OCCURRENCE AND MOVEMENT OF ARSENIC IN GROUND WATER IN RAJNANDGAON DISTRICT, CHHATTISGARH STATE

By

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Message from the Chairman

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Preface

In India, about 40 million people live in the risk zone of arsenic contamination of groundwater. The current state of affairs regarding the increasing arsenic levels in the groundwater resources of the country requires urgent attention to address the threat as groundwater is the most important resource for the population especially in rural areas. There is a need for a systematic evaluation of arsenic remediation success stories in the world and in the country and the development of a comprehensive action plan to combat arsenic. Elevated levels of arsenic in groundwater are one of the biggest problems worldwide.

Around ~43% of India's population lives in the Ganga basin, India's largest river basin, which covers 26% of the country's geographical area. The increasing arsenic contamination of groundwater in the Ganga plains poses a serious threat to human health and ecology. The threat of arsenic in groundwater was first reported in the state of West Bengal, but with increasing monitoring of groundwater quality, cases of arsenic in groundwater exceeding permissible limits have been reported from seven of the eleven states in the basin. In the aquifers of Uttar Pradesh, Bihar and West Bengal, the contamination is particularly high. Apart from the soft formations, arsenic in groundwater is reported at alarming levels in the hard rock of Ambagarh Chowki block in Rajnandgaon district in the state of Chhattisgarh. Despite a number of corrective and remedial measures taken by governmental and non-governmental agencies, the problem is gradually increasing and new areas have been added to the threat. The current situation of increasing arsenic occurrences in India calls for a systematic transfer of success stories of one place/region to others and formulation of a comprehensive plan to mitigate the arsenic problem through a wider consultation process. The present research and development (R&D) study on the occurrence and translocation of arsenic in groundwater of Rajnandgaon district of Chhattisgarh state is an attempt to develop actionable plans and to design future strategies for ensuring potable groundwater in arsenic contaminated areas, including remediation of arsenic contamination.

I believe, this R&D study will provide requisite perspectives for drawing workable plans for arsenic mitigation in the study area and can extrapolate the same strategy to the areas having similar hydrogeological set ups. The diligent efforts of the author and Rajiv Gandhi National Ground Water Training & Research Institute (RGNGWTRI) in bringing out this good report is acknowledged.

(Dr. P. Nandakumaran)
Chairman, CGWB

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The author would like to thank the Member and Regional Director, Rajiv Gandhi National Ground Water Training and Research Institute (RGNGWTRI), Central Ground Water Board, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India, Naya Raipur, Chhattisgarh for commissioning this R&D study and for providing necessary facilities and support throughout the research period. The author would like to place on record his sincere gratitude to the distinguished Chairman, Central Ground Water Board, Ministry of Jal Shakti, Government of India for approving this R&D study and for providing necessary support during the conduct of this research work. Thanks to all the government organizations like Public Health Engineering Department (PHED), Department of Irrigation, Department of Agriculture and Panchayati Raj Institutions for their support during field work and for providing the required data. Thanks to all colleagues who helped in conducting the field work and also in preparing this R&D report.

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Executive Summary

Rajnandgaon is a part of the Indian shield falling in the Central India Craton. Regionally, the area forms a part of Dongargarh – Kotri rift zone, surrounded by Dongargarh Batholithic Granites in west. Potential fractures at deeper depth have been recorded between 60 and 121 m bgl. Groundwater occurs in this formation within weathered zone and in the deeper aquifer system occurs within the structural features like joints and fractures under phreatic to semi-confined conditions. During the year 1999-2000, 45 drinking water sources (11 Dug Wells and 34 Bore wells) from 11 villages were identified by National Environmental Engineering Research Institute (NEERI), wherein arsenic in groundwater ranges from 0.05 to 1.86 mg/l. In 2015-16, 18 sources have identified by Central Ground Water Board (CGWB) with arsenic of > 0.05 mg/l in groundwater. In the year 2017, a detailed R&D study was taken to understand the spatio-temporal distribution of arsenic in the Rajnandgaon district.

Quarterly monitoring of water levels for different abstraction structures was carried out and water samples were collected for arsenic analysis from 72 no. of sources including river water samples four times in a year. Health survey also was conducted in detailed in the arsenic affected villages. It is observed that the sources of arsenic in the area have been established as geogenic in origin and are related to Kotri - Dongargarh rift zone. Kaudikasa, Bhagwantola and Sansaitola are the severely affected villages in study area. Arsenic is confined to the early Proterozoic meta-rhyolite and granite along the N-S trending Kotri - Dongargarh rift zone. High arsenic groundwater is restricted to wells in Kaudikasa Panchayat of Ambagarh Chowki block area of the district. Only 10 to 70% of the groundwater abstraction structures are found with high arsenic value (> 0.05 mg/l). The major population of arsenic affected Ambagarh Chowki block in Rajnandgaon district is tribal (51.49% of the total population, 2011 census). The geographical distribution of high arsenic ground water is sporadic in the area. A total of five villages are found severely affected Kaudikasa > Joratarai > Sonsaytola > Muletitola > Jadutola respectively in order of abundance. Even in the worst affected village in Kaudikasa, however, not all groundwater abstraction structures are found contaminated with arsenic (i.e.> 0.05 mg/l).

CHAPTER 1

1.0 INTRODUCTION

1.1 Introduction

Water is a very important resource that holds the key for the very existence of life. It is also the most overused and abused resource. Ground water is the most important source of fresh water on earth's surface. In India, the importance of groundwater is highly significant as around 62% of irrigated agriculture and 85% of rural drinking water is based on groundwater (CGWB). From drinking, washing, cleaning, use for agriculture to operation of high-power industries, groundwater plays a crucial role. Groundwater resources in hard rock regions like Chhattisgarh pose several problems. Its occurrence is limited, with low renewable potential, which is prone to geogenic and anthropogenic contamination. So, there is a need for a judicial management of groundwater resources to ensure adequate supplies of dependable quality and quantity.

Arsenic has been documented as a human poison since a long time. Oral intake of arsenic has proved to be deadly on many occasions. Arsenic is an element of VA group in the periodic table. It is a semi-metal and the symbol for arsenic is 'As'. The atomic number of arsenic is 33, the atomic weight is 75. Arsenic even in very low concentration has its adverse effect on health. The acceptable level as defined by WHO for maximum concentrations of arsenic in safe drinking water is 0.01 mg/L. At present, in India also both the acceptable and the permissible limit (in the absence of alternate sources) of arsenic in drinking water are 0.01 mg/l (10 μg/l). The same limit is endorsed by the Bureau of Indian Standard (IS 10500:2012) as well for drinking water-specifications.

Inorganic arsenic occurs combined with metals in igneous and sedimentary rocks; and also combined with elements like oxygen, chlorine, sulphur etc. Organic arsenic occurs combined with carbon and hydrogen. Both organic and inorganic arsenic compounds exist as white or silvery powder materials with no smell or unique taste. Arsenic is entered into soil and groundwater during weathering of rocks and minerals followed by leaching and runoff. It can also be entered into soil and groundwater from anthropogenic sources. Arsenic forms various compounds, either inorganic or organic. Inorganic arsenic is widely distributed in nature, usually in the trivalent (As^{3+}) form, but also as pentavalent arsenic (As^{5+}). Arsenic, a metalloid occurs naturally, being the 20th most abundant element in the earth's crust, and is a component of more than 245 minerals. These are mostly ores containing sulfide, along with copper, nickel, lead, cobalt, or other metals. Arsenic and its compounds are mobile in the environment. Weathering of rocks converts arsenic sulfides to arsenic trioxide, which enters the arsenic cycle as dust or by dissolution in rain, rivers, or groundwater. So, groundwater contamination by arsenic is a serious threat to mankind all over the world. It can also enter food chain causing wide spread distribution throughout the plant and animal kingdoms (Mandal, B.K. et al., 2002). Though arsenic occurs naturally in rocks and soil, the majority of arsenic released into the environment is from industrial smelting. Arsenic contamination in water poses a serious risk to human health. Inorganic arsenic is a class 1 carcinogen. Excessive and prolonged intake of inorganic arsenic with drinking water causes arsenicosis, a deteriorating and disabling disease characterized by skin lesions and pigmentation of the skin, patches on palm of the hands and soles of the feet. Arsenic poisoning culminates into potentially fatal diseases like skin and internal cancers.

The presence of arsenic in the food chain will remain as long-term risk to human and ecological systems (Tuli et al., 2010). Since water is the principal route through which arsenic enters into the human body (Chen et al., 2009), the understanding of the processes of arsenic contamination in ground water, associated health risks, and mitigation of arsenic problem is required. The first reports of water borne arsenicosis were reported in Argentina. The term “Bell Ville Disease’’ was used to describe arsenic-caused skin manifestations among population of Bell Ville Town. The source of the contamination was found to be natural due to the soil composition polluting the shallow well water. In the West Bengal region of India, the arsenic pollution is of geological origin confined within the meander belt zone of the upper delta plain comprising the late quaternary sediment. Arsenic poisoning is also reported in Inner Mongolia, P.R China, Taiwan, Thailand, Chile, U.S.A. and Bangladesh. Unlike the others regions in which the arsenic occurs in sedimentary beds and flood plains, the arsenic in ground water of Rajnandgaoan and Ambagarh Chowki area occurs in hard rock terrains, and is sporadic in occurrence. People in these affected areas have been exposed chronically to drinking arsenic contaminated water from hand pumps, tube wells and dug wells.

1.2 Literature Review

Arsenic contamination of groundwater has been reported in many countries including Bangladesh (Nickson et al., 1998; Ahmad, 2001), India (Das et al., 1995; Shraim et al., 2002), China (Wang et al., 2000; Guo et al., 2001), Taiwan (Chen et al., 1999), Vietnam (Berg et al., 2001), Nepal (Maharjan et al., 2006), Mexico (Wyatt et al., 1998), USA (Calderon et al., 1999), and Canada (Viraraghavan et al., 1999). The estimated number of people that are at risk of arsenic poisoning as a result of drinking arsenic-contaminated water only in Bangladesh and India is more than 60 million (Ahmad, 2001; Chakraborti et al., 2001).

Arsenic contamination in groundwater in the Ganga- Brahmaputra fluvial plains in India and Padma-Meghna fluvial plains in Bangladesh and its consequences to the human health have been reported as one of the world's biggest natural ground water calamities to the mankind. In India, seven states namely- West Bengal, Jharkhand, Bihar, Uttar Pradesh in the flood plain of the Ganga River; Assam and Manipur in the flood plain of the Brahamaputra and Imphal rivers and Rajnandgaon district in Chhattisgarh state in fractured consolidated rocks have so far been reported affected by arsenic contamination in ground water above the permissible limit of 10 μg/l. High arsenic concentration in ground water of Kaudikasa village of Ambagharchauki block, Rajnandgaon district, Chhattisgarh state has been reported by CGWB (1999), Acharyya (2005), Saha (2009) and Shah (2007).

The arsenic contamination in ground water of Ambagarh Chowki block of Rajnandgaon district, Chhattisgarh was first documented in a scientific journal during 1999 (Chakraborti et.al 1999, Pandey et. al, 1999). However, presence of arsenic contamination in the area was known to State Public Health Engineering Department (PHED) since 1997-98. Since then detailed study on the occurrence, extent, source, mobilization and impact of Arsenic contamination on human health was done by various organizations and individuals such as State Public Health Engineering Department (PHED), Raipur, Geological Survey of India (GSI), Raipur, Central Groundwater Board (CGWB), Raipur, National Environmental Engineering Research Institute (NEERI), Nagpur, Bhilai Institute of Technology (BIT), Bhilai, Chhattisgarh Council of Science and Technology (CCOST), Raipur, Agerkar Institute, Pune, Delhi University, Pandit

Ravishanker Shukla University (PRSU), Raipur, Action for Food Production (AFPRO), Raipur, Jadavpur University (J.U.), Kolkata, etc. State Government has also taken serious note of the issue and has constituted a high-level steering committee headed by the Principal Secretary, Ministry of Forest and Environment, Government of Chhattisgarh with Regional Director, CGWB, North Central Chhattisgarh Region as a member.

Arsenic, even in very low concentration has its adverse effect on health. In India, 0.01 ppm (10 ppb) concentration of arsenic has been considered the safe limit in drinking water. At present, the available infrastructure within the country to analyze the arsenic in groundwater in the constantly reproducible form and proper instrumentation etc. are limited. The present study has also been conducted with the said limitations.

1.3 Objectives

The objectives of this R&D study are:

i) to find out the occurrence and extent of arsenic in ground water in Ambagarh Chowki block, Rajnandgaon, district,
ii) to find out the severity of the arsenic problem and its effects on the local community,
iii) to assess the health hazards faced by the local people, and
iv) to find out the remedial measures needed for arsenic management in the region.

CHAPTER 2

2.0 STUDY AREA

2.1 Location and Demography

The present study area (i.e., Ambagarh Chowki block of Rajnandgaon district) is situated in the rural part of Chhattisgarh state in India. Ambagarh Chowki is a Nagar Panchayat city in district of Rajnandgaon, Chhattisgarh. It is a sacred place of goddess *Durga,* named after the *Mata Ambika* or *Amba* (Wikipedia). Ambagarh Chowki is placed adjacent to the western boundary of Chhattisgarh state. The block is located at a great location nearby the Sheonath River, and includes 17 small towns and around a hundred of little villages.

Ambagarh Chowki is lying under the administrative jurisdiction of Rajnandgaon district. Rajnandgaon district covers a total area of 6396.28 sq.km. of Chhattisgarh state. Ambagarh Chowki block is located at around 51 km distance from the Rajnandgaon district. Ambagarh is lying in between latitudes N 20°39' and N 20°52' and longitude E80°33'E to E80°50'E covering an area of 577.36 km^2 (Fig. 1A). The elevation of the area varies from 315 to 490 m amsl (above mean sea level).

Demographically, the study area (Ambagarh Chowki block) covers 92 villages, where total population is 98,445, as per Census 2011. Out of this, 47,929 are males, whereas the females count 50,516 here. This block has 12,035 children in the age group of 0–6 years. Among them, 6036 are boys and 5999 are girls (Wikipedia). In the 2001 census, the population of Chowki block was 74,604 and out of which around 22.44% (21,294) population from 29 villages were affected by arsenic contamination (CGWB 2010).

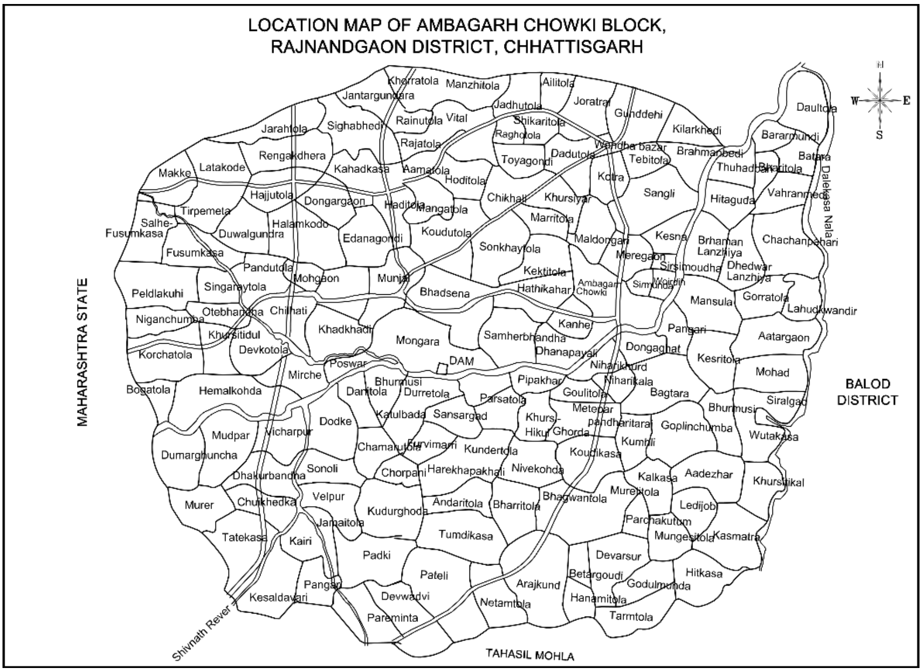

Fig. 1A: Village map of the Ambagarh Chowki block (Study Area)

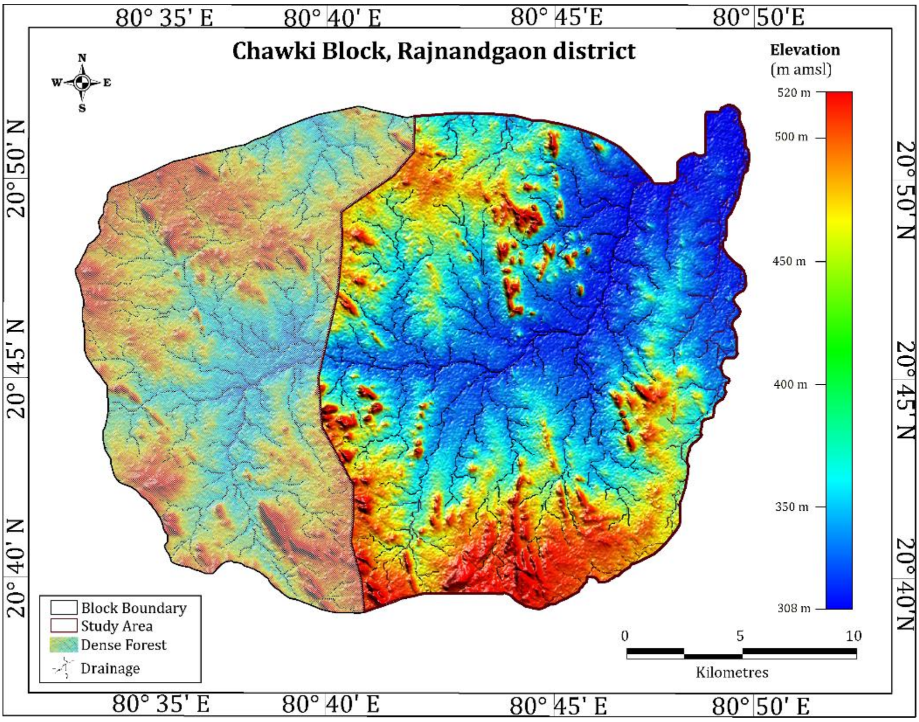

Fig. 1B: Physiographic map of the Ambagarh Chowki block (Study Area)

2.2 Climate

The study area is comprised of sub-tropical climate, characterized by extreme summer and extreme winter. During winter, the mean daily maximum temperature is at 30 °C and the mean daily minimum temperature is at 14.9°C, the night temperatures may sometimes drop below 10°C in the coldest month (i.e., January). The summer extends from March to May. April and May are the hottest month with mean daily maximum temperature at 46°C and the dust storms and heat waves are common during this period. The rainy season extends from June to September with well-distributed rainfall during southwest monsoon. Monsoon generally begins in the second week of June and rainfall is highest in July and August months. Winter season in the area is marked by dry and cold weather with intermittent showers during the month of December to February.

2.3 Literacy rate

Literacy rate in Chowki block is 67%. Out of the total 98,445 of population 66565 are literate here. Among males, the literacy rate is 76% as 36,727 males out of total 47,929 are literate. However female literacy rate is 59% as 29,838 out of total 50,516 females are educated in this block. The number of working people of Chowki block is 56,392; yet 42,053 are un-employed. Out of 56,392 working individual & 15,810 individuals are totally reliant on agriculture.

2.4 Physiography

Physiography of the area is controlled by geology and structures. The alluvium developed along Seonath River has also played an important role in the development of plains. The eastern portion of the area is characterized by a ridge with isolated hills. This ridge forms a surface divide, separating the Dalekasa and Motinala Rivers. The maximum elevation of this ridge is 380 meter above mean sea level (m amsl) and the general elevation ranges from 315 to 360 amsl. The divide towards east-west forms water divides between Seonath and Kotri river system. Southern part of the area is divided by few N-S trending ridges formed by quartz vein and basic rocks and the elevation range from 330 to 490 m amsl. Altitude decreases from south to north, with an average elevation of 360 m amsl. Volcanic rocks occupy the low valley plains and form isolated hills in the northern and western margin of the area. The highest elevation of the area is 490 m amsl near Kuwardli village. The western margin of the area is occupied by isolated hillocks with height from 380 to 490 m amsl. The intervening area of low elevation has the elevation ranging between 360 to 440 m amsl. Seonath River divides the area into two subunits. In southern unit the slope is towards north and the general slope is 3 m/km and in northern unit the slope is towards south and general slope is 3.4 m/km.

Elongated plain is underlain by volcanic rocks on bank of Seonath River, with variable thickness of colluvium / alluvium and black cotton soil with isolated intrusive of volcanic rocks. The southern portion of the area is occupied by shale, phyllite and quartzite of the Iron ore Group, which forms elongated ridges ranging in height from 440 to 490 m amsl. Physiographical setup of the study area is shown in the Fig. 1B.

2.5 **Drainage**

The area is drained by tributaries of the Mahanadi. Seonath is the major perennial tributary of Mahanadi draining the area. It originates in the Garhchiroli district of Maharashtra and in the study area, it flows from west to east up to Dongraghat where it changes its course towards north. Many stream joining the Seonath River both on north and south banks.

Drainage course of the area is in two major directions i.e. East–West and North –South which is also the strike direction of the major joints in the area. Hence, geological structure has played a major role in controlling the course of the drainage in the area. However, at places the river show sinuous and meandering course which may be due to local geology i.e. area underlain by alluvium and colluvium. River Seonath shows a right angle turn near Dongra ghat after forming loops and it has cut through the basic rocks and flows along rock contact zone

The drainage map of the area is presented in Fig. 2**.** The drainage pattern is generally sub-dendritic in nature. In areas of volcanic rocks the drainage density is high especially in the southern portion of the study area. The drainage density is poor to moderate in the area of granite terrain and laterite capping.

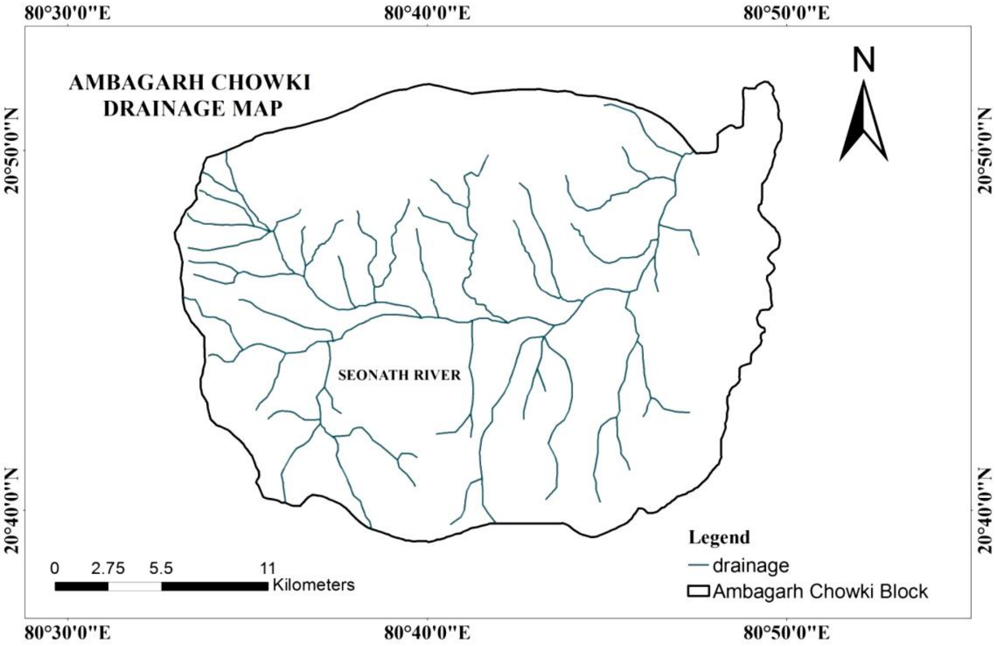

Fig. 2: Drainage map of Ambagarh Chowki

2.6 **Soil Type**

The study area is covered by mainly three types of soil. These main soil types are loam, lateritic soil and riverine alluvium. Loam is the dominant soil type in the area. The loam occupies more than 50% of the area. The second dominant soil type is lateritic soil followed by riverine alluvium deposited along the Seonath River and its tributaries. The loam is confined to forests and adjoining areas and is black in colour. The loam is characterized by organic content such as humus when compared with other soil types. The water holding capacity of this soil is high and is the product of weathering of crystalline rocks under forest cover, with pH value below 7. The forest soil is rich in nitrogen and poor in bases, because of heavy leaching.

The lateritic soils occur as detached patches formed due to lateritisation of the various formations. It is reddish brown in colour with very coarse sands and ferruginous pebbles. The fertility of the soil is generally poor with low contents of nitrogen, phosphorous, potash and organic components. The soil has pH value generally below 7. In some areas latertic soil is coarse sandy in nature with low organic matters. The riverine alluvium is restricted to the flood plains and river banks. The soil has moderate content of organic matter, nitrogen and potash.

2.7 Land Use & Land Cover

Based on the district wise statistics (as per the 2011 census of India), of the total area, 47.64% is net sown area (of which 5.92 % area is irrigated) and the remaining 8.94 % of the area comprises of fallow land, which includes waste land such as pasture and grazing land and uncultivable area. Of the total area 2.64% is culturable waste land. Land use pattern is given in Table 1.

Table 1: Land use pattern (areas in hectares)

Block	Total Geographical Area	Land under miscellaneous Tree and crops	Culturable waste land	Total Fallow Lands	Net sown Area	Total Irrigated Land Area	Total Un-Irrigated Land Area
Ambagarh Chowki	57736	3.2	1520.4	5161.4	27505.1	3420	23549.3
Rajnandgaon District	817233	634	18110.2	53321.7	341714.5	81444.7	297732

The main occupation of the people in the study area is agriculture and agro forestry. More than 95% of the people depend on the income from agriculture. The paddy cultivations dominate over other cultivations during kharif season. The other crops include various cereals, maize and pulses**.** The farmers cultivate wheat, pulses and vegetable during rabi season. The groundwater is being exploited through dug wells, dug cum bore wells and bore wells. Irrigation through dug wells and dug-cum bores wells is used for paddy cultivation during rabi season in these areas. Area irrigated by various sources is presented in Table 2.

Table 2: Area irrigated by various sources (in hectares)

Block	Area Irrigated by Canals	Area Irrigated by Wells / Tube Wells (W/TW)	Area Irrigated by Tanks/Lakes (T/L)
Ambagarh Chowki	2702	483.7	42
% to Net Area Sown	9.82%	1.76%	0.15%

The different sources for irrigation in the study area includes canals, dug wells, dug cum bore wells, bore wells, tanks and lakes etc. Mogra canal is a good example for Area irrigated by canals, which draws its water from Mogra dam.

2.8 Geological Setup

A major portion of Ambagarh Chowki is made up of Proterozoic age comprising of mainly granites and rhyolites which are blanketed by layers of laterite loam or alluvium. The Chowki area of Rajnandgaon district is part of the Indian shield and falls in the Central India Craton. Regionally the area forms part of Dongargarh- Kotri rift zone and is surrounded by Dongargarh Batholithic granites in west, Epicontinental platform sequence of Chhattisgarh Supergroup in NE and Supra Crustal sediments of Iron Ore Group in South.

The area is situated within one of the India’s most significant mineralised provinces, where Dalli Rajhra Iron Ore deposit, Malanjkhand Porphyry Copper deposit, Chandi-Dondri Fluoride - Lead deposit, Kotri Gold prospect and Bodal Uranium prospects are already being exploited. Base metal prospecting in the nearby area is under progress. The predominant rock types of the study area are Bijli Rhyolite comprising 70.21% of the total area, while Donagarh granite constitutes the remaining area of 29.79%. They belong to Kotri Supergroup stratigraphic sequence. The geology map of the area is given in Fig. 3.

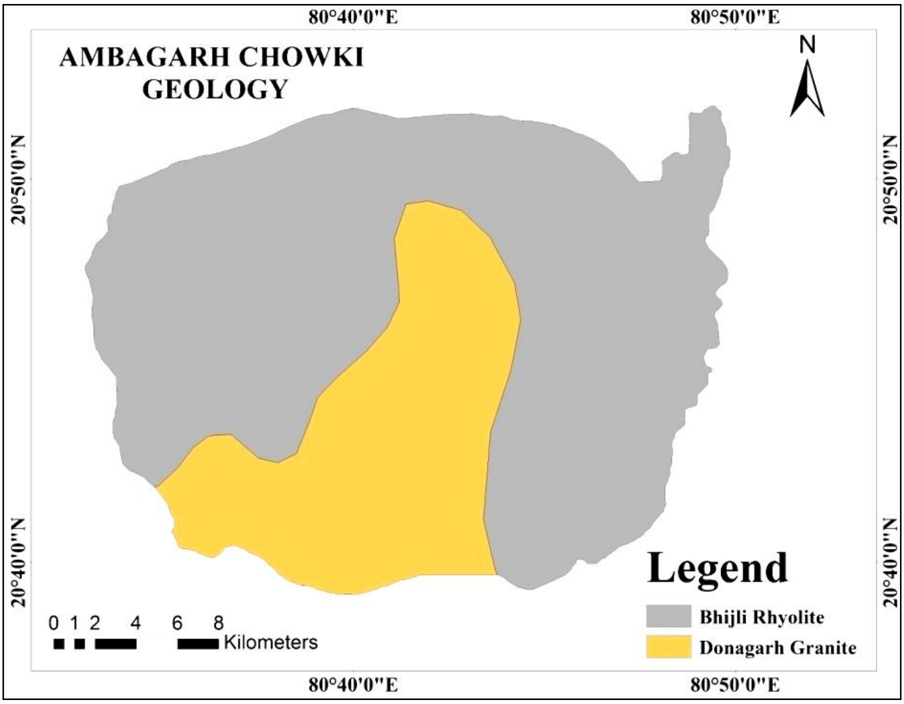

Fig. 3: Arsenic bearing major geological formations of Ambagarh Chowki

A detailed geological map of Ambagarh Chowki block is shown in Fig. 3A and groundwater monitoring stations in different geological formations of the R&D study area are shown in Fig. 3B.

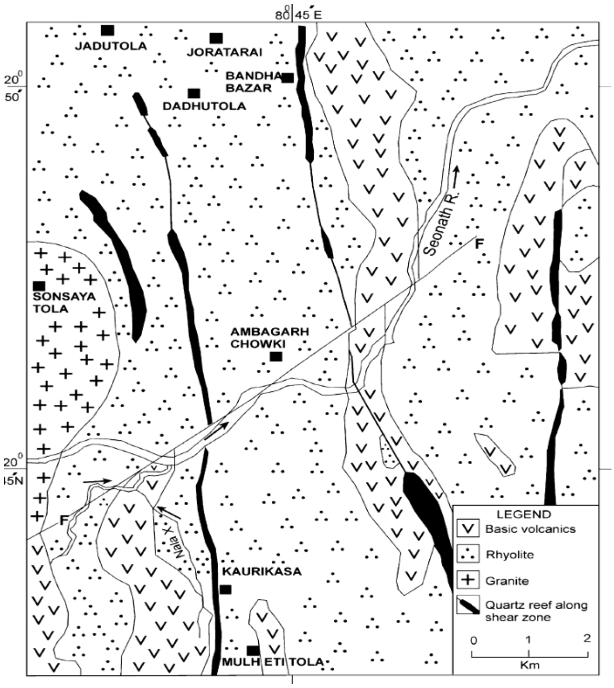

Fig. 3A: Detailed geological map of Ambagarh Chowki block (Source: Acharyya S.K. et al., 2007)

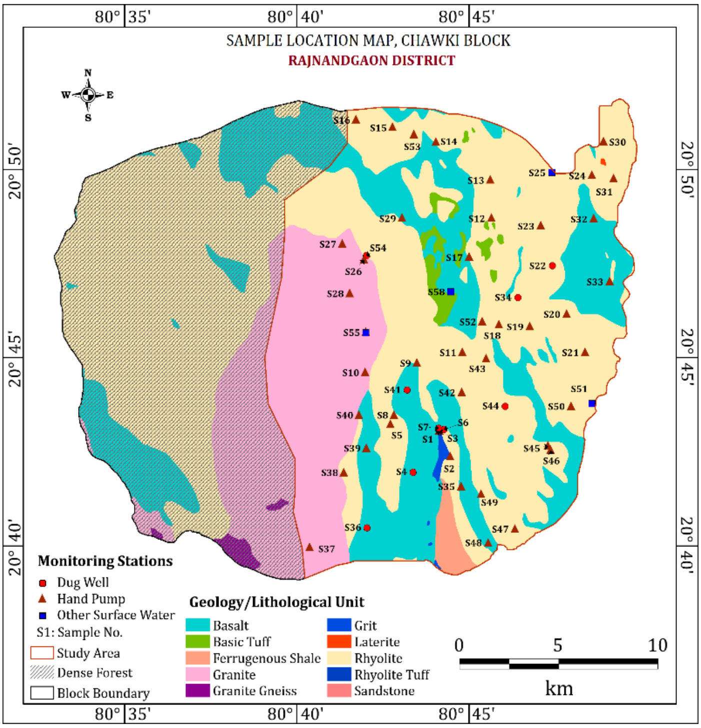

Fig. 3B: Groundwater monitoring stations in different geological formations of study area

2.9 Hydrogeology - Groundwater regime

Four months of water level data have been obtained and analyzed for the study area. The water level is measured in meter below ground level (m bgl). Pre- monsoon and Post-monsoon water level fluctuations are calculated for the months of May and December, respectively. The water level data of dug wells and bore wells are given separately as they represent the phreatic and confined aquifers respectively. Accordingly the water level maps were prepared. Depth to water levels (m bgl) is shown in Table 3 (dug well data) and Table 4 for (bore well data). Depths of wells with co-ordinates of sample locations are presented in Annexure - 1. For analysis of water level data 40 nos. bore well and 09 nos. dug well have been taken into account.

Table 3: Ranges of Depth to water level (in m bgl) for dug wells

Sl. No.	Particulars	May 2017	September 2017	December 2017	February 2018	Seasonal Fluctuation
1	Dug Wells of Ambagarh Chowki block	1.8–9.1	0.3-3.5	1.0-5.0	0.7-6.2	0.4-5.2

Table 4: Ranges of Depth to water level (in m bgl) for bore wells

Sl. No.	Particulars	May 2017	September 2017	December 2017	February 2018	Seasonal Fluctuation
1	Bore Wells of Ambagarh Chowki block	7.2–23.1	1.2-19.4	1.5-12.2	2.3-12.9	2.9-12.3

i) Pre-Monsoon scenario

The depth to groundwater level during pre-monsoon 2017 ranges from 1.50 to 25.90 mbgl for hand pumps (H.P.) (Fig. 4). The water for bore well is tapped from deeper fractured aquifers. The water level can be deeper in the North- Western Region of the block and as patches in the central region with a depth greater than 20.00 m bgl.

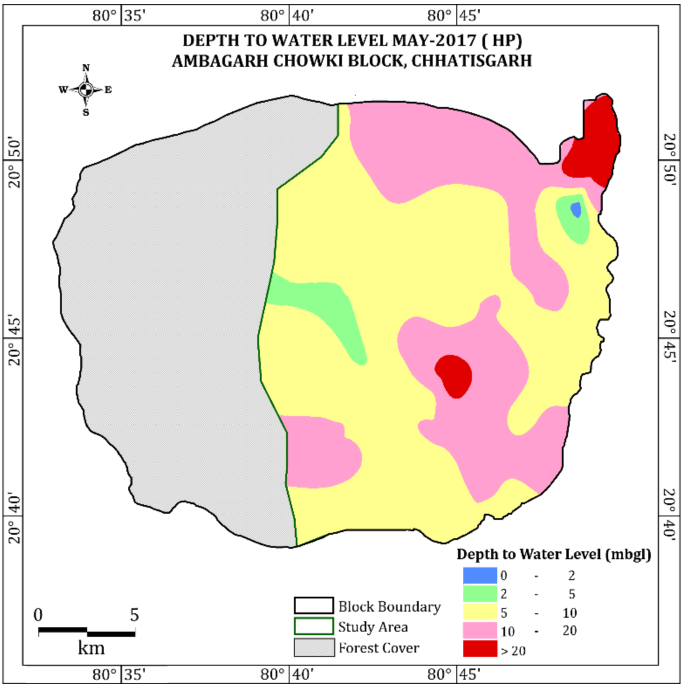

Fig. 4: Depth to water level during Pre-Monsoon 2017 for Bore Wells

In the case of dug wells water is tapped from unconfined aquifer. The water level for dug well ranges from 1.80 to 9.10 metres below ground level (mbgl) (Fig. 5).

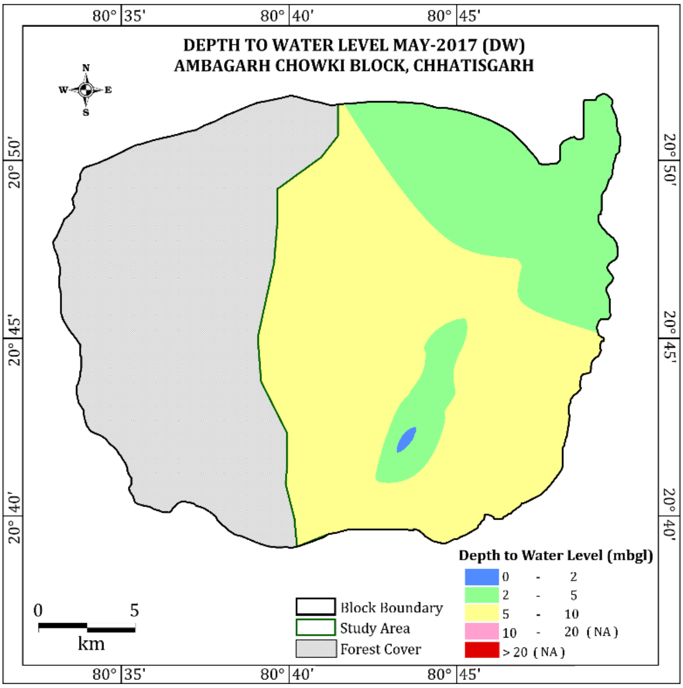

Fig. 5: Depth to water level during Pre-Monsoon 2017 for Dug Wells

ii) Post-Monsoon scenario

The depth to water level during the post monsoon season of 2017 ranges between 1.72 to 14.95 m bgl for the bore wells. Depth to water level in most of the area ranges between 5-10 m bgl (Fig. 6).

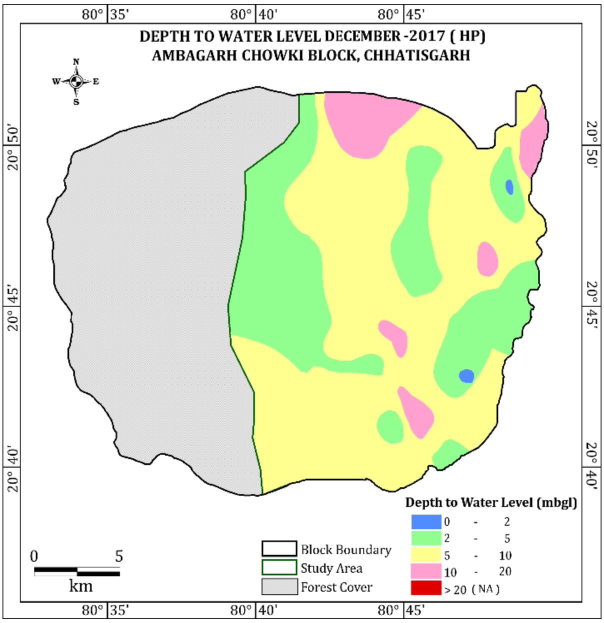

Fig. 6: Depth to water level during Post-Monsoon 2017 for Bore Wells

Depth to water level for dug wells tapping water from shallow phreatic aquifers ranges from 0.96 to 5.00 m bgl. (Fig. 7).

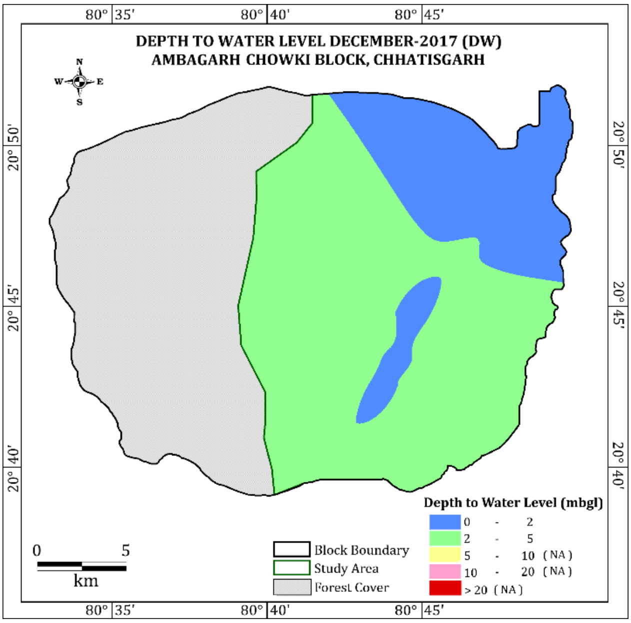

Fig. 7: Depth to water Level during Post-Monsoon 2017 for Dug Wells

iii) **Seasonal Fluctuations of water level**

The seasonal fluctuations of water level for bore well ranges from a least fluctuation of water level of 0.22 m to a highest fluctuation of 21.18 metres (shown in Fig. 8). The fluctuation of water level for dug well ranges from a least fluctuation value of 0.44 m to highest fluctuation of 5.24 metres (Fig. 9).

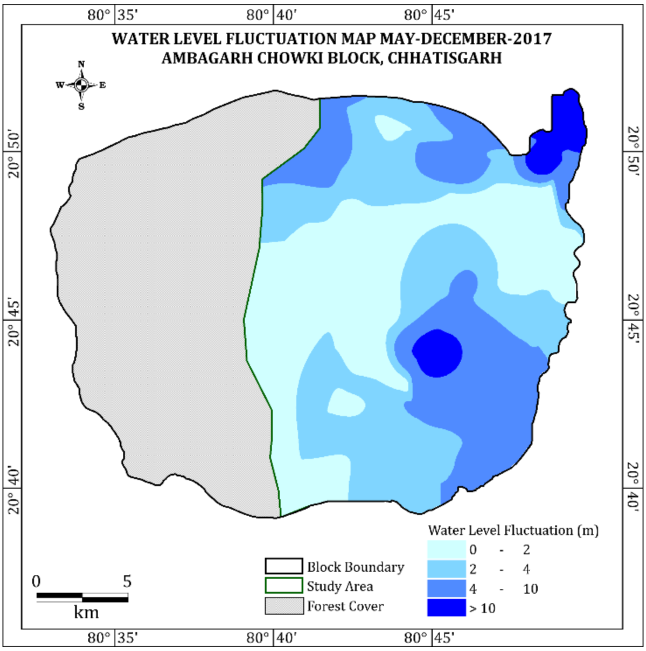

Fig. 8: Seasonal water level fluctuations during 2017 for Bore Wells in Ambagarh Chowki Block

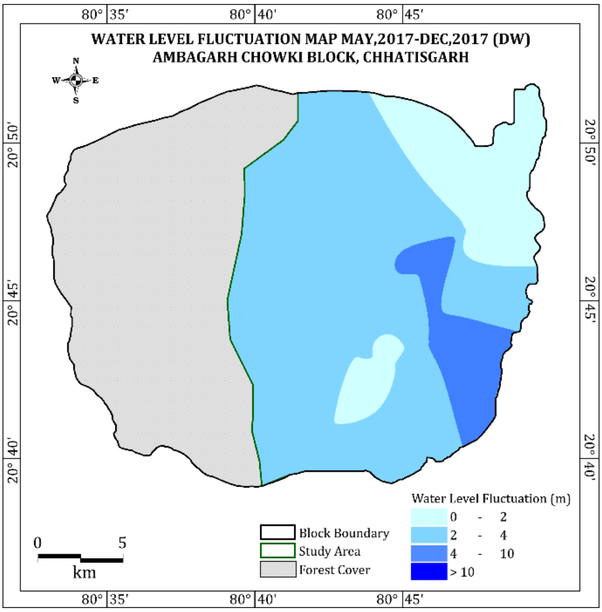

Fig. 9: Seasonal water level fluctuations for Dug Wells in Ambagarh Chowki

2.10 **Groundwater Exploration**

The details of the five exploratory wells constructed by Central Ground Water Board (CGWB), North Central Chhattisgarh Region (NCCR), Raipur have been studied (Fig. 10), which indicates that the main aquifers types of the study area are fractured granite and fractured rhyolite (Table 5).

Table 5: Exploratory Well Details

Sl.No.	Location	Longitude	Latitude	Elevation (m)	Depth in m bgl	Aquifer	Geology	Fracture Zone Tapped (m)
1	Kaudikasa	80.7333	20.7167	335	150	Fractured Rhyolite	Kotri Supergroup	20-21,35-36, 99
2	Sansaytola	80.7083	20.7833	345	152.7	Fractured Granite	Kotri Supergroup	16-17
3	Gaulitola	80.7333	20.7458	330	152.7	Fractured Rhyolite	Kotri Supergroup	20-21, 26.5
4	Jadutola	80.7167	20.85	343	150	Fractured Rhyolite	Kotri Supergroup	19-20
5	Bandhabazar	80.7458	20.8375	345	152.7	Fractured Rhyolite	Kotri Supergroup	12,34-36,60-61.50

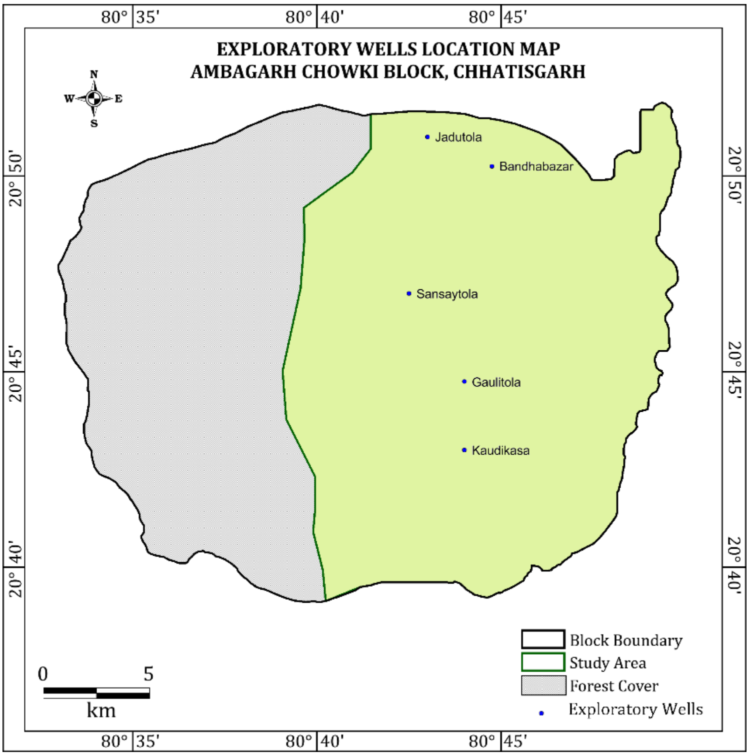

Fig. 10: Exploratory well location map

A cross-section depicting the regional aquifer system is drawn along the N-S direction with due consideration of lithological data of the exploratory wells constructed by CGWB in different locations like Bandhabazar, Gaulitola and Kaudikasa villages of the R&D study area. The analysis of cross-section indicates the disposition of a regional aquifer at around 310 metres above mean sea level (m amsl), which maintains continuity in all the three wells as shown in the cross-section (Fig. 11). The aquifer component in the cross-section is fractured rhyolite sandwiched along the layers of massive rhyolite. Another aquifer is found at the height of around 300 metres a msl along Gaulitola and Kaudikasa.

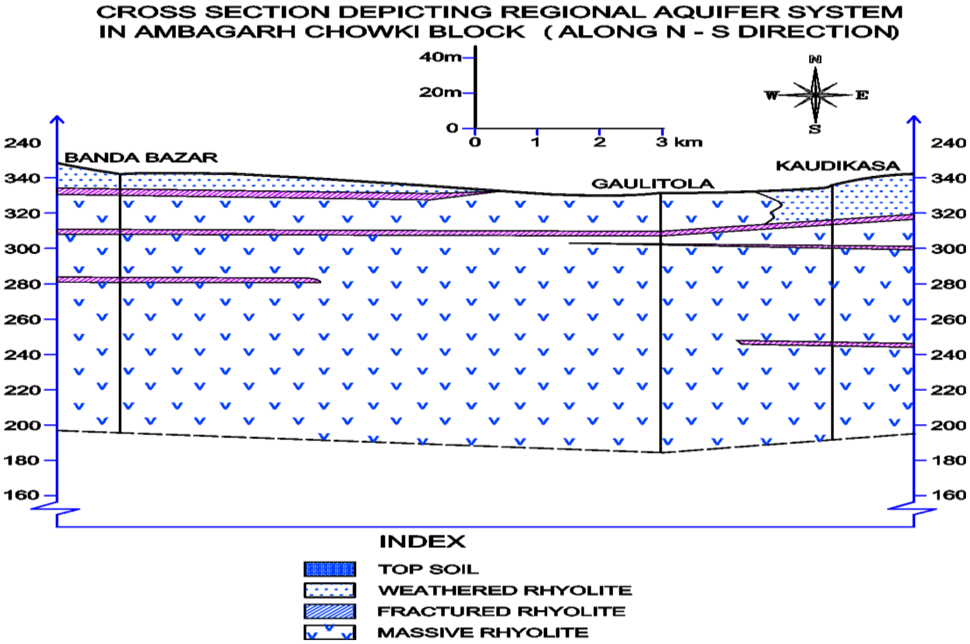

Fig. 11: Cross-section depicting the regional aquifer system in Ambagarh Chowki block (Along N-S Direction)

Regional aquifer system consists of two prominent aquifers, which are exclusively found along the Bandabazar region; a shallow aquifer along the height of 330 metres amsl (12 metres below ground level) and a deeper aquifer at around 280 metres amsl (60 - 61.50 metres below ground level). An aquifer zone is tapped exclusively for Kaudika at around 240 metres amsl (99 metres below ground level). At some regions arsenopyrite is found along with rhyolite which may be a reason for the presence of arsenic in the groundwater in some places in the Ambagarh Chowki Block.

2.11 Groundwater resources

As per Groundwater Estimation Committee (GEC), 2015 methodology CGWB has made groundwater resource estimation for the R&D study area. The groundwater resource estimation reveals that the net groundwater availability of Ambagarh Chowki block is 3898.31 ham. Existing gross groundwater draft for all purposes is 2286.32 ham, out of which 2002.03 ham accounts for irrigation and 284.29 ham is for domestic and industrial water supply. The stage of the groundwater development in the study area is 58.65%, which is lower than the Rajnandgaon district percentage i.e., 60.53% (Table 6 and 7).

Table 6: Groundwater resources of Ambagarh Chowki Block (in ham)

Assessment Unit/District	Command/ non-command	Net Groundwater availability	Existing Gross Groundwater draft for irrigation	Existing Gross Groundwater Draft for Domestic and industrial water supply
Ambagarh Chowki Block	Command	376.44	199.02	14.46
	Non-Command	3521.87	1803.01	269.83
	Block Total	3898.31	2002.03	284.29
Rajnandgoan District	District Total	52148.90	27677.98	3889.94

Table 7: Groundwater resources of the study area (in ham)

Command/ Non-Command	Existing Gross Ground Water Draft for All Uses	Allocation For Domestic & Industrial Water Supply	Net Ground Water Availability for Future Irrigation Development	Stage of Groundwater Development (in %)
Command	213.48	14.79	162.63	56.71
Non-Command	2072.84	275.67	1433.19	58.86
Block Total	2286.32	290.46	1605.82	58.65
District Total	31567.92	3976.66	20494.26	60.53

CHAPTER 3

3.0 HYDROCHEMISTRY

3.1 **Introduction**

The quality of water is a measure of its chemical, physical, biological and bacteriological properties with respect to its use. Quality of groundwater is controlled by composition of minerals and products of rock weathering. Qualitative study is carried out in the study area to find suitability of groundwater for domestic, irrigation and industrial uses. Water is a very important resource that holds the key to the very existence of life (Wagh et al. 2019a). In India, the importance of groundwater is highly significant as around 50% of irrigated agriculture and 85% of rural drinking water is based on groundwater (Singh et al. 2017a,b and 2018; Kumar et al., 2018; Wagh et al. 2018). A new study finds that up to 220 million people around the world, with ~94% of them in Asia may be at risk of drinking arsenic-contaminated groundwater (Zhou et al. 2021). Amongst the toxic metalloids found in ground water, As is detrimental to human health even at meager concentration (Xu et al. 2020). As has been documented as a human poison since a long times (Motlagh et al. 2020). Oral intake of arsenic has proved to be deadly on many occasions (Ma et al. 2020).

Arsenic contamination in water (inorganic and organic form), poses a serious risk to human health. Excessive and prolonged intake of inorganic arsenic with drinking water accelerates arsenicosis, a deteriorating and disabling disease characterized by skin lesions and pigmentation of the skin develops keratosis; i.e., patches on the palms and soles (Chakraborti et al. 2017). Arsenic poisoning culminates into potentially fatal diseases like skin and internal cancers. Besides carcinogen effects, long-term exposure of arsenic may result in cardiovascular and diabetic complications (WHO, 2016). Gilbert-Diamond et al. (2016) in his study revealed that there exists an association between arsenic exposure and reduced birth weight. The exposure of arsenic through the food chain will ultimately remain as long-term risks to human and ecological systems (Tuli et al. 2010). Since water is the principal route through which arsenic enters into the human body (Chen et al. 2010), the understanding of the processes of arsenic contamination in groundwater, associated health risks, and mitigation of arsenic problem is required.

Moreover, the arsenic contamination of groundwater has been reported in many countries including Bangladesh, India, China, Taiwan, Vietnam, Nepal, Mexico, USA, West Africa, and the foreland basins of the western USA and Canada (Berg et al. 2008; Bretzler et al. 2017; Srivastava 2020; Wang et al. 2020; Zeng and Zhang 2020). Across the world, the arsenic contamination reported is mostly from the deltas and river basins, for example, Paraiba do Sul delta (Brazil), Bengal Delta (India and Bangladesh), Mekong Delta (Cambodia), Danube River Basin (Hungary), Hetao River Basin (Mongolia), Duero Cenozoic Basin (Spain), Zenne River Basin (Belgium), etc. (Shankar et al. 2014). The estimated number of people that are at risk of arsenic poisoning, as a result of drinking arsenic-contaminated water from Bangladesh and India is more than 60 million (Ahmed et al. 2004; Milton et al. 2004). In India, dissolved arsenic concentration (>10 ppb) has been reported in West Bengal, Jharkhand, Bihar, Uttar Pradesh in the flood plain of the Ganga River; Assam and Manipur in the flood plain of the Brahmaputra and Imphal Rivers, the union territory of Chandigarh, Punjab, and in fractured consolidated rocks of Rajnandgaon district in Chhattisgarh state (Bhattacharya et al. 2011).

High arsenic concentration in groundwater of Kaudikasa village of Ambagarh Chowki block, Rajnandgaon district has been reported (Chakraborti et al. 1999; Acharyya et al. 2005; Shukla 2010; Patel et al. 2017; Singhal et al. 2018). According to the Environmental Protection Agency (EPA) and Agency for Research on Cancer (IARC), consumption of inorganic arsenic through drinking water is of major concern, as it has a potential to cause carcinogenic and non-carcinogenic effects on human health (Alidadi 2019). Some of the epidemiological studies conducted in the regions of arsenic contamination sites have shown that exposure to arsenic and its inorganic compounds may cause 0.1%–0.3% of cancers, even at about 10 ppb (IARC 2009; Sinha and Prasad 2019). A good number of researchers have assessed the human health risk assessment upon exposer of various contaminants in drinking water by classifying the population in adults (male and female) and children’s category by using hazard quotient (HQ) and carcinogenic risk (CR) methods (Aghapour et al. 2018; Adimalla and Li 2019; Shahab et al. 2019; Wu et al. 2019; Ricolfi et al. 2020). Very limited research has been undertaken regarding the status of health-risk assessments for arsenic in drinking water in the Ambagarh Chowki block of the study area (Singhal et al. 2018).

Unlike the other regions in which the arsenic occurs in strongly reducing aquifers often derived from alluvium, flood plains, deltas, and river basins; the arsenic contamination in groundwater of the current study area occurs in complex hard rock terrain in a sporadic manner, where oxidation of sulfide minerals in the host rock is the prime governing process (Mukherjee et al. 2019). Inhabitants from this area have been chronically exposed to arsenic contaminated drinking water through hand pumps, tube wells, and dug wells.

Therefore, there is a need for judicial management of resources to ensure adequate supplies of dependable quality and quantity. In the present study, an attempt has been made toward understanding the occurrence and extent of arsenic contamination in the complex crystalline aquifer system of inland or close basin and its variability over space and time. The health risk posed by excess arsenic exposure on adults and children, in terms of the HQ and CR has been studied. Field based health survey is conducted to trace the arsenic toxicity manifestation by inhabitants in the contaminated pockets. Finally, plausible remedial measures for the problem and management of arsenic in groundwater have been addressed. Groundwater sampling procedure has been detailed in the Annexure - 2. Groundwater and surface water sampling locations along with elevation control of the study area is shown in Fig. 12.

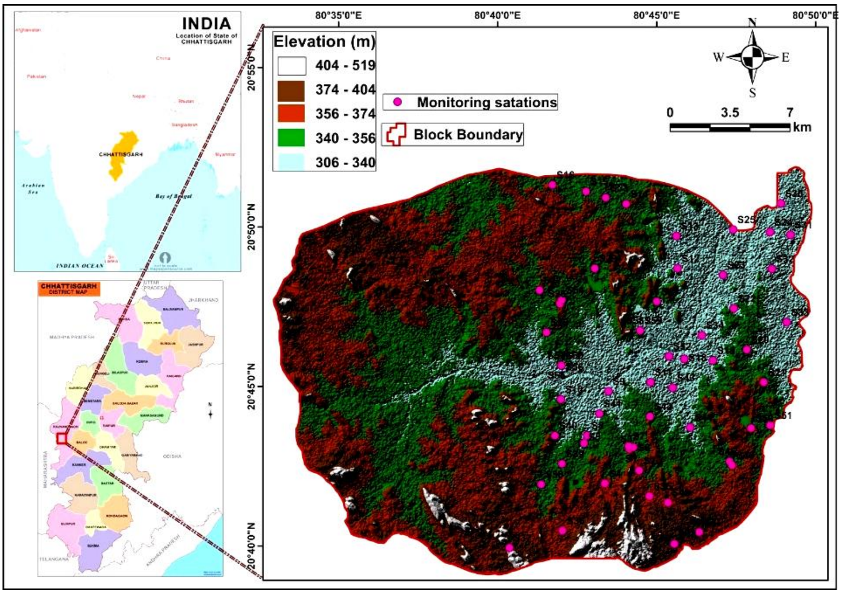

Fig. 12: Map depicting the groundwater and surface water sampling locations along with elevation control of the study area

3.2 Sample analysis

Total 13 nos. groundwater samples have been analyzed for basic parameters in the chemical laboratory of Central Ground Water Board (CGWB), NCCR, Raipur. The samples were collected during the months of December, 2017 and February, 2018 respectively. Major ion chemistry results of the groundwater samples in the study area shows that pH value varies from 6.07 to 7.61 showing acidic nature with a mean value of 6.79 with a Standard Deviation (S.D) of 0.50. Electrical conductivity value has a drastic variation between 1789 and 1343 µS/cm with a mean value of 629 µS/cm and has very high SD of 351 µS/cm. The sodium ranges from 13.4-106.5 mg/l having a mean of 39.7 mg/l with SD of 27 mg/l. The calcium ranges from 10-110 mg/l having a mean of 49.4 mg/l with SD of 30.1 mg/l. The magnesium ranges from 3.6-49.2 mg/l having a mean of 17.3 mg/l with SD of 14.4 mg/l. The Potassium ranges from 0.3-20 mg/l having a mean of 6.5 with SD of 7.8 mg/l. The TH values ranges from 40-390 mg/l with a mean of 195.38 mg/l having SD of 127.25 mg/l.

The bi-carbonate concentration ranges between 61-60.39 mg/l with a mean of 225.7 mg/l and Standard Deviation of 191.5 mg/l. The chloride concentration ranges between 21.30 - 131.35 mg/l with a mean of 72.1 mg/l and S.D of 40.6 mg/l. The concentration of sulphate ranges in between 2.5 and 40.2 mg/l with a mean of 16.7 mg/l and S.D of 13. The concentration of fluoride ranges between 0.01- 0.95 mg/l with a mean of 0.36 mg/l S.D of 0.29 mg/l. The procedure of water sample analysis has been explained in the Annexure - 3 and the detailed chemical analysis results are shown in the Table 8**.**

Table 8: Basic chemical parameters analysis results (mg/l)

Sl. No.	Name	Date	pH	EC	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	-HCO3	Cl^{-}	$SO4^{2-}$	F^{-}
1	Sansaytola H.P	12-12-17	7.61	705	135	38	9.6	64	20.0	109.8	120.70	5.4	0.20
2	Kaudikasa Middle School H.P	12-12-17	6.12	243	75	18	7.2	19.4	3.3	73.2	31.95	4.5	0.08
3	Bhagwantola H.P	12-12-17	7.12	814	385	72	49.2	15.5	0.4	481.9	39.05	16.0	0.78
4	Kaudikasa Boy’s Hostel D.W	12-12-17	7.11	1343	370	110	22.8	106.5	17.5	603.9	131.35	40.2	0.53
5	Kaudikasa Girl’s Hostel D.W	12-12-17	7.11	689	225	64	15.6	44.1	3.7	305.0	63.90	21.6	0.52

Sl. No.	Name	Date	pH	EC	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	-HCO3	Cl^{-}	$SO4^{2-}$	F^{-}
6	Joratarai H.P	12-12-17	6.43	342	125	32	10.8	13.4	0.8	97.6	39.05	4.9	0.07
7	Jadutola H.P	12-12-17	7	346	115	32	8.4	25.6	2.1	164.7	28.40	11.4	0.14
8	Sansaitola H.P	12-12-17	6.68	400	115	30	9.6	28.7	0.4	115.9	56.80	4.8	0.45
9	Netamtola D.W	12-12-17	7.31	1097	390	90	39.6	59.8	0.9	530.7	95.85	30.2	0.95
10	Mogra H.P	12-12-17	6.79	911	325	76	32.4	30.5	13.6	201.3	117.15	29.6	0.29
11	Kaudikasa H.P	15-2-18	6.07	179	40	10	3.6	14.6	2.4	61.0	21.30	2.5	0.01
12	Sansaytola H.P	15-2-18	6.07	398	100	30	6	32.6	0.3	73.2	67.45	12.3	0.51
13	Sansaytola D.W	15-2-18	6.89	709	140	40	9.6	62	18.5	115.9	124.25	33.8	0.21

3.3 Modified Piper Diagram

The groundwater is evaluated to determine its facies by plotting the percentages of select chemical constituents in modified Piper diagram (Chadha et al 1999) which is a simplified version of Piper plot. In Chadha´s diagram, the difference in milli equivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis, and the difference in milli equivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle, depending upon the size of the scales chosen for X and Y co-ordinates. The mill equivalent percentage differences between alkaline earths and alkali metals, and between weak acidic anions and strong acidic anions, would plot in one of the four possible sub-fields. The major advantage of this diagram is that it can be drawn in any spreadsheet software packages (Chadha 1999). Based on the plot the water can be classified into eight types, but for the convenience only four major water types are identified are Na-HCO3 Type, Ca-HCO3 Type, Ca-Mg-Cl Type and Na-Cl type. In the study area groundwater is evaluated to determine its facies by plotting the percentages of select chemical constituents in modified Piper diagram (Fig. 13), 31% of the samples belonging to Ca-Mg-Cl type and 69% samples belonging to Ca-HCO_3 type. The ionic dominance pattern among cation is $Ca^{2+} > Na^{2+} > Mg^{2+} > K^{+}$ and among anions the ionic dominance pattern is $HCO_3^{-} > Cl^{-} > SO_4^{2-}$.

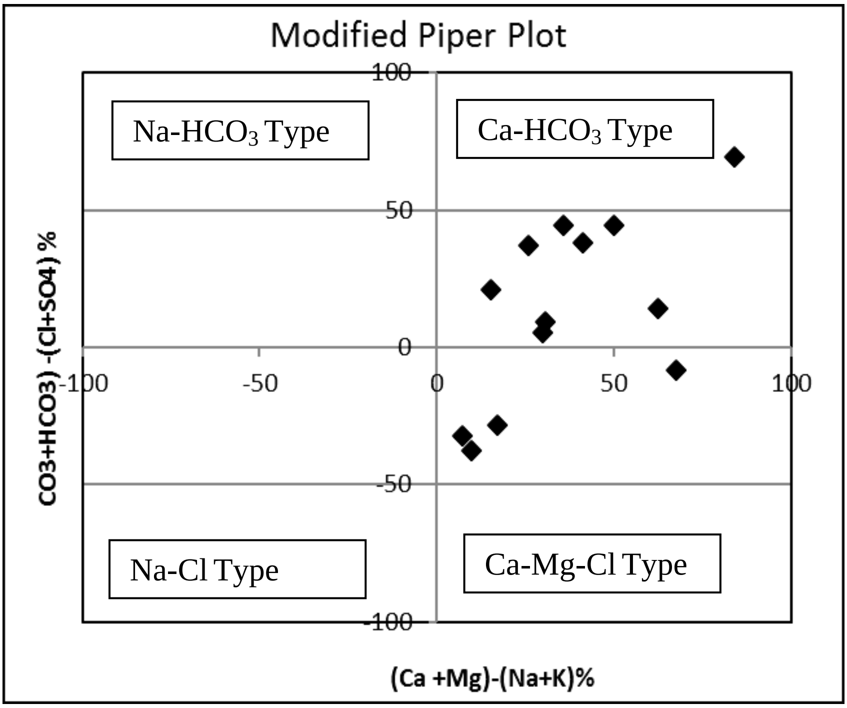

Fig. 13: Modified Piper Diagram for Ambagarh Chowki block

3.4 Hydrochemical classification and genesis of groundwater

Expanded Durov diagram (Durov, 1948) is employed to trace the processes responsible for the evolution of hydrochemical facies in groundwater, flow direction, mixing of different water types, ion-exchange and reverse ion exchange processes taking place in a given hydrological setup. It is evident from Fig. 14 that most of the samples fall within field 5, which is a result of the simple dissolution or mixing of two or more different types of groundwater facies (Ca^{2+} – Mg^{2+} – Na+ – SO^{2-} type). The rest of the samples fall in the transition zone of fields 5 and 6 relate to Na^{+} – HCO_3^{-} facies. This water type is attributed to the effect of ion change that leads to the exchange of Ca^{2+} and Mg^{2+} in the aqueous phase by Na^{+} from the aquifer matrix and consequently Na^{+}–HCO^{-} facies is evolved from a pristine Ca^{2+}–HCO_3^{-} facies (Yadav et al., 2020). The Schoeller plot generated for better understanding of the relative abundance of cations anions typically expressed in milliequivalents per liter. The generated plot Fig. 15 showed the high abundance of Ca^{2+} HCO_3^{-} and Cl^{-}.

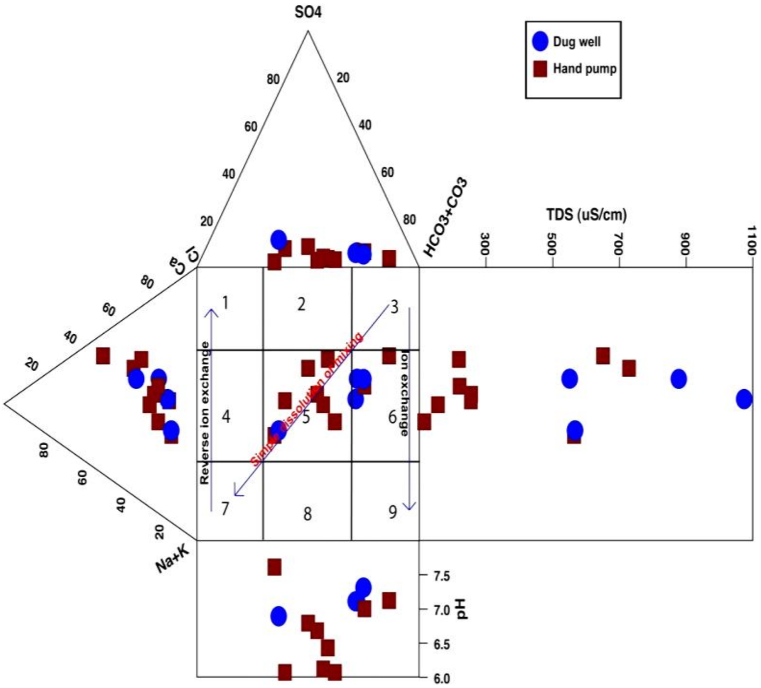

Fig. 14: Expanded Durov diagram of groundwater from the study area

Additionally, the base-exchange indices (BEI) and meteoric genesis indices (MGI) are computed using following Eqns. (1) and (2) (where all units are in meq/L) to identify the prevailing dominant groundwater facies and its plausible sources and the results are illustrated in Table 09. It indicates that most of the samples with BEI (85%) and MGI (77%) value less than unitary (<1) are regarded as Na^+– SO_4^{2-} facies and deeper meteoric percolation type. At the same time, the samples with BEI >1 and MGI>1 are classified as Na^+– HCO_3^- facies and shallow meteoric percolation type.

Statistically, pH value varies from 6.07 to 7.61 showing acidic nature with a mean value of 6.79 and a standard deviation of 0.49. The Schoeller plot (Fig. 15) illustrates the sequence of ion dominance pattern of $Ca^{2+} > Na^{2+} > Mg^{2+} > K^+$ among cations and whereas, anions in the groundwater follows the order of $HCO_3^- > Cl^- > SO^{2-} > F^-$. Therefore, the dominance of Ca and HCO_3 ions along with mean TDS<500 mg/L suggests that the study area is characterized by fresh water (Freeze and Cherry 1979).

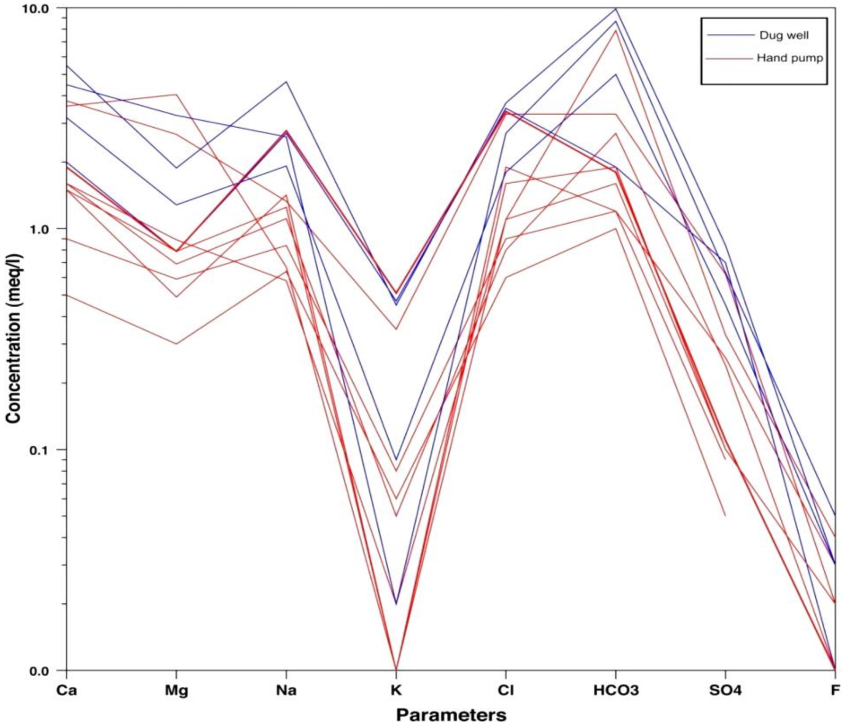

Fig. 15: Schoeller plot illustrates ionic dominance in the groundwater of study area

The statistical summary of various physico-chemical parameters analyzed in the groundwater samples and percent compliance of these parameters with respect to the drinking water standards (BIS 2012; WHO 2011) and associated probable health risk is summarized in Table 10. It is apparent from the results that none of the parameters exceeds the permissible limit baring pH at a few places and hence regarded as groundwater from the study area is suitable for potable use in terms of major ion chemistry.

Table 09: Groundwater classification according to Base-Exchange Index (BEI) and Meteoric Genesis Index (MGI) criteria and ionic ratios

Location	Indices				Ionic ratios						Process
	BEI	Water type	MGI	Water type	Na/ Na+Ca	Cl/ Cl+HCO_3	Ca/Na	Mg/Na	Ca/Mg	Ca+Mg/ HCO_3+SO_4	
Sansaytola H.P.	-5.52	$Na^1\text{-}SO_4^2$	-0.97	Deep meteoric water percolation type	0.59	0.65	0.68	0.28	2.40	0.52	Silicate weathering and ion exchange
Kaudikasa Middle School, H.P.	-0.61	$Na^1\text{-}SO_4^2$	0.29	Deep meteoric water percolation type	0.48	0.43	1.06	0.70	1.52	0.71	Silicate weathering and ion exchange
Bhagwantola H.P	-1.28	$Na^1\text{-}SO_4^2$	-1.25	Deep meteoric water percolation type	0.16	0.12	5.33	6.00	0.89	0.85	Silicate weathering and ion exchange
Kaudikasa Boy's Hostel, D.W	1.11	$Na^1\text{-}HCO_3$	1.64	Shallow meteoric water percolation type	0.46	0.27	1.18	0.40	2.93	0.54	Silicate weathering and ion exchange
Kaudikasa Girl's Hostel, D.W	0.26	$Na^1\text{-}SO_4^2$	0.47	Deep meteoric water percolation type	0.38	0.27	1.66	0.67	2.49	0.66	Silicate weathering and ion exchange
Joratarai H.P	-5.08	$Na^1\text{-}SO_4^2$	-4.88	Deep meteoric water percolation type	0.27	0.41	2.74	1.52	1.80	0.92	Silicate weathering and ion exchange
Jadutola H.P	1.32	$Na^1\text{-}HCO_3$	1.54	Shallow meteoric water percolation type	0.41	0.23	1.43	0.62	2.31	0.65	Silicate weathering and ion exchange
Sansaitola H.P	-3.54	$Na^1\text{-}SO_4^2$	-3.44	Deep meteoric water percolation type	0.45	0.46	1.20	0.63	1.90	0.65	Silicate weathering and ion exchange
Netamtola D.W	-0.16	$Na^1\text{-}SO_4^2$	-0.13	Deep meteoric water percolation type	0.37	0.24	1.73	1.25	1.38	0.68	Silicate weathering and ion exchange
Mogra H.P	-3.21	$Na^1\text{-}SO_4^2$	-2.65	Deep meteoric water percolation type	0.26	0.50	2.86	2.01	1.42	0.98	Silicate weathering and ion exchange
Kaudikasa H.P	0.66	$Na^1\text{-}SO_4^2$	1.84	Shallow meteoric water percolation type	0.56	0.38	0.79	0.47	1.69	0.50	Silicate weathering and ion exchange
Sansaytola H.P	-1.89	$Na^1\text{-}SO_4^2$	-1.86	Deep meteoric water percolation type	0.49	0.61	1.06	0.35	3.03	0.64	Silicate weathering and ion exchange
Sansaytola D.W	-1.15	$Na^1\text{-}SO_4^2$	-0.48	Deep meteoric water percolation type	0.57	0.65	0.74	0.29	2.53	0.52	Silicate weathering and ion exchange

$BEI = Na^{+}\,{}^{-}\,Cl^{-} / SO4^{2-}$, $MGI = (K^{+} + Na^{+}) - (Cl^{-}\,{}^{+}\,SO4^{2-})$

Table 10: Statistical summary of physicochemical parameters measured on groundwater of the study area

Chemical constituent	Minimum	Maximum	Mean	Standard Deviation (SD)	% of the sample above desirable limits	% of the sample above permissible limits	Desirable limit	Permissible limit	Potential health effect
pH	6.07	7.61	6.79	0.49	0.00	30.77	6.5–8.5	No relaxation	Taste, corrosion
EC	179.00	1343.00	628.92	350.96	0.00	0.00	–	1500[aa]	Gastrointestinal irritation
TDS	114.56	1074.40	479.66	302.37	53.85	0.00	500	2000	Gastrointestinal irritation
TH	40.00	390.00	195.38	127.25	38.46	0.00	200	600	Gastrointestinal irritation
TA	48.80	483.12	180.56	153.17	30.77	0.00	200	600	Gastrointestinal irritation
$Ca^{2þ}$	10.00	110.00	49.38	30.09	23.08	0.00	75	200	Scale formation
$Mg^{2þ}$	3.60	49.20	17.26	14.41	23.08	0.00	30	100	–
$Na^{þ}$	13.40	106.50	39.75	27.00	0.00	0.00	–	200[a]	Hypertensive effects
$K^{þ}$	0.30	20.00	6.45	7.79	0.00	30.77	–	12[a]	Bitter taste
CO_3^{2-}	0.00	0.00	0.00	0.00	0.00	0.00	–	–	
HCO^{-}	61.00	603.90	225.70	191.46			–	–	Bitter taste
SO^{2-}	2.50	40.20	16.71	12.99	0.00	0.00	200	400	Laxative effect
Cl^{-}	21.30	131.35	72.09	40.62	0.00	0.00	250	1000	Anesthetic effect, salty taste
F^{-}	0.01	0.95	0.36	0.29	0.00	0.00	1	1.5	Skeletal and dental fluorosis

[a] WHO (2011) standards and the rest of the parameters are referred to BIS (2012).

Groundwater compliance with respect to drinking water standards (BIS 2012; WHO 2011)

Chapter 4

4.0 ARSENIC CONTAMINATION AND HEALTH HAZARDS

4.1 Groundwater Arsenic Contamination Status

Acidified groundwater samples have been collected in 250 ml bottles and analyzed using AAS. 52 samples from month of May 2017 and 60 samples from month of September 2017 have been analyzed in the chemical laboratory of CGWB, NCCR, Raipur. The arsenic concentrations in groundwater samples during pre-monsoon and post-monsoon seasons (May & September 2017) are given in the Table 11. The location of sampling points for the two months along with the arsenic concentration is shown in Fig. 16 and Fig. 17.

Table 11: Arsenic contamination levels in groundwater

SN	Study Period	Arsenic Concentration (in ppb) of the Study Area			
		Minimum	Maximum	Average	Std. Dev.
1.	Pre-monsoon 2017	Traces	202	9	30
2.	Post-Monsoon 2017	Traces	59	5	12

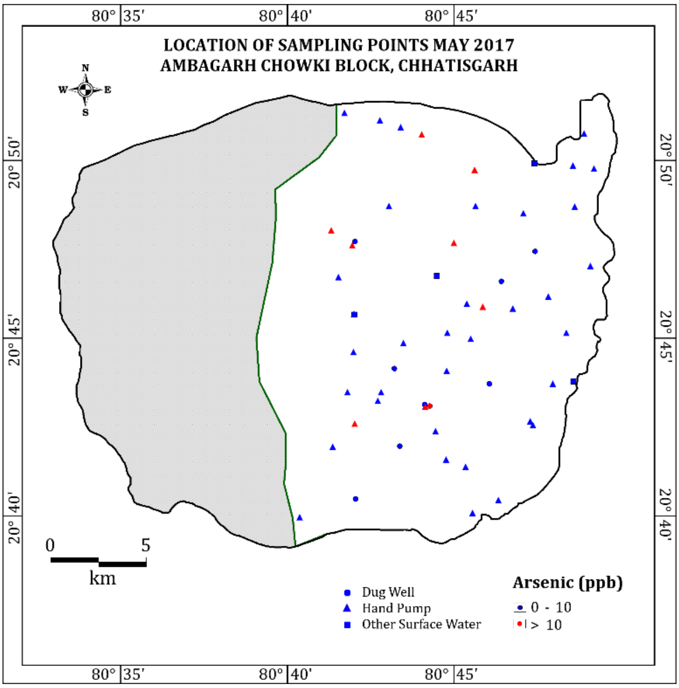

Fig. 16: Locations of sampling points in May 2017 (Pre-monsoon)

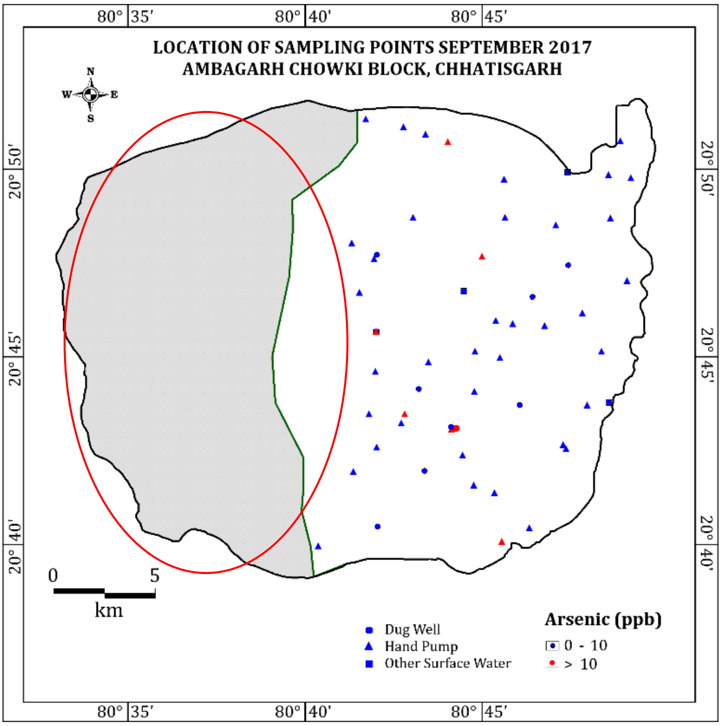

Fig. 17: Locations of sampling points in September, 2017 (Post-monsoon)

The geographic distribution of high arsenic in groundwater is sporadic in occurrence. Of the 52 samples analyzed in May 2017; 02 samples have shown arsenic above 50 ppb, the BIS permissible limit for arsenic in drinking water. The highest values were 202 ppb in Kaudikasa dug well (near boy's hostel) and 77.94 ppb in Kaudikasa hand pump. Seven locations have arsenic in range of 10 ppb to 49 ppb. Those locations are Telitola hand pump, Joratarai hand pump, Meregoan bore well, Pangri hand pump, Sansaitola hand pump, Kodutola and Bharritola hand pumps. The WHO guideline value for arsenic is 10 ppb, which means 09 samples lie above WHO guideline value. There are 43 samples in which arsenic value were found below 10 ppb. Out of the 60 samples analyzed in September 2017, 02 samples have shown arsenic above 50 ppb. They are Taramtola hand pump showing 59 ppb and Joratarai hand pump showing 53.4 ppb. Five locations have arsenic in range of 10 ppb and 49 ppb. Those locations are Kaudikasa dug well and hand pump, Meregaon bore well, Sansaitola hand pump (inside primary school) and Sansaitola hand pump (adjacent to arsenic removal plant). There are 53 samples in which arsenic value were found below 10 ppb. Summarized details of arsenic analysis in study area is given in Table 12.

Table 12: Summarized details of arsenic analysis of study area

Year and Month	No. of samples tested	Number of samples containing arsenic in different range (in ppb)			Locations having groundwater samples with Arsenic greater than 50 ppb
		>50	10-50	0-10	
May 2017	52	2	7	43	Kaudikasa H.P. (SL.No:1), Kaudikasa D.W. (Sl.No:6)
September 2017	60	2	5	53	Joratarai H.P. (SL.No.14), Taramtola H.P. (Sl.No:48)

Based on chemical analysis of water samples while considering locations shown in Fig. 18, it is observed that except three wells all seven wells are showing higher arsenic content during pre-monsoon period than during post-monsoon period.

High arsenic in groundwater may be due to declining water level in the hand pump during pre-monsoon period followed by release of arsenic from formation to groundwater. High arsenic in groundwater during post-monsoon have been observed for 03 locations, namely Joratarai H.P., Meregoan PHED office bore well, and Bharsena H.P. This may be due to the dissolution and mixing of arsenic from the top soil percolating down to the groundwater.

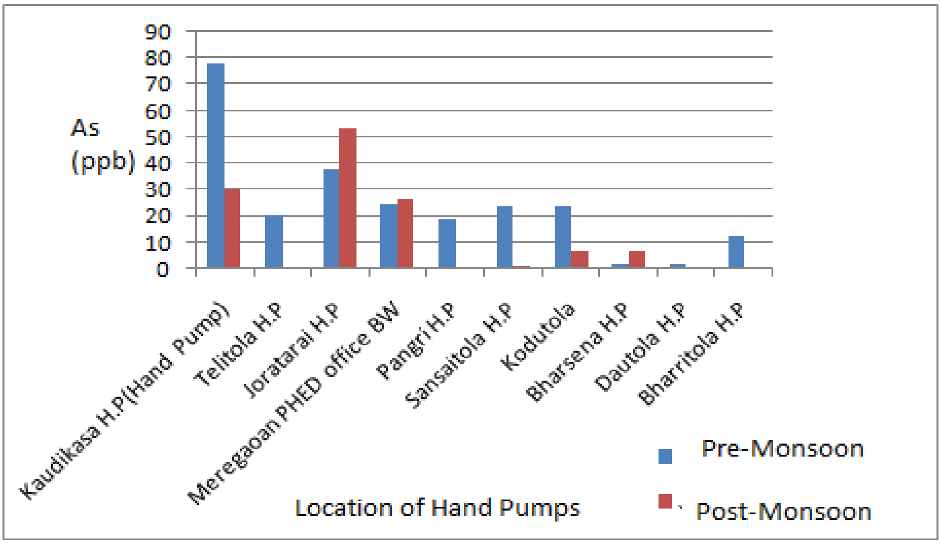

Fig.18: Comparison of arsenic content in groundwater during pre-monsoon and post-monsoon periods hand pumps

Out of all the 04 dug wells considered in Fig. 19, three dug wells show high arsenic in groundwater during pre-monsoon period except Tetwarilanjiya, where post monsoon arsenic content is high. But the dug well located in the backside of the Kaudikasa boys hostel show exceptionally high arsenic concentration during pre-monsoon period.

Arsenic in dug wells is less than the bore well. The dug wells in the area in less than 15 m in depth and invariably tap the phreatic aquifer. Pandey et al (1999, 2002) established negative correlation between diameter of dug well and arsenic concentration. This relationship is obvious as per the chemical behaviour of arsenic. Due to better atmospheric oxidation in dug well arsenic gets oxidised and removed from the aqueous phase. Due to the same reason and dilution effect the base flow to surface water body has not affected the level of arsenic in rivers and ponds. The surface water samples collected from Seonath River and Dangarh *nala* were found to be within permissible limits based on WHO guidelines

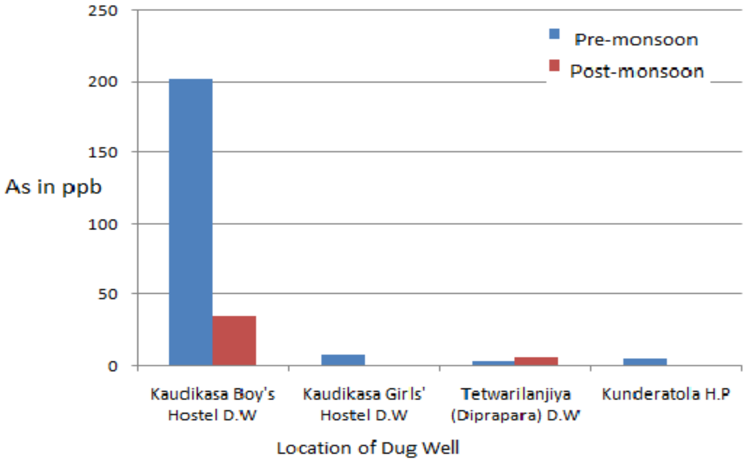

Fig. 19: Comparison of Arsenic content in groundwater during pre-monsoon and post-monsoon periods for dug wells

- **Spatio-temporal variation of arsenic concentration in groundwater**

The arsenic concentration measured for two different seasons has been used to prepare the arsenic contamination spatial distribution maps with three different classifications [i.e., low (AS < 10 ppb), medium (50<As>10) and high (As > 50 ppb)] in compliance with the drinking standards stipulated by BIS (2012) and WHO (2011). The geographic distribution of high arsenic in groundwater is sporadic in occurrence during both the seasons and mostly southern and northwestern parts of the study area are contaminated with elevated arsenic content (Fig. 19). In detail, of the 52 samples analyzed in May 2017, two samples exceed permissible limit 50 ppb and seven samples exceed desirable limit/acceptable limit of 10 ppb, but not the permissible limit as per (BIS, 2012). In contrast, the WHO guideline value for arsenic is 10 ppb that means groundwater from all these nine locations [Kaudikasa hand pump (S1), Kaudikasa dug well (S6), Telitola hand pump (S13), Joratarai hand pump (S14), Meregoan bore well (S17), Pangri hand pump (S18), Sansaitola hand pump (S26), Kodutola (S27), and Bharritola hand pumps (S39)] are not suitable for drinking (Fig.19). In contrast, groundwater samples collected from 43 samples show arsenic value well below 10 ppb and suitable for potable use. Likewise, out of the 60 samples analyzed in September 2017; 2 samples [Taramtola hand pump (S48) and Joratarai hand pump (S14)] have shown arsenic above 50 ppb, 5 locations [(Kaudikasa hand pump (S1), Kaudikasa dug well (S6), Meregaon bore well (S17), Sansaitola P.School hand pump (S26) and Sansaitola A.R.P hand pump)] have arsenic in the range of 10 and 49 ppb and rest of 53 samples in which arsenic value has found below 10 ppb.

Moreover, seasonal variation of arsenic content in groundwater during pre-monsoon and post-monsoon for dug wells and hand pumps are studied and the results show that higher arsenic content during pre-monsoon period than post-monsoon has been observed in terms of concentration and number of places in case of hand pumps. High arsenic in groundwater may be due to enhancement of drafts during recent past and consequent declining of water level in the hand pump during pre-monsoon period, which gradually leads to retardation of ancient water with the aquifer matrix and other mineral phases of the saturated fractures within the rhyolite and its comagmatically formed Dongargarh granite batholith emplacements. Ultimately, this As-laden groundwater oozes into the abstraction structures upon dwindling of hydrostatic pressure. Therefore, the sources of arsenic for the high arsenic groundwater in the study area has been established to be geogenic and which is related to Kotri-Dongargarh rift zone (Patel et al. 2017). As the study area is affected by the geothermal activity or sulfide mineralization, which leads to formation of arsenopyrite, together with other dominant arsenic sulfide minerals under high temperature conditions in the earth’s crust (Acharyya et al. 2005). The high arsenic in groundwater can be contributed from oxidation of these above minerals or from their weathered products (Mukherjee 2019).

Although high arsenic in groundwater during post-monsoon is endorsed to the dissolution and mixing of arsenic from the top soil percolating down to the groundwater. Likewise, two dug wells [Kaudikasa dug well (S6) and Kodutola (S27)] are showing high arsenic in groundwater during the pre-monsoon period, whereas during post-monsoon period the arsenic content is recorded as comparatively low.

In brief, the arsenic content in dug wells is comparatively less than the bore wells. This could be better explained by atmospheric oxidation in dug wells, which allows arsenic to get oxidized and removed from the aqueous phase (Pandey et al. 2002). This relationship is obvious as per the chemical behavior of arsenic. The arsenic content in the surface water samples collected from Seonath River and Dangarh rivulet were found to be within permissible limits of 10 ppb. The spatial distribution of arsenic concentration in the study area for different seasons (a) Pre-monsoon (May, 2017) (b) Post-monsoon (September, 2017) are shown in Fig. 20.

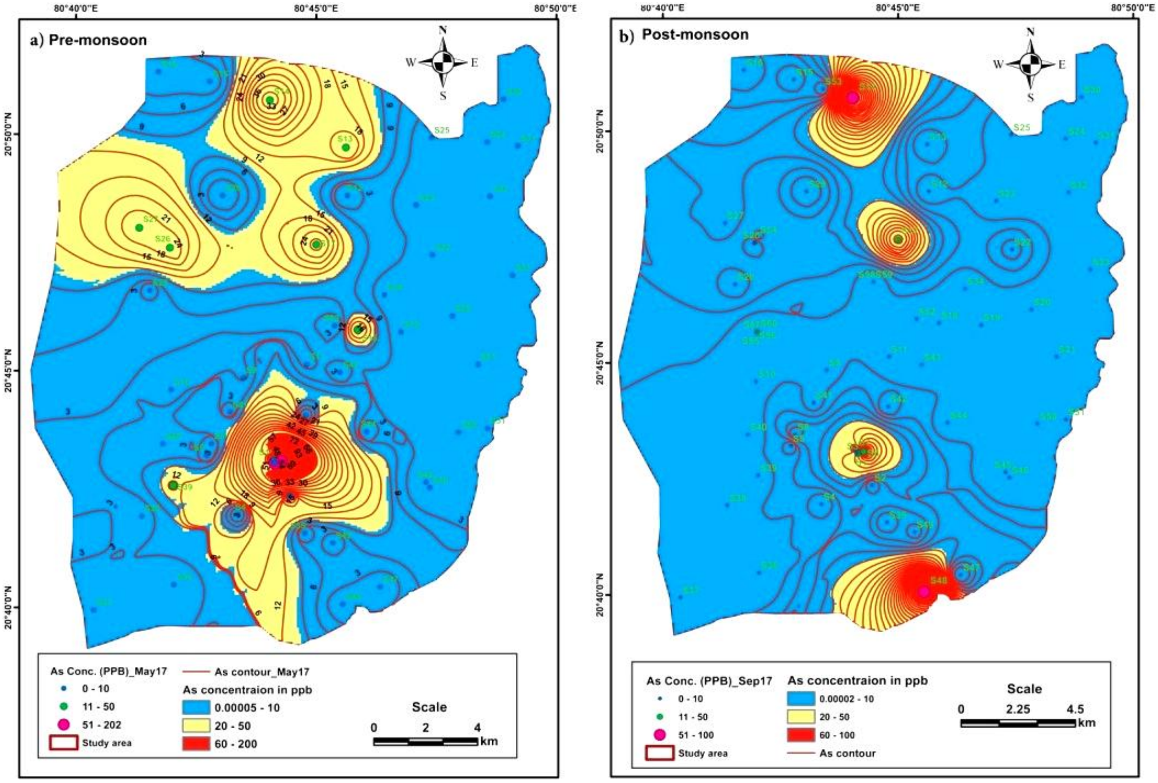

Fig. 20: Spatial distribution of arsenic concentration in the study area for different seasons (a) Pre-monsoon (May, 2017) (b) Post-monsoon (September, 2017)

4.2 Impact of Arsenic on Health

4.2.1 Arsenic: Human health risk assessment

Arsenic has been documented as a human poison for a long time. It may enter into the human body through the food chain, dermal contact, and inhalation (Shahab et al. 2019). However, oral intake of arsenic has proved to be deadly on many occasions. The magnitude and duration of human exposure to any toxic metal are typically reported as an average daily dose (USEPA 2014) as expressed in the Eq. (1):

$$ADD = (C \times IR \times EF \times ED) / (BW \times AT) \qquad (1)$$

where C is the As concentration in the groundwater (mg/L), IR is the daily water intake rate (L/day), EF is the exposure frequency (365 days/year), ED is the duration of exposure in years, BW is the body weight of exposed individuals (kg), and AT is the average time (in days) (Table 13).

Non-carcinogenic health risk due to excess arsenic exposure through drinking water is calculated as a HQ. HQ is defined as the ratio of the potential exposure to a level at which no adverse effects are expected. It is mathematically expressed as follows:

$$HQ = ADD / RfD \qquad (2)$$

In this equation, RfD signifies the reference oral dosage for arsenic (0.3 µg/kg/day) (USEPA, 2012). A non-carcinogenic effect is considered to be possible if the HQ is calculated to be greater than 1. If the calculated HQ is 1, then no hostile health effects are predictable as a result of exposure (Wagh et al. 2019b; Kadam et al. 2020).

Similarly, prolonged exposure of any contaminant like that of excess arsenic in drinking water to the human body leads to grievous effects on human health and sometime it may develop cancer over a lifetime. Hence, the following equation (USEPA, 2012) was employed to calculate CR in the study area:

$$CR = ADD \times CSF \ (3)$$

In the above equation, CSF is arsenic cancer slope factor (1.5 mg/kg/day) (USEPA 2012). CR values $\leq 1 \text{ x}10^{-6}$ is tolerable risk levels.

Furthermore, the various software, namely ArcGIS 10.3 for the preparation of spatial distribution maps, Aqua Chem 2010.1v for the Expanded Durov diagram and Schoeller plots and Grapher 15 version for the Boxplots were used.

Table 13: Standards used in computing the human health risk assessment of arsenic through drinking water

Parameters	Male	Female	Children	References
IR (L/day	**2.5**	**2.5**	**0.78**	**USEPA [2014]**
ED (Years)	**64**	**67**	**12**	**Narsimha and Rajitha [2018]**
EF (days/year	**356**	**365**	**365**	**USEPA [2014]**
BW (kg)	**65**	**55**	**15**	**ICMR [2009]**
AT(ED X EF) (days)	**23,360**	**24,455**	**4380**	**USEPA [2014] Present study**

- **Excess arsenic exposure and arsenic toxicity manifestation by inhabitants**
- **Non- carcinogenic health risk (HQ)**

As discussed above, arsenic concentration in groundwater is found to be higher than the permissible limit of 50 ppb (BIS, 2012) and consequently with regard to the non-CR (HQ) and CR of this arsenic exposure to humans in three categories (Children, adult-male and adult-female) has been studied (Table 18 and Supplementary Table 18 Continued.). The results disclosed that among the population non-CR exceeding the target value of 1, were almost same in the samples of both season [pre-monsoon: children (21.015%) > female (19.23%) > male (17.31%) and post-monsoon: children (20%) > female (20%) > male (13.33%)] for all the age groups (18). It is apparent from the box plot (Fig. 21) that pre-monsoon with the elevated HQ values (max: 35) than the post-monsoon (max: 10) suggests that non-CR is comparatively pre-dominant during pre-monsoon upon consumption of groundwater from the locations with HQ value more than unitary (Gayen et al, 2020). Non-CR of arsenic exposure was more in the children consumers in both seasons, in comparison to the male and female population. Higher risk for child population may be owed to their lower body weight (Kumar et al. 2019). Moreover, a thematic map prepared to epitomize the spatial-temporal distribution of Non-carcinogenic health risk (HQ) for children group of the study area and which reveals that the HQ values are following the spatial distribution trend similar to that of arsenic distribution. The HQ values are higher in the southern and north-western part of the study area during both the seasons, however, the intensity is low during the post-monsoon season, so consumers would be at considerable risk from these parts of the study area.

Additionally, the CR is computed to identify the probability of cancer risk in the populace of the study area upon exposer to the excess arsenic in groundwater. The results are provided in Table 15 and Fig. 21 respectively. The recommended standards of maximum allowed CR probability standard is 10^{-5}, while 10^{-6} (mg/kg/day) is the minimum threshold limit used to compare the obtained results. Where, CR probability standard indicates one in million will have probability of CR due to excess arsenic consumption. The outcome of this study reveals that a number of samples surpassing the minimum threshold value of 1×10^{-6} for CR was more in the samples collected in the month of May 2017 than compared to the samples collected in the month of September 2017, for all age groups.

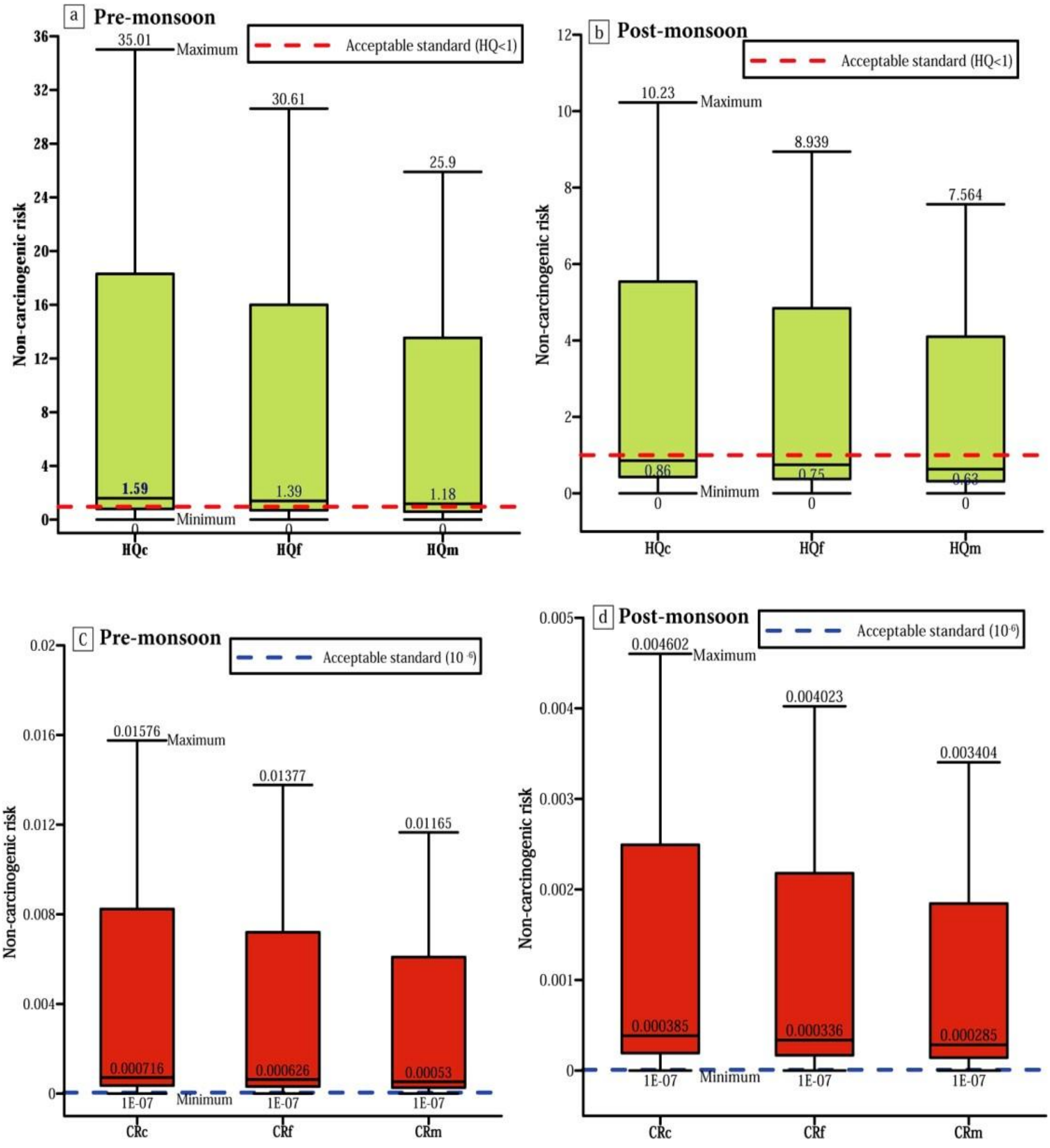

Fig. 21: Boxplots showing the result of non-carcinogenic risk (top) and cancer risk probability (bottom) for arsenic in pre-monsoon and post-monsoon

4.2.2 Arsenic toxicity manifestation by inhabitants

In general, the commonly reported symptoms of chronic arsenic exposures are melanosis (hyperpigmentation, depigmentation etc.), keratosis, Gangrene, peripheral vascular disorder, skin cancer and a number of internal cancers (Das et al. 2009; Wu et al. 2019). The most commonly manifested disease is skin lesions. Melanosis and keratosis are considered as the first and second stages of arsenicosis, which may turn into skin cancer if arsenic ingestion continues (Bulka et al. 2016). However, no relationship between arsenicosis and the average arsenic content of drinking water was found. The regional variation in the prevalence of arsenicos is is prominent. In view of this, a field survey was conducted in arsenic affected villages of Kaudikasa (S6) and Sansaitola (S26) and persons with arsenic toxicity manifestation are identified in two different categories:

Category I: The inhabitants exposed to a mid-dosage of arsenic contaminated water for lesser time witnessed by the first stage of arsenicosis/Melanosis: i.e., Leucomelanosis on the abdomen, chest and legs, spotted melanosis diffuse melanosis in the area (Fig. 22 a–c).

Category II: It explains the consumption of excessive arsenic content water for the prolonged duration triggers to the second stage of arsenicosis / keratosis: i.e., diffused and nodular keratosis on the palm (palmoplantar keratosis), and spotted keratosis on the soles and suspected bowens (Fig. 22 d – f).

Spatial-temporal distribution of non-carcinogenic Health risk (HQ) and Carcinogenic risk (CR) for children category along with arsenic concentration in groundwater for different seasons (Fig. 23).

Fig. 22: Field photographs collected from arsenic affected villages [i.e., Kaudikasa (Lat: 20.7183N Long: 80.7378E) and Sansaitola (Lat: 20.7933N Long: 80.6992E)] of the study area depicts cases of (a) leucomelanosis on abdomen (a1) chest (a2) and legs, (a3), (b) spotted melanosis, (c) diffuse melanosis, (d) diffused and nodular keratosis on palm (palmoplanter keratosis), (e) spotted keratosis on sole, and keratosis on the soles and suspected bowens

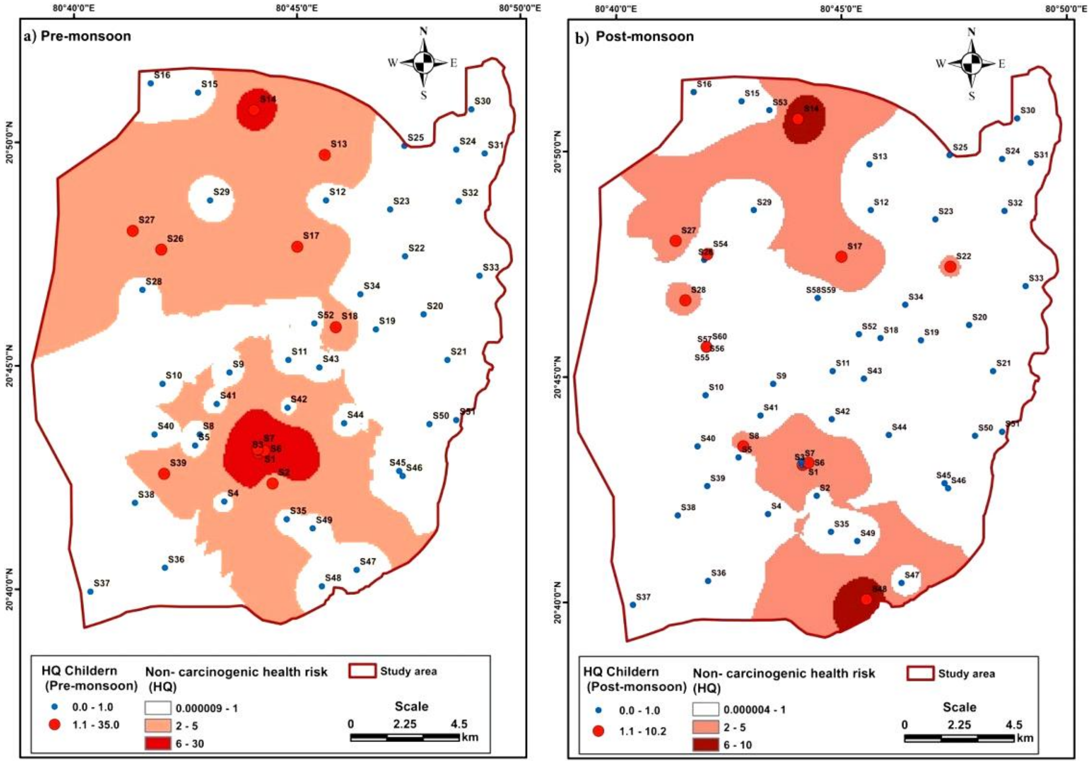

Fig.23: Spatial-temporal distribution of non-carcinogenic Health risk (HQ) and Carcinogenic risk (CR) for children category along with arsenic concentration in groundwater for different seasons

4.2.3 Geologic connection of arsenic contamination in groundwater and plausible mitigation strategies

The sources for the high arsenic content in the groundwater of the study area has been established to be the geogenic origin and is related to Kotri- Dongargarh rift zone (Acharyya et al. 2005). All over the rift zone, *in situ* soil, weathered rocks and fresh rocks are found locally enriched with arsenic (Patel et al., 2017). In the present study area, the Dongargarh granite batholith is emplaced into or formed comagmatically with rhyolite sequence (Fig. 3). The rhyolites are the prominent rock types in the study area and occur in several types, and metamorphosed to varying degrees. Both these are set in a pinkish-brown aphanitic matrix. Geochemically, these rhyolites are potassium-rich per-aluminous type and chemically comparable to Dongargarh granite (Deshpande et al. 2010). The intrusion of rhyolitic- granitic magma is followed by the hydrothermal phase, which is responsible for arsenic enriched sulfide mineralization and arsenic enrichment in bed rock.

Reductive dissolution of arsenic containing Fe-oxides lying in the aquifer matrix may be held responsible for the liberation of arsenic (Harvey et al. 2002; Postma et al. 2012) As a result of reduction of Fe oxyhydroxides generally arsenic gets mobilized but there is a possibility of *in situ* reoxidation of pyrite in the presence of oxygen inrush. Oxidized Fe and S may get reduced liberating arsenic in solution. According to Bhattacharya et al. (2011), water level fluctuations during pre and post precipitation delivers interchanging oxidation of sulfides and reduction of Fe oxyhydrides in soil pores. This further result in residual arsenic and S in the solution of the shallow aquifer. As gets dissociated into aquifer solution according to the following equation:

$$2\ FeAsS_{(S)} \rightarrow 2Fe^{2+}(aq) + As_2{}^{2-}{}_{(aq)} + S_2{}^{2-}{}_{(aq)} \qquad (6)$$

The most common forms of arsenic in natural waters are arsenite (As^{3+}) and arsenate (As^{5+}). In oxy-environments the principal ion is arsenate. In mildly anoxic conditions of well water, arsenite predominates. The redox reaction in a system comprising arsenite ($As^{3+)}$ and arsenate (As^{5+}) is shown in Eq. (7).

$$H_3AsO_4 + 2H^+ + 2e^- \rightarrow H_3AsO_3 + H_2O\ E0 = +0{:}56\ V \qquad (7)$$

Chapter 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion with possible remedial measures

The present study conducted on arsenic contamination in groundwater in the consolidated formations reveals that the high arsenic is available within both the phreatic aquifer and underlain fractured aquifer system. Bijli Rhyolite and Dongargarh granite are the host geological formations contributing arsenic in the groundwater through rock-water interactions in a recurring manner, which is geogenic in origin and sporadic in nature. Dongargarh-Kotri lineament is performing as a controlling factor of the phenomenon.

In principle, the geology of the study area when compared with the arsenic level in groundwater reveals that the most severely affected villages namely Kaudikasa (S1 and S6), and Taramtola (S48) in the southern part and Joratarai (S14) in the north- western part are situated on rhyolite and granite rocks close to shear zone (Fig.3). The relatively younger metabasic, basic and pyroclastic aquifers are less contaminated. This is an important finding since 28% of the area is covered with basic rock closely associated as anastomosing network with rhyolite, the dominant rock type of the area.

This study has highlighted the occurrence and extent of arsenic in groundwater in Ambagarh Chowki Blok, Rajnandgaon district, Chhattisgarh including the health impact of arsenic in groundwater on local people. Total 52 and 60 water samples have been collected during pre-monsoon and post- monsoon periods, respectively, for analyzing the presence of arsenic in different water sources. The geographic distribution of high arsenic in groundwater is sporadic in occurrence. Of the 52 samples analyzed in May 2017, two samples have shown arsenic above 50 ppb, the BIS permissible limit for arsenic in drinking water. The highest values were 202 ppb in Kaudikasa dug well (near boy’s hostel) and 77.94 ppb in Kaudikasa hand pump. Seven locations have arsenic in range of 10 ppb and 49 ppb. Those locations are Telitola hand pump, Joratarai hand pump, Meregaon bore well, Pangri hand pump, Sansaitola hand pump, Kodutola and Bharritola hand pump. If the WHO guideline value for arsenic i.e. 10 ppb is considered, 09 samples fall above WHO guideline value and 43 samples below 10 ppb.

Of the 60 samples analyzed in September 2017; two samples have shown arsenic above 50 ppb. They are Taramtola hand pump showing 59 ppb and Joratarai hand pump showing 53.4 ppb. Five locations have arsenic in range of 10 ppb and 49 ppb. Those locations are Kaudikasa dug well and hand pump, Meregaon bore well, Sansaitola hand pump (inside primary school) and Sansaitola hand pump (adjacent to arsenic removal plant). There are 53 samples in which arsenic value were found below 10 ppb.

Based on chemical analysis of water samples, it is observed that most of the hand pumps are showing arsenic content during pre-monsoon period, which may be due to declining of water level in the hand pump during pre-monsoon period followed by release of arsenic from formation to groundwater. Moreover, it has been observed that the level of arsenic in groundwater is reduced during the post- monsoon period; reason may be due to dilution of arsenic in groundwater. But an anomaly from the general trend has been observed in some well locations, where concentrations of arsenic have exceeded the permissible limit during post- monsoon period. The anomaly may be due to the dissolution followed by mixing of arsenic from the top soil percolating down to the groundwater table. Arsenic in dug wells is generally less than the bore well; this may be due to better atmospheric oxidation in dug wells.

Groundwater quality and hydrochemical facies have been analyzed through plotting the percentages of chemical constituents in the modified Piper diagram. The groundwater facies is characterized by Ca-HCO_3 type covering 69% of the total groundwater samples and rest of the samples (31%) are Ca-Mg-Cl type. The ionic dominance pattern among cation is $Ca^{2+} > Na^{2+} > Mg^{2+} > K^{+}$ and among anions the ionic dominance pattern is $HCO_3^{-} > Cl^{-} > SO_4^{2-}$.

The groundwater of the study area is characterized by $Ca^{2+}–Mg^{2+}–Na^{+}–SO_4^{2–}$ facies (i.e., mixing of two or more groundwater facies), whereas, the rest of the samples belonging to $Na^{+}–HCO_3^{–}$ facies. The BEI >1 and MGI >1 criteria indicate that the water is of $Na^{+}–SO4^{2–}$ facies and deeper meteoric percolation type at most of the locations. In terms of groundwater quality, excess arsenic content (>10ppb) is posing deleterious effects on consumers and the same is corroborated with HQ values >1 and CR values $>1.00x10^{–6}$ at various locations mostly from the southern and northwestern part of the study area during both the seasons. The health survey conducted in arsenic affected villages portrays arsenic toxicity in terms of leucomelanosis, spotted melanosis, diffuse melanosis, palmoplantar keratosis, spotted keratosis on the sole, and suspected Bowens due to consumption of excessive arsenic content water for the prolonged duration.

The scientific community dealing with arsenic toxicity in groundwater would be immensely benefited as this is a typical research on arsenic carried out in the hard rock terrain. Generally, high arsenic in groundwater is traced in the alluvial formation, but the occurrence of high arsenic in the consolidated formations is an almost rare. Hence, the research can be extrapolated to similar terrain conditions. The outcome of this research would definitely help the local inhabitants to have arsenic free water for drinking. The essence of research output would help the policymakers/planners to adopt short term solutions in the form of finding alternative arsenic free sources and rain water harvesting in a site-specific manner. Long term efficient solutions would be adopted through the implementation of the arsenic free surface water supply from the perennial sources to ensure sustainability even in the lean months. Therefore, this study suggests to appoint an *ad hoc* committee to implement mitigation strategies based on ground truth conditions to mitigate the arsenic toxicity and ensure safe drinking water supply.

5.2 Recommendations

The following are some of reasonable mitigation strategies that may contribute toward providing safe and alternative drinking and irrigation water:

i) Well switching is a popular and effective mitigation option in arsenic affected regions of the world. Replacement well should be drilled in the arsenic-free zone and supply of arsenic-free water should be ensured to arsenic affected inhabitants, besides the construction of rainwater harvesting ponds may be a suitable alternative in the study area.

ii) Testing of each water well should be conducted and arsenic affected wells should be pointed out and provided with community Arsenic removal plants.

iii) The provisional and alternative drinking water source should be provided to the affected people such as supplying of arsenic-free drinking water from the adjacent Seonath River.

iv) To ensure a supply of safe drinking water, arsenic contaminated groundwater can also be blended with arsenic-free surface water of the flowing Seonath River.

v) The results from this and similar studies can further contribute to developing a pragmatic management and mitigation policy options with a holistic approach for the future strategies of alternative of groundwater resources for drinking water supplies, where the sustainability of fresh surface water resources with treatment components remains a strong concern.

vi) Sensitization to rural people residing in the arsenic affected areas and regular health survey would be the appreciable proposition for combating the arsenic menace.

vii) Provisional and alternative drinking water source should be provided for the people, such as piped water supply with ground water and community arsenic removal plant. The PHED is already providing arsenic free drinking water in areas of Kaudikasa. It needs to be extended to more areas. Arsenic removal plant has been installed at Sansaitola village (Fig. 24) to provide arsenic free drinking water to the villagers.

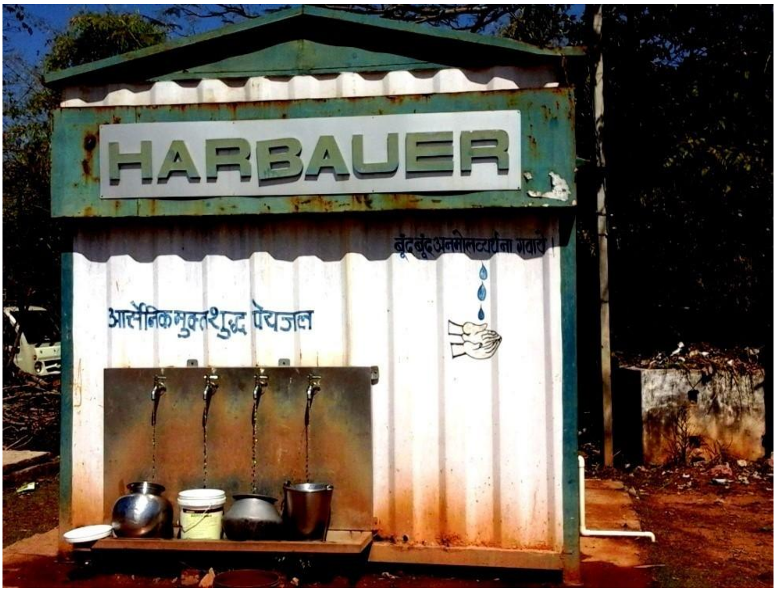

Fig. 24: Arsenic removal plant at Sansaitola village

viii) Construction of rain water harvesting systems should be done.

ix) Domestic Arsenic filters should be provided.

x) Production of materials for large scale Mass Awareness and training regarding effect of high arsenic groundwater and remedial measures is needed. Inventory of trained personals in the area has to be done. Massive awareness campaign throughout the year has to be conducted. The people in the area are in general poor in economic status and largely illiterate.

xi) Closing down of contaminated groundwater sources. For warning to the villagers, public notice board (Fig. 25) has been installed adjacent to the Dug well near boys' hostel at Kaudikasa not to drink that dug well water as that is arsenic contaminated.

Fig. 25: Warning showing the water is not suitable for drinking in dug well near boys' hostel at Kaudikasa

xii) Tapping of deeper arsenic free aquifers.

xiii) Field Arsenic testing facility should be provided at least at Panchayat level and lab testing facility at Block and District level.

xiv) Development of appropriate measures for supply of arsenic-free water.

xv) Watershed management and encouragement of people to use more surface water: Use of traditional surface water source or river water as drinking water is not possible until massive efforts are done with huge expenditure. However, recently installed Mogra dam, medium irrigation project with large canal network can be used for this purpose with suitable traditional treatment plant (Fig.26).

xvi) Development of appropriate measures for supply of arsenic free water through arsenic removal plant is shown in fig. 27.

Fig. 26: Mogra Dam and Irrigation Canal

Fig. 27: Arsenic Removal Plant at Ambagarh Chowki

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Annexure - 1

Table 14: Seasonal fluctuation of water level (in m bgl) for monitoring key wells

SN	Name	May, 2017	September 2017	December 2017	February 2018	Seasonal Fluctuation
1	Kaudikasa H.P.	3.9	2.8	3.56	3	0.34
2	Murerthitola H.P.	14.3	8.3	9.63	9.25	4.67
3	Bhagwantola Pry. School H.P.	5.75	3.35	3.38	5.12	2.37
4	Arajkund H.P.	7.75	8.3	3.98	3.8	3.77
5	Nichekohra H.P	6.2	5.9	6.54	10.4	0.34
6	Gaulitola H.P.	10.7	4.45	9.05	3.49	1.65
7	Parsatola H.P.	4.65	3.3	3.45	4.09	1.2
8	Sanghli H.P.	6.5	4.6	4.6	5.1	1.9
9	Telitola H.P.	12.5	3.5	3.65	5.2	8.85
10	Joratarai H.P.	14.35	10.2	12.46	11.25	1.89
11	Jadutola H.P.	17	5.42	14.95	23.15	2.05
12	Manjhitola H.P	9.88	2.6	3.2	4.1	6.68
13	Pangri H.P.	11.48	7.2	4.62	7.35	6.86
14	Kesritola H.P.	7.68	3.78	5.51	6.47	2.17
15	Atargoan H.P.	12.6	6.1	11.08	7.25	1.52
16	Mohar H.P.	5.38	1.85	2.52	3.3	2.86
17	Hitaguta H.P.	10.8	6.15	9.25	6.95	1.55
18	Wararmundi H.P.	25.9	7.6	4.72	7.35	21.18
19	Sansaitola H.P.	11.1	8	7.88	6.83	3.22
20	Kodutola H.P.	7.1	4.3	5.81	6.65	1.29
21	Bharsena H.P.	5	3.15	3.76	4.88	1.24
22	Bhirritola H.P	9.92	5.9	7.8	9.82	2.12
23	Dautola H.P.	21.9	10.3	9.38	14.15	12.52
24	Atra H.P.	23.1	4.9	13.8	18.75	9.3
25	Boharanbheri H.P	1.5	1.7	1.72	2.4	0.22
26	Mahudmachandr H.P	6.55	4.6	5.7	6.5	0.85
27	Dewarsur H.P.	6.8	2.5	4.4	5.65	2.4
28	Dewarvi H.P.	8.9	7.45	7.7	8.6	1.2
29	Tumrikasa H.P	11.8	5.1	8.76	7.15	3.04
30	Bharritola H.P.	6.9	11.65	7.8	9.6	0.9
31	Kunderatola H.P	7.65	2.5	3.8	5.38	3.85
32	Pandritarai H.P.	23.1	19.35	10.8	12.95	12.3
33	Bagnara H.P.	14.5	7.5	5.21	8.04	9.29
34	Adhejhar H.P.	8.4	1.2	1.52	2.33	6.88
35	Karamtara H.P.	11	6.1	6.6	9.28	4.4

SN	Name	May, 2017	September 2017	December 2017	February 2018	Seasonal Fluctuation
36	Hitkasa H.P.	9.45	3.8	4.65	6.88	4.8
37	Taramtola H.P.	9.35	3.82	5.3	6.58	4.05
38	Mungesitola H.P.	15.8	10.9	12.18	12.55	3.62
39	Butakasa H.P.	9.35	5.45	5	7.95	4.35
40	Donghaghat H.P.	7.2	3.75	4.3	4.45	2.9

Table 15: Depth to water level (in m bgl) for dug wells

Sl. No.	Location of Dug Wells	May 2017	September 2017	December 2017	February 2018	Seasonal Fluctuation
1	Bhagwantola	1.80	1.00	1.36	1.21	0.44
2	Kaudikasa Boy's Hostel	2.50	1.30	1.48	1.45	0.62
3	Kaudikasa Girls' Hostel	2.85	0.60	0.96	0.72	1.89
4	Bihari Kala	4.00	0.30	1.00	1.7	3.00
5	Tetwarilanjiya (Diprapara)	2.50	1.30	1.14	1.05	1.36
6	Bhansula	8.00	0.50	2.76	4.46	5.24
7	Netamtola	6.60	2.45	3.28	4.8	3.32
8	Ghorda	6.65	1.80	3.85	5.8	2.80
9	Goplinchua	9.10	3.50	5.00	6.24	4.10

Table 16: Depth of the sampling locations with co-ordinate of the study area

Sl.No.	Code	water sampling locations	Latitude	Longitude	Depth	Well Type
1.	S1	Kaudikasa H.P. (Hand Pump)	20.71750	80.73560	60	Hand Pump
2.	S2	Murerthitola H.P.	20.70610	80.74080	50	Hand Pump
3.	S3	Bhagwantola Primary School H.P., Near Pond	20.71750	80.73550	55	Hand Pump
4.	S4	Bhagwantola Peepal Chowk D.W. (Dug Well)	20.69940	80.72280	10	Dug Well
5.	S5	Arajkund H.P.	20.72030	80.71190	60	Hand Pump
6.	S6	Kaudikasa Boy's Hostel D.W.	20.71830	80.73780	8.8	Dug Well
7.	S7	Kaudikasa Girls' Hostel D.W.	20.71890	80.73520	8.6	Dug Well
8.	S8	Nichekohra H.P.	20.72440	80.71360	100	Hand Pump
9.	S9	Gaulitola H.P.	20.74750	80.72470	60	Hand Pump

10.	S10	Parsatola H.P.	20.74330	80.69970	50	Hand Pump
11.	S11	Bihari Kala H.P.	20.75220	80.74670	55	Hand Pump
12.	S12	Sanghli H.P.	20.81170	80.76080	45	Hand Pump
13.	S13	Telitola H.P.	20.82860	80.76030	55	Hand Pump
14.	S14	Joratarai H.P.	20.84530	80.73390	60	Hand Pump
15.	S15	Jadutola H.P.	20.85190	80.71300	55	Hand Pump
16.	S16	Manjhitola H.P.	20.85530	80.69530	55	Hand Pump
17.	S17	Meregaoan PHED office Bore Well	20.79440	80.75000	60	Hand Pump
18.	S18	Pangri H.P.	20.76440	80.76440	77	Hand Pump
19.	S19	Kesritola H.P.	20.76360	80.77940	60	Hand Pump
20.	S20	Atargoan H.P.	20.76920	80.79720	60	Hand Pump
21.	S21	Mohar H.P.	20.75220	80.80610	50	Hand Pump
22.	S22	Tetwarilanjiya (Diprapara) D.W.	20.79080	80.79030	9.2	Dug Well
23.	S23	Hitaguta H.P.	20.80830	80.78470	60	Hand Pump
24.	S24	Wararmundi H.P.	20.83060	80.80940	50	Hand Pump
25.	S25	Seonath River Sample (Thudabdri)	20.83200	80.79000		Surface Water
26.	S26	Sansaitola H.P.	20.79330	80.69920	55	Hand Pump
27.	S27	Kodutola	20.80030	80.68860	55	Hand Pump
28.	S28	Bharsena H.P.	20.77830	80.69220	50	Hand Pump
29.	S29	Bhirritola H.P.	20.81170	80.71750	55	Hand Pump
30.	S30	Dautola	20.84560	80.81500	45	Hand Pump
31.	S31	Atra H.P.	20.82920	80.82000	67	Hand Pump
32.	S32	Boharanbheri H.P	20.81140	80.81030	50	Hand Pump
33.	S33	Mahudmachandur H.P.	20.78360	80.81810	55	Hand Pump
34.	S34	Bhansula D.W.	20.77670	80.77360	10	Dug Well
35.	S35	Dewarsur H.P.	20.69280	80.74610	60	Hand Pump
36.	S36	Netamtola D.W	20.67470	80.70060	8.9	Dug Well
37.	S37	Dewarvi H.P	20.66580	80.67280	60	Hand Pump
38.	S38	Tumrikasa H.P.	20.69890	80.68940	50	Hand Pump
39.	S39	Bharritola H.P.	20.70970	80.70030	55	Hand Pump
40.	S40	Kunderatola H.P.	20.72440	80.69670	70	Hand Pump
41.	S41	Ghorda D.W.	20.73580	80.72000	10	Dug Well
42.	S42	Pandritarai H.P.	20.73440	80.74640	45	Hand Pump
43.	S43	Bagnara H.P.	20.74940	80.75830	50	Hand Pump
44.	S44	Goplinchua D.W.	20.72860	80.76750	10	Dug Well
45.	S45	Adhejhar H.P.	20.71080	80.78810	55	Hand Pump
46.	S46	Karamtara H.P.	20.70890	80.78940	45	Hand Pump
47.	S47	Hitkasa H.P.	20.67390	80.77220	50	Hand Pump
48.	S48	Taramtola H.P.	20.66780	80.75920	45	Hand Pump
49.	S49	Mungesitola H.P.	20.68940	80.75580	60	Hand Pump
50.	S50	Butakasa H.P.	20.72830	80.79940	55	Hand Pump
51.	S51	Dangarh Nala	20.72980	80.80940		Surface Water
52.	S52	Donghaghat H.P.	20.76580	80.75640	45	Hand Pump
53.	S53	Thalitola Irrigation Bore Well	20.84860	80.72330	50	Hand Pump
54.	S54	Sansaitola D.W. Behind A.R Plant	20.79530	80.70030	9	Dug Well
55.	S55	Sansaitola H. P. inside pry. School	20.76110	80.70000	43	Hand Pump

56.	S56	Mogra Ram chatta chowk H.P.	20.76110	80.70000	60	Hand Pump
57.	S57	Mogra Dam Water Sample	20.76110	80.70000		Surface Water
58.	S58	Ambagarh Chowki Arsenic Removal Plant (250 ml)	20.77920	80.74120		Surface Water
59.	S59	Ambagarh Chowki Arsenic Removal Plant(1 litre)	20.77920	80.74120		Surface Water
60.	S60	Sansaitola A.R.P. Adjacent H.P.	20.76110	80.70000	52	Hand Pump

Table 17: Arsenic contamination levels in groundwater

Sl. No.	Name of the water sampling locations	As (in ppb) May 2017	As (in ppb) September 2017
1	Kaudikasa H.P. (Hand Pump)	77.94	30.45
2	Murerthitola H.P.	5.815	2.54
3	Bhagwantola Primary School H.P., Near Pond	2.121	0
4	Bhagwantola Peepal Chowk D.W. (Dug Well)	0	0
5	Arajkund H.P.	0	0
6	Kaudikasa Boy's Hostel D.W.	202	34.95
7	Kaudikasa Girls' Hostel D.W.	7.583	0.834
8	Nichekohra H.P.	0	10
9	Gaulitola H.P.	0	0
10	Parsatola H.P.	0	0
11	Bihari Kala H.P.	0	0
12	Sanghli H.P.	0	0
13	Telitola H.P.	20.66	0
14	Joratarai H.P.	37.63	53.4
15	Jadutola H.P.	0.158	0
16	Manjhitola H.P.	0	0.059
17	Meregaoan PHED office Bore Well	24.91	26.89
18	Pangri H.P.	19.25	0
19	Kesritola H.P.	0.865	1.455
20	Atargoan H.P.	0.512	0
21	Mohar H.P.	0	0
22	Tetwarilanjiya (Diprapara) D.W.	2.987	6.882
23	Hitaguta H.P.	0	0
24	Wararmundi H.P.	0	0
25	Seonath River Sample (Thudabdri)	0.865	0
26	Sansaitola H.P.	24.2	1.61
27	Kodutola	23.85	7.34
28	Bharsena H.P.	1.926	7.34
29	Bhirritola H.P.	0	0

30	Dautola	1.956	0.99
31	Atra H.P.	0	0
32	Boharanbheri H.P	0	0
33	Mahudmachandur H.P.	0.865	0
34	Bhansula D.W.	0	0
35	Dewarsur H.P.	0	0
36	Netamtola D.W	0	0
37	Dewarvi H.P	0	0
38	Tumrikasa H.P.	0	0
39	Bharritola H.P.	12.53	0.059
40	Kunderatola H.P.	4.754	0
41	Ghorda D.W.	0	0
42	Pandritarai H.P.	0	0
43	Bagnara H.P.	0	0
44	Goplinchua D.W.	0	0
45	Adhejhar H.P.	0	0
46	Karamtara H.P.	0	0
47	Hitkasa H.P.	0	0
48	Taramtola H.P.	0	59
49	Mungesitola H.P.	0	0.99
50	Butakasa H.P.	1.572	0
51	Dangarh Nala	2.633	0
52	Donghaghat H.P.	0	0
53	Thalitola Irrigation Bore Well	-	0
54	Sansaitola D.W. Behind A.R Plant	-	7.192
55	Sansaitola H. P. inside pry. School	-	15.72
56	Mogra Ram chatta chowk H.P.	-	0
57	Mogra Dam Water Sample	-	0
58	Ambagarh Chowki Arsenic Removal Plant	-	0
59	Ambagarh Chowki Arsenic Removal Plant (1 litre)	-	0
60	Sansaitola A.R.P. Adjacent H.P.	-	28.3

Table 18: Results of the non-carcinogenic health index (HQ) and cancer risk (CR) probability in ground and surface water of the study area

	Pre-monsoon (*N* ¼ 52)								Post-monsoon (*N* ¼ 60)						
	Non- carcinogenic				carcinogenic				Non- carcinogenic				Carcinogenic		
Sample code	HQc	HQf	HQm		CRc	CRf	CRm		HQc	HQf	HQm		CRc	CRf	CRm
S1	13.51	11.81	9.99		0.006079320	0.005314091	0.004496538		5.28	4.61	3.90		0.0023751	0.0020761	0.0017567
S2	1.01	0.88	0.75		0.000453570	0.000396477	0.000335481		0.44	0.38	0.33		0.0001981	0.0001732	0.0001465
S3	0.37	0.32	0.27		0.000165360	0.000144545	0.000122308		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S4	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S5	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S6	35.01	30.61	25.90		0.015756000	0.013772727	0.011653846		6.06	5.30	4.48		0.0027261	0.0023830	0.0020163
S7	1.31	1.15	0.97		0.000591474	0.000517023	0.000437481		0.14	0.13	0.11		0.0000651	0.0000569	0.0000481
S8	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		1.73	1.52	1.28		0.0007800	0.0006818	0.0005769
S9	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S10	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S11	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S12	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S13	3.58	3.13	2.65		0.001611480	0.001408636	0.001191923		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S14	6.52	5.70	4.82		0.002935140	0.002565682	0.002170962		9.26	8.09	6.85		0.0041652	0.0036409	0.0030808
S15	0.03	0.02	0.02		0.000012324	0.000010773	0.000009115		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S16	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.01	0.01	0.01		0.0000046	0.0000040	0.0000034
S17	4.32	3.77	3.19		0.001942980	0.001698409	0.001437115		4.66	4.07	3.45		0.0020974	0.0018334	0.0015513
S18	3.34	2.92	2.47		0.001501500	0.001312500	0.001110577		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S19	0.15	0.13	0.11		0.000067470	0.000058977	0.000049904		0.25	0.22	0.19		0.0001135	0.0000992	0.0000839
S20	0.09	0.08	0.07		0.000039936	0.000034909	0.000029538		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S21	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S22	0.52	0.45	0.38		0.000232986	0.000203659	0.000172327		1.19	1.04	0.88		0.0005368	0.0004692	0.0003970
S23	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S24	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S25	0.15	0.13	0.11		0.000067470	0.000058977	0.000049904		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S26	4.19	3.67	3.10		0.001887600	0.001650000	0.001396154		0.28	0.24	0.21		0.0001256	0.0001098	0.0000929
S27	4.13	3.61	3.06		0.001860300	0.001626136	0.001375962		1.27	1.11	0.94		0.0005725	0.0005005	0.0004235
S28	0.33	0.29	0.25		0.000150228	0.000131318	0.000111115		1.27	1.11	0.94		0.0005725	0.0005005	0.0004235
S29	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S30	0.34	0.30	0.25		0.000152568	0.000133364	0.000112846		0.17	0.15	0.13		0.0000772	0.0000675	0.0000571
S31	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S32	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S33	0.15	0.13	0.11		0.000067470	0.000058977	0.000049904		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S34	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
S35	0.00	0.00	0.00		0.000000100	0.000000100	0.000000100		0.00	0.00	0.00		0.0000001	0.0000001	0.0000001
															(*continued*)

Table 18 (Continued....)

	Pre-monsoon (*N* ¼ 52)						Post-monsoon (*N* ¼ 60)					
	Non- carcinogenic			carcinogenic			Non- carcinogenic			Carcinogenic		
Sample code	HQc	HQf	HQm	CRc	CRf	CRm	HQc	HQf	HQm	CRc	CRf	CRm
S36	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S37	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S38	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S39	2.17	1.90	1.61	0.000977340	0.000854318	0.000722885	0.01	0.01	0.01	0.0000046	0.0000040	0.0000034
S40	0.82	0.72	0.61	0.000370812	0.000324136	0.000274269	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S41	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S42	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S43	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S44	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S45	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S46	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S47	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S48	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	10.23	8.94	7.56	0.0046020	0.0040227	0.0034038

S50	0.27	0.24	0.20	0.000122616	0.000107182	0.000090692	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S51	0.46	0.40	0.34	0.000205374	0.000179523	0.000151904	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S52	0.00	0.00	0.00	0.000000100	0.000000100	0.000000100	0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S53							0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S54							1.25	1.09	0.92	0.0005610	0.0004904	0.0004149
S55							2.72	2.38	2.02	0.0012262	0.0010718	0.0009069
S56							0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S57							0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S58							0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S59							0.00	0.00	0.00	0.0000001	0.0000001	0.0000001
S60							4.91	4.29	3.63	0.0022074	0.0019295	0.0016327
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	35.01	30.61	25.90	0.02	0.01	0.01	10.23	8.94	7.56	0.00	0.00	0.00
Mean	1.59	1.39	1.18	0.00	0.00	0.00	0.86	0.75	0.63	0.00	0.00	0.00

Note: HQ (mg/kg/day) hazard quotient, CR (mg/kg/day) cancer risk (cancer risk probability): $10^{—5}$ is the maximum safe standard for cancer risk and $10^{—6}$ is the lowest safe limit for cancer risk.

Annexure - 2

WATER SAMPLING PROCEDURES

1.0 Introduction

Before sample collection begins, field personnel must take steps to ensure that the samples collected will be representative of the aqueous system being investigated. A representative sample is one that typifies (“represents”) in time and space that part of the aqueous system to be studied, and is delineated by the objectives and scope of the study. Obtaining representative samples is of primary importance for a relevant description of the environment. In order to collect a representative sample that will yield the information required - (1) Study objectives, including data-quality requirements, must be understood in the context of the water system to be sampled and (2) Artefacts of the sampling process must be minimized. Field personnel must be alert to conditions that could compromise the quality of a sample.

1.1 Collection of Representative Water Sample

Use appropriate methods and quality-assurance measures to ensure that the field sites selected and the samples collected accurately represent the environment intended for study and can fulfil data-quality objectives.

1.2 Contamination Perspectives

To ensure the integrity of the sample, be aware of possible sources of contamination. Contamination introduced during each phase of sample collection (and processing) is additive and usually is substantially greater than contamination introduced elsewhere in the sample-handling and analysis process. Therefore, collect a sufficient number of quality-control samples, appropriately distributed in time and space, to ensure that data-quality objectives and requirements are met. (U.S. Geological Survey TWRI Book 9 revised, 2006).

2.0 Objectives of water sampling

The main objectives of the water sample collection are following:

(a) To study the composition of groundwater in its natural state for quality assessment.
(b) Protection of aquifer against pollutions.
(c) To monitor the water quality and support the control of hazardous constituents.
(d) Assess the suitability of water for drinking and irrigation purposes.
(e) To observe the speed of groundwater movement for hydrogeological and geochemical mapping, temporal variation in groundwater regimes.
(f) For exploration of mineral water and geothermal water, and disposal of liquid and solid waste

2.1 Details of water sampling

For this R&D project, detailed hydrogeological field investigation conducted in combination with collection of 1 litre water samples for general chemical analysis (Cations and Anions) and acidified water samples for arsenic analysis. The water sampling (both surface water and groundwater) was carried out for four months like May, September, December during 2017 and in February during 2018. The chemical analysis of the collected water samples were analysed in the Chemical Laboratory of CGWB, North Central Chhattisgarh Region (NCCR), Raipur.

The objective of sampling is to collect a portion water sample which can be transported conveniently and handled in the laboratory. This objective implies that the relative proportions or concentration of all pertinent components will be the same in the sample as in the material being sampled, and the sample will be handled in such a way that no significant changes in composition occur before the tests are made. In many instances samples are presented to the laboratory for specific determinations with the responsibility of the sample collector for the validity of the sample. For the accuracy and representativeness of the sample data greater emphasis is placed on proper sample collection and preservation techniques.

2.2 Methods of water sample collection

In the final interpretation of water analysis data, it is of considerable importance to know the point of collection of water samples The I.D. of sampling station(point) has to be well defined supported with latitude and longitude, so that the data is well documented on map and prevailing geographical conditions are well known to the user of the data. Following are the point of collection:

2.2.1 Groundwater samples:

In the case of groundwater samples, the point of collection is also of importance whether the water sample is collected at the point where the water is brought out from the well or in the distribution system itself or by dipping the sample container in the well itself. Sample can be collected from the flowing artesian source or continuous pumping source with a siphon.

- ***Dug well samples:***

To collect samples from dug well a bucket and a rope is used. The plastic bucket used should be thoroughly cleaned and dropped in to the well. The sample bottle is rinsed three times with sample water, filled with sample and sealed. Purging of the well before sampling is essential to ensure that aquifer water is collected. Complete removal of stagnant water is however not possible because of accelerated in flow to the well resulting in mixing of aquifer and well water during purging.

- ***Pumped well sample:***

  The groundwater is normally collected in a sample bottle from a well head tap or discharge pipe. In cases where no such fittings exist, the sample is taken from nearest tap in water distribution system. If the sample collected from pumped well is analyzed for potable drinking water quality this is useful but if sample is analyzed for groundwater chemistry then it has limitations because samples get contaminated due to pumping plant by air and due to gases present in atmosphere.

2.2.2 Surface water samples:

If the water sample is collected near the point where the city waste water enters the stream the analytical data may be considerably misleading. In such cases water samples may be collected a few kilometers downstream preferably mid-stream so that sufficient mixing has occurred. Depth or breadth integrated samples are in such cases better guide to the composition of the stream water.

- **Rain water samples:**

  In case of rain water samples for examples the height from ground level at which the water sample is collected may have considerable influence on its contamination by atmospheric dust and as such on its composition.

- **Lake water samples:**

In lake waters the concentration of some constituents at the surface may be much different from that at depth particularly at the interface sediment water. Both natural and artificial lakes show variations of composition with both depth and horizontal location. However there are conditions under which neither total nor average results are especially useful, bit local variations are more important. In such cases samples are not integrated but examined separately.

2.2.3 Integrated samples:

For certain purposes the information needed is provided best by analysing mixtures of grab samples collected from different points simultaneously or as nearly so as possible. To evaluate average composition or total loading use a mixture of samples representing various points in the cross section, in proportion to their relative flows. For example sampling in a river or stream that varies in composition across its depth and width. A suitable integrated sample may provide more useful information.

2.2.4 Samples for bacteriological examination:

Samples for bacteriological examination are collected in glass bottles that have been carefully cleaned and auto cleaved for 20 minutes at 121^0C and 15 psi. Contamination of sample at the time of collection must be avoided. The bottle being kept un-opened until the moment water sample is to be collected. Ample air space must be left in the sample bottle to facilitate mixing of sample by shaking. To collect a surface sample from the stream or lake, open the sterile bottle, grasp it near its base and plunge it neck down wards below the surface, allow the bottle to fill by slightly turning the bottle until the neck points slightly upward and against the current.

3.0 Techniques of water sample collection

Sampling techniques cover the entire sampling planning - from the selection of sampling point to the delivery of sample for analysis in laboratory. Sampling techniques include general consideration such as purpose of sampling, sampling equipment, methods of sampling and sampling statistics.

- **Manual sampling:**

  Manual sampling involves minimal equipment. For routine or large scale sampling programs manual sampling may be unduly costly and time consuming. Manual sampling with glass container and in accordance with appropriate safety procedure may be best.

- **Automatic sampling:**

  Automatic sampling can eliminate human errors in manual sampling, can reduce labour costs, may provide means for frequent sampling, samples collected are not contaminated.

3.1 Quantity of water samples required

The quantity of water samples required in analysis depends upon the concentration of the constituents to be determined and on the analytical method applied. For the Arsenic analysis we have taken 250 ml Samples in polyethylene bottles. For basic analysis one litre water samples is have been collected.

3.2 Procedures for collection of water sample

i) In the case of water samples for Basic Analysis all polyethylene bottles thoroughly with dilute HCl, then rinse with tap water till free of acid and wash twice with distilled water. Rinse twice with the water sample to be collected and fill up the bottle with the sample leaving only a small air bubble. Close and seal the bottle immediately.

ii) For the Arsenic analysis we have taken 250 ml Samples in polyethylene bottles. The bottle was filled up to top by sample water, rinsed thoroughly by distilled water first and then by sample water. Two ml of ultra-pure HCL (1:1) was added for bringing the pH <3 and the cap was placed.

iii) While collecting water samples from a well not in use, it is desirable to let the pump run for some time before collection of water samples.

iv) Water samples containing turbidity, should preferably be filtered in the field itself, as the sediments may add some constituents to the water sample during transport and storage.

v) The following information should be supplied with each water sample:
(a) Location - Village, City, District.
(b) Source - Well, Stream, Lake, Springs
(c) Point of collection
(d) Date and Time of collection
(e) Depth of collection
(f) Water bearing formation (g)Appearance (h)Temperature

Collection of groundwater samples for Arsenic analysis

4.0 Water Samples Preservation

Samples collected from river, industrial and domestic waste water and groundwater cannot be completely preserved. Temperature changes quickly and pH may change significantly in a matter of minutes, dissolved gases may be lost. Iron and Manganese may be oxidized. Microbiological activity may change the nitrate - nitrite - ammonia system. In general shorter the time that elapses between collection of a samples and its analysis the more reliable will be analytical results. Some samples contain phase or component which cannot be determined quantitatively in each other presence. For example, determination of aluminium is influenced in presence of colloidal materials. Such water samples require separation immediately after collection. Separation procedures enable the isolation and concentration of the components to be studied prior to transfer for analysis.

It is impossible to state exactly how much elapsed time may be allowed between sample collection and analysis. Techniques which will be followed are given as under.

1. If turbidity is present in the sample should be filtered.
2. Add 2 ml. double distilled reagent grade HNO_3. Shape it for one minute to allow the escape of CO_2 and then stopper it tightly. This is preserved and may be used for determination of Na, K, Li, Ca, Mg, Sr, Ba, Al, As, Fe, Cd, Co, Cu, Pb, Mn, Mo, Ni, V and Zn.
3. **Nitrogen Ammonia NO_3:**
4. Refrigerate the water sample and add chloroform 5 ml per litre of water sample to inactivate the microorganisms. For Ammonia determination, collect a separate sample and treat as above but add also 2 ml of 1:3 H_2SO_4 to lower pH of the sample to minimize loss of Ammonia. Keep the bottles thoroughly sealed in a dark place.
5. **Sulphide:** Add 2 gm Zinc Acetate to water sample taking care not to aerate it.
6. **Phosphorous:** Add 5 ml. of Chloroform per litre of water sample to prevent micro biological conversion of organic phosphorous to orthophosphate.
7. **Dissolved Oxygen:** Clarify the sample collected in 500 ml bottle by displacing at least 2 times its volume and add 1 ml 10% alum solution and 1 to 2 ml concentrated NH_3 mix by inversion and allow the suspended matter to settle. Decant the supernatant into 300 ml BOD bottle and proceed as follows: Add 1 ml 25% KF solution, 2 ml. 32% $MnSO_4$ solution and 2 ml alkaline iodide - sodium azide reagent, stopper and mix by inversion. Allow the precipitate to settle and add 2 ml conc. H_2SO_4 In the absence of organic or oxidized material titration of released iodide may be postponed to 48 - 72 hrs.
8. **Oil and Waxes:** Collect the sample in a separate bottle and fix with 2 ml conc. HNO_3.
9. **Iron:** Add 10 ml 1% O-phenanthroline or bathophenanthroline solution & 1 ml glacial acetic acid.
10. **Chlorine:** Because of its instability residual chlorine should be determined immediately after the collection of the sample.
11. **Cyanide:** Add 5% NaOH solution to raise the pH of the water sample to 11 and store in a cool place.

4.1 Samples Preservation Techniques

1. To minimize the potential for volatilization or biodegradation between sampling and analysis keep samples as cool as possible without freezing. Preferably pack samples in crushed, avoid using dry ice because it will freeze samples & container may break.
2. Use Chemical - preservatives only when they are shown not to interfere with the analysis being made.
3. All methods of preservation may be inadequate when applied to suspended matter.
4. No single method of preservation is entirely satisfactory, choose the preservative with due regard to the determinations to be made.
5. Preservation methods are limited to pH control, chemical addition, the use of amber and opaque bottles refrigeration, filtration and freezing.

5.0 Storage of water samples

The sample collected must be transported to the concern laboratory with care and precautions. Any damage between collection of samples and storage may prove failure of whole analysis planning. It is very important that minimum time should be taken between collection and actual storage of sample. Although this recommendation cannot be followed because distance between sampling site and laboratories. The storage should be normally at 4^0-10^0C and recommended maximum time for different determinants may vary from 24 hrs to 6 months.

Annexure - 3

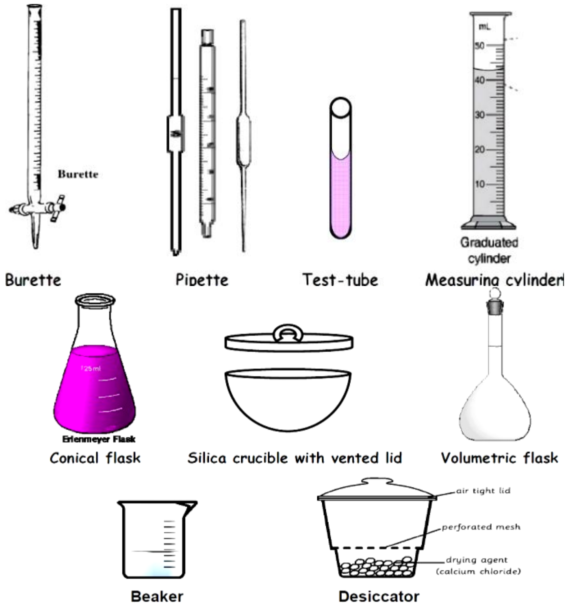
WATER SAMPLE ANALYSIS

1.0 Analytical experiments and instruments used

Analysis for concentration of arsenic has been carried for 52 samples for the month of May and 60 samples for the month of September using Atomic Absorption Spectrophotometer (AAS) and Basic Parameter analysis has also been carried out for 13 general samples for major chemical ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, SO_4^{2}, F^-), pH, electrical conductivity, and total hardness in Chemical Lab NCCR Raipur.

1.1 Analytical Experiments

Hydrogeochemical analysis was carried out by following American Public Health Association (APHA, 2012) water sample analysis methods. Brief description and procedures adopted and common laboratory glassware are as below.



Common laboratory glass

1.2 pH Apparatus

Portable pH meter operated by battery were used to find pH. Combined glass and reference electrode pH meter was also used to measure pH.

Procedure:

Essential aspects to use combined glass and reference electrode pH meter are to calibrate it with suitable buffer, whose values was near to the expected value pH 7 and pH 9 and pH 4.2). After the calibration pH of the samples were noted by dipping the electrode.

Portable pH meter

Digital Conductivity Meter

1.3 Conductivity and TDS

Most of the salts in the water are present in the ionic forms capable of conducting current, therefore conductivity is a good and rapid measure of the total dissolved solids (TDS). These are measured with the help of a digital conductivity meter by dipping the cell in the sample. The digital conductivity meter is shown as below.

1.4 Alkalinity

Alkalinity of water is its capacity to neutralize a strong acid and is characterized by the presence of all hydroxyl ions capable of combining with the hydrogen ion. Alkalinity in natural water is due to free hydroxyl ions and hydrolysis of salts formed by weak acids and strong base such carbonates and bi- carbonates.

Reagents:

1) 0.02N H_2SO_4: Dilute 6 ml of con. H_2SO_4 (35N) with distilled water under cooling and make up to one liter with more water in a volumetric flask. This stock gives 0.2N H_2SO_4. Dilute 100 ml of this 0.2N H_2SO_4 with 1000ml to get a 0.02N H_2SO_4 in a volumetric flask. Standardize this acid against a standard solution of sodium carbonate.

2) Sodium carbonate solution (0.02N): Dissolve 0.108 g of sodium carbonate Na_2Co_3 in distilled water and make up to 100 ml.

Find out the exact normality of H_2SO_4 (N) from the relation.

$$N_1 V_1 = N_2 V_2$$

N1 is the normality of Sodium carbonate solution (0.02N) V1 is the Volume of Sodium carbonate solution (0.02N) = 10ml V2 = Volume of H_2SO_4 used in Standardization

3) Phenolphthalein indicator: Dissolve 0.25g of Phenolphthalein powder in 50ml of 50% alcohol.

4) Methyl orange indicator - bromocresol green: Dissolve 0.01g methyl orange and 0.05g of bromocresol green in 100 ml of water. Colour change at end point (pH 4.3) is sharper than that shown by methyl orange alone.

Procedure:

100 ml of filtered sample is taken in a conical flask and add few drops of alcoholic phenolphthalein indicator. If a pink colour develops, titrate the solution with 0.02N H_2SO_4 until it becomes colourless. This is the phenolphthalein alkalinity (PA). Note the titer value. If the sample was colourless after the addition of phenolphthalein indicator, added few drops of aqueous methyl orange indicator and titrate against the acid till an end point (blue green to orange). This is the total alkalinity (TA). The nature of alkalinity was then predicated from the titration as follows:

1. If the titration to the phenolphthalein end point was zero, alkalinity was regarded as due to bicarbonate alone.
2. When there was no further titration to the methyl orange end point after the phenolphthalein end point, the alkalinity was only due to hydroxides.
3. When the phenolphthalein end point titration was half the total titration, only carbonate alkalinity was expected to be present.
4. When the phenolphthalein end point titration was greater than half the total titration, the alkalinity is due to both carbonate and hydroxides.
5. When the phenolphthalein end point was less than half the total titration, the alkalinity was due to carbonate and bicarbonates.

Calculation:

Volume of water sample taken = 100ml

Volume of 0.02N H_2SO_4 used for phenolphthalein end point = X ml Volume of 0.02N H_2SO_4 used for methyl orange end point = Y ml

Volume of 0.02N H_2SO_4 required for neutralize the carbonate alone = 2X ml Volume of 0.02N H_2SO_4 required for neutralize the bicarbonate alone = (Y – 2X) Normality of H_2SO_4 (0.02N)

$$CO_3^{2-}\ (\text{mg L}^{-1}) = \frac{(2X) * \text{Normality of } H_2SO_4 * 30 \times 1000}{100}$$

$$HCO_3^{-}\ (\text{mg L}^{-1}) = \frac{(Y - 2X) * \text{Normality of } H_2SO_4 * 61 \times 1000}{100}$$

1.5 Chlorinity Reagents:

1)Silver nitrate solution: Dissolve 25 g silver nitrate (AR) in1000 ml distilled water. Store in an amber glass bottle.

2)Potassium chromate solution: Dissolve 8 g potassium chromate (AR) in 100 ml distilled water. Store in a stoppered glass bottle.

Apparatus:

1)Burette: 25 ml, accuracy 0.1 ml

2)Bulb pipette: 5 ml, Accuracy 0.1 ml

3)Conical flask: 50 ml

4)Magnetic stirrer

5)Magnetic needle

Procedure:

Total 50 ml of the sample is pipetted out into a clean conical flask. Add 3 drops of K_2CrO_4 as indicator and filtrate against standard 0.1 N $AgNO_3$. End point is the disappearance of yellow colour to dirty orange colour.

1.6 Sulphate

It is a naturally occurring anion found almost in kinds of water bodies.it may undergo transformations to sulphur or hydrogen sulphide depending largely upon the redox potential of the water. This is also an important anion imparting hardness to water**.**

Reagents:

1) Barium chloride

2) Sulphate standard solution: take 5.55 ml concentrated sulphuric acid and dilute it to 100 ml thus gives 2N H_2SO_4. Take 10 ml of 2N H_2SO_4 and dilute to 100ml (0.2N). Again take 10 ml of 0.2N H_2SO_4 and dilute to 100 ml (0.02N). Take 10ml of 0.02N H_2SO_4 and made up to 100ml (10 mg/L). Take 20 ml of 0.02N H_2SO_4 and made up to 100 ml (20 mg/L). Take 30 ml of 0.02N H_2SO_4 and made up to 100 ml (30 mg/L).

Procedure:

Take 20ml of sample in a test tube and add a pinch of barium chloride solution into it. Stir for 1minute and take the absorbance using spectrophotometer at 420nm. Then find out the concentration of sulphide from the standard curve.

Calculation:

$F=f1+f2+f3/3$

Where F= Factor, f= concentration of standard/ Absorbance of standard f1= 1/Absorbance of first standard

f2= 2/ Absorbance of second standard f3= 3/ Absorbance of third standard

Amount of sulphate (mg/L) = F × Absorbance of sample

1.7 Fluoride Apparatus:

1) **Distillation apparatus:** 1L round bottom long neck, borosilicate glass boiling flask, thermometer adapter, connecting tube and an efficient condenser, with thermometer adapter and a thermometer reading up to 200°C. Alternative types of distillation apparatus may be used.

2) **Spectrophotometer** for use at 570 nm: it must provide a light path of at least 1cm or a spectrophotometer with a greenish yellow filter (550 to 580 nm).

Spectrophotometer

Reagents:

1) Stock fluoride solution: Dissolve 221.0 mg anhydrous sodium fluoride, NaF, in distilled water and dilute to 1000 ml; 1 ml = 100 µgF.

2) SPADNS solution: Dissolve 985mg SPADNS, sodium 2- (parasulphophenylazo) -1, 8-dihydroxyl-3, 6-naphthalenedisulphonate, in distilled water and dilute to 500mL; protect from light - stable for 1 year.

3) Zirconyl-acid reagent: Dissolve 133 mg zirconyl chloride octahydrate, $ZrOCl_2.8H_2O$, in about 25 ml distilled water, add 350 ml concentrated HCL and dilute to 500 ml.

4) Mixed acid zirconyl-SPADNS reagent: Mix equal volumes of SPADNS solution and zirconyl - acid reagent - stable for 2 years.

Procedure:

a)Preparation of working standard solution:

1)Transfer 10 ml of fluoride stock solution into a 100 ml of volumetric flask and dilute to the mark with water. This solution contains 100 µmol F/L

2)Again transfer 1ml of the above 100 µmol solution into another 100 ml volumetric flask and dilute to the mark with water. This solution contains 1µmol F/L. Prepare similarly for following standards as 2, 3, 4 and 5 µmol F/L.

b) Calibration of standards and blank:

Measure out 100 ml of water for blank in triplicate. Similarly measure out 100 ml of working standard solutions in clean stopper glass tubes in triplicate. Add 10 ml of mixed reagent, mix well and wait for 10 min for the development of colour. Measure the absorbance of blank (b) and standard solutions (st.) in a spectrophotometer using 1 cm cell at 810 nm using water as reference.

c) Sample analysis:

Measure out 100 ml of the sample in a clean stopper glass tube and add 10 ml of mixed reagent, mix well and wait for 10 min for the development of colour. Measure the absorbance of the sample in 1 cm cell at 810 nm (As).

Calculation

F=f1+f2+f3/3, Where F=Factor, F=concentration of standard / Absorbance of standard
Amount of fluorite (mg/L) = F × Absorbance of sample

1.8 **Arsenic Apparatus:**

1)Atomic Absorption Spectrophotometer with Hydride generator (VGA.).

2) Beakers for preparing standard solutions and standard pipettes.

Reagents:

1) 5 to 10 Molar HCL for the acid container for the hydride generator

2) Solution of 0.6% of $NaBH_4$; 0.5% NaOH for Reduct and container

3) 1000 ppm As Standard for preparing standard solutions

Procedures:

a) Preparation of working standard solutions standards

1) Preparation of 5 to 10 M HCL for acid container for hydride generator

To prepare 5 M HCL solution (approx. 250 ml). Take 100 ml conc. HCL+150 ml water in 250 ml Volumetric Flask.

2) Preparation of 0.6% of$NaBH_4$; 0.5% NaOH for Reductant container in Hydride Generator.

Take 1.25 gm of NaOH dissolve it in approx. 250 ml DM (MiliQ water) in 250 ml Volumetric Flask. Take 1.5 gm of NaBH4 dissolve in NaOH solution.

3) Prepare Blank, 5ppb As^{-3}, 10 ppb As^{-3},20ppb As^{-3}40ppb As^{-3}. 100 ml of As standards are prepared from 1000 ppm As Std. And 8 ml concentrated HCL and 10 ml of 10% KI solution is also added.

Atomic Absorption Spectrophotometer (AAS)

b) Calibration of standards

The AAS is set for a wavelength 193.7 nm. The standard solutions of 100 ml is passed to the reaction chamber of Hydride Generator along with the concentrated HCL and Mixture of 0.6% ofNaBH4; 0.5% NaOH - Nitrogen gas is also passed on to the reaction chamber and then it is conveyed in to T-Shaped Quartz glass tube inside the AAS. And a concentration to absorbance calibration straight line should be obtained and the instrument is calibrated for the curve.

c) Sample Analysis

The AAS is set for a wavelength 193.7 nm. 25 ml of the sample is mixed with 8 ml concentrated HCL and 10 ml of 10% KI solution and is then passed to the reaction chamber of hydride generator (VGA Apparatus) along with the Conc. HCL and Mixture of 0.6% of NaBH4; 0.5% NaOH - Nitrogen gas is also passed on to the reaction chamber and then it is conveyed in to T- Shaped Quartz glass tube inside the AAS and the Absorbance is measured. Concentration in parts per billion (ppb) is given by the software from the Concentration v/s Absorbance Line.

2.0 Units of expression of chemical analysis results and conversion factor -

2.1 Milli equivalents per liter (meq/L) or Micro equivalents per liter (µeq/L):

One equivalent per liter is equal to one thousand milligram-equivalents per one thousand milliliters (meq/mL). Chemical analyses of solutes in a sample are expressed in unit concentrations that are chemically equivalent in terms of atomic or molecular weight and electrical charge.

2.2 Milligrams per liter (mg/L) or micrograms per liter (µg/L):

Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Concentration data reported in milligrams per liter (mg/L) can be converted to milli-equivalents per liter (meq/L), and vice versa.

Simply use the following formula: mg/L = meq/L × equivalent weight (see table below).

Equivalent weight of selected ions

Constituent	**Equivalent weight**
Sodium (Na^+)	23
Calcium (Ca2+)	20
Magnesium (Mg2+)	12
Ammonium (NH4+)	18
Potassium (K+)	39
Bicarbonate (HCO3-)	61
Carbonate (CO32-)	30
Chloride (Cl-)	35
Sulphate (SO42-)	48
Nitrate (NO3-)	62
Phosphate (H2PO4-)	97

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