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Presence of Trihalomethanes in Chlorinated Drinking Water: Indore City-based study

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ABSTRACT

Trihalomethanes (THMs) are the most common disinfection byproducts (DBPs). When chlorine is added to the water, it reacts with the organic matter in water such as skin scales and residuals from body care products. Reaction of chlorine and organic matter results in formation of various DBPs, including THMs. Higher concentration of THMs in drinking water network may be hazardous and can cause cancer in human beings. Chloroform, the most abundant THM, and is generally abundantly observed in the samples from drinking-water supply. However, excessive exposure to DBPs may be harmful to humans. The present study was aimed to detect the presence of THMs in drinking water samples supplied to Indore, Madhya Pradesh, India. Raw, treated and finished water samples were collected from the water distribution systems of the Indore city and were subjected to gas chromatography for analysis of THMs. The study reveals that the concentration of THMs was within the acceptable limit as defined in BIS 10500: 2012 and WHO Standard.

Key words: Disinfection by products, Trihalomethanes, Water treatment, Chlorinated water.

Introduction

Treatment of drinking water involves removal of contaminants including physical processes such as settling and filtration, chemical processes such as disinfection and coagulation and biological processes such as slow sand filtration. Worldwide, a combination of processes based on the constituents listed in Table 1 are typically used for drinking water treatment.

Pre-chlorination helps in algae control and restrict biological growth. It has been observed that aeration at the time of pre-chlorination can remove dissolved ions present with small amounts of manganese. Further, coagulant aids, also known as polyelectrolyte helps to improve coagulation and floc

formation. In addition, filtration helps in removal of particles from water either by sand bed that can be washed and reused or by designed filter that may be washable.

Chlorination is a process in which harmful pathogens are eliminated from the water. However, during chlorination, not only the unwanted microorganisms are removed but several organic halogenated compounds known as chlorination disinfection byproducts (DBPs) are also formed at the same time. It has been well reported that excessive exposure to DBPs may be harmful to humans. The most common DBPs are trihalomethanes (THMs). When chlorine is added to the water, it reacts with the organic matter in water such as skin scales and residuals from body care products to form various DBPs,

Table 1.

Constituent	Unit processes for removal
• Turbidity and particles	Coagulation/ flocculation, sedimentation, granular filtration
• Major dissolved inorganics	Softening, aeration, membranes
• Minor dissolved inorganics	Membranes
• Pathogens	Sedimentation, filtration, disinfection
• Major dissolved organics	Membranes, adsorption

including THMs. The most common THMs include Chloroform (CHCl_3), Dichlorobromomethane (DCBM) (CHCl_2Br), Dibromochloromethane; (DBCM) (CHClBr_2) and Bromoform (CHBr_3). The amount of each THM formed depends on the temperature, pH and chlorine and bromide ion concentrations. THMs are often present in finished water (treated water).

Since THMs are one of the most common DBPs following chlorination, Madhya Pradesh Pollution Control Board, performed a study on presence of THMs in chlorinated drinking water of Indore city of Madhya Pradesh during the year 2018-19. For the study, samples from water treatment plant, supply chain and consumer end (raw, treated, finished, user end) were collected, characterized for concentrations of various THMs. It was observed that concentration of available THMs were within the regulated limits of drinking water as per Indian Standard 10500 (2012).

Table 2. Standard Norms for Concentrations of THMs in Potable Water (2)

S. No.	Compounds	WHO ($\mu\text{g}/\text{l}$)	BIS 10500 (2012) ($\mu\text{g}/\text{l}$)
1.	Chloroform	200	100
2.	Dichlorobromomethane	60	60
3.	Dibromochloromethane	100	100
4.	Bromoform	100	200

Materials and Method

Study Area

Indore is the most populous and the largest city of Madhya Pradesh, located on the southern edge of Malwa Plateau, at an average altitude of 550 meters above sea level and has the highest elevation among major cities of Central India. The city is 190 km west of the State capital of Bhopal. Indore lies on a borderline between a humid subtropical climate and a

tropical savanna climate. Because of its high elevation and inland location even during the hottest months the nights are relatively cool, which is known as Shab-e-Malwa. Three distinct seasons are observed: summer, monsoon and winter. Indore gets moderate rainfall of 700 to 800 millimeters during July–September due to the southwest monsoon.

Surface Water Sources

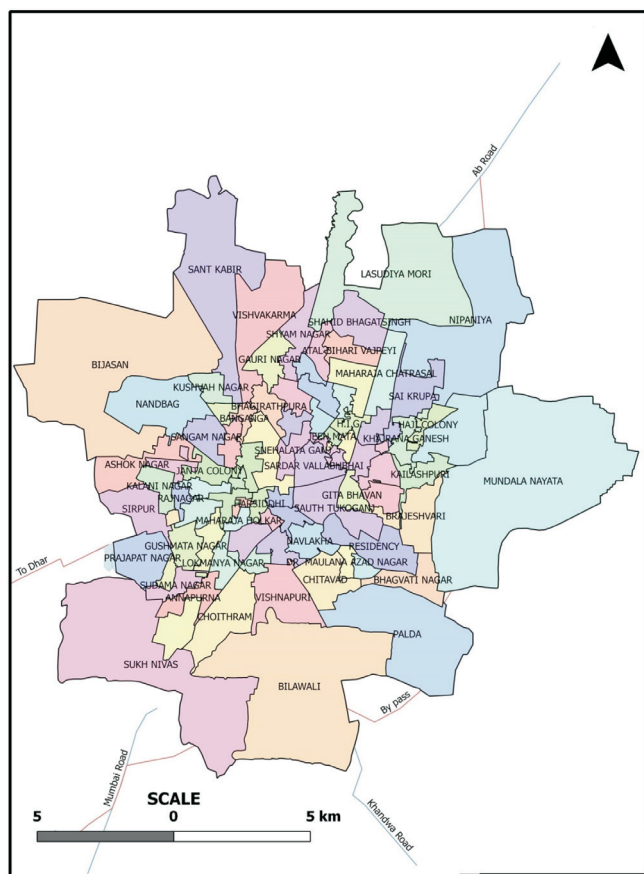
Yashwant Sagar Dam Yashwant Sagar is a dam on Gambhir river, located around 26 kilometers west of Indore near Hatod village on Indore-Depalpur road in Indore district of Madhya Pradesh. It supplies water to Indore. It is spread over around 2,650 hectares. It was built in 1939.

Jalud Water Treatment Plant Jalud Water Treatment Plant is located in Jalud village in Maheshwar Tehsil of Khargone district in Madhya Pradesh, India. The source of water supply to this plant is river Narmada.

Study Area Map

Sample Handling and Analysis

Water samples were collected from different parts of the Municipal Corporation representing main distribution network of water supply. Sampling locations are depicted in Table 3. In total, two water filtration plants and sixteen end-users were selected for sampling on a quarterly basis. Samples for THMs determination were collected in headspace-free borosilicate glass bottles, containing 1.7 ml of 10% sodium thiosulfate as quenching solution to remove any residual chlorine. Temperature, pH and concentration of free residual chlorine was measured at sampling locations. Once collected, samples were stored in the dark at 6 °C and transported to Central Laboratory, MPPCB, Bhopal for analysis. THMs including chloroform, dichlorobromomethane, dibromochloromethane and bromoform were analyzed by using the “Standard Method for the Examination of Water and Waste Water 23rd edition (2017), American Public Health Association (APHA).



Method for analysis of THMs has been developed, standardized and verified at the Central Laboratory, Madhya Pradesh Pollution Control Board, Bhopal. Analysis was done using Perkin Elmer Clarus 500 Gas Chromatography. Operating condition of the instrument during analysis is listed in Table 4.

Results and Discussion

The present study focused on the determination of trihalomethanes in chlorinated drinking water in Indore city. The results of the study reveals that THMs were not observed in raw water samples of river Narmada and Yashvant Sagar Lake. However, the occurrences of the THMs in other samples in varied concentrations were observed.

It was observed that chloroform is generated in higher concentration in all the quarters during the study period as compared to other THMs. The concentration of chloroform observed during the study is depicted in Tables 5 to 8. More specifically, the data of Narmada water filtration plant Jalod demonstrated that the concentration of chloroform was observed in range of 24.5 to 41.32 µg/l and 47.38 to 86.3 µg/l in the treated and samples

Table 3. List of sampling locations for study in different parts of Indore City

Yeshwant Sagar Water Treatment Plant Indore	Source of Sample	Type of Sample
BSF Over Head Tank	Gambhir river	Raw Treated (Chlorinated) Finished (Reservoir/Sump) stored chlorinated
Gandhi Nagar Indore Kalani Nagar Indore Tirupati Nagar Indore Sukhdev Nagar Indore Venkatesh Nagar Indore	Yeshwant Sagar Water Treatment Plant Indore	Finished (Chlorinated)
Narmada Water Treatment Plant Jalod	Narmada Water Treatment Plant Jalod	Raw Treated (Chlorinated) Finished (Reservoir/Sump) stored chlorinated
Vanchu Point near Indore Mhow Back Pressure Tank Bijalpur Station near Indore Khajrana Indore M.I.G Colony Indore L.I.G Colony Indore Nanda Nagar Indore Rajwada Indore Prem Nagar Indore Pink City 78 Scheme Indore	Narmada Water Treatment Plant Jalod	Finished (Chlorinated)

Table 4. Operating conditions of gas chromatography for analysis of trihalomethanes

Instrument		Perkin Elmer Clarus 500 GAS Chromatography		
Column	Elit-608, 30 m × 0.32 mm × 0.5 µm (film thickness)			
Detector	Electron Capture			
Carrier Gas	Nitrogen			
Flow rate	1 ml/min			
Makeup flow for detector	Nitrogen 30 ml/min			
Split Ratio	1:50			
Injector Temperature	200 °C			
Detector Temperature	290 °C			
Oven Temperature	Temp (°C)	Hold time (min)	Rate (°C)	
	35	0	10	
	180	1	0	

taken from reservoir respectively. In contrast, the concentration of chloroform at the end-user was found in the range of 28.4 to 97.41 µg/l.

Further, the concentration of chloroform, in Yashwant Sagar water filtration plant was observed in the range of 10.15 to 31.74 µg/l after treatment and concentrations of chloroform in the reservoir-stored water was found to be in the range of 78.93 to 96.71 µg/l. To add to this, the concentration at the level of end-user was found to be in the range of 47.16 to 87.66 µg/l.

In addition, the levels of free residual chlorine were found in the range of 2 to 3 ppm.

Concentration of dichlorobromomethane (DCBM) observed during the study is depicted in Tables 9 to 12.

The average concentration of DCBM was noticed in the range of 11.27 to 17.82 µg/l in the treated samples and in the range of 21.6 to 34.27 µg/l in reservoir samples of the Narmada water treatment plant, Jalod. At the end-user level, the concentration was between 1.18 to 24.85 µg/l.

At Yashwant Sagar water filtration plant, the average concentration of DCBM was found as 1.33 to 27.36 µg/l in treated and 8.15 to 24.95 µg/l in the samples obtained from the reservoir. The concentration of DCBM in the end-user samples ranged between 1.11 to 30.5 µg/l.

Further, the levels of dibromochloromethane (DBCM) were evaluated and the results are depicted in Table 13-16. It was observed that the concentration of DBCM were in the range of 10.31 to 16.85 µg/l and 7.33 to 18.74 µg/l in the treated and reservoir-stored samples of Narmada WTP and in the range of 10.06 to 21.08 and 13.14 to 25.94 µg/l in the treated and reservoir-stored samples of Yeshvant Sagar WTP, respectively .

However, at the level of end-users, the concentration of DBCM was observed in the range of 1.94 to 33.42 µg/l. More specifically, at the end-user level, the maximum concentration observed during third quarter was 34.9 µg/l at Rajwada Indore.

Lastly, the concentration of bromoform were evaluated and the results are summarized in Table 17 to 20.

It was observed that the average concentration of bromoform of treated and reservoir-stored water of Narmada water treatment plant was found as 0.46 µg/l and 1.67 µg/l respectively whereas at the end-user level, it was observed in the range between 0.4 to 4.82 µg/l.

In addition, in the Yashvant Sagar Lake WTP, the concentration of bromoform was found to be in between 0.85 µg/l to 2.11 µg/l and 1.22 to 3.62 µg/l in treated and reservoir-stored water respectively. Whereas, at the end-user level, the range varied from 0.23 to 4.17 µg/l.

In conclusion, the occurrence pattern of THMs compounds in Potable water samples of Indore city during 2018-19 observed in the order $\text{CHCl}_3 > \text{CHCl}_2\text{Br} > \text{CHBr}_2\text{Cl} > \text{CHBr}_3$

THMs compounds are found in highest concentrations during the months of July to December. This can be attributed to rainfall and winter season wherein the surface water dissolves much more solids and natural organic matter. In order to remove the solids, increased quantity of chemicals are used by treatment plants such as poly-aluminium chloride (AlCl_3) and Maxfloc T. As a result, formation of trihalomethanes is enhanced during the rainy season. In contrast, low temperature during the winter season results in reduced evaporation of chlorine which in increases the contact time of chlorine further leading to formation of trihalomethane. In the

Table 5. Average Occurrence of Concentration of Chloroform

Narmada Water Treatment Plant Jalod			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	24.5	41.32	23.74
Reservoir	47.38	86.3	67.85

Table 6. Average Occurrence of Concentration of Chloroform

Yeshwant Sagar Water Treatment Plant Indore			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	10.15	31.74	20.68
Reservoir	78.93	96.71	88.8

Table 7. Average Occurrence of Concentration of Chloroform

User End at various area of Indore city of Narmada Water Treatment Plant			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	10.15	31.74	20.68
Reservoir	78.93	96.71	88.8

Table 7. Average Occurrence of Concentration of Chloroform

User End at various area of Indore city of Narmada Water Treatment Plant			
(Unit) => µg/l			
Location	Minimum	Maximum	Average
Vanchu Point near Indore	81.75	97.41	91.42
Mhow Back Pressure Tank	66.27	88.2	78.11
Bijalpur Station near Indore	38.91	63.85	50.22
Khajrana Indore	28.4	59.58	44.73
M.I.G Colony Indore	41.08	87.19	67.14
L.I.G Colony Indore	39.82	85.27	64.04
Nanda Nagar Indore	33.61	76.45	55.23
Rajwada Indore	48.5	87.02	64.06
Prem Nagar Indore	37	76.05	58.05
Pink City 78 Scheme Indore	48.42	91.6	70.94

Table 8. Average Occurrence of Concentration of Chloroform

User End at various area of Indore city of Yeshwant Sagar Water Treatment Plant			
(Unit) => µg/l			
Location	Minimum	Maximum	Average
BSF Over Head Tank	54.17	86.09	63.52
Gandhi Nagar Indore	47.16	75.04	59.58
Kalani Nagar Indore	55.71	87.66	58.47
Tirupati Nagar Indore	57.44	82.05	69.35
Sukhdev Nagar Indore	65.11	94.82	80.33
Venkatesh Nagar Indore	48.21	81.04	65.78

present study, the observed concentrations of THMs were within the acceptable limits of BIS 10500 and WHO.

Conclusion

The main objective of the study was to determine

the concentration of trihalomethanes in chlorinated drinking water supplied to Indore city, Madhya Pradesh. The study also aimed to determine whether the drinking water supplied to residents of Indore city were within the prescribed limit of BIS 10500: 2012. It was observed that among the four

Table 9. Average Occurrence of Concentration of Dichlorobromomethane

Narmada Water Treatment Plant Jalod			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	11.27	17.82	11.44
Reservoir	21.6	34.27	28.91

Table 10. Average Occurrence of Concentration of Dichlorobromomethane

Yeshwant Sagar Water Treatment Plant Indore			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	1.33	27.36	14.06
Reservoir	8.15	24.95	14.3

Table 11. Average Occurrence of Concentration of Dichlorobromomethane

User End at various area of Indore city of Narmada Water Treatment Plant			
(Unit) => µg/l			
Location	Maximum	Minimum	Average
Vanchu Point near Indore	11.62	24.85	17.5825
Mhow Back Pressure Tank	6.55	12.83	9.2925
Bijalpur Station near Indore	3.65	23.8	12.65
Khajrana Indore	3.25	10.6	8.14
M.I.G Colony Indore	2.93	11.84	6.135
L.I.G Colony Indore	4.17	15.62	9.435
Nanda Nagar Indore	2.91	22.82	11.19
Rajwada Indore	3.45	24.16	11.8375
Prem Nagar Indore	1.18	7.45	4.8025
Pink City 78 Scheme Indore	3.82	17.25	9.045

Table 12. Average Occurrence of Concentration of Dichlorobromomethane

User End at various area of Indore city of Yeshwant Sagar Water Treatment Plant			
(Unit) => µg/l			
Location	Minimum	Maximum	Average
BSF Over Head Tank	8.05	28.33	17.885
Gandhi Nagar Indore	1.11	6.28	4.15
Kalani Nagar Indore	5.95	9.27	7.7425
Tirupati Nagar Indore	2.05	22.4	9.5275
Sukhdev Nagar Indore	3.55	30.5	13.8325
Venkatesh Nagar Indore	6.03	12.86	8.6075

Table 13. Average Occurrence of Concentration of Dibromochloromethane

Narmada Water Treatment Plant Jalod			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	10.31	16.85	10.54
Reservoir	7.33	18.74	13.75

Table 14. Average Occurrence of Concentration of Dibromochloromethane

Yeshwant Sagar Water Treatment Plant Indore			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	10.06	21.8	12.35
Reservoir	13.16	25.94	19.49

Table 15. Average Occurrence of Concentration of Dibromochloromethane

User End at various area of Indore city of Narmada Water Treatment Plant			
(Unit) => µg/l			
Location	Maximum	Minimum	Average
Vanchu Point near Indore	9.78	33.42	20.69
Mhow Back Pressure Tank	8.22	32.18	16.63
Bijalpur Station near Indore	6.28	18.33	12.33
Khajrana Indore	2.85	21.54	12.67
M.I.G Colony Indore	2.61	9.83	5.81
L.I.G Colony Indore	3.94	28.1	11.31
Nanda Nagar Indore	1.94	14.75	7.08
Rajwada Indore	3.04	24.06	17.33
Prem Nagar Indore	2.47	8.21	8.42
Pink City 78 Scheme Indore	3.86	14.06	9.5

Table 16 Average Occurrence of Concentration of Dibromochloromethane

User End at various area of Indore city of Yeshwant Sagar Water Treatment Plant			
(Unit) => µg/l			
Location	Minimum	Maximum	Average
BSF Over Head Tank	6.2	15.21	7.83
Gandhi Nagar Indore	3.89	6.46	5.61
Kalani Nagar Indore	2.25	14.56	7.59
Tirupati Nagar Indore	1.44	24.32	13.65
Sukhdev Nagar Indore	2	3.91	2.82
Venkatesh Nagar Indore	4.27	15.25	9.62

Table 17. Average Occurrence of Concentration of Bromoform

Narmada Water Treatment Plant Jalod			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	BDL	BDL	BDL
Treated	BDL	1.86	0.46
Reservoir	0.75	3.44	1.67

Table 18. Average Occurrence of Concentration of Bromoform

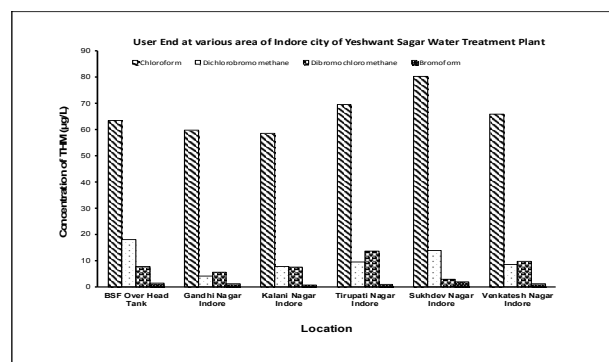
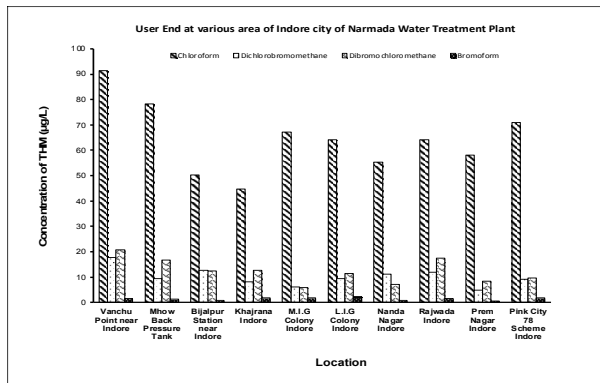
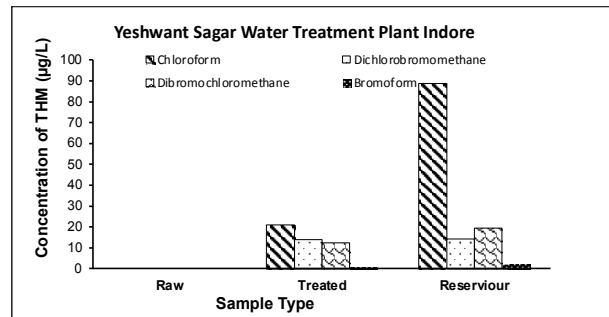
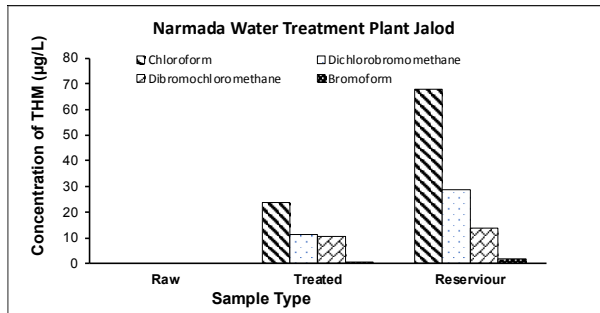
Yeshwant Sagar Water Treatment Plant Indore			
(Unit) => µg/l			
Sample Type	Minimum	Maximum	Average
Raw	ND	BDL	BDL
Treated	0.85	2.11	0.96
Reservoir	1.22	3.62	2.25

Table 19. Average Occurrence of Concentration of Bromoform

User End at various area of Indore city of Narmada Water Treatment Plant			
(Unit) => µg/l			
Location	Maximum	Minimum	Average
Vanchu Point near Indore	0.14	4.7	1.44
Mhow Back Pressure Tank	0.57	3.45	1.35
Bijalpur Station near Indore	0.58	1.02	0.81
Khajrana Indore	0.92	3.2	1.91
M.I.G Colony Indore	0.28	4.82	1.71
L.I.G Colony Indore	0.91	3.84	2.37
Nanda Nagar Indore	0.2	1.35	0.70
Rajwada Indore	0.23	3.51	1.49
Prem Nagar Indore	0.21	0.76	0.53
Pink City 78 Scheme Indore	0.38	4.17	1.68

Table 20. Average Occurrence of Concentration of Bromoform

User End at various area of Indore city of Yeshwant Sagar Water Treatment Plant			
(Unit) => µg/l			
Location	Minimum	Maximum	Average
BSF Over Head Tank	0.26	4.17	1.39
Gandhi Nagar Indore	0.23	2.95	1.3
Kalani Nagar Indore	0.28	1.21	0.69
Tirupati Nagar Indore	0.66	1.33	0.91
Sukhdev Nagar Indore	0.58	3.3	1.76
Venkatesh Nagar Indore	0.45	2.75	1.31



trihalomethanes, chloroform was generated at the highest concentration in all the quarters during the study period as compared to other THMs. Further, trihalomethanes were not found in raw water samples of Narmada water treatment plant, Jalod and Yashwant Sagar Dam water treatment plant, Indore. However, the concentration of trihalomethanes were found in the treated and reservoir-stored as well as at the end-user level indicating the formation of THMs after chlorination which is used as disinfectant in different concentration at two different treatment plants of Indore city.

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