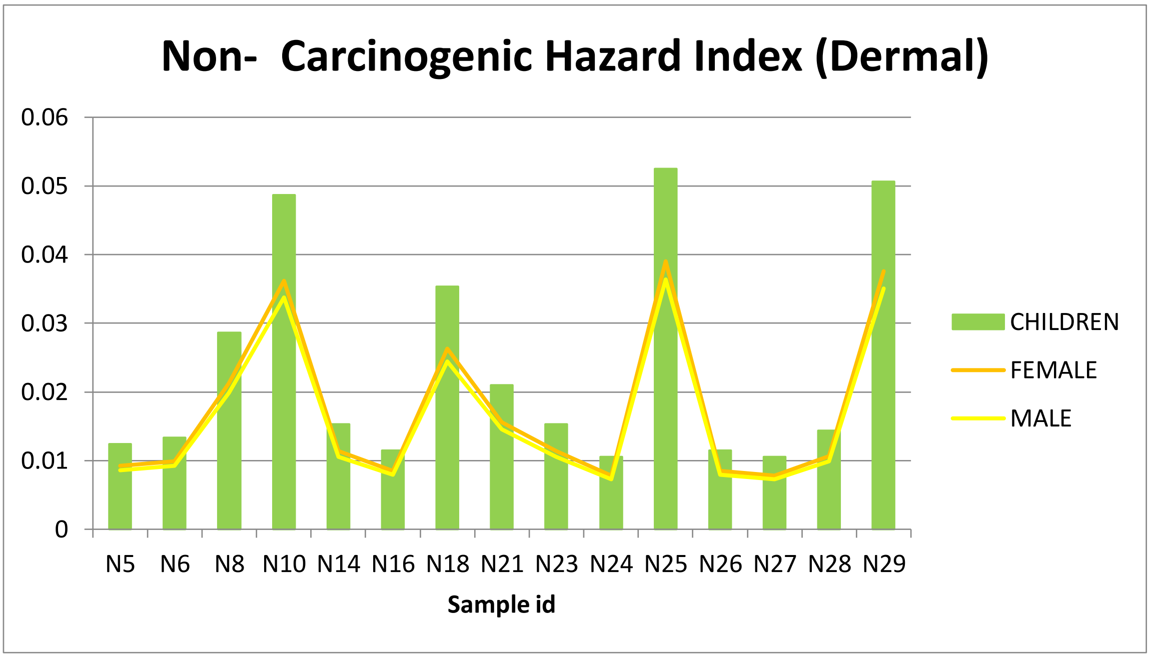

Fig - 7.4 Non carcinogenic Hazard Index in Nagaon district through dermal intake of arsenic (N– Nagaon)

Figure 7.4 shows that the hazard index for dermal contact with arsenic-contaminated drinking water is less than 1 across all locations in Nagaon district. According to the USEPA guidelines (2004), a hazard index below 1 indicates that no significant health effects are expected to occur.

Table – 7.7 Statistical Analysis of Non carcinogenic Hazard Index in Nagaon district through dermal intake of arsenic.

STATISTICS	CHILDREN	FEMALE	MALE
MAX	0.052525	0.039034	0.036385
MIN	0.010505	0.007807	0.007277
AVG.	0.023429	0.017411	0.01623
STD DEV.	0.015717	0.01168	0.010887

Kumar et al. (2016) investigated the health impacts of arsenic contamination in drinking water in the Nagaon district, revealing significant concerns for both males and females.

Health Indices (HIs) for arsenic exposure ranged from 0 to 18.7 in males and 0 to 16.4 in females during pre-monsoon, and from 0.6 to 17.9 in males and 0 to 15.6 in females during monsoon. In both periods, the upper limits of HI exceeded 1, indicating potential adverse non-carcinogenic health effects and heightened cancer risk. Notably, children showed higher susceptibility to cancer risk compared to adults, with 100% of children at high cancer risk during the monsoon, a significant increase from 47.4% during the pre-monsoon. The HI values for both genders were similar in pre-monsoon, but the monsoon period exacerbated health risks across all age groups. Overall, the study highlights a pronounced impact of monsoon on health risk and emphasizes children's increased vulnerability to arsenic-related health issues.

According to the data in our study from Tables 7.4 and 7.6, there is a notable difference in non-carcinogenic hazard indices between Darrang and Nagaon districts for children. The average non-carcinogenic hazard index for children in Darrang district is 17.92, significantly higher than the 13.9 recorded in Nagaon district. This suggests that children in Darrang are exposed to a greater overall risk of non-carcinogenic hazards compared to their counterparts in Nagaon. For adult females, the hazard index ranges from 8.54 to 1.77 in Darrang, while in Nagaon, it ranges from 8.53 to 1.70. These ranges are quite similar, indicating that the exposure levels for females are nearly equivalent in both districts. However, for adult males, the hazard index ranges from 9.69 to 1.93 in both Darrang and Nagaon, showing that male exposure levels are also similar across the two districts. Despite these comparable ranges, the higher average hazard index in Darrang implies that a greater proportion of children there are exposed to higher non-carcinogenic risks. Conversely, Nagaon shows a lower overall exposure risk for children, with fewer instances of high-risk levels. Additionally, although the ranges for adult males and females are similar, the slightly higher average hazard indices for adults in Nagaon compared to Darrang suggest that, overall, adults in Nagaon experience marginally higher non-carcinogenic hazards. This pattern highlights a broader concern about elevated risk levels, especially among children in Darrang, while suggesting a need for targeted interventions to address these risks.

7.6.2 Carcinogenic Risk Assessment –

The CR assessment focuses primarily on arsenic due to its classification as a Category 1 carcinogen by the WHO. Our comprehensive analysis indicates that the cancer risks associated with arsenic in contaminated groundwater are alarmingly high significantly surpassing the established safe threshold in certain areas. The study identifies Hati Bakar in

Darrang district and Gomotha in Nagaon district as the most vulnerable location with respect to arsenic-related cancer risks, while Konwarpara in Darrang and Gumuthagaon in Nagaon district exhibit lower risks (as shown in Figure 7.5 and 7.6). This disparity highlights the geographical variability in arsenic contamination and its associated health impacts. Another striking aspect of our findings is the higher potential danger posed to children compared to adults.

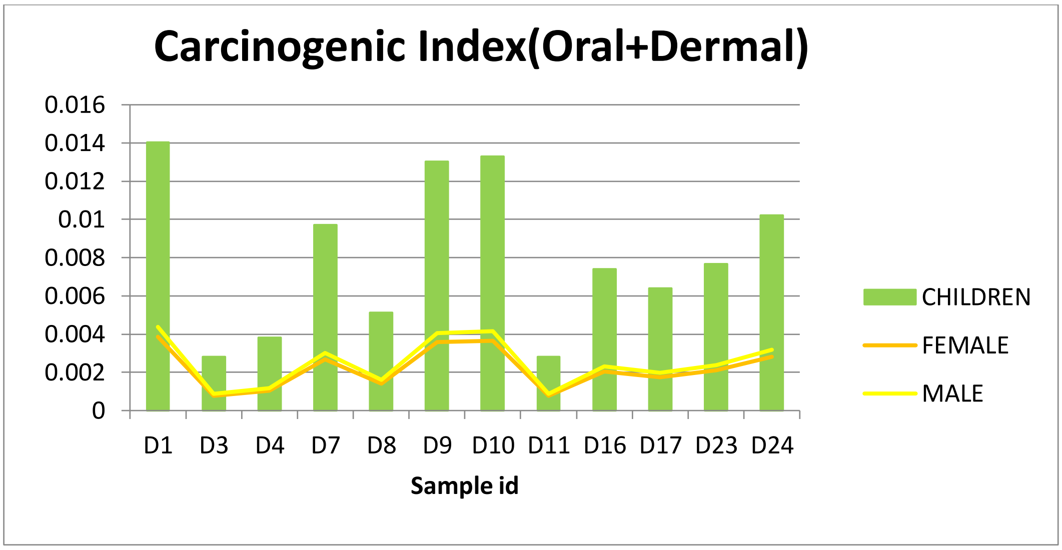

Fig - 7.5 Carcinogenic Index in Darrang district through oral and dermal intake of arsenic.

The figure above illustrates that children are more susceptible to cancer risks compared to adults, with the risk levels for children being significantly higher in Darrang district of Assam.

Table – 7.8 Statistical Analysis of Carcinogenic Index in Darrang district through oral and dermal intake of arsenic.

Sample id	CHILDREN	FEMALE	MALE
MAX	0.014049	0.003858	0.004377
MIN	0.00281	0.000772	0.000875
AVG.	0.008023	0.002203	0.0025
STD DEV.	0.004051	0.001112	0.001262

The Carcinogenic Index,CI values for both oral and dermal in children range from 1.4×10^{-2} to 2.8×10^{-3}, substantially exceeding the female range of 3.8×10^{-3} to 7.7×10^{-4} and male range of 4.3×10^{-3} to 8.7×10^{-4} in Darrang district.

Mouttoucomarassamy et al. (2024) assessed the concentrations of potentially toxic elements (PTEs), including arsenic, uranium, iron, and nitrate, in groundwater across the Majha Belt in Punjab, India, encompassing Tarn Taran, Amritsar, Gurdaspur, and Pathankot districts. The study found that some locations had average concentrations exceeding WHO-recommended values. The Trace Element Evaluation Index identified Amritsar as particularly affected by toxic elements. The HQ value for arsenic exceeded one, indicating a significant health risk. Over 44% of the samples had a total hazard index greater than four for arsenic, highlighting a severe health risk from groundwater use. Cancer risk assessments showed elevated arsenic risk in children (5.69E + 0) and adults (4.07E + 0), surpassing the USEPA acceptable limits (10−4 to 10−6). Radiological cancer risk values for children and adults were 8.68E-07 and 9.45E-06, respectively, remaining below the permissible limit set by the Atomic Energy Regulatory Board of DAE, India. The findings underscore a serious health risk from arsenic contamination in Amritsar and uranium in Tarn Taran.

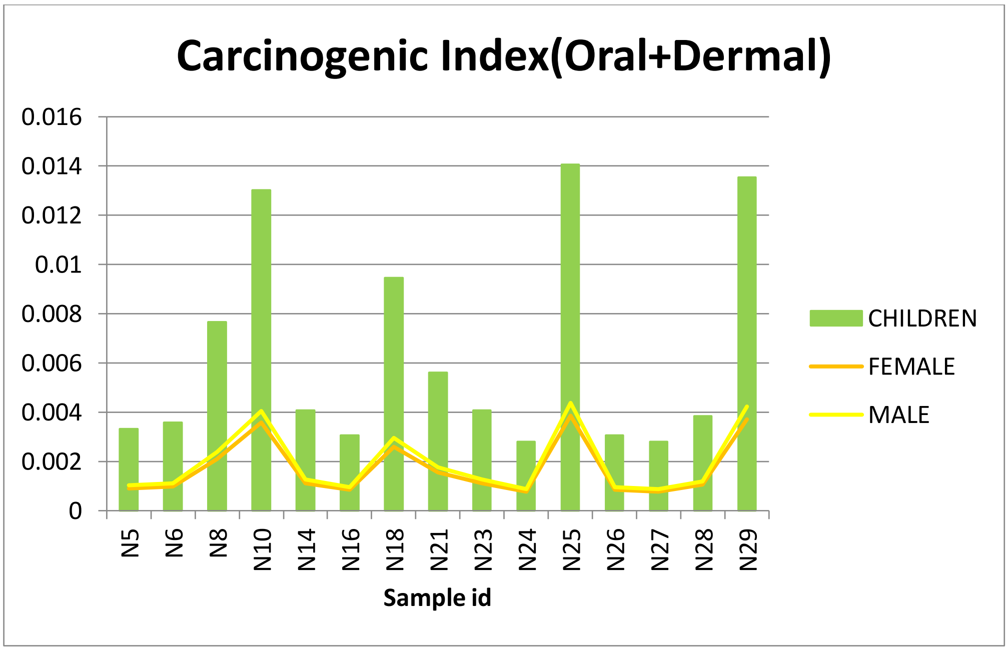

Fig - 7.6 Carcinogenic Index in Nagaon district through oral and dermal intake of arsenic.

In Figure 7.6, the highest carcinogenic index is observed in sample ID N25, identified as Gomotha. This sample exhibits the greatest potential for carcinogenic risk compared to others. Following Gomotha, the samples with the next highest carcinogenic indices are N29 and N10, which are labeled as Bamunigaon and Niz Laokhowa, respectively. Both of these samples are also from the Nagaon district, indicating that they, too, present significant carcinogenic risks, albeit lower than Gomotha.

Table – 7.9 Statistical Analysis of Carcinogenic Index in Nagaon district through oral and dermal intake of arsenic.

STATISTICS	CHILDREN	FEMALE	MALE
MAX	0.014049	0.003858	0.004377
MIN	0.00281	0.000772	0.000875
AVG.	0.006267	0.001721	0.001952
STD DEV.	0.004204	0.001154	0.00131

The Carcinogenic Index ,CI values for both oral and dermal in children range from 1.40×10^{-2} to 2.81×10^{-3}, which is comparatively higher than the female range of 3.85×10^{-3} to 7.77×10^{-4} and male range of 4.37×10^{-3} to 8.75×10^{-4} in Darrang district.

From Table 7.8 and 7.9 it can be seen that the range of carcinogenic index for both Darrang and Nagaon district is same but the average value of Carcinogenic Index through oral and dermal in Darrang district is 8×10^{-3} greater than 6×10^{-3} in Nagaon district, From this an conclusion can be derived that Darrang is at higher risk as compared to Nagaon district.

The Average values of Hazard Quotient, Hazard Index, Carcinogenic risk/Cancer risk and Carcinogenic Index/Cancer Index are formulated below.

Table7.10: Average of HQ, CR and CI calculated for Darrang district.

Factor	Category	Maximum	Minimum	Average	Std Dev
HQ for oral	Children	31.16666667	6.233333333	17.79805556	8.986153485
	Female	8.534482759	1.706896552	4.873706897	2.460711401
	Male	9.69047619	1.938095238	5.533849206	2.794014109
HQ for dermal	Children	0.052525337	0.010505067	0.029995151	0.015144409
	Female	0.039033607	0.007806721	0.022290555	0.011254395
	Male	0.036384898	0.00727698	0.020777982	0.010490704
HI	Children	31.21919201	6.2438384	17.92805071	9.001297895
	Female	8.573516366	1.714703273	4.895997452	2.471965796
	Male	9.726861089	1.945372218	5.554627188	2.804504813
LCR for	Children	0.014025	0.002805	0.008009125	0.004043769

oral	Female	0.003840517	0.000768103	0.002193168	0.00110732
	Male	0.004360714	0.000872143	0.002490232	0.001257306
LCR for dermal	Children	2.36459E-05	4.72917E-06	1.35032E-05	6.81771E-06
	Female	1.75721E-05	3.51443E-06	1.00348E-05	5.0665E-06
	Male	1.63798E-05	3.27595E-06	9.35383E-06	4.72271E-06
CI	Children	0.014048646	0.002809729	0.008022628	0.004050587
	Female	0.003858089	0.000771618	0.002203203	0.001112387
	Male	0.004377094	0.000875419	0.002499586	0.001262029

In Table 7.10 Average Hazard Index is 17.9 , 4.89 and 5.55 for children, female and male respectively which is greater than 1, given by USEPA 2004 and is considered to cause high probability of adverse systemic effects from chronic ingestion of water contaminated by As through oral. Through dermal there is low probability of such effects as Hazard index is less than 1.

Table7.11: Average of HQ, CR and CI calculated for Nagaon district.

Factor	Category	Maximum	Minimum	Average	Std Dev
HQ for oral	Children	31.16666667	6.233333333	13.90222222	9.325723655
	Female	8.534482759	1.706896552	3.806896552	2.553697147
	Male	9.69047619	1.938095238	4.322539683	3.106132826
HQ for dermal	Children	0.052525337	0.010505067	0.023429484	0.015716688
	Female	0.039033607	0.007806721	0.017411354	0.011679678
	Male	0.036384898	0.00727698	0.01622987	0.01622987
HI	Children	31.219192	6.243838401	13.92565171	9.341440343
	Female	8.573516366	1.714703273	3.824307906	2.565376825
	Male	9.726861089	1.945372218	4.338769552	2.910481878
LCR for oral	Children	0.014025	0.002805	0.006256	0.004196576
	Female	0.003840517	0.000768103	0.001713103	0.001149164
	Male	0.004360714	0.000872143	0.001945143	0.001304818
LCR for dermal	Children	2.36459E-05	4.72917E-06	1.05475E-05	7.07534E-06
	Female	1.75721E-05	3.51443E-06	7.83824E-06	5.25796E-06
	Male	1.63798E-05	3.27595E-06	7.30636E-06	4.90117E-06

CI	Children	0.014048646	0.002809729	0.006266547	0.004203651
	Female	0.003858089	0.000771618	0.001720942	0.001154422
	Male	0.004377094	0.000875419	0.001952449	0.001309719

Supplementary Tables 7.1 and 7.2 shows that HQ for oral exposure ranged from 6.23 to 31.16 in both Darrang and Nagaon districts of Assam. But the average value for oral exposure in Darrang district is 17.79 which are more than 13.9 in Nagaon district. The potential average CI values for Darrang district are 8×10^{-3} , 2.2×10^{-3} and 2.4×10^{-3} for children, female and male respectively. Whereas in Nagaon district it is 6.2×10^{-3} , 1.7×10^{-3} and 1.9×10^{-3} for children, female and male respectively. It has been found that the CI value is higher than the US-EPA limit 10^{-6} which implies that the people are at high risk for carcinogenicity. Therefore, it is suggested that continuos monitoring of arsenic level in the groundwater is a must to keep the individual safe from the threat of As-contaminated drinking water in both the exposure rout via dermal and oral pathways.

Mouttoucomarassamy et al. (2024) assessed the concentrations of potentially toxic elements (PTEs), including arsenic, uranium, iron, and nitrate, in groundwater across the Majha Belt in Punjab, India, encompassing Tarn Taran, Amritsar, Gurdaspur, and Pathankot districts. The study found that some locations had average concentrations exceeding WHO-recommended values. Specifically, arsenic and iron toxicity were notably high in Amritsar, while uranium was more prevalent in Tarn Taran. The Trace Element Evaluation Index identified Amritsar as particularly affected by toxic elements. According to US Environmental Protection Agency (USEPA) guidelines, the hazard quotient (HQ) values for uranium, iron, and nitrate were below one, suggesting no non-carcinogenic health risk. However, the HQ value for arsenic exceeded one, indicating a significant health risk. Over 44% of the samples had a total hazard index greater than four for arsenic, highlighting a severe health risk from groundwater use. Cancer risk assessments showed elevated arsenic risk in children (5.69E + 0) and adults (4.07E + 0), surpassing the USEPA acceptable limits (10−4 to 10−6). Radiological cancer risk values for children and adults were 8.68E-07 and 9.45E-06, respectively, remaining below the permissible limit set by the Atomic Energy Regulatory Board of DAE, India. The findings underscore a serious health risk from arsenic contamination in Amritsar and uranium in Tarn Taran.

It is widely established that Arsenic induces gene proliferation thereby promoting damages in the DNA and causes alteration in the signal transduction pathways (Sun h et al., 2014). Further, methylated metabolites of arsenic are emerging as a potent carcinogenic risk. The problem is more challenging with the trivalent forms of arsenic, especially which forms DMA and MMA, as it is suspected to be the leading cause of diabetes (Paul D et al., 2007). In our study area 50 percent groundwater is contaminated with arsenic, where 22% in Darrang district and 27% in Nagaon district, groundwater has arsenic concentration above 10 ppm. Non-carcinogenic hazard index due to oral ingestion of As-contaminated groundwater has been found highest among the children in the two districts, followed by adult male and female respectively whereas for the dermal contact this value is less than 1(Supplementary Tables 7.3 and 7.4). Hazard Index >1(is not considered safe for the drinking purpose but in our study people of Darrang district are at higher risk to non-carcinogenic hazard than Nagaon district. The increased risk for non-carcinogenic hazard in children is due to the low body weight and more consumption of As contaminated water. It has been reported by WHO 2008 that 13% of the people died of cancer among all the cause of death (57million) due to various disease, which account for nearly 7.6 million people. Arsenic could cause a carcinogenic effect but still, it is vague about the type of cancer, which is associated with the As toxicity (Smith A et al., 2000). 20% and 80% cause of cancer in human are due to endogenic and exogenous factors respectively (Nguyen v et al., 2009).

Supplementary Table 7.12. Human Health Risk Assessment among children, adult (male and female) in Nagaon district due to the consumption of As contaminated water for the sample showing As concentration >10μL^{-1}.***[N - Nagaon]***

Sample ID	Category	Concentration of heavy metals in water (Cw)	Ingestion rate (IR)	Exposure duration (ED)	Exposure frequency (EF)	Average life time (AT)	Body weight (BW)	Average Daily Dose (CDI) (mg/kg/day)	Cancer Risk Oral (CR)	Oral hazard quotient (HQ)	Susceptibility
		mg/L	L/day	Year	Days/Year	Days	Kg	(mg/kg/day)	mg/Kg/day		1 in 1000
N5	Children	0.013	1.7	8	365	2920	10	0.00221	0.0033	7	3
	Female	0.013	2.7	70	365	25550	58	0.0006	0.0009	2	1
	Male	0.013	3.7	70	365	25550	70	0.0006	0.001	2	1
N6	Children	0.014	1.7	8	365	2920	10	0.00238	0.0035	7	4
	Female	0.014	2.7	70	365	25550	58	0.0006	0.0009	2	1
	Male	0.014	3.7	70	365	25550	70	0.00074	0.0011	2	1
N8	Children	0.03	1.7	8	365	2920	10	0.0051	0.0076	17	8
	Female	0.03	2.7	70	365	25550	58	0.00139	0.002	4	2
	Male	0.03	3.7	70	365	25550	70	0.00158	0.0023	5	2
N10	Children	0.051	1.7	8	365	2920	10	0.00867	0.013	29	13
	Female	0.051	2.7	70	365	25550	58	0.00237	0.0035	7	4
	Male	0.051	3.7	70	365	25550	70	0.00269	0.004	8	4

Sample ID	Category	Concentration of heavy metals in water (Cw)	Ingestion rate (IR)	Exposure duration (ED)	Exposure frequency (EF)	Average life time (AT)	Body weight (BW)	Average Daily Dose (CDI) (mg/kg/day)	Cancer Risk Oral (CR)	Oral hazard quotient (HQ)	Susceptibility
		mg/L	L/day	Year	Days/Year	Days	Kg	(mg/kg/day)	mg/Kg/day		1 in 1000
N14	Children	0.016	1.7	8	365	2920	10	0.00272	0.004	9	4
	Female	0.016	2.7	70	365	25550	58	0.00074	0.00112	2	1
	Male	0.016	3.7	70	365	25550	70	0.000846	0.0012	2	1
N16	Children	0.012	1.7	8	365	2920	10	0.00204	0.003	6	2
	Female	0.012	2.7	70	365	25550	58	0.00055	0.00084	1	1
	Male	0.012	3.7	70	365	25550	70	0.000634	0.00095	2	1
N18	Children	0.037	1.7	8	365	2920	10	0.00629	0.0094	21	6
	Female	0.037	2.7	70	365	25550	58	0.001722	0.0025	5	2
	Male	0.037	3.7	70	365	25550	70	0.00195	0.0029	6	2
N21	Children	0.022	1.7	8	365	2920	10	0.00374	0.0056	12	4
	Female	0.022	2.7	70	365	25550	58	0.00102	0.0015	3	1
	Male	0.022	3.7	70	365	25550	70	0.0011	0.0017	3	1

Sample ID	Category	Concentration of heavy metals in water (Cw)	Ingestion rate (IR)	Exposure duration (ED)	Exposure frequency (EF)	Average life time (AT)	Body weight (BW)	Average Daily Dose (CDI) (mg/kg/day)	Cancer Risk Oral (CR)	Oral hazard quotient (HQ)	Susceptibility
		mg/L	L/day	Year	Days/Year	Days	Kg	(mg/kg/day)	mg/Kg/day		1 in 1000
N23	Children	0.016	1.7	8	365	2920	10	0.00272	0.004	9	4
	Female	0.016	2.7	70	365	25550	58	0.00074	0.00112	2	1
	Male	0.016	3.7	70	365	25550	70	0.000846	0.0012	2	1
N24	Children	0.011	1.7	8	365	2920	10	0.00187	0.0028	6	2
	Female	0.011	2.7	70	365	25550	58	0.00051	0.00077	1	1
	Male	0.011	3.7	70	365	25550	70	0.000581	0.0008	1	1
N25	Children	0.055	1.7	8	365	2920	10	0.00935	0.014	31	14
	Female	0.055	2.7	70	365	25550	58	0.00256	0.00384	8	4
	Male	0.055	3.7	70	365	25550	70	0.0029	0.0043	9	4
N26	Children	0.012	1.7	8	365	2920	10	0.00204	0.003	6	3
	Female	0.012	2.7	70	365	25550	58	0.00055	0.00084	1	1
	Male	0.012	3.7	70	365	25550	70	0.000634	0.0009	2	1

Sample ID	Category	Concentration of heavy metals in water (Cw)	Ingestion rate (IR)	Exposure duration (ED)	Exposure frequency (EF)	Average life time (AT)	Body weight (BW)	Average Daily Dose (CDI) (mg/kg/day)	Cancer Risk Oral (CR)	Oral hazard quotient (HQ)	Susceptibility
		mg/L	L/day	Year	Days/Year	Days	Kg	(mg/kg/day)	mg/Kg/day		1 in 1000
N27	Children	0.011	1.7	8	365	2920	10	0.00187	0.0028	6	3
	Female	0.011	2.7	70	365	25550	58	0.000512	0.0007	1	1
	Male	0.011	3.7	70	365	25550	70	0.000581	0.00087	1	1
N28	Children	0.015	1.7	8	365	2920	10	0.00255	0.0038	8	4
	Female	0.015	2.7	70	365	25550	58	0.000698	0.001	2	1
	Male	0.015	3.7	70	365	25550	70	0.000793	0.0011	2	1
N29	Children	0.053	1.7	8	350	2920	10	0.00901	0.0135	30	14
	Female	0.053	2.7	70	350	25550	58	0.00246	0.0037	8	4
	Male	0.053	3.7	70	350	25550	70	0.002801	0.0042	9	4

Supplementary Table 7.13. Human Health Risk Assessment among children, adult (male and female) in Darrang district due to the consumption of As contaminated water for the sample showing As concentration >10µL^{-1}.***[D - Darrang]***

Sample ID	Category	Concentration of heavy metals in water (Cw)	Ingestion rate (IR)	Exposure duration (ED)	Exposure frequency (EF)	Average life time (AT)	Body weight (BW)	Average Daily Dose (CDI) (mg/kg/day)	Cancer Risk Oral (CR)	Oral hazard quotient (HQ)	Susceptibility
		mg/L	L/day	Year	Days/Year	Days	Kg	(mg/kg/day)	mg/Kg/day		1 in 1000
D1	Children	0.055	1.7	8	365	2920	10	0.0093	0.014	31	14
	Female	0.055	2.7	70	365	25550	58	0.0025	0.0038	8	4
	Male	0.055	3.7	70	365	25550	70	0.0029	0.004	9	4
D3	Children	0.011	1.7	8	365	2920	10	0.0018	0.002	6	2
	Female	0.011	2.7	70	365	25550	58	0.00051	0.0007	1	1
	Male	0.011	3.7	70	365	25550	70	0.00058	0.0008	1	1
D4	Children	0.014	1.7	8	365	2920	10	0.0025	0.0038	8	4
	Female	0.014	2.7	70	365	25550	58	0.00069	0.001	2	1
	Male	0.014	3.7	70	365	25550	70	0.00078	0.0011	2	1
D7	Children	0.038	1.7	8	365	2920	10	0.0064	0.0096	21	10
	Female	0.038	2.7	70	365	25550	58	0.0017	0.0026	5	3
	Male	0.038	3.7	70	365	25550	70	0.002	0.003	6	3

Sample ID	Category	Concentration of heavy metals in water (Cw) mg/L	Ingestion rate (IR) L/day	Exposure duration (ED) Year	Exposure frequency (EF) Days/Year	Average life time (AT) Days	Body weight (BW) Kg	Average Daily Dose (CDI) (mg/kg/day) (mg/kg/day)	Cancer Risk Oral (CR) mg/Kg/day	Oral hazard quotient (HQ)	Susceptibility 1 in 1000
D8	Children	0.02	1.7	8	365	2920	10	0.0034	0.0051	11	5
	Female	0.02	2.7	70	365	25550	58	0.00093	0.0013	3	1
	Male	0.02	3.7	70	365	25550	70	0.001	0.0015	3	2
D9	Children	0.051	1.7	8	365	2920	10	0.0086	0.013	28	13
	Female	0.051	2.7	70	365	25550	58	0.0023	0.0035	7	4
	Male	0.051	3.7	70	365	25550	70	0.0026	0.004	8	4
D10	Children	0.052	1.7	8	365	2920	10	0.0088	0.013	29	13
	Female	0.052	2.7	70	365	25550	58	0.0024	0.0036	8	4
	Male	0.052	3.7	70	365	25550	70	0.0027	0.0041	9	4
D11	Children	0.011	1.7	8	365	2920	10	0.0018	0.0028	6	3
	Female	0.011	2.7	70	365	25550	58	0.0005	0.00076	1	1
	Male	0.011	3.7	70	365	25550	70	0.0005	0.00087	1	1

Sample ID	Category	Concentration of heavy metals in water (Cw)	Ingestion rate (IR)	Exposure duration (ED)	Exposure frequency (EF)	Average life time (AT)	Body weight (BW)	Average Daily Dose (CDI) (mg/kg/day)	Cancer Risk Oral (CR)	Oral hazard quotient (HQ)	Susceptibility
		mg/L	L/day	Year	Days/Year	Days	Kg	(mg/kg/day)	mg/Kg/day		1 in 1000
D16	Children	0.029	1.7	8	365	2920	10	0.0049	0.0073	16	7
	Female	0.029	2.7	70	365	25550	58	0.0013	0.002	4	2
	Male	0.029	3.7	70	365	25550	70	0.00153	0.0022	5	2
D17	Children	0.025	1.7	8	365	2920	10	0.0042	0.0063	14	6
	Female	0.025	2.7	70	365	25550	58	0.0011	0.0017	3	2
	Male	0.025	3.7	70	365	25550	70	0.00132	0.0019	4	2
D23	Children	0.03	1.7	8	365	2920	10	0.0051	0.0076	17	8
	Female	0.03	2.7	70	365	25550	58	0.0013	0.002	4	2
	Male	0.03	3.7	70	365	25550	70	0.00158	0.0023	5	2
D24	Children	0.04	1.7	8	365	2920	10	0.0068	0.01	22	10
	Female	0.04	2.7	70	365	25550	58	0.0018	0.0027	6	3
	Male	0.04	3.7	70	365	25550	70	0.00211	0.0031	7	3

Supplementary Table 7.14. Human Health Risk Assessment among children, adult (male and female) in Nagaon district due to the dermal exposure of As contaminated water sample showing concentration >10µL^{-1}

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
N5	Children	0.013	4900	0.001	8	0.25	350	0.001	2920	10	1.53E-06	1.20E-02	5.58E-06	5.58E-03
	Female	0.013	16000	0.001	30	0.33	350	0.001	10950	58	1.13E-06	9.20E-03	4.25E-06	4.25E-03
	Male	0.013	18000	0.001	30	0.33	350	0.001	10950	70	1.06E-06	8.60E-02	3.87E-06	3.87E-03
N6	Children	0.014	4900	0.001	8	0.25	350	0.001	2920	10	1.64E-06	1.30E-02	6.01E-06	6.01E-03
	Female	0.014	16000	0.001	30	0.33	350	0.001	10950	58	1.22E-06	9.90E-03	4.47E-06	4.47E-03
	Male	0.014	18000	0.001	30	0.33	350	0.001	10950	70	1.14E-06	9.20E-02	4.16E-06	4.16E-03
N8	Children	0.03	4900	0.001	8	0.25	350	0.001	2920	10	3.52E-06	2.80E-02	1.28E-05	1.28E-02
	Female	0.03	16000	0.001	30	0.33	350	0.001	10950	58	2.62E-06	2.12E-02	9.58E-06	9.58E-03
	Male	0.03	18000	0.001	30	0.33	350	0.001	10950	70	2.44E-06	1.98E-02	8.93E-06	8.93E-03
N10	Children	0.051	4900	0.001	8	0.25	350	0.001	2920	10	5.99E-05	4.80E-02	2.19E-05	2.19E-02
	Female	0.051	16000	0.001	30	0.33	350	0.001	10950	58	4.45E-06	3.61E-02	1.62E-05	1.62E-02
	Male	0.051	18000	0.001	30	0.33	350	0.001	10950	70	4.15E-06	3.37E-02	1.51E-05	1.51E-02
N14	Children	0.016	4900	0.001	8	0.25	350	0.001	2920	10	1.88E-06	1.50E-02	6.87E-06	6.87E-03
	Female	0.016	16000	0.001	30	0.33	350	0.001	10950	58	1.40E-06	1.13E-02	5.11E-06	5.11E-03
	Male	0.016	18000	0.001	30	0.33	350	0.001	10950	70	1.30E-06	1.05E-02	4.76E-06	4.76E-03

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
N16	Children	0.012	4900	0.001	8	0.25	350	0.001	2920	10	1.41E-06	1.10E-02	5.15E-06	5.15E-03
	Female	0.012	16000	0.001	30	0.33	350	0.001	10950	58	1.05E-06	8.50E-03	3.83E-06	3.83E-03
	Male	0.012	18000	0.001	30	0.33	350	0.001	10950	70	9.76E-07	7.90E-03	3.57E-06	3.57E-03
N18	Children	0.037	4900	0.001	8	0.25	350	0.001	2920	10	4.35E-06	3.50E-02	1.59E-05	1.59E-02
	Female	0.037	16000	0.001	30	0.33	350	0.001	10950	58	3.23E-06	2.60E-02	1.18E-05	1.18E-02
	Male	0.037	18000	0.001	30	0.33	350	0.001	10950	70	3.01E-06	2.44E-02	1.10E-05	1.10E-02
N21	Children	0.022	4900	0.001	8	0.25	350	0.001	2920	10	2.58E-06	2.10E-02	9.45E-06	9.45E-03
	Female	0.022	16000	0.001	30	0.33	350	0.001	10950	58	1.92E-06	1.50E-02	7.02E-06	7.02E-03
	Male	0.022	18000	0.001	30	0.33	350	0.001	10950	70	1.79E-06	1.45E-02	6.55E-06	6.55E-03
N23	Children	0.016	4900	0.001	8	0.25	350	0.001	2920	10	1.88E-06	1.52E-02	6.87E-06	6.87E-03
	Female	0.016	16000	0.001	30	0.33	350	0.001	10950	58	1.40E-06	1.10E-02	5.11E-06	5.11E-03
	Male	0.016	18000	0.001	30	0.33	350	0.001	10950	70	1.30E-06	1.05E-02	4.76E-06	4.76E-03
N24	Children	0.011	4900	0.001	8	0.25	350	0.001	2920	10	1.29E-06	1.05E-02	4.72E-06	4.72E-03
	Female	0.011	16000	0.001	30	0.33	350	0.001	10950	58	9.60E-06	7.00E-03	3.51E-06	3.51E-03
	Male	0.011	18000	0.001	30	0.33	350	0.001	10950	70	8.95E-06	7.20E-03	3.27E-06	3.27E-03

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
N16	Children	0.012	4900	0.001	8	0.25	350	0.001	2920	10	1.41E-06	1.10E-02	5.15E-06	5.15E-03
	Female	0.012	16000	0.001	30	0.33	350	0.001	10950	58	1.05E-06	8.50E-03	3.83E-06	3.83E-03
	Male	0.012	18000	0.001	30	0.33	350	0.001	10950	70	9.76E-07	7.90E-03	3.57E-06	3.57E-03
N18	Children	0.037	4900	0.001	8	0.25	350	0.001	2920	10	4.35E-06	3.50E-02	1.59E-05	1.59E-02
	Female	0.037	16000	0.001	30	0.33	350	0.001	10950	58	3.23E-06	2.60E-02	1.18E-05	1.18E-02
	Male	0.037	18000	0.001	30	0.33	350	0.001	10950	70	3.01E-06	2.44E-02	1.10E-05	1.10E-02
N21	Children	0.022	4900	0.001	8	0.25	350	0.001	2920	10	2.58E-06	2.10E-02	9.45E-06	9.45E-03
	Female	0.022	16000	0.001	30	0.33	350	0.001	10950	58	1.92E-06	1.50E-02	7.02E-06	7.02E-03
	Male	0.022	18000	0.001	30	0.33	350	0.001	10950	70	1.79E-06	1.45E-02	6.55E-06	6.55E-03
N23	Children	0.016	4900	0.001	8	0.25	350	0.001	2920	10	1.88E-06	1.52E-02	6.87E-06	6.87E-03
	Female	0.016	16000	0.001	30	0.33	350	0.001	10950	58	1.40E-06	1.10E-02	5.11E-06	5.11E-03
	Male	0.016	18000	0.001	30	0.33	350	0.001	10950	70	1.30E-06	1.05E-02	4.76E-06	4.76E-03
N24	Children	0.011	4900	0.001	8	0.25	350	0.001	2920	10	1.29E-06	1.05E-02	4.72E-06	4.72E-03
	Female	0.011	16000	0.001	30	0.33	350	0.001	10950	58	9.60E-06	7.00E-03	3.51E-06	3.51E-03
	Male	0.011	18000	0.001	30	0.33	350	0.001	10950	70	8.95E-06	7.20E-03	3.27E-06	3.27E-03

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
N25	Children	0.055	4900	0.001	8	0.25	350	0.001	2920	10	6.46E-06	5.25E-02	2.36E-05	2.36E-02
	Female	0.055	16000	0.001	30	0.33	350	0.001	10950	58	4.80E-06	3.90E-02	1.75E-05	1.75E-02
	Male	0.055	18000	0.001	30	0.33	350	0.001	10950	70	4.48E-06	3.63E-02	1.63E-05	1.63E-02
N26	Children	0.012	4900	0.001	8	0.25	350	0.001	2920	10	1.41E-06	1.14E-02	5.15E-06	5.15E-03
	Female	0.012	16000	0.001	30	0.33	350	0.001	10950	58	1.05E-06	8.50E-03	3.83E-06	3.83E-03
	Male	0.012	18000	0.001	30	0.33	350	0.001	10950	70	9.76E-07	7.90E-03	3.57E-06	3.57E-03
N27	Children	0.011	4900	0.001	8	0.25	350	0.001	2920	10	1.29E-06	1.05E-02	4.72E-06	4.72E-03
	Female	0.011	16000	0.001	30	0.33	350	0.001	10950	58	9.60E-07	7.00E-03	3.51E-06	3.51E-03
	Male	0.011	18000	0.001	30	0.33	350	0.001	10950	70	8.95E-07	7.20E-03	3.27E-06	3.27E-03
N28	Children	0.015	4900	0.001	8	0.25	350	0.001	2920	10	1.76E-06	1.43E-02	6.44E-06	6.44E-03
	Female	0.015	16000	0.001	30	0.33	350	0.001	10950	58	1.31E-06	1.00E-02	4.79E-06	4.79E-03
	Male	0.015	18000	0.001	30	0.33	350	0.001	10950	70	1.22E-06	9.90E-03	4.46E-06	4.46E-03
N29	Children	0.053	4900	0.001	8	0.25	350	0.001	2920	10	6.23E-06	5.06E-01	2.27E-05	2.27E-02
	Female	0.053	16000	0.001	30	0.33	350	0.001	10950	58	4.63E-06	3.70E-02	1.69E-05	1.69E-02
	Male	0.053	18000	0.001	30	0.33	350	0.001	10950	70	4.31E-06	3.50E-02	1.57E-05	1.57E-02

Supplementary Table 7.15. Human Health Risk Assessment among children, adult (male and female) in Darrang district due to the dermal exposure of As contaminated water sample showing concentration >10µL^{-1}

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
D1	Children	0.055	4900	0.001	8	0.25	350	0.001	2920	10	6.46E-06	5.25E-02	2.36E-05	2.36E-02
	Female	0.055	16000	0.001	30	0.33	350	0.001	10950	58	4.80E-06	3.90E-02	1.75E-05	1.75E-02
	Male	0.055	18000	0.001	30	0.33	350	0.001	10950	70	4.47E-06	3.60E-02	1.63E-05	1.63E-02
D3	Children	0.011	4900	0.001	8	0.25	350	0.001	2920	10	1.29E-06	1.00E-02	4.72E-06	4.72E-03
	Female	0.011	16000	0.001	30	0.33	350	0.001	10950	58	9.60E-07	7.00E-03	3.51E-06	3.51E-03
	Male	0.011	18000	0.001	30	0.33	350	0.001	10950	70	8.95E-07	7.20E-03	3.27E-06	3.27E-03
D4	Children	0.014	4900	0.001	8	0.25	350	0.001	2920	10	1.75E-06	1.40E-02	6.40E-06	6.40E-03
	Female	0.014	16000	0.001	30	0.33	350	0.001	10950	58	1.30E-06	1.05E-02	4.76E-06	4.76E-03
	Male	0.014	18000	0.001	30	0.33	350	0.001	10950	70	1.21E-06	9.80E-03	4.43E-06	4.43E-03
D7	Children	0.038	4900	0.001	8	0.25	350	0.001	2920	10	4.46E-06	3.60E-02	1.63E-05	1.63E-02
	Female	0.038	16000	0.001	30	0.33	350	0.001	10950	58	3.31E-06	2.69E-02	1.21E-05	1.21E-02
	Male	0.038	18000	0.001	30	0.33	350	0.001	10950	70	3.09E-06	2.51E-02	1.13E-05	1.13E-02
D8	Children	0.02	4900	0.001	8	0.25	350	0.001	2920	10	2.34E-06	1.90E-02	8.59E-06	8.59E-03
	Female	0.02	16000	0.001	30	0.33	350	0.001	10950	58	1.74E-06	1.41E-02	6.38E-06	6.38E-03
	Male	0.02	18000	0.001	30	0.33	350	0.001	10950	70	1.62E-06	1.32E-02	5.95E-06	5.95E-03

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
D9	Children	0.051	4900	0.001	8	0.25	350	0.001	2920	10	5.99E-06	4.80E-02	2.19E-05	2.19E-02
	Female	0.051	16000	0.001	30	0.33	350	0.001	10950	58	4.45E-06	3.61E-02	1.62E-05	1.62E-02
	Male	0.051	18000	0.001	30	0.33	350	0.001	10950	70	4.14E-06	3.37E-02	1.51E-05	1.51E-02
D10	Children	0.052	4900	0.001	8	0.25	350	0.001	2920	10	6.10E-06	4.90E-02	2.23E-05	2.23E-02
	Female	0.052	16000	0.001	30	0.33	350	0.001	10950	58	4.53E-06	3.69E-02	1.66E-05	1.66E-02
	Male	0.052	18000	0.001	30	0.33	350	0.001	10950	70	4.23E-06	3.44E-02	1.54E-05	1.54E-02
D11	Children	0.011	4900	0.001	8	0.25	350	0.001	2920	10	1.29E-06	1.05E-02	4.72E-06	4.72E-03
	Female	0.011	16000	0.001	30	0.33	350	0.001	10950	58	9.60E-06	7.80E-03	3.51E-06	3.51E-03
	Male	0.011	18000	0.001	30	0.33	350	0.001	10950	70	8.95E-07	7.20E-03	3.27E-06	3.27E-03
D16	Children	0.029	4900	0.001	8	0.25	350	0.001	2920	10	3.40E-06	2.70E-02	1.24E-05	1.24E-02
	Female	0.029	16000	0.001	30	0.33	350	0.001	10950	58	2.53E-06	2.05E-02	9.26E-06	9.26E-03
	Male	0.029	18000	0.001	30	0.33	350	0.001	10950	70	2.35E-06	1.91E-02	8.63E-06	8.63E-03

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
D9	Children	0.051	4900	0.001	8	0.25	350	0.001	2920	10	5.99E-06	4.80E-02	2.19E-05	2.19E-02
	Female	0.051	16000	0.001	30	0.33	350	0.001	10950	58	4.45E-06	3.61E-02	1.62E-05	1.62E-02
	Male	0.051	18000	0.001	30	0.33	350	0.001	10950	70	4.14E-06	3.37E-02	1.51E-05	1.51E-02
D10	Children	0.052	4900	0.001	8	0.25	350	0.001	2920	10	6.10E-06	4.90E-02	2.23E-05	2.23E-02
	Female	0.052	16000	0.001	30	0.33	350	0.001	10950	58	4.53E-06	3.69E-02	1.66E-05	1.66E-02
	Male	0.052	18000	0.001	30	0.33	350	0.001	10950	70	4.23E-06	3.44E-02	1.54E-05	1.54E-02
D11	Children	0.011	4900	0.001	8	0.25	350	0.001	2920	10	1.29E-06	1.05E-02	4.72E-06	4.72E-03
	Female	0.011	16000	0.001	30	0.33	350	0.001	10950	58	9.60E-06	7.80E-03	3.51E-06	3.51E-03
	Male	0.011	18000	0.001	30	0.33	350	0.001	10950	70	8.95E-07	7.20E-03	3.27E-06	3.27E-03
D16	Children	0.029	4900	0.001	8	0.25	350	0.001	2920	10	3.40E-06	2.70E-02	1.24E-05	1.24E-02
	Female	0.029	16000	0.001	30	0.33	350	0.001	10950	58	2.53E-06	2.05E-02	9.26E-06	9.26E-03
	Male	0.029	18000	0.001	30	0.33	350	0.001	10950	70	2.35E-06	1.91E-02	8.63E-06	8.63E-03

Sample ID	Category	Concentration of heavy metals in water (Cw)	Skin-surface Area (SA)	Skin permeability coefficient (Kp)	Exposure duration (ED)	Exposure time (ET)	Exposure frequency (EF)	Conversion Factor (CF)	Average time (AT)	Body Weight (BW)	Dermal Absorbed Dose (DAD)	Dermal Hazard Quotient (HQ)	Cancer Risk Dermal (CR)	Susceptibility
		mg/L	cm^2	cm/hr	Year	h/day	Days/year	L/cm^2	Days	Kg	mg/kg/day		mg/Kg-day -1	1 in 1000
D17	Children	0.025	4900	0.001	8	0.25	350	0.001	2920	10	2.93E-06	2.30E-02	1.07E-05	1.07E-02
	Female	0.025	16000	0.001	30	0.33	350	0.001	10950	58	2.18E-06	1.77E-02	7.98E-06	7.98E-03
	Male	0.025	18000	0.001	30	0.33	350	0.001	10950	70	2.03E-06	1.65E-02	7.44E-06	7.44E-03
D23	Children	0.03	4900	0.001	8	0.25	350	0.001	2920	10	3.52E-06	2.80E-02	1.28E-05	1.28E-02
	Female	0.03	16000	0.001	30	0.33	350	0.001	10950	58	2.61E-06	2.12E-02	9.58E-06	9.58E-03
	Male	0.03	18000	0.001	30	0.33	350	0.001	10950	70	2.41E-06	1.98E-02	8.93E-06	8.93E-03
D24	Children	0.04	4900	0.001	8	0.25	350	0.001	2920	10	4.69E-06	3.80E-02	1.71E-05	1.71E-02
	Female	0.04	16000	0.001	30	0.33	350	0.001	10950	58	3.49E-06	2.83E-02	1.28E-05	1.28E-02
	Male	0.04	18000	0.001	30	0.33	350	0.001	10950	70	3.25E-06	2.64E-02	1.19E-05	1.19E-02

CHAPTER – 8

Visualization of Groundwater Arsenic Distribution Pattern Using MODFLOW

8.1 Introduction -

Groundwater is a precious and most widely distributed resource of the earth, which is required for agriculture, industry and domestic purposes. It gets annual replenishment from the meteoric precipitation.70 percent of the earth's surface is covered with water. The reality, however, is that 97.3 % of the total water on earth is saline and only 2.7 % is available as fresh water. About 77 % percent of this fresh water is locked up in glaciers and permanent snow. About 11 percent of the resources are available as extractable ground water within 800 m depth and about 1 percent is available as surface water in lakes and rivers (CGWB, 2007; MoWR, 2009). Due to rapid urbanization and industrialization, the need for water is ever increasing. The requirement of water in a developing country like India, where more than 90% of rural and nearly 30% of urban population depend on groundwater for meeting their drinking and domestic requirements (CGWB, 2007). Due to rapid urbanization and industrialization, the need for water is ever increasing. The requirement of water in a developing country like India, where more than 90% of rural and nearly 30% of urban population depend on groundwater for meeting their drinking and domestic requirements (CGWB, 2007). As present, nearly one fifth of all the water used in the world is from groundwater resources. Currently, water resources management has to consider a river basin as an integrated system where interactions among surface water, groundwater, and water resources use and effects on ecosystems take place. Decision makers require adequate information on these interactions in order to formulate sustainable water resources development strategies. Groundwater models play an important role in the development and management of groundwater resources, and in predicting effects of management measures.

With rapid increases in computation power and the wide availability of computers and model software, groundwater modelling has become a standard tool for professional hydro geologists to effectively perform most tasks. GIS has emerged as an effective tool for handling spatial data and decision making in several areas including engineering and environmental fields (Stafford, 1991; Goodchild, 1993). GIS provides a means of representing the real world through integrated layers of constituent spatial information (Corwin, 1996). Visual MODFLOW is also a user friendly software that has ability to generate 3D visualization graphics and import GIS data. Xu et al., (2009) used MODFLOW 2000 (Harbaugh et al., 2000) coupled with GIS to simulate the groundwater dynamics. All of them vary both in space and time, thus adopting a Geographic Information System (GIS) in association with a model is helpful. Coupling GIS technology with a process based groundwater model may facilitate hydro geological and hydrologic system conceptualization and characterization (Hinaman, 1993; Kolm, 1996; Gogu et al., 2001), thus also a proper adaptation of the groundwater flow model to the area under study (Brodie, 1998). In most of groundwater modelling software's such as FEFLOW, MODFLOW, GMS (Groundwater Modelling System) there is an interface that links vector data through compatible GIS formats i.e. .shp, .lin, .dxf etc. and raster data formats i.e. .tif, .bmp, .img etc Groundwater flow models have been used: (1) as interpretative tools for investigating groundwater system understanding the dynamics and flow patterns; (2) assimilation tools for analyzing responses of the groundwater system to stresses; (3) as assessment tools for evaluating recharge, discharge and aquifer storage processes, and for quantifying sustainable yield; (4) as predictive tools for predicting future conditions or impacts of human activities; (5) as supporting tools for planning field data collection and designing practical solutions; (6) as screening tools for evaluating groundwater development scenarios; (7) as management tools for assessing alternative Polices; and (8) as visualization tools for communicating key messages to public and decision-makers (Pathak R et al., 2018).

This paper provides a comprehensive overview of groundwater flow modelling conducted in the Darrang and Nagaon districts of Assam, focusing on the visualization of groundwater arsenic distribution patterns. The study leverages MODFLOW, a widely used groundwater modelling software, to simulate the movement and distribution of groundwater within these districts. By integrating MODFLOW with MT3DMS, a modular transport model designed for simulating solute transport, the research aims to map the spatial variation and concentration of arsenic in the groundwater. This approach allows for analysis of how arsenic, a toxic element that poses significant health risks, is distributed across different areas within the study region. The modelling results are crucial for understanding the contamination levels and guiding appropriate interventions to manage and mitigate the risks associated with arsenic exposure. The insights gained from this study are expected to aid in developing effective groundwater management strategies and public health policies in Assam, addressing both the environmental and health challenges posed by arsenic contamination.

8.2 Study Area –

8.2.1 General –

The performance of the proposed objective is evaluated through an illustrative study focusing on two districts in Assam, namely Darrang and Nagaon. This evaluation involves examining and visualising the flow and transport processes of arsenic contaminant concentrations within the specified study area. The analysis is conducted using the Grid Approach available in the Groundwater Modelling System (GMS). By employing this method, the study aims to accurately assess how arsenic disperses and behaves in these districts, providing valuable insights into the contaminant dynamics and aiding in the formulation of effective management strategies.

8.2.2 Overview of the study area –

Refer to Chapter 3 Page 18-24 for detailed description of study area.

8.3 Methodology –

Our dissertation focuses on the simulation of an unconfined aquifer system within the study areas of Darrang and Nagaon, which are characterized by their expansive dimensions of 1582 km^2 and 2287 km^2, respectively. The aquifer is modelled as a single-layer system within a computational grid, with an irregular boundary and a grid size of 200 meters by 200 meters, encompassing 115 rows and 141 columns. The boundary conditions for this unconfined aquifer are defined as static. The southern boundary of the Darrang district and the northern boundary of the Nagaon district are set as fixed head boundaries. This configuration accounts for the flow of the Brahmaputra River, which flows southward through the Darrang district and northward through the Nagaon district. Flow boundary conditions are assumed to be constant along the east and west sides of the aquifer. Specifically, in the Darrang district, the hydraulic head at the west side varies from 70 meters to 53.78 meters, while at the east side, it ranges from 51.45 meters to 45 meters. For the Nagaon district, the west side head varies from 64.35 meters to 52.0 meters, and the east side ranges from 49.38 meters to 41.0 meters. The initial head within the aquifer is set at the surface of the model, which represents the top layer. The aquifer's horizontal and vertical hydraulic conductivities (Kxx and Kyy) are both set at 20 meters per day, with an effective porosity (ŋ) of 0.3. Additionally, the aquifer's longitudinal dispersivity (αL) is 10.0 meters, and the transverse dispersivity (αT) is 1 meter. To assess the arsenic concentration, flow and transport simulations are conducted over a two-year period, divided into eight stress periods of three months each. This comprehensive simulation aims to provide detailed insights into the behaviour of arsenic within the aquifer and its potential impact on the surrounding environment.

8.3.1 Source Flux for the study area –

Tables 4.3 and 4.4 in Chapter 4 present the concentrations of arsenic at various locations within the illustrative study areas of Darrang and Nagaon. For detailed information on these concentrations and their corresponding habitations, please refer to page 38 - 40 in Chapter 4. These tables provide critical data on arsenic levels across different sites, offering valuable insights into the distribution of this contaminant within the study areas and its potential impact on local communities.

8.3.2 Grid Approach –

In our study, we utilized the Grid Approach for simulating the groundwater flow model using MODFLOW and transport of arsenic using MT3DMS. This method involved discretizing the aquifer system into a structured grid to accurately represent and analyze groundwater flow dynamics. By applying this approach, we were able to capture the complex interactions within the aquifer and assess various hydrological processes effectively. The Grid Approach in MODFLOW is a foundational component of groundwater modeling used to simulate flow and transport processes in aquifer systems. MODFLOW, developed by the United States Geological Survey (USGS), is a widely used modular finite-difference groundwater flow model. The grid approach involves working directly with the 3D grid to apply sources/sinks and other model parameters on a cell-by cell basis.

8.3.3 Simulation Model –

Simulation is a modelling technique that approximates the behaviour of a system on the computer, representing all the characteristics of the system by mathematical relationships. It is an effective tool for studying the management of a complex water resource system, for it can incorporate the experience and judgment of the planner or designer into the model. Various practitioners successfully have used simulation models.

Thus, simulation is the imitation of the operation of real-world process or system over time. It is a model which constructs a conceptual framework that describes a system. The behaviour of a system that evolves over time is studied by developing a simulation model. The model takes a set of expressed assumption, be it mathematical, logical or symbolic relationship between the entities.

8.3.4 Development of simulation model using GMS -

In the study, GMS has been used to simulate the flow and transport processes in the unconfined aquifer of Darrang and Nagaon. GMS are a complete program for building and simulating groundwater models. It features 2D and 3D geostatistics, stratigraphic modelling and a unique conceptual model approach. Currently supported models include MODFLOW, MODPATH, MT3DMS, RT3D, FEMWATER, SEEP2D, and UTEXAS. In our study we have used MOFLOW and MT3DMS for simulation of groundwater model. GMS is the quickest and most intuitive groundwater modelling interface available Three dimensional groundwater flow equation and three dimensional advective-dispersive groundwater transport equation are solved by the two computer programs MODFLOW and MT3DMS which are available in the most advanced groundwater simulation model GMS. The two approaches that can be used to construct a MODFLOW and MT3DMS simulation in GMS are the Grid approach and Conceptual approach. Here in our study Grid Approach is followed for developing the model. When GMS executes MODFLOW and MT3DMS, it saves input and output data's in a number of files. MODFLOW generates some output data after its execution. These output data's are used by MT3DMS for its execution. Therefore, there should always be a MODFLOW simulation before a MT3DMS simulation.

8.3.5 Use of Modular Finite Difference Flow Model (MODFLOW) -

MODFLOW is the U.S. Geological Survey modular finite difference flow model, which a computer code that solves the groundwater flow equation. The program is used by hydro geologists to simulate the flow of groundwater using aquifers. The main objective in designing MODFLOW is to produce a program that can be readily modified, is simple to use and maintain, can be executed on a variety of computers with minimal changes, and has the ability to manage the large data sets required when running large projects. The modular structure of MODFLOW consists of a main program and a series of highly-independent subroutines called modules. The modules are grouped in packages. Each package deals with a specific feature of the hydrologic system which is to be simulated such as flow from rivers or flow into drains or with a specific method of solving linear equations which describe the flow system such as the Strongly Implicit Procedure or Preconditioned Conjugate Gradient. In MODFLOW, layers can also be simulated as confined, unconfined, or a combination of both. Flows from external sources such as flow to wells, areal recharge, evapo-transpiration, flow to drains, and flow through riverbeds can also be simulated.

8.3.6 Use of Modular Solute Transport Model (MT3DMS) –

MT3D was originally developed by Zheng (1990) at S.S. Papadopulos & Associates,Inc., and subsequently documented for the Robert S. Kerr Environmental Research Laboratory of the U.S. Environmental Protection Agency. MT3DMS is a comprehensive numerical model for simulating solute transport in complex hydro geologic settings. It is a multispecies transport model for simulation of Advection, Dispersion or Dilution and Chemical reactions of contaminants in groundwater systems. MT3D uses a modular structure similar to the structure utilized by MODFLOW. MT3D is used in conjunction with MODFLOW in a two step flow and transport simulation. Heads and cell to cell flux terms are computed by MODFLOW during the flow simulation and are written to a specially formatted file. This file is then read by MT3D and utilized as the flow field for the transport portion of the simulation.

MT3DMS can accommodate very general spatial discretization schemes and transport boundary conditions, including: (a) confined, unconfined, or variably confined/unconfined aquifer layers; (b) inclined model layers and variable cell thickness within the same layer; (c) specified concentration or mass flux boundaries; and (d) the solute transport effects of external hydraulic sources and sinks such as wells, drains, rivers, areal recharge, and evapotranspiration.

8.4 Results and Discussion –

8.4.1 Groundwater Flow Model –

A groundwater flow model is a computational tool used to simulate the movement of groundwater through an aquifer system. These models are crucial for understanding and managing groundwater resources, predicting how water will flow through geological formations, and assessing the impacts of various factors such as pumping, recharge, and contamination.

8.4.2 The Head Distribution in Darrang District using MODFLOW through the Grid Approach -

A groundwater flow model was developed using MODFLOW for the Darrang district, where the hydraulic head distribution varies significantly across the region. Specifically, at the west side of the district, the head ranges from 70 meters to 53.78 meters, while at the east side, it spans from 51.45 meters to 45 meters. The head distribution data has been obtained from the Central Ground Water Board (CGWB) website, as detailed in the Central Ground Water Year Book 2022. Figure 8.1 illustrates the head distribution within the unconfined aquifer, providing a visual representation of these variations. For the model, we assumed a recharge rate of 0.0001 meters per day, as sourced from the Central Ground Water Board (CGWB) website. This parameter plays a crucial role in the simulation, influencing the overall groundwater flow dynamics in the model.

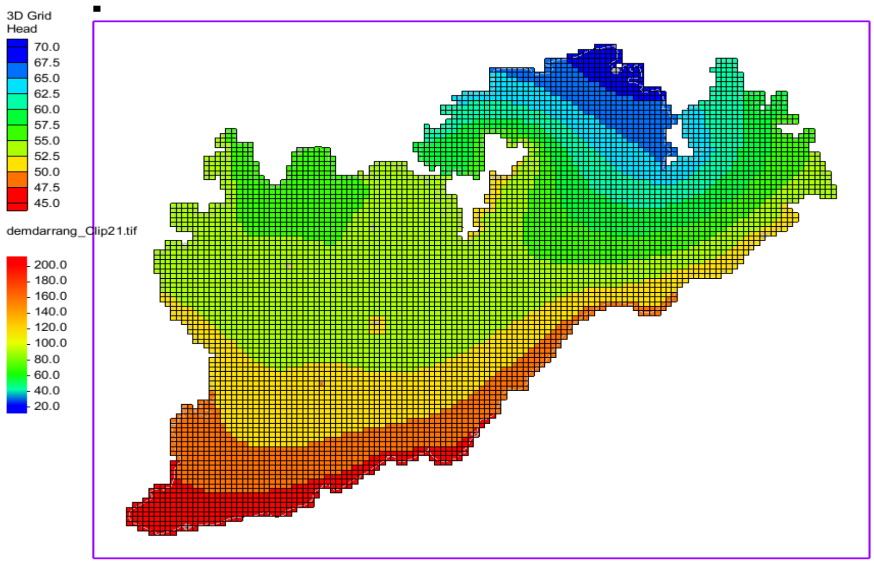

Fig 8.1 – Ground water flow model of Darrang district using MODFLOW.

The results of the groundwater flow model for the Darrang district, developed using MODFLOW, provide valuable insights into the dynamics of the aquifer system. The model reveals a notable variation in hydraulic head across the district. At the western boundary, the hydraulic head ranges from 70 meters to 53.78 meters. In contrast, the eastern boundary exhibits a lower range, with the head varying from 51.45 meters to 45 meters. This gradient indicates a west-to-east decline in hydraulic head, which is crucial for understanding groundwater flow direction and potential sources of recharge or discharge. The model simulates the flow of groundwater from areas of higher head to areas of lower head, consistent with the observed head distribution. This flow pattern suggests a predominant movement of groundwater from the western parts of the district towards the eastern regions, reflecting the influence of the hydraulic gradient. With an assumed recharge rate of 0.0001 meters per day, the model indicates how this relatively low rate influences the groundwater levels and flow patterns. The recharge rate affects the overall water balance in the unconfined aquifer, contributing to the gradual increase in head levels in recharge zones and influencing the flow towards discharge areas. Recharge was assumed to be distributed uniformly in the entire study area. The simulated hydraulic conductivity value 20m/day, which dictate the ease with which water can flow through the aquifer, play a significant role in determining the flow rates and head distribution. The results offer critical insights for water resource management in the Darrang district. Understanding the flow patterns and head distribution helps in predicting potential areas of water scarcity or excess, informing decisions related to groundwater extraction, recharge strategies, and sustainable management practices. Figure 8.1, included in the study, provides a visual representation of the head distribution within the unconfined aquifer. This figure helps in interpreting the spatial variations and flow dynamics observed in the model, facilitating a clearer understanding of the groundwater system's behavior. In summary, the groundwater flow model for Darrang district, developed with MODFLOW, highlights the key aspects of head distribution, flow patterns, and the impact of recharge rates, offering valuable information for effective groundwater management and planning.

8.4.3 The Head Distribution in Nagaon District using MODFLOW through the Grid Approach –

The head distribution in the Nagaon district was examined using MODFLOW through the Grid Approach, which involved discretizing the aquifer into a structured grid for detailed simulation. A groundwater flow model was also developed for the Nagaon district using MODFLOW, showcasing significant variations in hydraulic head across the region. In Nagaon, the hydraulic head on the western side ranges from 64.35 meters to 52.0 meters, while on the eastern side, it varies between 49.38 meters and 41.0 meters. The Reduced level data has been collected from Public Health Laboratory, Nagaon for computations of head distributions using MODFLOW within GMS software. These variations in head levels are depicted in Figure 8.2, which provides a detailed visual representation of the head distribution throughout the unconfined aquifer. The model incorporates a recharge rate of 0.0001 meters per day, based on data from the Central Ground Water Board (CGWB) website.

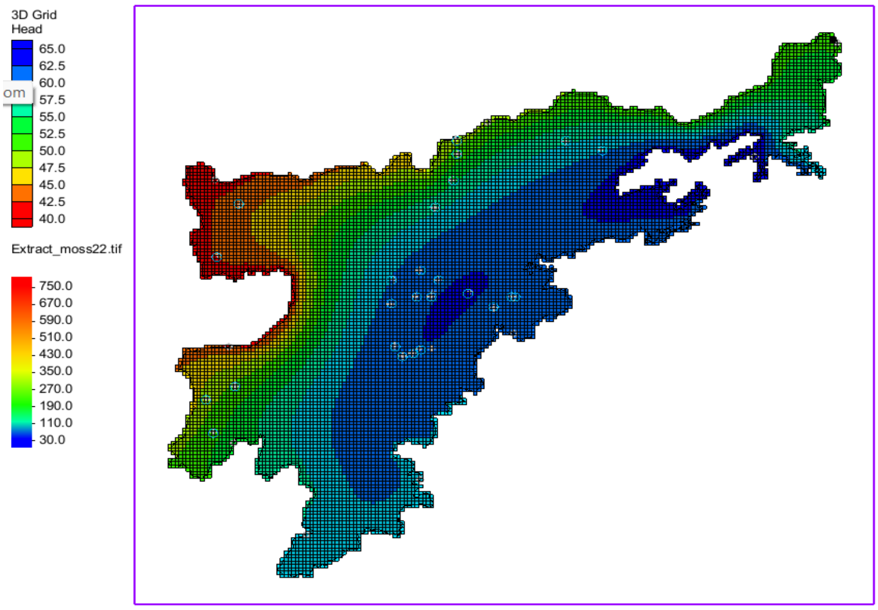

Fig 8.2 – Ground water flow model of Nagaon district using MODFLOW.

The results of the groundwater flow model for the Nagaon district, developed using MODFLOW, reveal significant insights into the aquifer's behavior and dynamics. The simulation demonstrates considerable variation in hydraulic head across the district. Specifically, the hydraulic head on the western boundary ranges from 64.35 meters to 52.0 meters, whereas the eastern boundary shows a head range from 49.38 meters to 41.0 meters. These variations are illustrated in Figure 8.2, which provides a clear visual representation of the head distribution within the unconfined aquifer. The model incorporates a recharge rate of 0.0001 meters per day, as provided by the Central Ground Water Board (CGWB) website. This recharge rate is crucial for assessing the impact of groundwater replenishment on the overall head levels and flow patterns within the aquifer.

8.4.4 Distribution of Arsenic concentration in Darrang district using MT3DMS -

The distribution of arsenic concentration in the Darrang district was analyzed using MT3DMS, a widely used groundwater transport model that simulates contaminant transport in conjunction with MODFLOW. Arsenic transport distribution can be calculated using MT3DMS only after running a MODFLOW simulation. Therefore, it is essential to first complete the MODFLOW simulation before setting up the MT3DMS simulation. Figure 8.3 illustrates the results of the MODFLOW simulation, which serves as the foundation for the subsequent MT3DMS analysis.

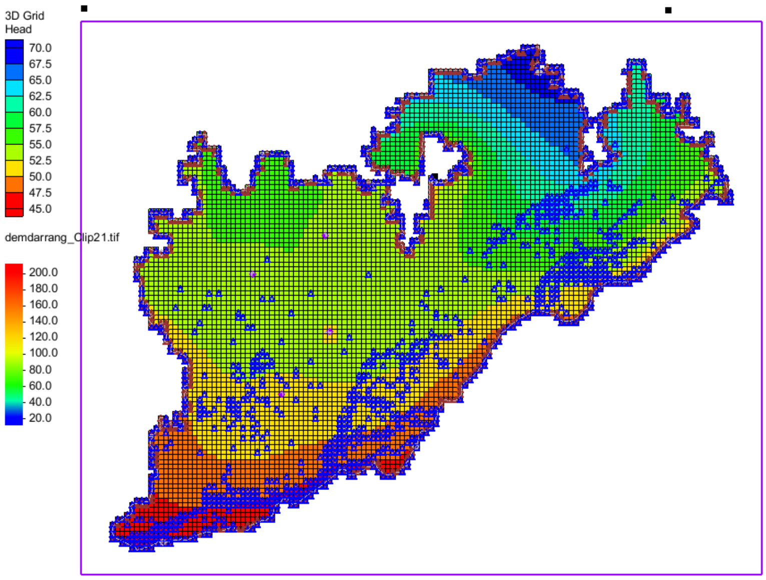

Fig 8.3 MODFLOW simulated model of study area – Darrang.

The MODFLOW simulation was completed prior to the development of the MT3DMS model, which is essential for analyzing contaminant transport. The MT3DMS simulation, conducted over a two-year period and divided into eight stress periods, is detailed in the following figures. These figures provide a comprehensive view of the arsenic transport distribution in the Darrang district of Assam, illustrating how arsenic concentrations evolve over time and across different stress periods.

The figure 8.4 shows the Arsenic distribution after 9 days.

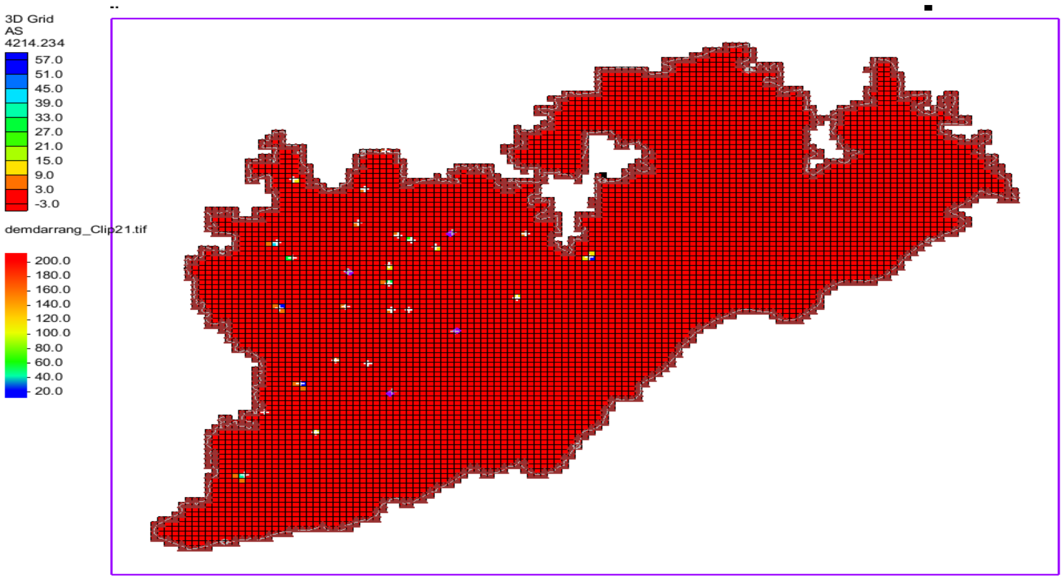

Figure 8.4: Transport of arsenic over a 9-day period simulated using MT3DMS in Darrang

The MT3DMS simulation for arsenic transport over a 9-day period indicates that the transport of arsenic is minimal within this short timeframe. The minimal transport observed reflects the early phase of arsenic migration. During this period, arsenic has not yet significantly spread from its source or reached a broader area, indicating that substantial dispersion and transport require more extended simulation periods. The limited movement observed suggests that significant transport of arsenic occurs over extended periods. The short duration of 9 days is insufficient to detect substantial changes in arsenic concentration. However, there is an indication of a decreasing trend over this period. Specifically, arsenic concentrations decrease from 51 ppm to a range of 9-15 ppm and from 27 ppm to a range of 3-9 ppm. Figure 8.4 visually depict the simulation of limited transport and concentration changes over a 9 day period. These illustrations highlight the areas with minimal variation, emphasizing that more significant changes may emerge in extended simulations.

The figure 8.5 shows the arsenic distribution in the aquifer after 90 days.

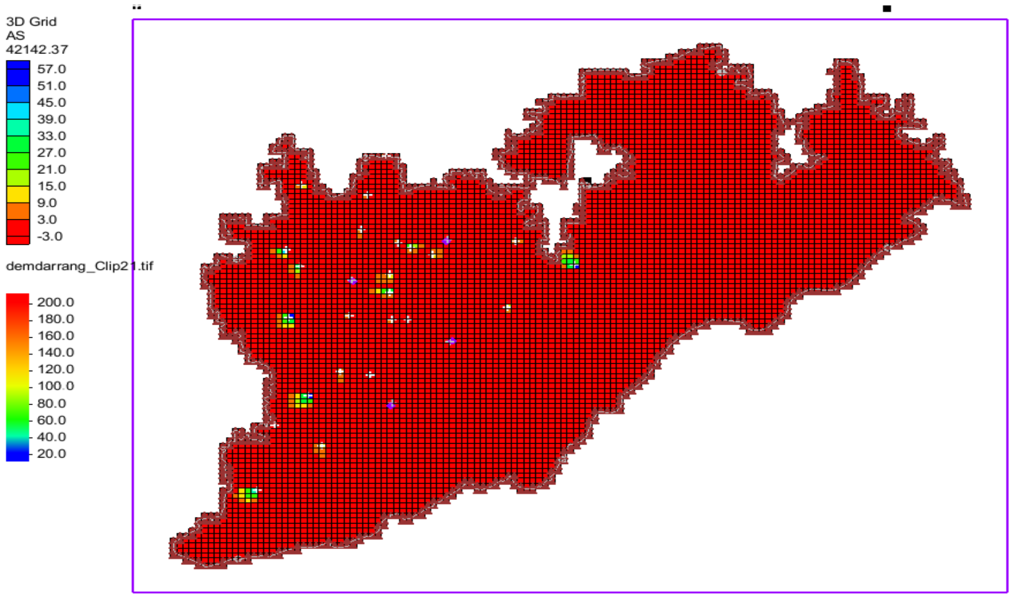

Figure 8.5: Transport of arsenic over a 90-day period simulated using MT3DMS in Darrang.

The MT3DMS simulation reveals that arsenic transport begins to move after 90 days. This observation indicates that, while initial arsenic movement is minimal, the contaminant starts to migrate significantly after this period. Significant arsenic movement starts after 90 days, suggesting that the contaminant requires a certain amount of time to initiate substantial migration within the aquifer system. The simulation using MT3DMS indicates a decline in arsenic concentrations from a point source over a 90-day period. Specifically, concentrations decrease from 51 ppm to a range of 21-27 ppm, from 39 ppm to 9 ppm, and from 15 ppm to a range of 3-9 ppm. Figures from the simulation illustrate the progression of arsenic transport after 90 days, providing a visual representation of how the contaminant disperses over time.

After 90 days, next is the arsenic distribution after 180 days. After 180 days, the distribution of arsenic transport is slightly increasing here. The figure 8.6 shows the arsenic distribution in the aquifer after 180 days.

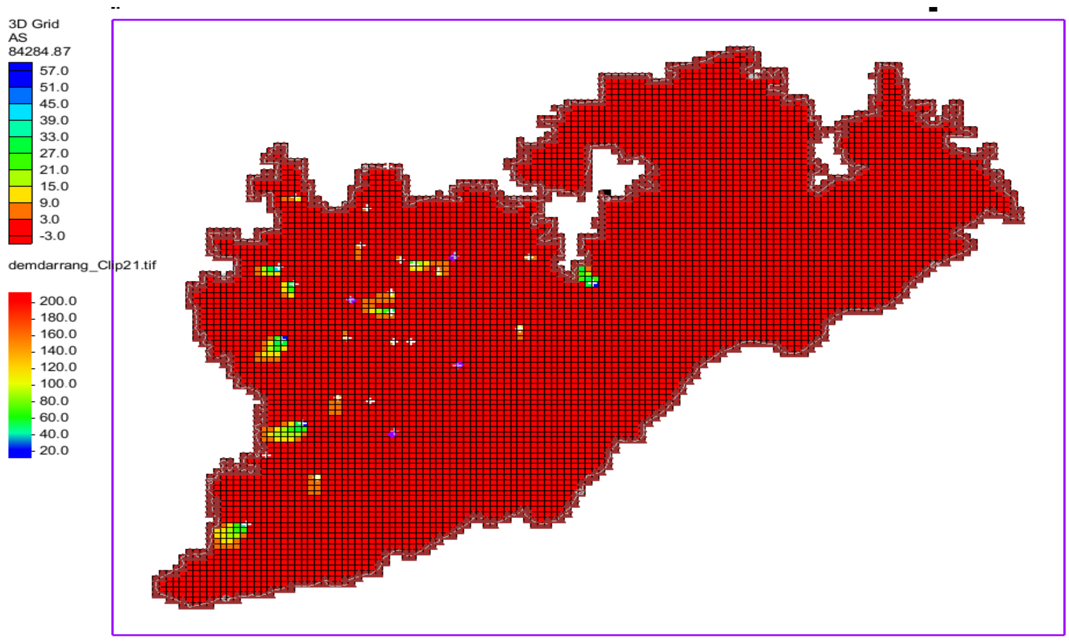

Figure 8.6: Transport of arsenic over a 180-day period simulated using MT3DMS in Darrang.

The MT3DMS simulation results show that arsenic transport dynamics evolve significantly over time. After 90 days, the distribution of arsenic begins to show movement, but it is not until 180 days that a more noticeable change occurs. Specifically, after 180 days, the distribution of arsenic transport begins to exhibit a slight increase, indicating a gradual escalation in the movement and spread of arsenic within the aquifer system. Although transport increases daily, arsenic concentrations appear to be decreasing because it is treated as a point source pollutant. Specifically, concentrations decrease from 45 ppm to a range of 15-21 ppm, from 27 ppm to a range of 9-15 ppm, and from 15 ppm to a range of 3-9 ppm. The increase in arsenic distribution after 180 days suggests that the contaminant is progressively spreading through the aquifer. This change in distribution can be attributed to ongoing groundwater flow and the processes of advection and dispersion.

After 270 days and 360 days, it is observed that arsenic transport is expected to show more pronounced dispersion throughout the unconfined aquifer as shown in figure 8.7 and 8.8.

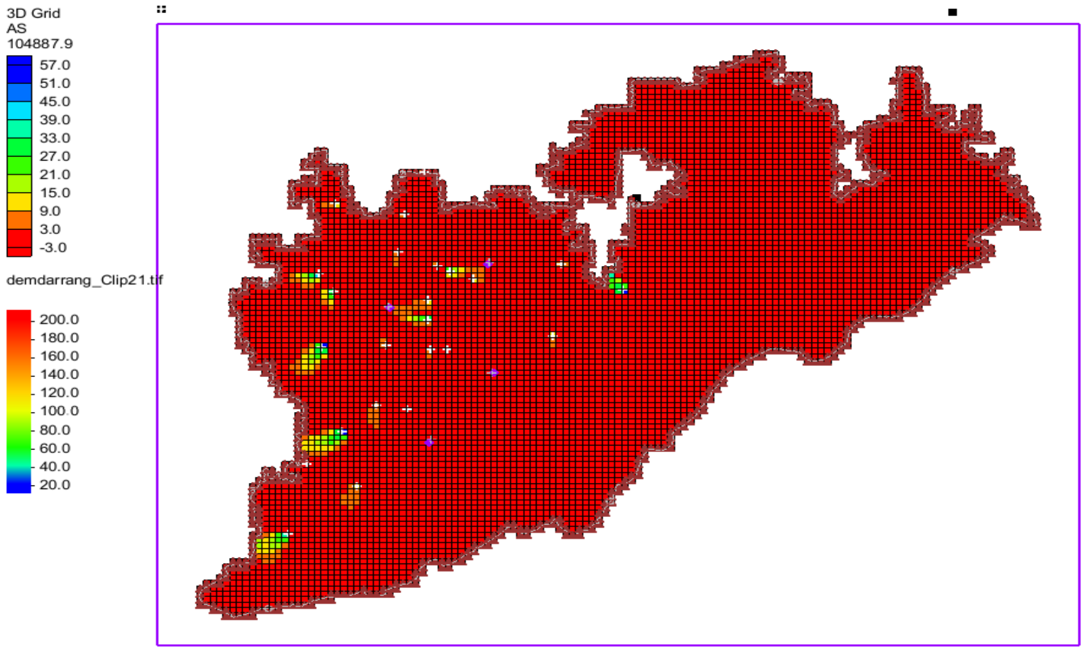

Figure 8.7: Transport of arsenic over a 240-day period simulated using MT3DMS in Darrang

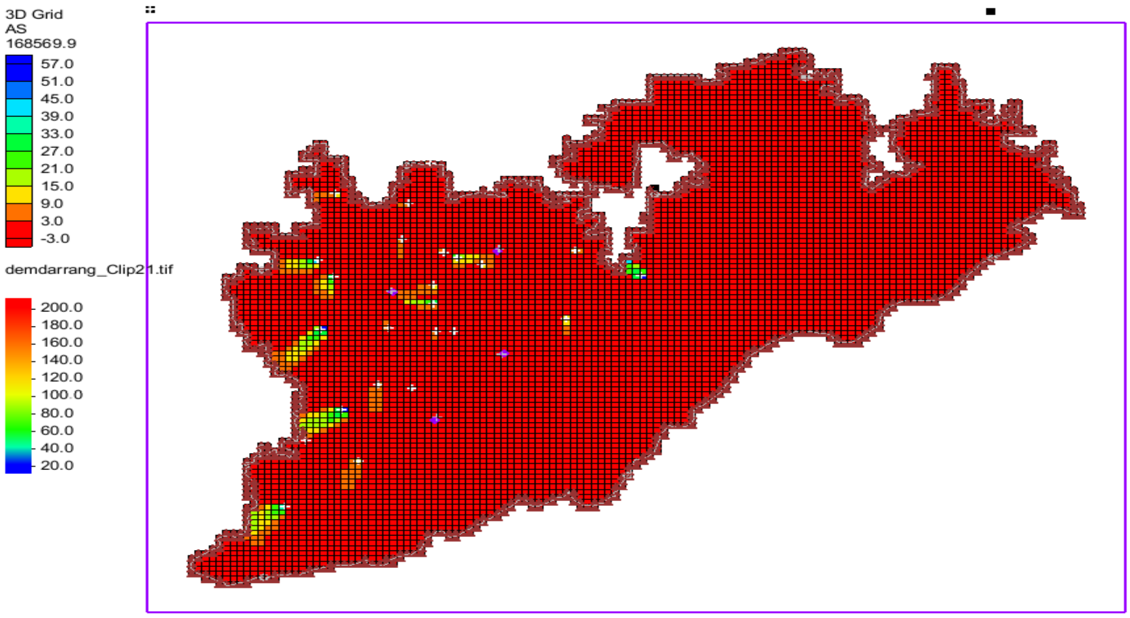

Figure 8.8: Transport of arsenic over a 360-day period simulated using MT3DMS in Darrang.

Based on the MT3DMS simulation, arsenic transport in groundwater after 240 days dispersion is increased. By 240 days, arsenic transport is expected to show more pronounced dispersion throughout the aquifer. The contaminant will have had additional time to spread and migrate further from its source. This period marks a continuation of the trend observed at 180 days, with arsenic concentrations likely increasing and spreading over a larger area. The concentrations appear to be decreasing, with values reducing from 45 ppm to a range of 15-21 ppm, from 27 ppm to a range of 9-15 ppm, and from 15 ppm to a range of 3-9 ppm. The spatial distribution of arsenic will become more extensive, with noticeable concentrations appearing in previously less affected areas. The aquifer will show a more significant pattern of contamination, reflecting the impact of continued advection and dispersion processes.

After 360 days, the transport of arsenic is likely to be more stable and widespread. Over a 360-day period, the concentrations during transport decrease as follows: from 51 ppm to a range of 39-45 ppm, from 39 ppm to a range of 3-9 ppm, from 27 ppm to a range of 9-15 ppm, and from 21 ppm to a range of 3-9 ppm. The contaminant will have dispersed significantly, and the distribution pattern may start to stabilize. This extended period allows for a more complete assessment of how arsenic spreads through the aquifer. There may be areas where arsenic concentrations peak due to accumulation from prolonged transport. These peaks reflect regions where arsenic has concentrated over time, potentially posing higher risks to groundwater quality. Ongoing monitoring and analysis are crucial to manage the long-term impacts of arsenic contamination effectively.

After 450 days, it is observed from the figure 8.9 that the transport of groundwater arsenic is increasing, but the concentrations seem to decrease in a similar manner.

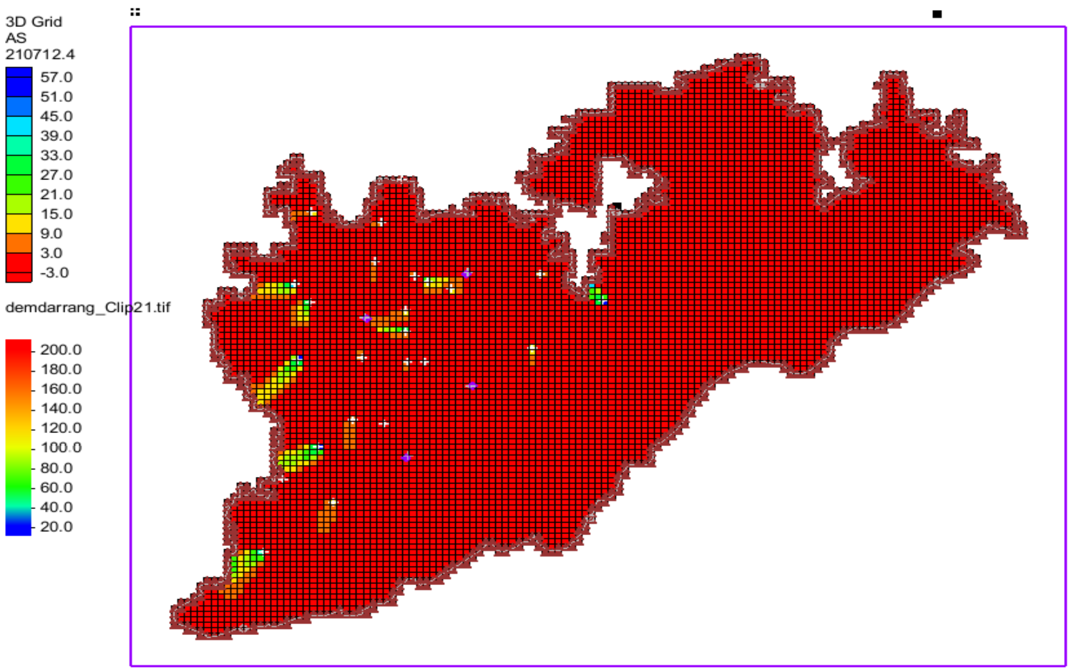

Figure 8.9: Transport of arsenic over a 450-day period simulated using MT3DMS in Darrang

As the MT3DMS simulation extends to 540, 630, and 720 days, the behaviour of arsenic transport in the groundwater will continue to evolve as shown in the figure 8.10, 8.11 and 8.12.

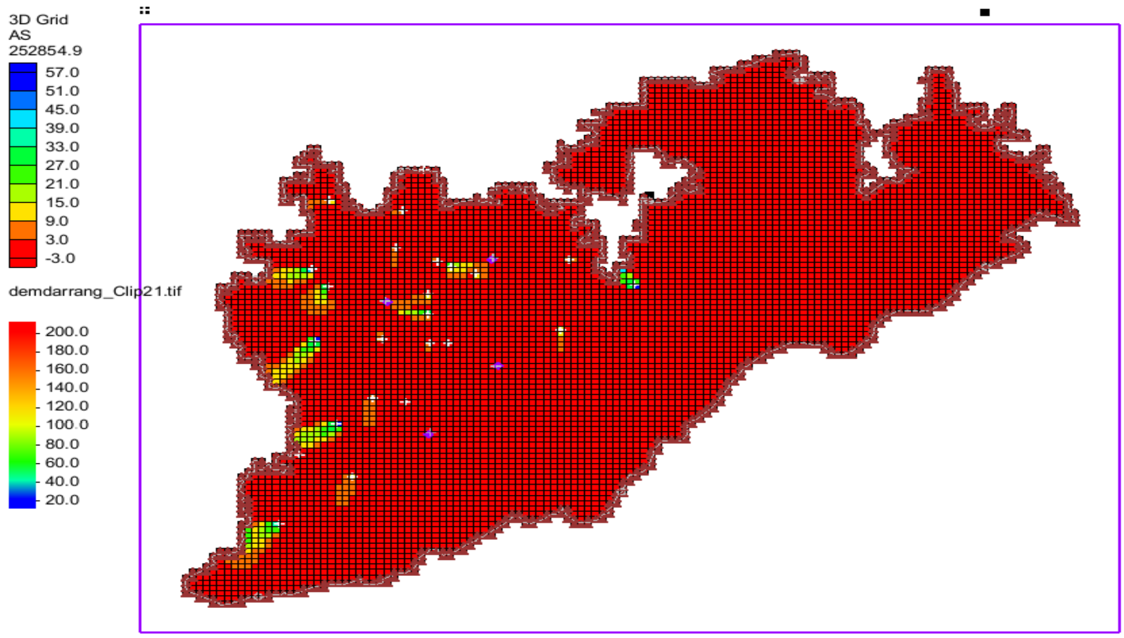

Figure 8.10: Transport of arsenic over a 540-day period simulated using MT3DMS in Darrang

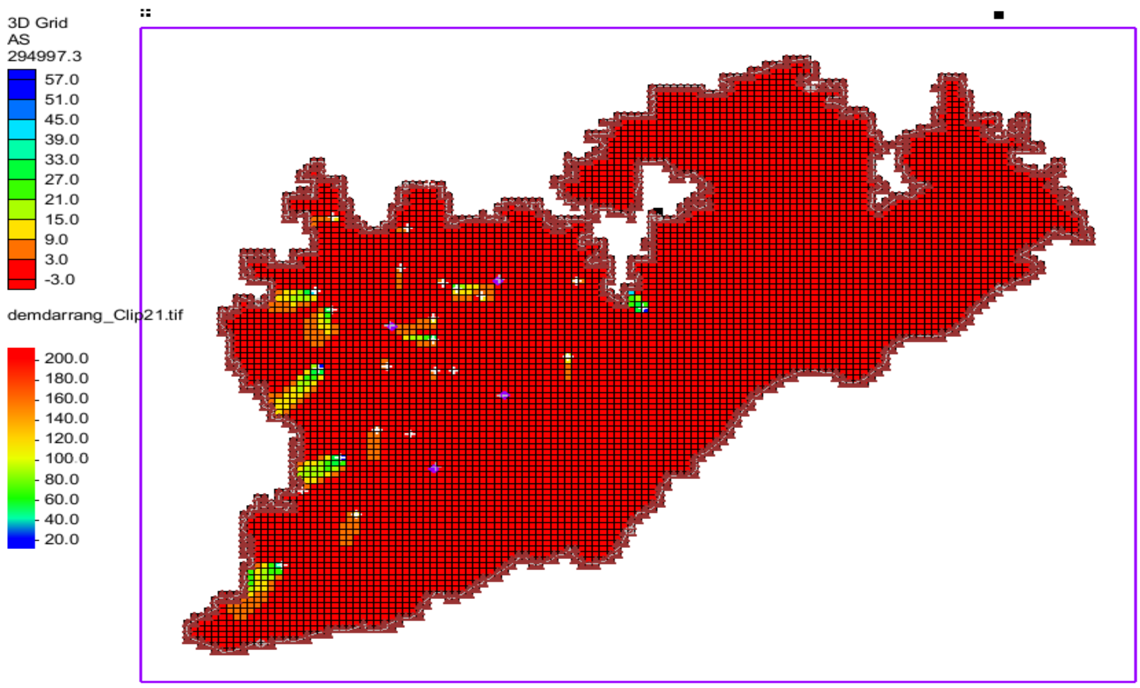

Figure 8.11: Transport of arsenic over a 630-day period simulated using MT3DMS in Darrang

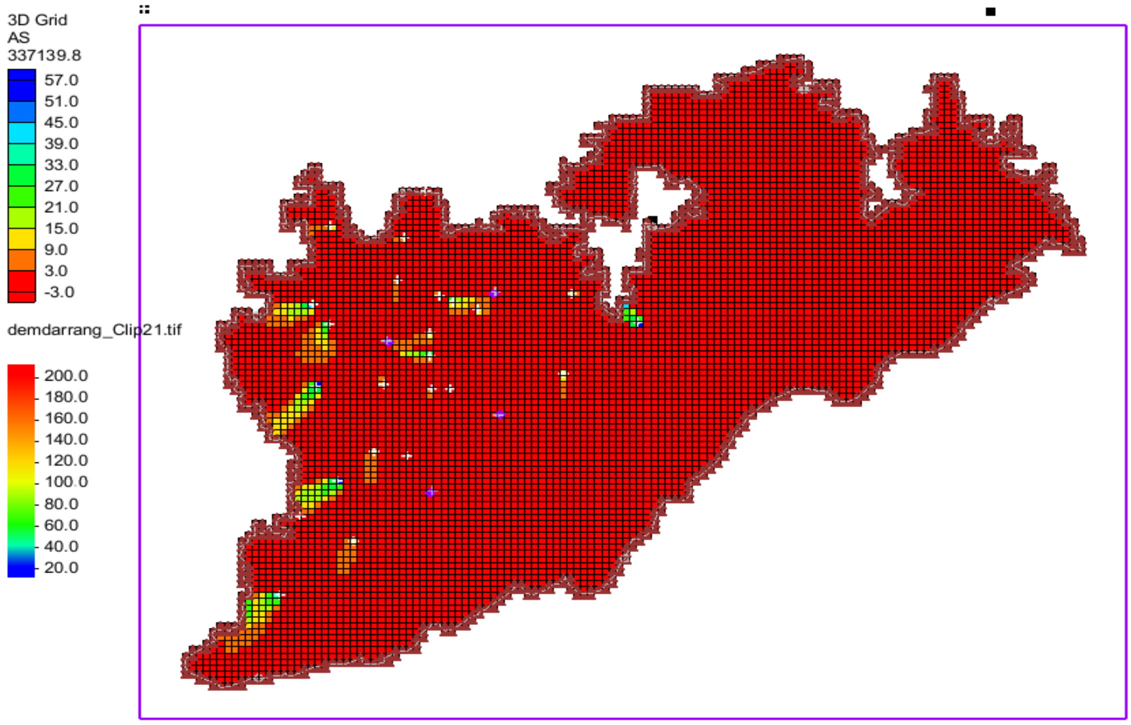

Figure 8.12: Transport of arsenic over a 720-day period simulated using MT3DMS in Darrang

Arsenic Transport after 540 Days:

1. **Extended Dispersion**:
   - By 540 days, arsenic transport will have further dispersed throughout the aquifer. The contaminant will spread across a larger area, and its concentration patterns will reflect the extended duration of groundwater flow and dispersion processes.
2. **Concentration Changes**:
   - The distribution of arsenic concentrations will show more pronounced patterns, with potential peaks in areas where arsenic has accumulated due to prolonged movement. The concentration changes over time during transport are as follows: from 51 ppm to a range of 39-45 ppm, from 27 ppm to a range of 9-15 ppm, and from 21 ppm to a range of 3-9 ppm. Similarly, other concentrations also decrease over the transport period.
3. **Impact on Groundwater Quality**:
   - The prolonged transport could impact groundwater quality more broadly. Areas previously less affected might now experience elevated arsenic levels,

highlighting the need for comprehensive water quality monitoring and management.

Arsenic Transport after 630 Days:

1. **Further Spread and Stabilization**:
    - After 630 days, arsenic transport will likely exhibit continued spread with a more defined pattern. The contaminant's distribution will become increasingly stable, reflecting the long-term behavior of arsenic in the groundwater system.
2. **Potential Accumulation Zones**:
    - Certain regions may show higher arsenic concentrations due to accumulation effects. These zones will indicate where arsenic has been consistently transported and may have reached peak levels. Although the decreasing trend in concentration is expected to be similar across different stress periods, this is because the point source is considered during the simulation of arsenic transport in MT3DMS.
3. **Ongoing Monitoring and Risk Assessment**:
    - At this stage, the data will be critical for assessing long-term risks and planning mitigation strategies. Understanding the stable distribution patterns will help in addressing potential public health concerns and guiding remediation efforts.

Arsenic Transport after 720 Days:

1. **Mature Transport Patterns**:
    - By 720 days, arsenic transport patterns will be well-established. The contaminant will have reached a more mature stage of dispersion, with its distribution becoming more predictable based on the groundwater flow and transport dynamics observed throughout the simulation.
2. **Concentration Peaks and Zones of Impact**:
    - Concentration peaks may become more defined, and specific zones of high contamination will be evident. These peaks will be critical for evaluating the extent of arsenic pollution and identifying areas needing urgent intervention.
3. **Long-Term Management Implications**:

- The results at 720 days will provide a comprehensive view of long-term arsenic behavior, essential for developing effective management strategies. The data will inform decisions regarding long-term water treatment, monitoring programs, and potential remediation actions.

4. **Visual and Quantitative Insights**:
   - Figures and data from the 720-day simulation will offer detailed visual and quantitative insights into arsenic distribution, helping stakeholders understand the full scope of contamination and plan accordingly. Figure 8.12 illustrates that the concentration of arsenic decreases over the course of transport.

8.4.5 Distribution of Arsenic concentration in Nagaon district using MT3DMS –

To analyze arsenic concentration distribution in the Nagaon district, MT3DMS was employed—a prominent groundwater transport model designed to simulate contaminant movement in conjunction with MODFLOW. It is crucial to run the MODFLOW simulation before initiating the MT3DMS model, as the latter relies on MODFLOW results for accurate transport calculations. The MODFLOW simulation results, which are depicted in Figure 8.13 provide the necessary groundwork for the MT3DMS analysis, ensuring a comprehensive assessment of arsenic transport in the aquifer system.

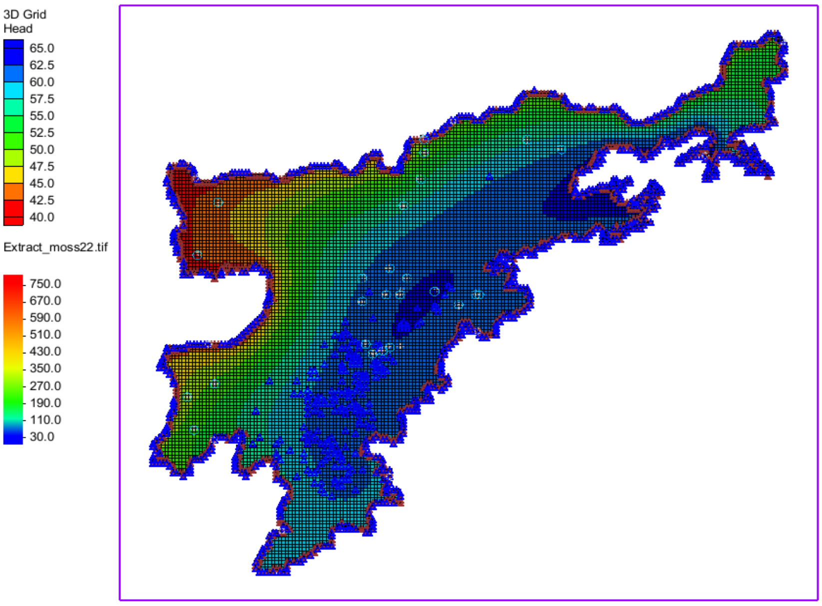

Fig 8.13 MODFLOW simulated model of study area – Nagaon

Figure 8.13 presents the MODFLOW simulated model of the study area in Nagaon. The completion of the MODFLOW simulation was a prerequisite for developing the MT3DMS model, which is crucial for evaluating contaminant transport. Following the MODFLOW simulation, the MT3DMS model was executed over a two-year period, segmented into eight stress periods. The results from these simulations are illustrated in the subsequent figures, offering a detailed analysis of arsenic transport distribution in the Nagaon district of Assam. These figures effectively showcase the evolution of arsenic concentrations over time and through various stress periods.

Figure 8.14 illustrating the 9-day transport of arsenic provide a visual depiction of concentration changes over time.

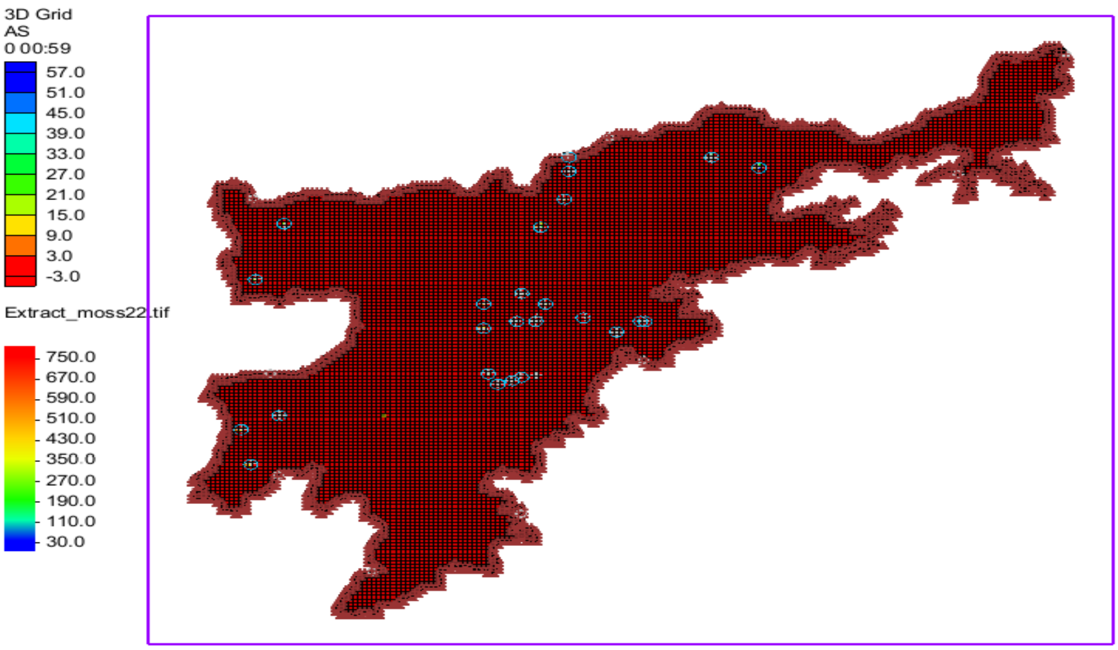

Figure 8.14: Transport of arsenic over a 9-day period simulated using MT3DMS in Nagaon

The 9-day MT3DMS simulation of arsenic transport provides crucial insights into the early stages of contaminant movement and dispersion, aiding in the understanding and management of arsenic contamination in the aquifer system.

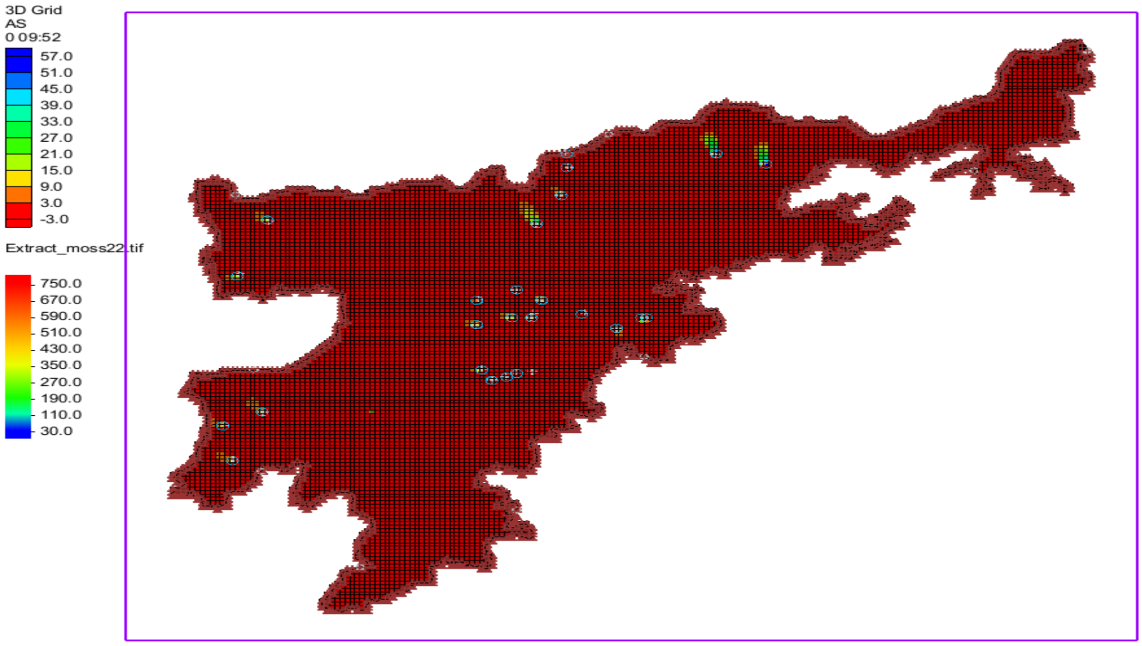

Figure 8.15: Transport of arsenic over a 90-day period simulated using MT3DMS in Nagaon

Figure 8.15 shows the delay in significant transport highlights the importance of considering longer simulation periods to fully understand contaminant behaviour and to anticipate future impacts on water resources. The concentrations appear to decrease to a range of 3-9 ppm across nearly all point sources.

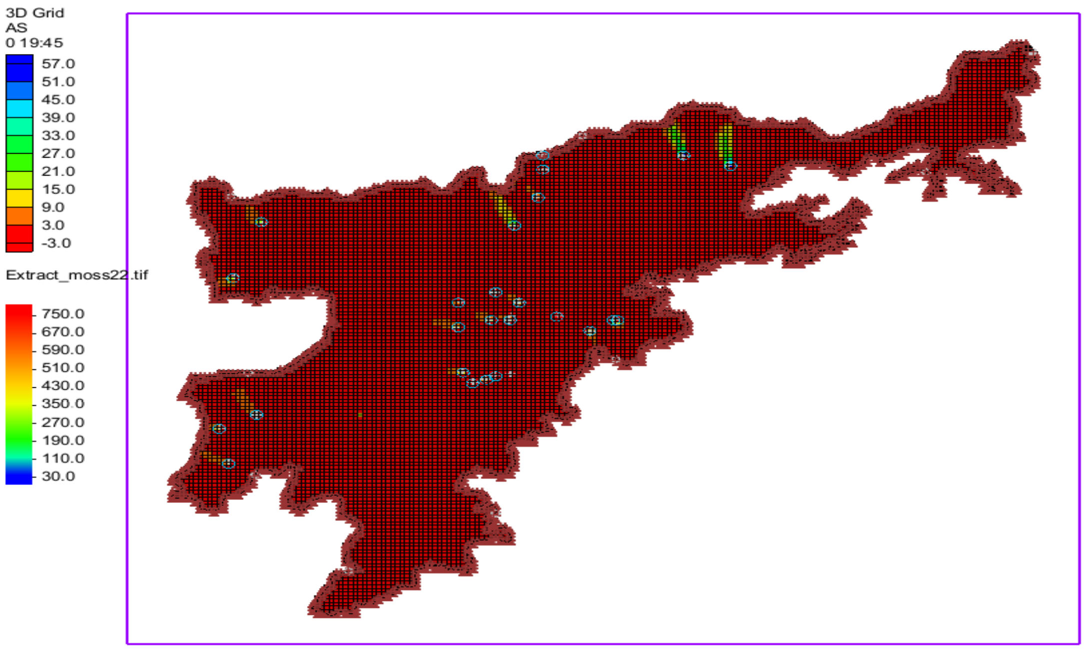

Figure 8.16: Transport of arsenic over a 180-day period simulated using MT3DMS in Nagaon

The MT3DMS simulation over a 180 day period in figure 8.16 indicates that after an initial period of minimal movement, arsenic transport starts to slightly increase after 180 days. This gradual rise highlights the evolving nature of arsenic dispersion and the need for ongoing observation to address any potential implications for water quality. Over a 180-day period, the concentration decreases in a manner similar to that observed over the 90-day period: from 52 ppm to a range of 3-9 ppm, from 33 ppm to a range of 3-9 ppm, and other point sources exhibit a similar decreasing trend.

After 270 and 360 days, the arsenic transport is anticipated to exhibit more significant dispersion throughout the unconfined aquifer. This enhanced dispersion is illustrated in Figures 8.17 and 8.18, which depict the evolving distribution of arsenic concentrations over these time periods.

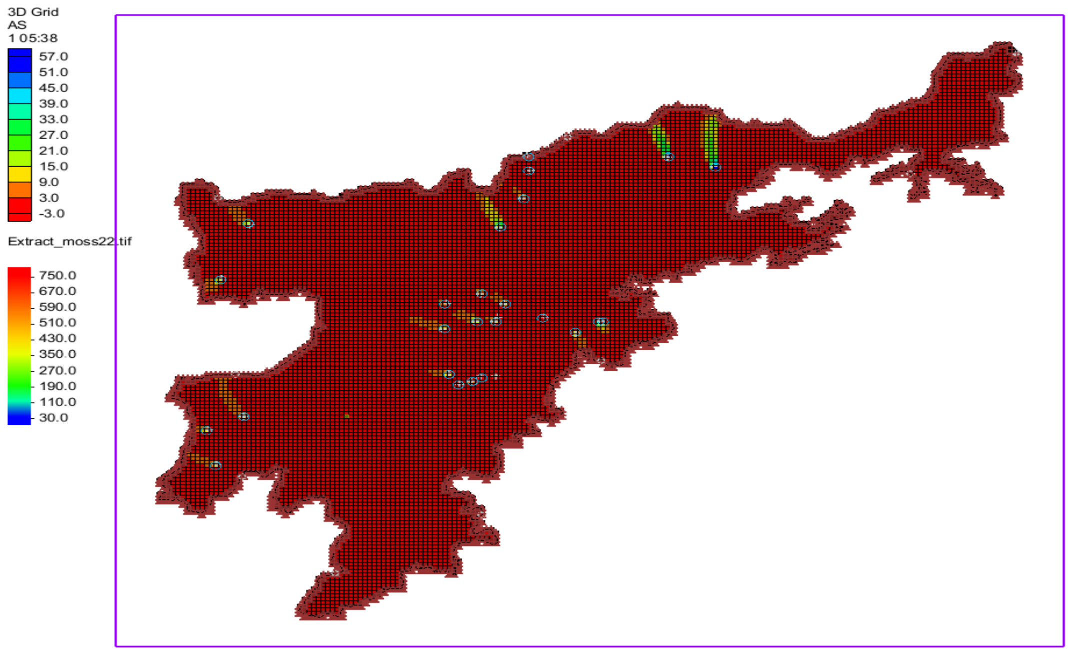

Figure 8.17: Transport of arsenic over a 270-day period simulated using MT3DMS in Nagaon

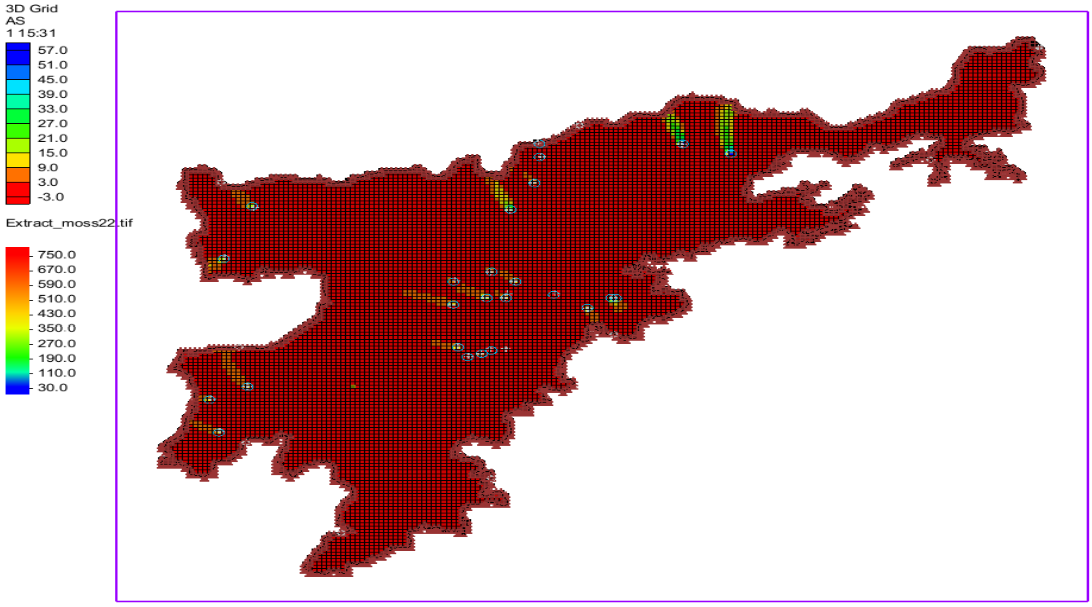

Figure 8.18: Transport of arsenic over a 360-day period simulated using MT3DMS in Nagaon

The period over 270 days illustrated in figure 8.17 marks a continuation of the trend observed at 180 days, with arsenic concentrations likely increasing and spreading over a larger area. And the simulation after 360 days provides valuable insights into long-term arsenic behaviour, helping to predict future trends and impacts. It emphasizes the need for long-term management strategies to mitigate the risks associated with prolonged arsenic contamination. The concentration decline is similar across both stress periods: from 52 ppm to a range of 3-9 ppm, from 33 ppm to a range of 3-9 ppm, with other concentrations also decreasing in a comparable manner.

After 450 days, Figure 8.19 shows a noticeable increase in the transport of arsenic concentration through groundwater. However, the concentrations in ppm appear to be declining when compared to other stress periods. This observation indicates that, over the extended period, the levels of arsenic within the groundwater have risen, highlighting ongoing dispersion and accumulation within the aquifer system.

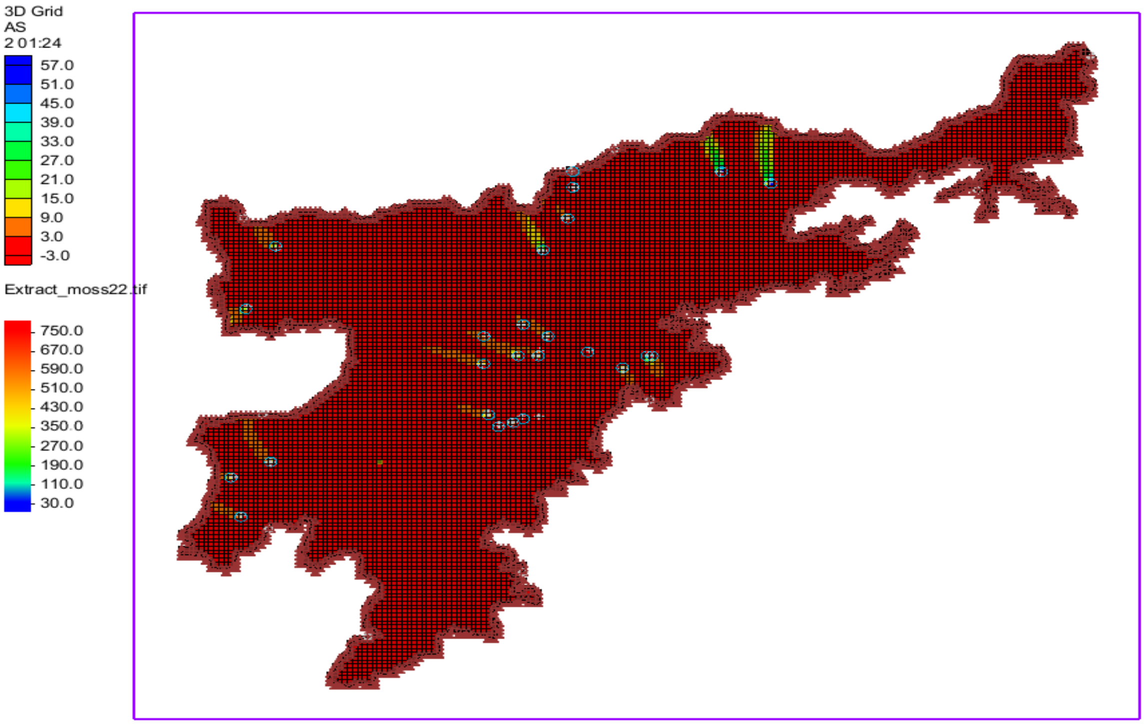

Figure 8.19: Transport of arsenic over a 450-day period simulated using MT3DMS in Nagaon

The transport of arsenic over a 450-day period was simulated using MT3DMS shown in figure 8.19. This simulation provides insights into the behaviour and movement of arsenic within the groundwater system throughout the extended timeframe. The results illustrate how arsenic concentrations evolve, showing patterns of dispersion and migration within the aquifer over the 450-day period.

As the MT3DMS simulation progresses to 540, 630, and 720 days, the behaviour of arsenic transport in the groundwater continues to evolve, as illustrated in Figures 8.20, 8.21, and 8.22. These figures provide a detailed view of how arsenic concentrations change over these extended periods, reflecting the ongoing dynamics of dispersion and migration within the aquifer system.

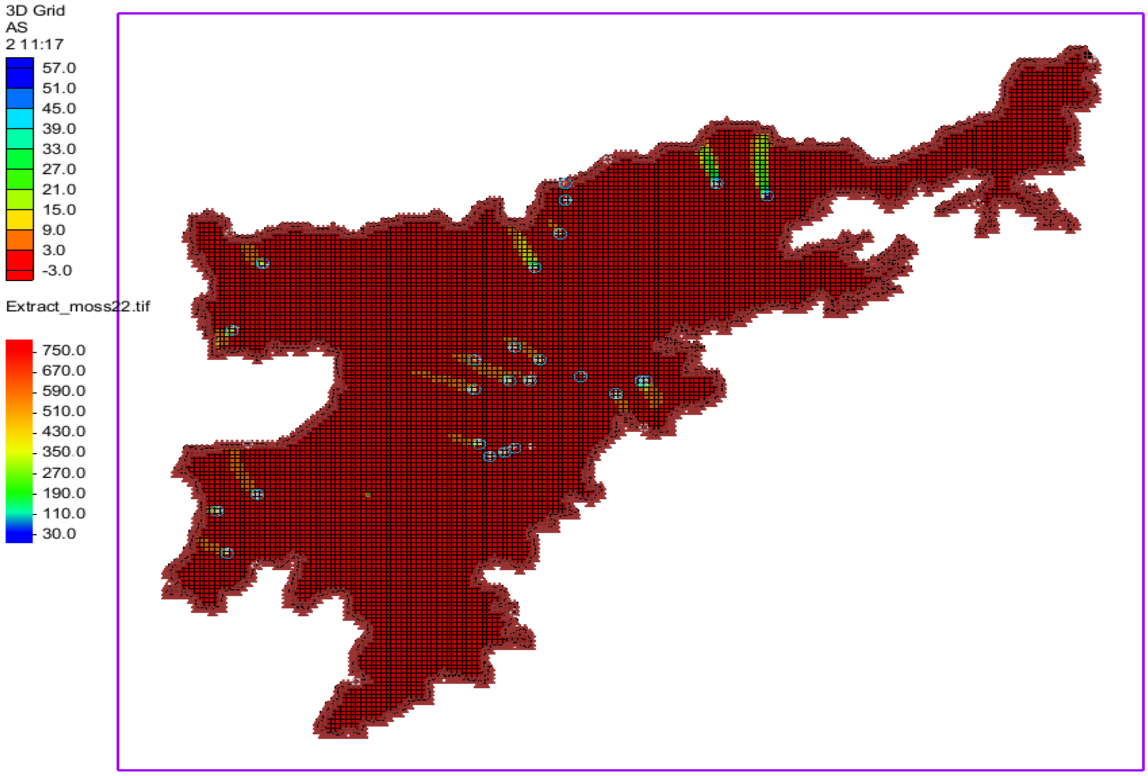

Figure 8.20: Transport of arsenic over a 540-day period simulated using MT3DMS in Nagaon

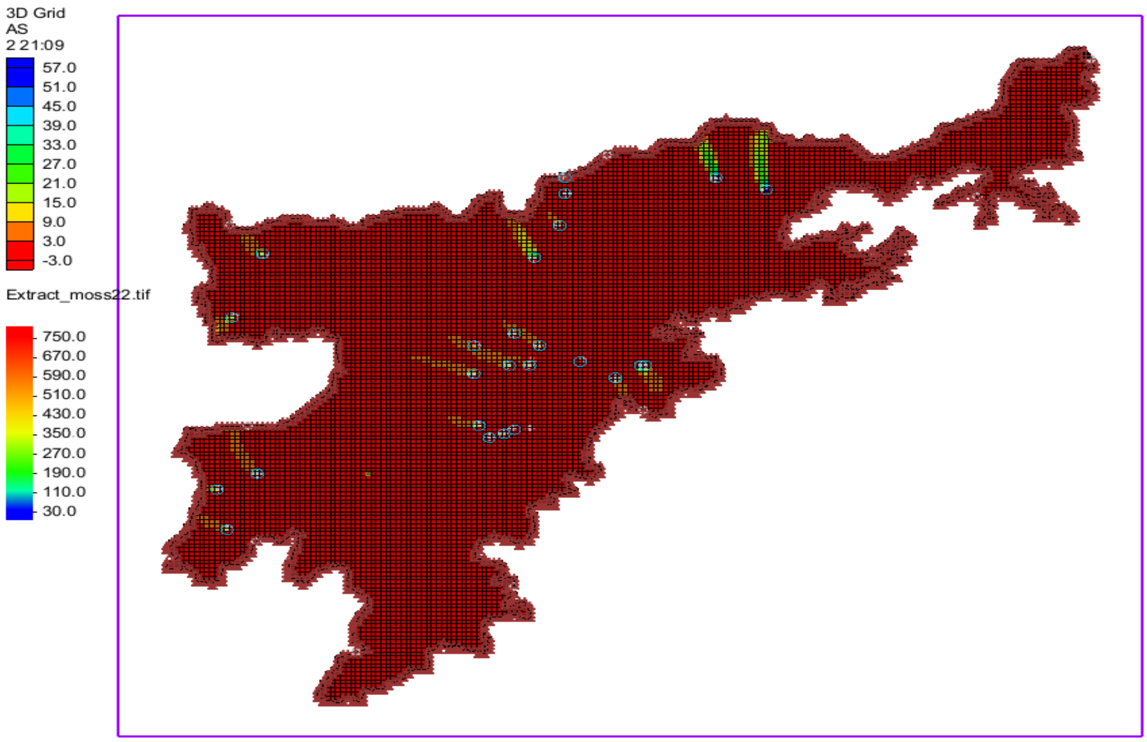

Figure 8.21: Transport of arsenic over a 630-day period simulated using MT3DMS in Nagaon

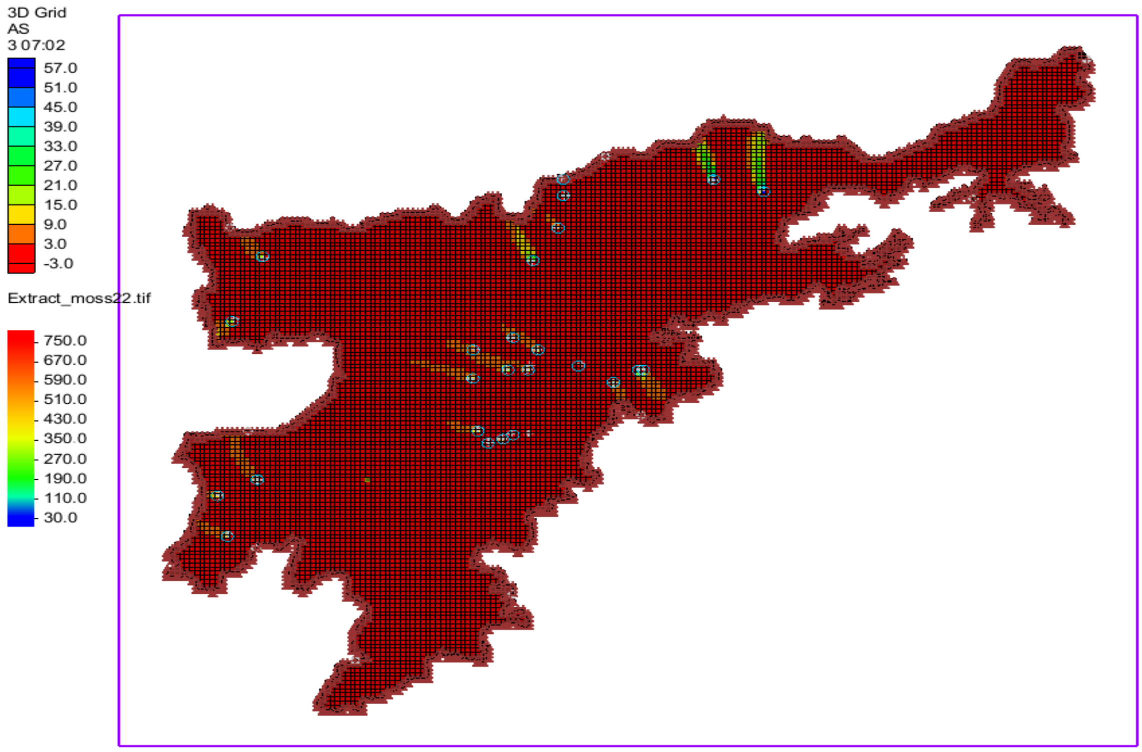

Figure 8.22: Transport of arsenic over a 720-day period simulated using MT3DMS in Nagaon

As the simulation progresses to 540, 630, and 720 day period, arsenic transport will show increased dispersion and stable distribution patterns. Concentration peaks will become more defined, highlighting areas of significant contamination. The data from these extended timeframes are crucial for understanding long-term impacts, guiding effective groundwater management, and planning remediation strategies. After 450 days, while there is an observable increase in the transport of arsenic through groundwater, the concentrations themselves appear to be declining compared to earlier stress periods. This suggests that while arsenic is spreading further, its concentration is reducing over time. The data indicates a consistent trend of decreasing arsenic concentrations across different stress periods, with the transport of arsenic becoming more stable and widespread as time progresses.

The application of MT3DMS in the Darrang and Nagaon district has provided a detailed assessment of arsenic concentration distribution, revealing spatial patterns and temporal trends that are crucial for managing groundwater quality and addressing contamination issues effectively.

The two-year MT3DMS simulation, divided into eight stress periods, has provided comprehensive insights into the transport dynamics of arsenic through groundwater in the study area. Over the simulation period, arsenic dispersion and migration patterns have been thoroughly analyzed. The results indicate that arsenic concentrations gradually spread through the unconfined aquifer, with dispersion becoming more pronounced as time progresses. The transport dynamics illustrate how arsenic moves from higher to lower concentration areas, influenced by groundwater flow and dispersion processes. The simulation highlighted significant temporal changes in arsenic distribution. Initial periods showed minimal movement, but after 180 days, more substantial transport was observed. By the end of the simulation, significant dispersion and changes in arsenic concentration were evident, with concentrations showing a steady increase and reaching notable levels in various regions of the aquifer. The eight stress periods provided a detailed view of how arsenic transport evolves under varying conditions. Each stress period contributed to understanding the progression of contamination and how different factors affect arsenic distribution over time. The spatial distribution of arsenic concentrations, as depicted in the simulation figures, reflects a broadening of affected areas over the two-year period. Regions of higher concentration emerged, particularly in areas closer to the groundwater flow paths and discharge zones. The findings underscore the need for ongoing monitoring and effective management strategies to address arsenic contamination. The simulation results can guide remediation efforts and inform policies aimed at mitigating the impact of arsenic on groundwater quality. The simulation results provide a valuable benchmark for validating the model against observed data. Future work should focus on refining the model with updated data and exploring additional scenarios to better understand long-term arsenic behaviour and impacts.

The two-year MT3DMS simulation for both the study area – Darrang and Nagaon has successfully demonstrated the evolving nature of arsenic transport in groundwater, highlighting both temporal and spatial changes in concentration. These insights are crucial for developing targeted strategies to manage and remediate arsenic contamination effectively.

CHAPTER 9

CONCLUSION AND RECOMMENDATION

9.1 Conclusion –

1) The assessment of arsenic contamination in groundwater across Darrang and Nagaon districts of Assam reveals a concerning scenario. Analysis of water samples from both districts demonstrates a significant presence of arsenic, with 27 out of 54 samples exceeding the WHO guideline value of 0.01 ppm, indicating widespread contamination. Specifically, 12 samples from Darrang district and 15 samples from Nagaon district were found to surpass this threshold, highlighting a substantial public health concern. The data shows notable variability in arsenic levels, with concentrations ranging from 0 to over 50 ppb in both districts. Despite this variability, a considerable proportion of samples from both districts exceed the WHO permissible limit. Darrang district shows particularly high levels of contamination, with 12% of its samples exceeding both WHO and BIS guidelines, compared to 6.89% in Nagaon district.

The findings underscore an urgent need for targeted monitoring and effective remediation strategies, particularly in Darrang district where contamination levels are more severe. The elevated arsenic concentrations in both districts, particularly near the Brahmaputra River in Nagaon and in hand-pumps in Hati Bakar, call for immediate action to mitigate the risks and ensure safe drinking water. Addressing this issue promptly is crucial for protecting public health and improving the overall quality of water in the affected areas.

2) The analysis of elevation and arsenic contamination in Darrang and Nagaon districts using Arc -GIS highlights a significant inverse relationship between surface elevation and arsenic concentration in groundwater. In Darrang district, low-elevation areas (28-57 meters above sea level) exhibit the highest arsenic levels, with concentrations averaging 21 ppb, compared to higher elevations where contamination is minimal or undetectable. Similarly, in Nagaon district, the majority of the land area (96%) falls within the lowest elevation category (38-120 meters), where average arsenic contamination is 15.8 ppb, while higher elevations show negligible arsenic levels. The study reveals discrepancies between reported and calculated areas due to factors such as different data sources, methodologies, updates, and precision. Despite these variations, the analysis consistently demonstrates that lower elevations are

more prone to arsenic contamination. The use of Arc-GIS has proven essential for visualizing and understanding the spatial distribution of arsenic contamination, aiding in more effective decision-making and ensuring safer drinking water.

3) The comprehensive analysis of arsenic contamination in groundwater across Darrang and Nagaon districts of Assam, using ArcGIS and hazard mapping techniques using Inverse Distance Weighing interpolation method, reveals significant insights into the spatial distribution and risk levels of arsenic exposure. The study categorizes arsenic concentrations into five risk categories: No Risk, Low Risk, Moderate Risk, High Risk, and Very High Risk. In Darrang district, arsenic levels show a distinct inverse relationship with elevation. Low-elevation areas (28-57 meters) exhibit the highest contamination, with significant portions falling into the Very High Risk category. Conversely, high-elevation areas show minimal to no arsenic contamination. This pattern underscores the critical need for targeted monitoring and intervention in lower elevations to address high arsenic levels. In Nagaon district, a similar trend is observed with 96% of the area in the low-risk category, while higher elevations experience negligible contamination. The hazard map indicates that substantial areas fall into the No Risk and Very High Risk categories, guiding targeted remediation efforts.

By providing a detailed spatial distribution of arsenic risks, the research supports policymakers and health authorities in implementing targeted interventions to safeguard public health. The findings also pave the way for future research on other contaminants and comprehensive water quality management, contributing to the broader goal of environmental health and sustainability.

4) The health risk assessment of arsenic contamination using USEPA methods in groundwater across Darrang and Nagaon districts reveals critical insights into both non-carcinogenic and carcinogenic risks. The Chronic Daily Intake (CDI), Hazard Quotient (HQ), Hazard Index (HI), Carcinogenic Risk (CR), and Carcinogenic Index (CI) were evaluated to understand the impact of arsenic on human health, focusing on both dermal absorption and oral ingestion pathways.

In Darrang district, the maximum Hazard Index (HI) indicates a significant non-carcinogenic risk, especially for children, with values exceeding 1, which signifies a potential risk of chronic health effects. The average HI for children in Darrang is notably higher (17.92) compared to Nagaon (13.9), highlighting greater exposure risks for younger populations. This underscores the urgent need for targeted interventions in Darrang to mitigate health impacts, particularly for children who are more vulnerable due to higher water consumption relative to body weight.

While the non-carcinogenic risks are lower in Nagaon district as compared to Darrang, the average HI for adults in Nagaon is slightly higher than in Darrang, indicating marginally greater risks for adults in this district. However, all hazard indices for dermal contact remain below 1, suggesting no significant health effects from this exposure route.

The study also identifies elevated carcinogenic risks in both districts, with areas such as Hati Bakar in Darrang and Gomotha in Nagaon exhibiting high Carcinogenic Indices (CI). Children in both districts are at a higher risk compared to adults, with CI values significantly surpassing the US-EPA threshold of 10^(-6), indicating a critical need for cancer risk management and continuous monitoring.

Darrang district shows a higher average CI (8×10^{-3}) compared to Nagaon (6×10^{-3}) indicating that the population in Darrang is at a greater risk for carcinogenic effects due to arsenic contamination. This is particularly concerning given the substantial percentage of groundwater exceeding safe arsenic levels in both districts.

The study highlights the urgent need for addressing arsenic contamination in both Darrang and Nagaon districts to protect public health and ensure safe drinking water.

5) The detailed groundwater flow and arsenic transport simulations for the Darrang and Nagaon districts using MODFLOW and MT3DMS have provided significant insights into the dynamics of groundwater flow and contaminant distribution. The MODFLOW simulations revealed distinct hydraulic head distributions in both districts, with a clear west-to-east gradient in Darrang and Nagaon. In Darrang, the hydraulic head ranged from 70 meters to 45 meters, while in Nagaon, it varied from 64.35 meters to 41 meters. These findings highlight the gradient-driven flow from higher to lower head regions, crucial for understanding groundwater movement and recharge patterns. The assumed recharge rate of 0.0001 meters per day, along with a hydraulic conductivity of 20 m/day, significantly influenced the flow dynamics and groundwater levels in both districts. These insights are essential for predicting water availability, managing extraction, and planning recharge strategies.

The MT3DMS simulations demonstrated how arsenic transport evolves over time, revealing both temporal and spatial changes in contaminant distribution. In Darrang, arsenic concentration showed minimal movement within the first 9 days, but substantial transport and dispersion were observed over longer periods. By 720 days, the arsenic distribution had broadened significantly, with concentrations stabilizing at lower levels but showing pronounced peaks in certain areas. Similar trends were observed in Nagaon, where arsenic transport initially progressed slowly but exhibited more significant dispersion over time. The concentrations decreased, indicating a spreading pattern, with areas of higher contamination emerging towards the end of the simulation. The evolving distribution patterns and concentrations indicate that arsenic contamination is a dynamic process, with significant dispersion occurring over extended periods. .

9.2 Recommendation -

Arsenic contamination is caused by various natural and man-made variables that were not considered in this study. To better understand arsenic contamination, this study suggests future integrated research for examining natural and anthropogenic components of arsenic scientifically, seasonal and temporal fluctuations spatially, and health concerns with appropriate demographic evidence. This study can also guide professionals and policymakers to find a cost-effective way of monitoring arsenic contamination levels and evaluating the level of vulnerability. Develop and deploy targeted remediation strategies in areas with the highest arsenic contamination, particularly in low-elevation zones and near the Brahmaputra River. Consider technologies such as reverse osmosis or ion exchange for arsenic removal. Provide health screenings for affected populations, particularly children, to detect and address potential health impacts early. Invest in alternative and safer water sources for affected areas, such as filtered or treated water supplies. Upgrade existing water supply systems to reduce reliance on contaminated groundwater. Establish a long-term groundwater surveillance program to continuously monitor arsenic levels and assess the effectiveness of remediation measures.

By implementing these recommendations, both Darrang and Nagaon districts can better manage arsenic contamination, safeguard public health, and improve overall water quality.

9.3 Future Research –

1. To investigate the sources and pathways of arsenic contamination in groundwater to identify key contributors and mechanisms of transport.

2. To Explore and develop advanced technologies for arsenic removal and water treatment, focusing on cost-effectiveness, scalability, and sustainability.

3. To Study the effects of climate change on arsenic contamination in groundwater. Investigate how changing precipitation patterns, temperature variations, and extreme weather events influence arsenic levels and distribution.

4. To Enhance hydro geological models to better predict arsenic transport and dispersion in groundwater. Incorporate more detailed data on soil properties, recharge rates, and hydraulic conductivity to improve model accuracy.

By addressing these research areas, future studies can provide deeper insights into arsenic contamination, improve mitigation strategies, and enhance public health outcomes in affected regions.

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