

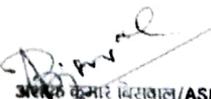
BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL, CENTRAL
ZONE, BHOPAL, M.P.

O.A. NO. 732/2023

In Re.: News item appearing in Hindu dt.03.12.23 titled " Battling water woes
in Land of Tragedy"

FRESH REPORT ON BEHALF OF CENTRAL GROUND WATER
AUTHORITY

1. That Principle Bench of the Hon'ble National Green Tribunal, New Delhi took Suo Moto cognizance on the news report titled "Battling Water Woes in Land of Tragedy" and issued notice to Central Ground Water Authority.
2. That the Central Ground Water Authority filed a report from the study conducted in the year 2011. The Hon'ble Tribunal taking note of the said report vide order dt.22.12.23 directed the Central Ground Water Authority file a fresh report for which samples were already taken from 36 places.
3. That the Hon'ble Tribunal further directed the CGWA to specify in the report the places from where the samples were collected and that matter was transferred to Central Zone Bench of Hon'ble Tribunal.


अशोक कुमार बिशवाल/ASHOK KUMAR BISHW
क्षेत्रीय निदेशक/Regional Director
भारत सरकार/Government of
जल शक्ति मंत्रालय/Ministry of
जल संसाधन, नदी विकास और गंगा
Department of WR, RD
केन्द्रीय भूमि जल बोर्ड/Central Ground
उत्तर मध्य क्षेत्र, भोपाल/North Central

- 4. That the Central Ground Water Authority has done a detailed study regarding the issue in this O.A. and the report in this regard is annexed as Annexure A1.
- 5. That the Central Ground Water Authority will abide by any of the directions passed by this Hon'ble Tribunal .

For Central Ground Water Authority

Through

GIGI.C.GEORGE
 ADVOCATE
 STANDING COUNSEL(UOI)
 CH.NO.457, DELHI HIGH COURT
 Email:gigicgeorge.adv42@yahoo.in
 M-9810625315

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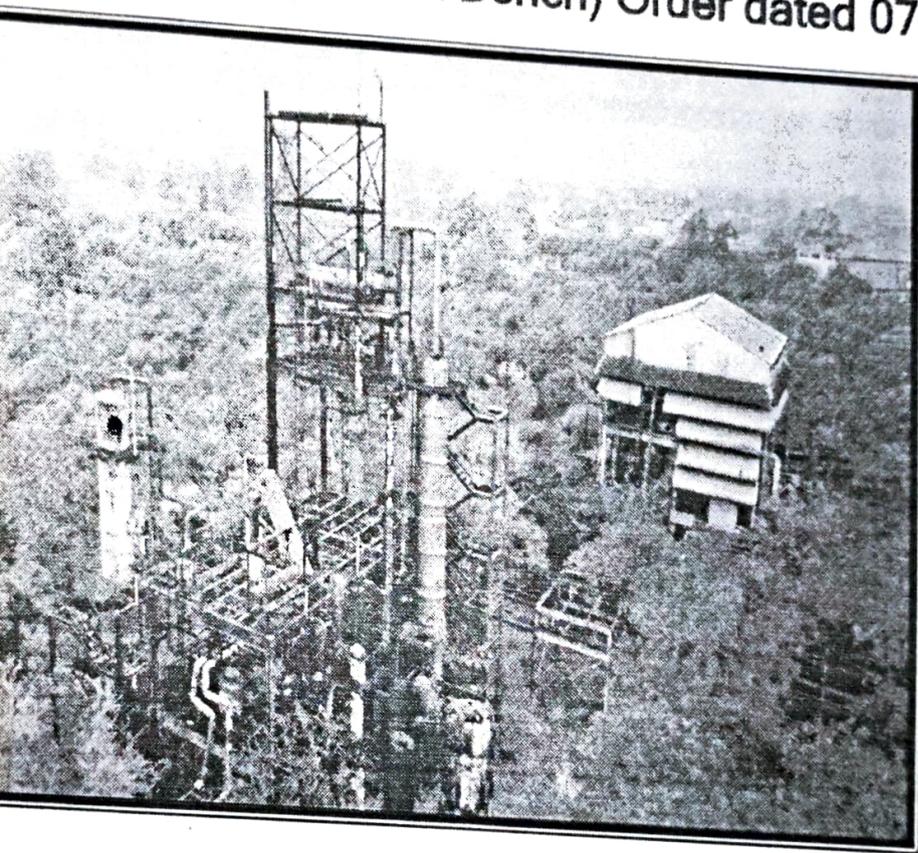
**Heavy Metals Contamination and Basic Water Quality
and Union Carbide India Limited (UCIL), Bhopal**

In the Matter of

ORIGINAL APPLICATION NO. 732/ 2023

W.r.t.

Green Tribunal (Central Bench) Order dated 07.12.2023



**Location: Union Carbide India Limited (UCIL)
District-Bhopal, M.P.**

THE HON'BLE NATIONAL GREEN TRIBUNAL

**Data Analysis, Interpretation and Report writing
by**

Dr. V. K. Kulshreshtha, Scientist-C

Mr. Tej Singh, Assist. Chemist

Sample Analysis

by

Mr. Rahul Vashishtha, Assist. Chemist

Mr. Jitendra Kumar, STA-Chemist

Abstract

In 1984, a tragic gas leak at the Union Carbide factory in Bhopal resulted in loss of lives, environmental damage, and adverse effects on flora and fauna. Despite challenges in quantifying the losses, various institutions have studied the immediate and long-term effects. In 2011, the Central Ground Water Board found saline groundwater due to geogenic mineral dissolution. Recently "The Hindu", a newspaper article highlighted groundwater contamination risks from poorly managed toxic waste at the UCIL premises. Prompted by this, the National Green Tribunal took Suo Motu action, summoning relevant CGWA and MP-PCB. The CGWA initiated a new investigation w.r.t. heavy metal contamination in groundwater near UCIL.

The primary objective of this investigation was to examine the potential groundwater contamination resulting from the consequences of the gas tragedy. The research employed field surveys and laboratory investigations, involving the collection of 72 groundwater samples (36 samples for basic parameters + 36 for heavy metals including U) from various directions within a 5 km radius of UCIL. The assessment of groundwater quality was conducted by comparing observations of different parameters against the Indian Standard (BIS, 1991) and WHO (1999).

Key findings revealed that pH values within the permissible range, Electrical Conductivity of Water (EC_w) below the BIS permissible limit, and absence of carbonate ions. Total Alkalinity (ALKT) values were within limits, and chloride concentrations indicated partial pollution. Nitrate concentrations exceeded the BIS desirable limit in 7 (four shallow and three deeper) out of 36 locations. Sulphate levels were below the BIS limit, while fluoride concentrations absolutely met BIS standards. Phosphate levels exceeded WHO permissible limits at two locations. Silica distribution varied, and nearly 99% of samples were categorized as hard or very hard water for household use. Some locations showed hardness (one shallow and two deeper), calcium, and magnesium concentrations exceeding BIS limits. Sodium concentrations at two locations exceeded WHO standards. Potassium concentrations in 27.77% locations were above WHO limits.

The study investigated concentrations of eighteen heavy metals in groundwater near UCIL. Iron concentrations exceeded BIS limits in eleven locations, reaching a maximum of 11.664 mg/l. Manganese pollution affected 8.33 % of locations, exceeding the BIS limit. Aluminum concentrations reported within the BIS permissible limit. Zinc contamination was minimal, with only one location exceeding the BIS-acceptable limit but remained under permissible limit (15 mg/l). Arsenic concentrations were generally below BIS limits, except for one location.. Other tested parameters, including Silver, Boron, Molybdenum, Nickel, Copper, Selenium, Chromium, Cadmium, Barium, Mercury, Lead, and Uranium, fell within permissible limits. Strontium, not regulated either by BIS or WHO standards, was reported at concentrations from '0.198' to 2.223 $\mu\text{g/l}$ with an average of 0.833 mg/l.

Furthermore, the Gibbs (1970) diagram suggested that most of the samples lie in the rock dominance zone, indicating that rock weathering is the primary source that controls groundwater chemistry and its evolution.

It may be concluded that the study area had saline ground waters due to the inherent geogenic high degree of mineral dissolution from parental material.

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ASHOK KUMAR BISWAL
 Regional Director
 Ministry of Jal Shakti
 Department of WRA, RD & GA
 North Central Region, Bhopal

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Location of Ground Water Samples

I. INTRODUCTION

In the tragic events of 1984, on the fateful night of December 2nd, a catastrophic gas leak occurred at the Union Carbide factory in Bhopal. The released gas, highly poisonous in nature, resulted in the loss of numerous human lives and livestock. Beyond the immediate human toll, the incident had far-reaching consequences, causing substantial environmental damage and adversely affecting the quality of flora and fauna in the surrounding areas.

Quantifying the extensive losses incurred by natural resources, including air and water in the city of Bhopal, due to the release of these poisonous gases has proven to be an intricate challenge. Despite this difficulty, various governmental entities, including state and central agencies, non-governmental organizations (NGOs), and autonomous bodies, have diligently undertaken efforts to comprehensively study both the immediate and long-term effects of the gas leakage. These studies aimed to provide a basis for future planning, enabling effective measures to overcome the adverse consequences of the gas leak.

A crucial aspect of post-gas tragedy investigation focuses on the examination of water quality in and around the affected area, notably the Union Carbide factory in Bhopal. The Madhya Pradesh State Pollution Control Board, Bhopal has been actively engaged in the routine monitoring of groundwater quality across various locations in Bhopal, with special attention to areas closely adjacent to the Union Carbide facility. This monitoring involves the collection of groundwater samples from representative hand pumps, dug wells, and tube wells.

In 2011, the Central Ground Water Board (CGWB), NCR, Bhopal, conducted a study around the Union Carbide factory area to assess groundwater quality. Samples were meticulously collected from hand pumps, tube wells, and dug wells at 12 different locations during July 2011. The study reported that the study area had saline groundwaters due to the inherent geogenic mineral dissolution from parental material.

A recent newspaper article dated 03.12.2023, published in *"The Hindu"* under the title *"Battling Water Woes in the Land of Tragedy,"* spotlights the critical issue of groundwater contamination. The article drew attention to the substantial volume of inadequately managed toxic wastes within the UCIL premises, highlighting the potential risk of contaminants seeping into the groundwater from the poorly contained toxic waste.

Prompted by this article, the National Green Tribunal (NGT), Principal Branch, New Delhi, took *Suo Motu* action, recognizing the urgent need for attention and remediation of toxic waste within the UCIL premises. Subsequently, the Hon'ble Tribunal summoned the

Central Ground Water Authority (CGWA) and Madhya Pradesh Pollution Control Board (MP-PCB) to appear before it on December 22nd.

In a proactive initiative to underline the significance of the environmental concern at hand, the New Delhi office of the Central Ground Water Authority (CGWA) directed its Bhopal regional office to undertake a new investigation into the presence of heavy metal contamination in the vicinity of Union Carbide India Limited (UCIL), Bhopal. Therefore, this study was initiated in response to the directives from the Regional Director, with the specific objective of assessing the extent of chemical contamination in groundwater surrounding residential areas closely situated to the Union Carbide India Limited Factory.

II. OBJECTIVE

The primary aim of this study was to evaluate the potential groundwater contamination in the proximity of the former UCIL plant, with a specific focus on the substantial volume of inadequately managed toxic wastes lying unheeded inside. Therefore, the purpose of this monitoring was to examine the likelihood of contaminants seeping from the plant into the groundwater.

III. METHODOLOGY

As explained earlier, the main objective of the present study was to determine the potential groundwater contamination in the proximity of the former UCIL plant. In order to do the assessment, water samples were collected from groundwater sources used by the low-income community residing in the area. The sources of groundwater in the area were Hand pumps (HP), Tube wells (BW) and Dug wells (DW).

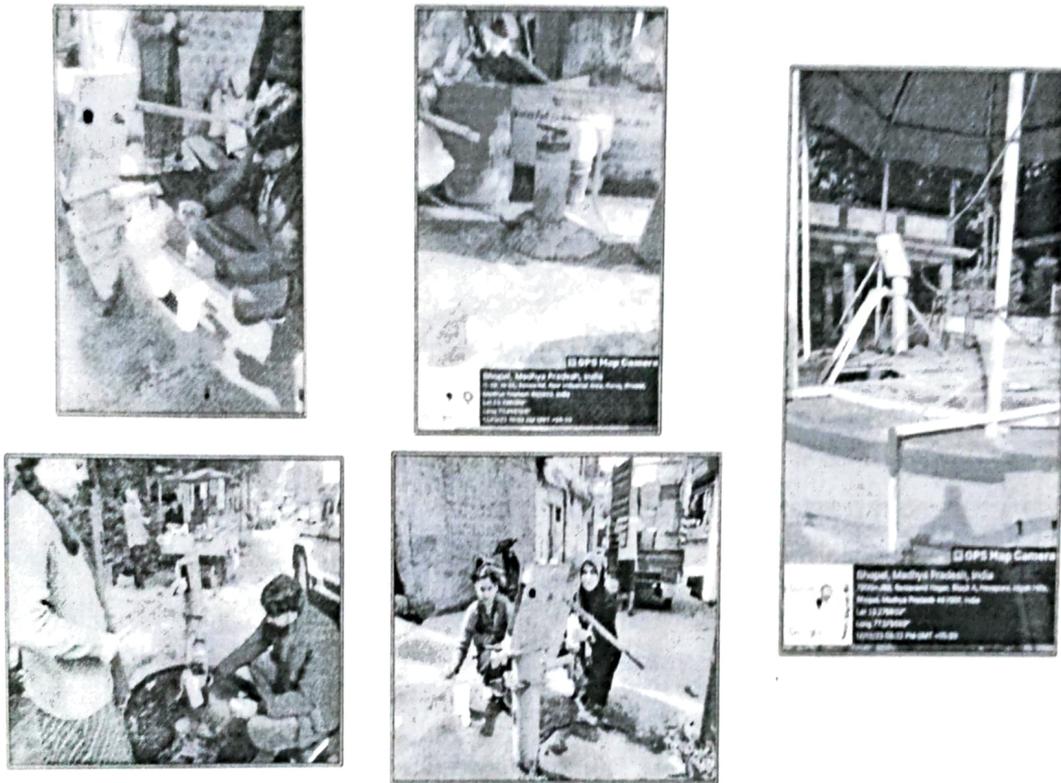
a. Sample Collection: To assess groundwater quality, a reconnaissance survey was conducted, scanning the geographical area surrounding UCIL. Grab samples were obtained from bore wells (BW), dug wells (DW), and hand pumps (HP). A total of 72 groundwater samples were systematically collected in duplicate, with 36 reserved for basic parameters and the other 36 acidified for heavy metals, including uranium. The sampling strategy encompassed a comprehensive network that covered all feasible sites within a 5 km radius of the UCIL factory premises. Sampling took place from December 12th to 14th, 2023 (See **Figure 1 & Annexure I**). Following the guidelines of the American Public Health Association (APHA, 2022), one-liter pre-rinsed airtight polythene bottles were used for sample collection after on-site filtration to eliminate turbidity, sealed securely with wax. **Figure 2** depicts a map of the study area, featuring the locations of groundwater sampling points indicated by red

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शशि कृष्ण बिहारी/ASHOK KUMAR BISWAL
जिला निदेशक/Regional Director
मध्य प्रदेश/Government of India
जन स्वास्थ्य विभाग/Ministry of Jal Shakti
नगर विकास, नई दिल्ली
Department of WR, RD & GR
केंद्रीय भूजल प्राधिकरण/Central Ground Water Authority
आंध्र प्रदेश, कोयंबटूर/North Central Region

dots. Detailed geographical coordinates of these sampling points can be found in Annexure-I.

Figure 1: Illustrates the collection of groundwater samples from the study area.



b. Analysis of Samples: The collected samples, adhering to proper handling protocols, underwent analysis at the Regional Chemical Laboratory, CGWB, Bhopal. The analysis included basic parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), temperature (Temp. °C), carbonate (CO₃), bicarbonate (HCO₃), sulphate (SO₄), chloride (Cl), phosphate (PO₄), silica (SiO₂), nitrate (NO₃), total hardness (TH), calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). Additionally, 18 specific heavy metals—namely, iron (Fe), zinc (Zn), manganese (Mn), cadmium (Cd), nickel (Ni), chromium (Cr), lead (Pb), aluminum (Al), boron (B), selenium (Se), silver (Ag), mercury (Hg), molybdenum (Mo), copper (Cu), Barium (Ba), Strontium (Sr), Arsenic (As) and uranium (U)—were analyzed. The determination of basic parameters followed Standard Methods (APHA, 2022) employing various volumetric methods, Flame-photometer (Systonics-128), and Spectrophotometer (Shimadzu, UV-1201). The analysis of heavy metals was conducted using ICP-MS (ThermoFisher Scientific, model icap RQ).

IV. RESULTS AND DISCUSSION

A. Appraisal of Ground Water Quality Based on Basic Parameters

The groundwater quality of the study area has been evaluated for different parameters, adhering to the specified limits established by the Bureau of Indian Standards (BIS-2012) and, for those parameters not covered under BIS, World Health Organization (WHO-1999) guidelines have been followed.

The chemical parameter of Electrical Conductivity (EC_w) took precedence as the key indicator to analyze spatial variations of salinity in different locations. The pH values ranged between 6.74 and 7.61, with an average of 7.11, and did not exceed the permissible limit for pH (6.5 to 8.5) as defined by **BIS (2012)**. The Electrical Conductivity of Water (EC_w) ranged from 502 to 2497 $\mu\text{S}/\text{cm}$ at 25°C, with an average of 1209. All locations around Union Carbide India Limited (UCIL) exhibited EC_w values below the BSI's maximum permissible limit of 3000 $\mu\text{S}/\text{cm}$ at 25°C (**Table 1 & 3**).

The study found groundwaters in and around the UCIL area to be free from carbonate (CO_3) ions. However, fluctuations in bicarbonate (HCO_3^-) concentrations were considered for calculating Total Alkalinity (ALKT), which ranged from 164.96 to 559.88 (average 318.3). None of the locations had ALKT values exceeding the BIS permissible limit of 600 mg/l (**Tables 1 & 3**).

Results indicated partial chloride contamination in the study area, with 19.44% of examined locations remained below the permissible limit (1000 mg/l). Chloride concentrations varied from 40 (**HP₇, Lalghati**) to 465 (**BW₄, Geetanjali College**) mg/l in samples covering the area close to UCIL (**Tables 1 & 3**).

Nitrate (NO_3^-) concentrations exceeding the acceptable limit of 45 mg/l set by BIS were found in 7 out of 36 locations around UCIL. The range varied from 1 mg/l in DIG Banglow (**DW₂**) to 142 mg/l in Bhopal Railway Junction (**HP₄**). Among these locations, four were associated with shallow aquifers, while three were linked to deep aquifers.

The area around UCIL was free from sulphate, with 100% examined locations reporting concentrations below the BIS acceptable limit of 200 mg/l, ranging from 09 mg/l in Jhangirabad (**HP₁₁**) to 95 mg/l in Bhopal Railway Junction (**HP₄**). Fluoride concentrations in the circumventing area of UCIL were below the BIS permissible limit of 1.5 mg/l, as suggested by this study (**Tables 1 & 3**).

There is no nutritional basis for the regulation of phosphate levels in the Bureau of Indian Standards for drinking water supplies. The World Health Organization (**WHO, 1999**) recommends 0.1 mg/l and 1.0 mg/l concentrations of PO_4^{3-} respectively as acceptable and permissible levels for drinking water. The findings revealed that phosphate levels exceeded

the WHO recommended permissible level of 1.0 mg/l at only two locations namely **HP₅** (Mangalwara) with a maximum level of 2.33 mg/l and Golghar Museum (**BW₁₁**) with a level of 1.09 mg/l. Increasing phosphate levels, can be attributed to human activities such as farming and the disposal of sewage.

There are no agreeable primary or secondary contaminants limits of silica for drinking water prescribed either by the Bureau of Indian Standards (BIS) or any other slimier agency like US-EPA & WHO. The results of silica analysis in the study area revealed a non-uniform distribution, ranging from 8 mg/l (**DW₁, Gufa Mandir**) to 74 mg/l (**BW₉, RGPV University**), with an average concentration of 32 mg/l. This variation may be attributed to factors such as the water saturation deficit of the aeration zone, seasonal fluctuations in precipitation and temperature, bedrock reactivity, and mineral stability, as described by **Dobrzynski (2005)**.

According to the classification provided by **Sawyer & McCarty (1996)**, nearly 99% of the water samples were categorized as hard or very hard for household use. The hardness values ranged from 193 to 827 mg/l, with an average of 364 mg/l (*See Tables 1 & 3*); further three locations namely Bhopal Railway Junction (**HP₄; shallow Aquifer**), Geetanjali College (**BW₄; Deep Aquifer**), and Badwai(**HP₁₀; shallow Aquifer**) showed the hardness greater than BIS permissible limit (600 mg/l) respectively as 827,683 and 634 mg/l. Calcium content in water samples only from one location namely Bhopal Railway Junction (**HP₄; shallow Aquifer**) marginally exceeded the BIS maximum permissible limit of 200 mg/l, with concentrations reported as 212 mg/l. Around 27.77% of the locations recorded magnesium concentrations that exceeded the BIS acceptable limit of 30 mg/l, although they remained below the permissible limit of 100 mg/l(**Tables 1 & 3**).

The BIS did not provide specific limits for sodium; therefore, WHO standards were applied. The analysis revealed that sodium concentrations at two locations, namely Badwai (**HP₁₀**) and Bhopal Memorial Hospital (**BW₁₈**), exceeded the WHO limit of 200 mg/l, with an average concentration of 102 mg/l (**Tables 1 & 3**).

Similarly, no numerical BIS guideline exists for potassium, so WHO standards were followed. 27.77 locations (10 out of 36) recorded potassium concentrations above the WHO limit of 10 mg/l, with maximum, minimum, and average values of 40, 2.2, and 9.4 mg/l, respectively (**Tables 1 & 3**).

B. Appraisal of Ground Water Quality Based on Heavy Metals

The upcoming text describes the concentrations of eighteen environmentally significant heavy metals were investigated. These heavy metals include iron (Fe), manganese (Mn), aluminum (Al), zinc (Zn), arsenic (As), silver (Ag), boron (B), molybdenum

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Department of WRA, RD & GR
Central Ground Water Board

(Mo), nickel (Ni), copper (Cu), selenium (Se), chromium (Cr), cadmium (Cd), barium (Ba), mercury (Hg), lead (Pb), uranium (U) and Strontium(Sr). The presence and levels of above metals are of concern due to their potential environmental impact and toxicity.

In eleven out of thirty-six locations, iron concentrations exceeded the Bureau of Indian Standards (BIS) allowable limit of 1.0 mg/l. In these locations, the recorded iron levels were as follows: **HP₁**(1.436 mg/l), **HP₂**(1.023 mg/l), **HP₃**(5.383 mg/l), **HP₄**(1.657 mg/l), **HP₆**(4.707 mg/l), **HP₇**(10.073 mg/l), **HP₉**(1.879 mg/l), **BW₁₀**(4.398 mg/l), **DW₄**(3.981 mg/l), **HP₁₁**(11.664, maximum), **BW₁₆**(1.310) (**Tables 2 & 3**). Out of these 11 locations, 7 locations were associated with shallow aquifers while 4 locations belonged to deeper aquifers.

The area surrounding Union Carbide India Limited (UCIL) is affected with partially manganese pollution as 8.33 % of locations (3 out of 36) recorded manganese concentration more than BIS's permissible limit of 0.3 mg/l. The maximum and minimum concentrations of 0.581 and 0.00 mg/l were recorded in **BW₈** (Deeper Aquifer) and **BW₁₈** locations respectively (**Tables 2 & 3**). These three locations were associated with deeper aquifers.

Examinations revealed (refer to Tables 1 and 3) that within the study area, there is no evidence of arsenic pollution, as nearly all locations recorded arsenic concentrations below the permissible guideline set by the Bureau of Indian Standards (BIS) of 0.01 mg/l. The sole exception is the **DW₃** location (Golghar Museum), where the arsenic concentration was slightly elevated at 0.012 mg/l (**Tables 2 & 3**).

Additional tested parameters, including Silver(Ag), Aluminum (Al), Zinc(Zn), Boron (B), Molybdenum (Mo), Nickel (Ni), Copper (Cu), Selenium (Se), Chromium (Cr), Cadmium (Cd), Barium (Ba), Mercury (Hg), Lead (Pb), and Uranium (U), were observed to register concentrations consistently below their respective permissible limits across all locations (refer to **Tables 2 & 3**). This implied that the levels of these substances in the sampled locations fell within the acceptable range defined by the regulatory standards of **BIS (2012)**.

Strontium is not a regulated contaminant under the BIS (2012); although not routinely tested for, strontium was reported in this study at concentrations from 0.198 to 2.223 mg/l with an average of 0.833 mg/l.

C. Mechanisms Controlling Groundwater Chemistry

Gibbs (1970) proposed a chemical diagram of mechanisms controlling the chemistry of groundwater to understand the relationship of the chemical components of waters with their respective aquifer lithologies. The diagram is divided into zones based on the contribution of recharging precipitation, rock/mineral weathering, and evaporation/crystallization on the hydrochemistry. Various researchers have followed this type of chemical relationship of groundwater in different parts of India (**Srinivasan, 1992**). The

Signature
अशोक कुमार बिस्वा/ASHOK KUMAR BISWA
देशीय निदेशक/Regional Director
जल संसाधन/Department of Water Resources
भारत सरकार/Ministry of Jal Sanchay
जल संसाधन, नदी निदेशन और जल संयंत्र
Department of WR, RD & J
केन्द्रीय जल संसाधन विभाग/Central...

discretion of the origin of the lithology has been explained by the following assumptions (Day *et. al.*, 1998):

- (1) Atmospheric precipitation dominance waters should come from rocks which contain dominantly Na^+ and K^+ , which are less soluble and producing only small quantities of TDS with a moderate to high $\text{Na}/\text{Ca}+\text{Na}$ ratio.
- (2) Rocks dominance waters (mineral weathering processes) show high concentrations of Ca^{2+} , Mg^{2+} , and HCO_3^- resulting in moderate TDS and moderate $\text{Na}/\text{Ca}+\text{Na}$ ratio.
- (3) Evaporation dominance waters show high concentrations of Na^+ and Cl^- ions and low concentrations Ca^{2+} and Mg^{2+} ions due to calcite precipitation resulting in high TDS and high $\text{Na}/\text{Ca}+\text{Na}$ ratio.

Gibbs used two ratios in his diagrams, representing the **Ratio-I** for cations $[(\text{Na}+\text{K})/(\text{Na}+\text{K}+\text{Ca})]$ and **Ratio-II** for anions $[\text{Cl}/(\text{Cl}+\text{HCO}_3)]$ as a function of TDS which are widely employed to assess the functional sources of dissolved chemical constituents in waters either through precipitation-dominance, rock-dominance and evaporation dominance.

One of the major shortcomings with **Gibbs's (1970)** diagram is that no place for waters have been affected by domestic/industrial contamination or other sources of hydrochemical enrichment outside of the three sources outlined above since a lot of studies have shown the origin of the lithology away from the three major factors, namely, precipitation dominance, rock-water interaction, and evaporation-crystallization. It is probably on account of this reason that the diagram is often used together with other hydrochemical assessment diagrams such as Piper, Wilcox, etc. integrated with multivariate statistical analyses.

Lastly, to know the mechanisms controlling groundwater chemistry and the relationship of the chemical components of water from their respective aquifers, the chemical data about UCIL of Bhopal was plotted on Gibb's diagram (*See Figures 3a & 3b*). **Gibbs's ratio-1 (Cation)** ranged from 0.183 to 0.839 with an average of 0.513 whereas **Gibbs's ratio-2 (Anions)** varied from 0.144 to 0.258 with an average of 0.285 respectively.

Figures 3a and 3b indicate that all samples are situated within the zone characterized by rock dominance indicating that rock weathering is the primary source that controls groundwater chemistry and its evolution. Parent rock weathering facilitates the process by which dissolvable salts and minerals become incorporated with groundwater. Moreover, the long residence time of rock-water interaction also aids mineral dissolution (**Selvakumar *et. al.*, 2017**).

IV. Conclusion

In a concise summary, the study observed that the pH values of the groundwater were within acceptable limits, and the Electrical Conductivity of Water (EC_w) remained below the permissible limits set by the Bureau of Indian Standards (BIS). Additionally, carbonate ions were found to be absent. The investigation covered various parameters, including chloride, nitrate, sulphate, fluoride, phosphate, and silica.

The nitrate concentrations (NO_3^-) exceeding the BIS approved limit of 45 mg/l, were found in seven out of 36 locations surrounding UCIL. Of these, four were associated with shallow aquifers, and three were connected to deep aquifers. Nitrate is acknowledged as a well-established environmental contaminant originating from diverse human activities. Human-induced contributors encompass the production and utilization of nitrate fertilizers, the combustion of fossil fuels, and the discharge of domestic sewage (Gutierrez et. al., 2018; Ward, M. et al., 2018 and Torres-Martinez, J. A. et al., 2020)

Three locations namely **HP₄; shallow Aquifer, BW₄; Deep Aquifer**, and **HP₁₀; shallow Aquifer** showed the hardness greater than BIS permissible limit (600 mg/l) respectively as 827,683 and 634 mg/l.

Furthermore, the study highlighted into the concentrations of eighteen heavy metals, revealing elevated levels of iron and manganese in certain locations. Notably, strontium concentrations, which are not regulated by BIS, ranged from 0.198 to 2.223 mg/l, with an average of 0.833 mg/l.

In eleven out of thirty-six locations, iron concentrations exceeded the BIS allowable limit of 1.0 mg/l. Among these 11 sites, 7 were connected to shallow aquifers (all through hand pumps), while 4 were affiliated with deeper aquifers (all accessed through bore wells). Iron naturally exists in the aquifer; however, concentrations in groundwater can be elevated due to the dissolution of components from ferrous boreholes and hand pumps. This refers to the gradual breakdown or disintegration of materials, specifically components from ferrous boreholes and hand pumps, which introduces additional iron into the groundwater.

The area surrounding Union Carbide India Limited (UCIL) is affected with partially manganese pollution as 8.33 % of locations (3 out of 36) recorded manganese concentration more than BIS's permissible limit of 0.3 mg/l. These three locations were associated with deeper aquifers. Examinations revealed that within the study area, there is no evidence of arsenic pollution, as nearly all locations recorded arsenic

concentrations below the permissible guideline set by the Bureau of Indian Standards (BIS) of 0.01 mg/l. The sole exception is the **DW₃** location (Golghar Museum), where the arsenic concentration was slightly elevated at 0.012 mg/l (**Tables 2 & 3**).

The application of the Gibbs diagram in the analysis suggested that rock weathering played a pivotal role as the primary source influencing groundwater chemistry. This process, in turn, contributed to the presence of saline groundwaters in the study area.



अशोक कुमार बिस्वाल/ASHOK KUMAR BISWAL
क्षेत्रीय निदेशक/Regional Director
भारत सरकार/Government of India
जल सक्ति मंत्रालय/Ministry of Jal Shakti
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग
Department of WR, RD & GR
केंद्रीय भूमि जल बोर्ड/Central Ground Water Board
उत्तर मध्य क्षेत्र, भोपाल/North Central Region, Bhopal

Figure 2 Groundwater Sampling Points Map: Union Carbide India Ltd., Bhopal, Madhya Pradesh.

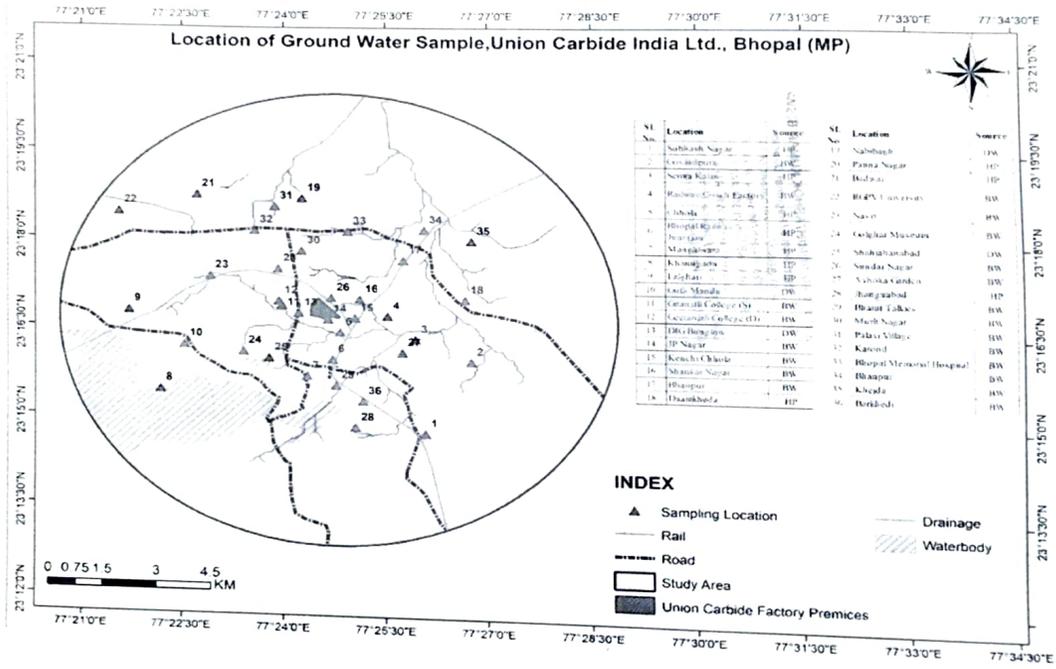


Figure 3 b (Ratio-II Anion)

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Figure 3 Gibb's Diagram Illustrating the Mechanism Controlling Ground Water Chemistry for Sample Sites Belonging to UCIL, Bhopal.

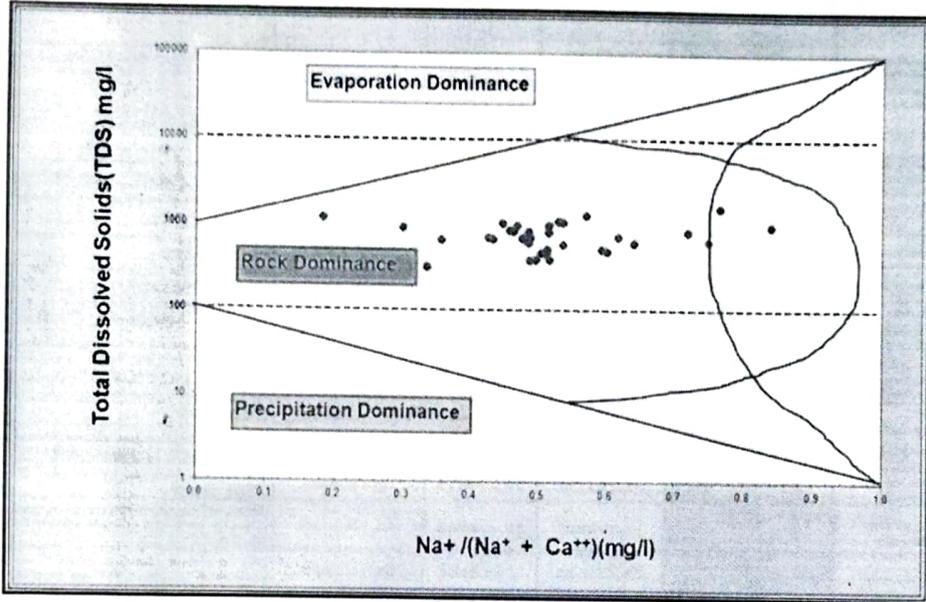


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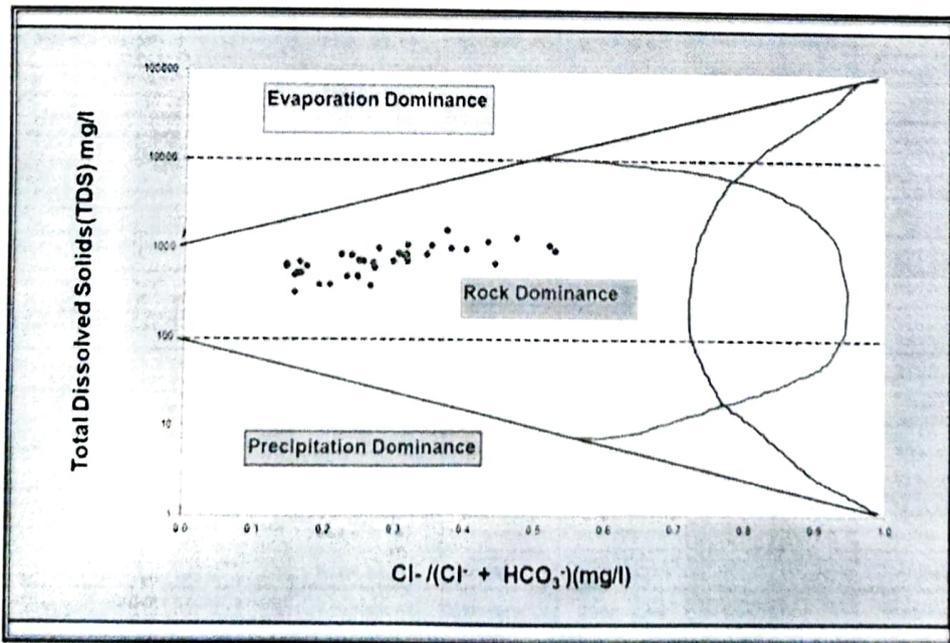


Figure 3 b (Ratio-II Anion)

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अशोक कुमार बिसवाल/ASHOK KUMAR BISW
राज्य निदेशक/Regional Director
भारत सरकार/Government of India
जल संचयन विभाग/Ministry of Water
जल संसाधन, नदी विकास और जल शक्ति
Department of WR, RD &
केन्द्रीय भूमि जल बोर्ड/Central Ground
जल बोर्ड क्षेत्र, भोपाल/North Central

Annexure I: List of Groundwater Sampling Locations.							
Sl No.	Location	Source	Type of Aquifer	Lat.	Long.	Date of Collection	Address
1	Subhash Nagar	HP ₁	S	23 24605	77 434716	12 12 2023	HP located in the Premises of Shameshan Ghat, Near Krishna Service Centre, Mehta Market
2	Govindpura	BW ₁	D	23 266389	77 446031	12 12 2023	BW located in Slum Area of Govindpura Industrial Area behind Yadav Tea Stall
3	Senva Kalan	HP ₂	S	23 272425	77 432282	12 12 2023	HP located in front of Ganesh Bhawan in the lane of Pawan Public School
4	Railway Coach Factory	BW ₂	D	23 278843	77 425424	12 12 2023	TW No. 12 of Railway Coach factory in front of Pump house No. 1, Near Water Supply Tank and Senior Section Engineer (Works) Office
5	Ohloia	HP ₃	S	23 274109	77 413787	12 12 2023	HP located near Bharat Petroleum in front of Ram Mandir, 50 m from Main Road
6	Bhopal Railway Station	HP ₄	S	23 2664	77 411942	12 12 2023	HP located in front of Pipleshwar Mahadev Mandir Near Platform No. 6
7	Mangalwara	HP ₅	S	23 261599	77 405747	12 12 2023	HP Located in Front of Police Station Mangalwara
8	Khanugaon	HP ₆	S	23 257333	77 369683	12 12 2023	HP Located in front of Temple Near Khanu Gaon
9	Laighati	HP ₇	S	23 279547	77 361819	12 12 2023	HP Located Opposite to Manubhawan Tekri Entry Gate Near SBI Branch
10	Gufa Mandir	DW ₁	S	23 27	77 37559	12 12 2023	DW Located in The Premises of Laighati Gufa Mandir (NHS Well)
11	Gitanjali College (S)	BW ₃	S	23 28154	77 399615	12 12 2023	BW located in College Garden.
12	Geetanjali College (D)	BW ₄	D	23 28273	77 3989	12 12 2023	BW located in Sport Complex of College
13	DIG Bungalow	DW ₂	S	23 279407	77 403673	12 12 2023	NHS Well
14	JP Nagar	BW ₅	D	23 277756	77 41085	12 12 2023	In Front of Rajeev Gandhi Bal Udhyan, Water used for Gardening Purpose
15	Kenchi Ohloia	BW ₆	D	23 278124	77 417419	13 12 2023	BW in the House of Manta Chocksey (Pico Shop)
16	Shankar Nagar	BW ₇	D	23 283507	77 418568	13 12 2023	BW of Poonam Sharma in Nagar Nigam Colony in front of lochapuri Mahadev Mandir
17	Bhanpur	BW ₈	D	23 294669	77 42932	13 12 2023	BW of Patal Ganga Bore Wells adjacent to Bharat Petroleum Pump
18	Damkheda	HP ₈	S	23 283767	77 444567	13 12 2023	200 mtr inside the village from Rajput Bhawan
19	Nabibagh	HP ₉	S	23 311641	77 404511	13 12 2023	NHS Well
20	Panna Nagar	HP ₁₀	S	23 291739	77 398653	13 12 2023	HP located adjacent to Temple in Seed Colony
21	Badwai	BW ₉	D	23 312366	77 378705	13 12 2023	HP located in front of Temple near Vaishno Devi HS School in Badwai Village
22	RGPV University	BW ₁₀	D	23 307436	77 359275	14 12 2023	BW located near Guest House and Girls Hostel of Rajeev Gandhi Technical University
23	Navri	BW ₁₁	D	23 28949	77 382052	14 12 2023	HP Located Near Mahakali Mandir Navri Village Near Aangan Wadi Kendra
24	Golghar Museum	DW ₃	S	23 268322	77 390149	14 12 2023	BW Located in the Premises of Golghar Museum
25	Shahjahan abad	BW ₁₂	D	23 266507	77 396477	13 12 2023	NHS Well
26	Sundar Nagar	BW ₁₃	D	23 283852	77 411594	13 12 2023	BW located near Shiv Mandir in the house of Raja Singh
27	Ashoka Garden	HP ₁₁	S	23 26867	77 42904	14 12 2023	BW of Vardhman Green Park, 80 Feet Road
28	Jhangirabad	BW ₁₄	D	23 247465	77 417516	14 12 2023	HP located in Ahir Mohalla in front of Matri Chhaya House
29	Bharat Talkies	BW ₁₅	D	23 259057	77 4127277	14 12 2023	BW of HP Water Supply Near Patra Mandi Road in front Bhopal Wood Works
30	Murli Nagar	BW ₁₆	D	23 296865	77 4044092	14 12 2023	BW of Jaishree Auto Sales Petrol Pump Karond Circle Berasia Road
31	Palasi Village	BW ₁₇	D	23 30933	77 3978585	14 12 2023	In front of Small Temple
32	Karond	BW ₁₈	D	23 302549	77 392928	14 12 2023	BW of Vishwakarma Car Care Near Hiya Diagnostic and Sagar Gaire Karond
33	Bhopal Memorial Hospital	BW ₁₉	D	23 302584	77 4156704	14 12 2023	BW of Yukti Traders and Dheeraj Jai Sewa Near Bhopal Memorial Hospital
34	Bhanpur	BW ₂₀	D	23 303234	77 4344388	14 12 2023	BW of Neeraj Marriage Garden located in Pashu Bazaar Bhanpur
35	Khejda	BW ₂₁	D	23 300351	77 4461524	14 12 2023	BW located in the house of Vinod Pal Krana Store near Hanuman Mandir
36	Barhedi	BW ₂₂	D	23 254822	77 4193222	14 12 2023	BW of Sajjad Hussain Indian Oil Petroleum Pump on Pul Bogda Road

HP = Hand Pump, BW = Bore Well & DW = Dug Well
 S = Shallow Aquifer & D = Deep Aquifer

Table 1: Presentation of Major Ions Concentrations in the Study Area.

S. No.	Parameters Analyzed		Type of Analyte	mg/l																
	Description and Permissible Limits of BIS standards	Location		PH		EC	CO ₂	HCO ₃	ALK	Cl	SO ₄	NO ₃	F	PO ₄	BIO ₅	TH	Ca	Mg	Na	K
				6.5-8.5	750 to 3000*	120 to 360**	244 to 732***	260 to 500	250 to 1000	200 to 400	45 to NR	1.0 to 1.5	0.1 to 1.0	200 to 500	75 to 200	50 to 100	200 (max)	10 (max)		
1	Subhash Nagar	HP	S	7.1	1106	0	421	145	82	40	13	0.41	0.03	13	342	107	18	57	40	
2	Kovindpura	BW	D	7.25	1544	0	378	316	252	44	36	0.34	0.04	35	480	119	45	117	84	
3	Bakra Pahan	HP	S	6.96	1654	0	470	385	178	52	66	0.39	0.02	28	400	156	17	134	2.9	
4	Railway Cess	BW	D	7.11	1332	0	378	316	198	72	6	0.1	0.03	23	351	137	2	126	2.2	
5	Chhola	HP	S	7.02	1354	0	464	485	141	36	11	0.31	0.04	20	421	135	20	109	8.8	
6	Shree Railway Junction	HP	S	6.94	1845	0	378	316	287	95	142	0.57	0.02	22	827	212	72	45	2.6	
7	Mangalore	HP	S	7.13	745	0	275	325	89	18	9	0.05	2.33	43	262	87	23	45	25.1	
8	Rameshpur	HP	S	6.86	936	0	268	229	99	20	58	0.16	0.21	26	257	83	12	89	26.5	
9	Leihar	HP	S	6.86	502	0	214	175	40	18	5	0.05	0.09	68	203	53	17	24	2.9	
10	Gula Manoh	DW	S	6.74	606	0	201	165	72	44	8	0.05	0.11	8	203	61	12	51	7	
11	Gangaji (College St)	BW	S	6.91	812	0	378	316	72	14	8	0.3	0.08	17	243	85	7	87	2.3	
12	Chhatrapati Sambhaj (J)	BW	D	6.93	2051	0	519	425	465	34	8	0.44	0.08	22	683	135	84	175	2.5	
13	Old Bungalow	DW	S	7.54	972	0	397	325	67	26	1	0.7	0.25	29	278	55	24	92	0.1	
14	JF Nagar	BW	D	7.04	1301	0	519	425	161	12	1	0.41	0.08	24	406	113	30	116	3.4	
15	Parade Ground	BW	D	6.88	1669	0	458	375	248	48	104	0.22	0.07	23	545	182	22	142	4.5	
16	Chhatrapati Sambhaj	BW	D	6.9	1332	0	403	336	186	36	44	0.22	0.54	20	421	133	22	108	6.3	
17	Shree	BW	D	7.16	1125	0	409	335	139	18	10	0.28	0.1	26	351	131	6	93	5.5	
18	Chhatrapati Sambhaj	HP	S	7.17	1358	0	416	349	181	20	114	0.44	0.09	27	465	145	25	106	10.5	
19	Chhatrapati Sambhaj	HP	S	7.23	1074	0	354	299	129	20	24	0.52	0.1	48	351	99	25	71	4.3	
20	Chhatrapati Sambhaj	HP	S	7.23	1074	0	354	299	129	20	24	0.52	0.1	48	351	99	25	71	4.3	
21	Chhatrapati Sambhaj	HP	S	7.3	1185	0	415	349	181	20	114	0.44	0.09	27	465	145	25	106	10.5	
22	Chhatrapati Sambhaj	BW	D	7.14	2497	0	683	565	406	88	54	0.56	0.15	56	834	103	82	314	19.8	
23	Chhatrapati Sambhaj	BW	D	7.23	812	0	220	189	67	30	14	0.35	0.18	74	193	55	13	50	4.4	
24	Chhatrapati Sambhaj	BW	S	6.75	1066	0	256	219	203	26	4	0.16	0.09	25	388	143	2	75	3.6	
25	Chhatrapati Sambhaj	BW	S	7.37	745	0	275	325	82	22	15	0.31	1.09	20	228	71	12	58	10.2	
26	Chhatrapati Sambhaj	BW	D	7.07	615	0	262	215	62	16	2	0.19	0.31	24	198	61	11	47	18.1	
27	Chhatrapati Sambhaj	BW	D	7.1	1685	0	336	275	364	36	3	0.91	0.1	18	475	131	38	145	5.2	
28	Chhatrapati Sambhaj	BW	D	7.1	1685	0	336	275	364	36	3	0.91	0.1	18	475	131	38	145	5.2	
29	Chhatrapati Sambhaj	HP	S	7.61	1126	0	342	286	144	38	32	0.42	0.08	23	322	113	10	98	4.7	
30	Chhatrapati Sambhaj	HP	S	6.97	777	0	336	275	62	9	2	0.31	0.09	24	208	59	14	69	18.6	
31	Chhatrapati Sambhaj	BW	D	7.1	862	0	390	329	82	10	3	0.12	0.34	37	297	83	22	80	18.2	
32	Chhatrapati Sambhaj	BW	D	7.1	862	0	390	329	82	10	3	0.12	0.34	37	297	83	22	80	18.2	
33	Chhatrapati Sambhaj	BW	D	7.39	1020	0	405	335	65	32	9	0.76	0.13	59	223	40	30	112	5.2	
34	Chhatrapati Sambhaj	BW	D	7.17	1731	0	465	406	225	32	62	0.36	0.1	48	485	133	37	142	8.4	
35	Chhatrapati Sambhaj	BW	D	7.21	1322	0	415	349	188	30	21	0.52	0.12	56	332	61	43	151	4.9	
36	Chhatrapati Sambhaj	BW	D	7.21	1322	0	415	349	188	30	21	0.52	0.12	56	332	61	43	151	4.9	
37	Chhatrapati Sambhaj	BW	D	7.67	1563	0	416	349	252	46	6	0.11	0.09	44	292	44	37	222	5.3	
38	Chhatrapati Sambhaj	BW	D	7.67	1563	0	416	349	252	46	6	0.11	0.09	44	292	44	37	222	5.3	
39	Chhatrapati Sambhaj	BW	D	7.07	1126	0	364	296	163	26	35	0.32	0.11	30	351	109	16	88	5.5	
40	Chhatrapati Sambhaj	BW	D	7.07	1126	0	364	296	163	26	35	0.32	0.11	30	351	109	16	88	5.5	
41	Chhatrapati Sambhaj	BW	D	7.04	1456	0	275	223	207	34	32	0.31	0.11	38	515	194	7	18	5.2	
42	Chhatrapati Sambhaj	BW	D	7.04	1456	0	275	223	207	34	32	0.31	0.11	38	515	194	7	18	5.2	
43	Chhatrapati Sambhaj	BW	D	6.97	612	0	342	286	67	12	6	0.34	0.18	19	213	87	11	75	22.1	

* Derived value determined from BIS limits given for TDS ** Derived value determined from BIS limits given for Alkalinity *** Derived value determined from BIS limits given for Hardness

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Table 3 : The Summary of Water Quality Data of the Study Area Surrounding UCIL Compared with BIS (2012).

S. No.	Parameters	Min	Max	Average	Bureau of Indian Standards (IS 10500:2012)	
					Acceptable Limit	Permissible limit in the absence of alternate sources
1	pH	6.74	7.61	7.11	6.5	8.5
2	Electrical Conductivity (ECw)	502	2497	1209	750*	3000*
3	Carbonate (CO ₃)	0	0	0	120 [†]	360 [†]
4	Bi-carbonate (HCO ₃)	201	683	376	244 [†]	732 [†]
5	Alkalinity	164.96	559.88	318.30	200	600
6	Chloride (Cl)	40	465	165	250	1000
7	Sulphate (SO ₄)	9	95	33	200	400
8	Nitrate (NO ₃)	1	142	27	45	No relaxation
9	Fluoride (F)	0.05	0.91	0.34	1	1.5
10	Phosphate (PO ₄)	0.02	2.33	0.21	0.10 [#]	1.0 [#]
11	Silica (SiO ₂)	8	74	32		
12	Total Hardness (TH)	193	827	364	200	600
13	Calcium (Ca)	40	212	104	75	200
14	Magnesium (Mg)	2	92	25	30	100
15	Sodium (Na)	24	314	102	200 [#]	
16	Potassium (K)	2.2	40	9.4	10 [#]	
17	Total Dissolve Solids (TDS)	326	1623	786	500	2000
18	Boron (B)	0.00	0.228	0.066	0.5	1
19	Aluminium (Al)	0.00	0.133	0.020	0.03	0.2
20	Chromium (Cr)	0.00	0.001	0.000	0.05	No relaxation
21	Manganese (Mn)	0.00	0.581	0.102	0.1	0.3
22	Iron (Fe)	0.00	11.664	1.453	1	No relaxation
23	Nickel (Ni)	0.00	0.007	0.001	0.02	No relaxation
24	Copper (Cu)	0.00	0.012	0.003	0.05	1.5
25	Zinc (Zn)	0.001	8.373	0.315	5	15
26	Arsenic (As)	0.00	0.012	0.001	0.01	No relaxation
27	Selenium (Se)	0.00	0.006	0.000	0.01	No relaxation
28	Molybdenum (Mo)	0.00	0.011	0.003	0.07	No relaxation
29	Silver (Ag)	0.00	0.042	0.010	0.1	No relaxation
30	Cadmium (Cd)	0.00	0.001	0.000	0.003	No relaxation
31	Barium (Ba)	0.013	0.190	0.096	0.7	No relaxation
32	Mercury (Hg)	0.000	0.000	0.000	0.001	No relaxation
33	Lead (Pb)	0.000	0.020	0.002	0.05	No relaxation
34	Uranium	0.000	0.014	0.004	0.03	No relaxation
35	Strontium	0.000	0.006	0.0005	Not Mentioned	Not Mentioned

* = Derived from BIS' TDS value, † = Derived from BIS' Alkalinity value & # = WHO Values

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 Department of W.R., R.D & GR
 Central Ground Water Board
 North Central Region, Jaipur

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अशोक कुमार बिस्वास/ASHOK KUMAR BISWA
क्षेत्रीय निदेशक/Regional Director
भारत सरकार/Government of India
जल संचयन विभाग/Ministry of Jal Shiksha
जल संचयन, नदी विकास और शहरी जल आपूर्ति
Department of WRS, RD & UWS
केन्द्रीय नदी जल बोर्ड/Central Ground Water Board
अहमदाबाद-380 014/North Central