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EVALUATION OF HEAVY METAL POLLUTION INDEX (HPI) IN GROUNDWATER SOURCES OF A PART OF BRAHMAPUTRA FLOODPLAIN ASSAM, NORTH-EAST INDIA

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ABSTRACT

Heavy metal contamination of the groundwater of a part of Brahmaputra floodplain was assessed. Around 30 samples were analyzed for heavy metals (As, Fe, Mn, Cd, Zn, Cu and Pb) using Atomic Absorption Spectrophotometer. From the study it was found that the metal As, Fe, Mn and Cd were found to be above the permissible limits. The order of their dominance was Fe>Cd>As>Mn. The concentrations of Cu, Zn and Pb were found within permissible limit. Heavy metal pollution index based on these seven heavy metals indicated that groundwater quality of this area is showing low to high degree of pollution. The mean HPI of the study area was found to be 125.55 which is above the critical HPI value of 100. The HPI shows that 63.33% of the sampling sites were found to be above the critical range. The results obtained from this study suggest a significant risk to this population given the toxicity of these metals and the fact that for many, hand dug wells and bore holes are the only sources of water supply in this region.

KEY WORDS : Heavy metals, Groundwater, Heavy Metal Pollution Index (HPI), Brahmaputra Floodplains.

INTRODUCTION

Water is considered the most valuable natural resource of this earth. It is the most vital component for sustaining life in this universe. Safe drinking water is also considered a human right. However, the resource is becoming scarce and its quality detoriating day by day pertaining to the various natural as well as anthropogenic factors. Lots of studies have also focused on the different chemicals which are present in quantities beyond the permissible limit which causes serious health concern to the population. Groundwater is a replenishable source of human water supply and it is estimated that approximately one third of the world's population uses groundwater for drinking purpose (UNEP, 1999; Nickson *et al*., 2005). It is an important water source for agricultural purposes, industrial sectors and majorly used as potable water in India (Singh *et al*., 2014; Chandra *et al*., 2015).

Among the wide range of contaminants that affect water quality, heavy metals are of particular concern due to their strong toxicity even at low concentrations and persistent nature (Marcovecchio *et al*., 2007). In the human body, trace elements can be divided into essential trace elements, such as manganese (Mn), cobalt (Co), copper (Cu), chromium (Cr), zinc (Zn), and iron (Fe), and non-essential trace elements, such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb). Essential trace elements are critical for life processes and sustainability, though they are only needed at trace level. However, excess intake of essential trace elements can also lead to adverse health effects (Magge *et al*., 2013; Zoni and Lucchini, 2013). They become detrimental to human health when their concentrations exceed the permissible level in drinking water (Prasanna *et al*., 2011). Heavy metal can cause serious health effects with varied symptoms depending on the nature and quantity of the metal ingested (Adepoju-Bello and Alabi, 2005).

There are various sources of these heavy metals in the environment. Anthropogenic activities such as industrial production, unsafe disposal of industrial wastes, agricultural wastes and domestic sewage release heavy metals into the environment (Sirajudeen *et al*., 2014). Various metals from agricultural, industrial, domestic and urban wastes may enter river and lake waters through leaching, runoff, effluents and dry deposition (Bineyand Christopher, 1991; Okoye *et al*., 1991). Many trace metals are regarded as serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity and ability to be incorporated into food chains (Abolude *et al*., 2009). Heavy metals are non-degradable and can accumulate in the human body system, causing damage to nervous system and internal organs (Lee *et al*., 2007; Lohani *et al*., 2008; Reza and Singh, 2010). Accumulation of the bio-toxic heavy metals in crops and subsequent transport in the food chain pose potential risk to human health (Nouri *et al*., 2008, Wongsasuluk *et al*., 2014; Lu *et al*., 2016). Even where no sources of anthropogenic contamination exist, there is the possibility for natural levels of toxic metals and other chemicals in groundwater becoming harmful to human health (Prasanth *et al*., 2012). Usually in unaffected environments, the concentration of most of the metals is very low and is mostly derived from the mineralogy and the weathering (Karbassi *et al*., 2008).

The heavy metal pollution index (HPI) is a rating technique that provides the composite influence of individual heavy metal on the overall quality of water. HPI is a powerful tool for ranking amalgamated influence of individual heavy metal on the overall water quality (Reza and Singh 2010, Balakrishnan and Ramu, 2016, Rizwan *et al.*, 2011) and to assess the suitability of ground water for human consumption.

Rural dwellers of Nalbari district of Assam in India, like thousands of their counterparts elsewhere in the country, rely basically on hand pumps for potable water supply, as the government water supply does not reach more than two third of the population. Since habitations are widely dispersed here unlike urban areas, monitoring and treatment is not available. Moreover, people in this area have little knowledge about the quality of their drinking water. The infrastructure needed for treatment and transportation of surface water does not exist. Besides drinking water requirements, due to very poor irrigation facilities, people of the study area have to depend on the groundwater for agricultural purpose as well. Further, the high yield rice variety, which is cultivated in these areas, requires huge quantity of water, which is extracted from shallow aquifers, ignoring its present and long-term consequences. Considering the above reasons, the present study was carried out to assess the health risk to the human population due to drinking of heavy metal contaminated groundwater with the help of heavy metal pollution index (HPI). As this type of risk assessment study has not been done in this part of the country, such a study will be of immense significance.

Study area

Nalbari district lies between latitude 26º08’03" and 26º52’15"N and longitudes 91º14’30" and 91º38’10" E and is located in the western part of the state of Assam, India (Fig. 1). The district forms a part of the Great Brahmaputra valley and is constituted of thick alluvium of Quaternary Group. The alluvium is comprised of silt, clay, sand and gravels (Central Ground Water Board Report, 1995).

It is an integral part of the sub- tropical climatic region. Summers are typically hot and humid, with day temperature ranging between 25 -39 ºC and winters are cold and dry, with day temperature ranging between 15 -25 ºC. The study area enjoys an average annual rainfall in excess of 2,318 mm. Rainfall generally occurs in the month of June to September. It is caused by the moisture-laden south-west monsoon, on striking the foothills of the north. Floods occur frequently in some parts causing great variation in the mechanical composition and chemical properties of the soil due to the deposition of the sediments.

Agriculture is the main occupation of the people of this region which demands great physical labour. Hence their intake of water and food is slightly more than their urban counterpart.

MATERIALS AND METHODS

Groundwater samples were collected from 30 locations in the Brahmaputra river basin during January 2018 (Fig 1). The samples were collected from tubewells after pumping for approximately half an hour and were stored in one-liter polyethylene bottles. For analysis of heavy metals, the sampling bottles were rinsed with the water to be sampled and the samples were preserved by acidifying to pH approximately 2 with HNO_3 and keep at a temperature of 4 ºC until analysis. These

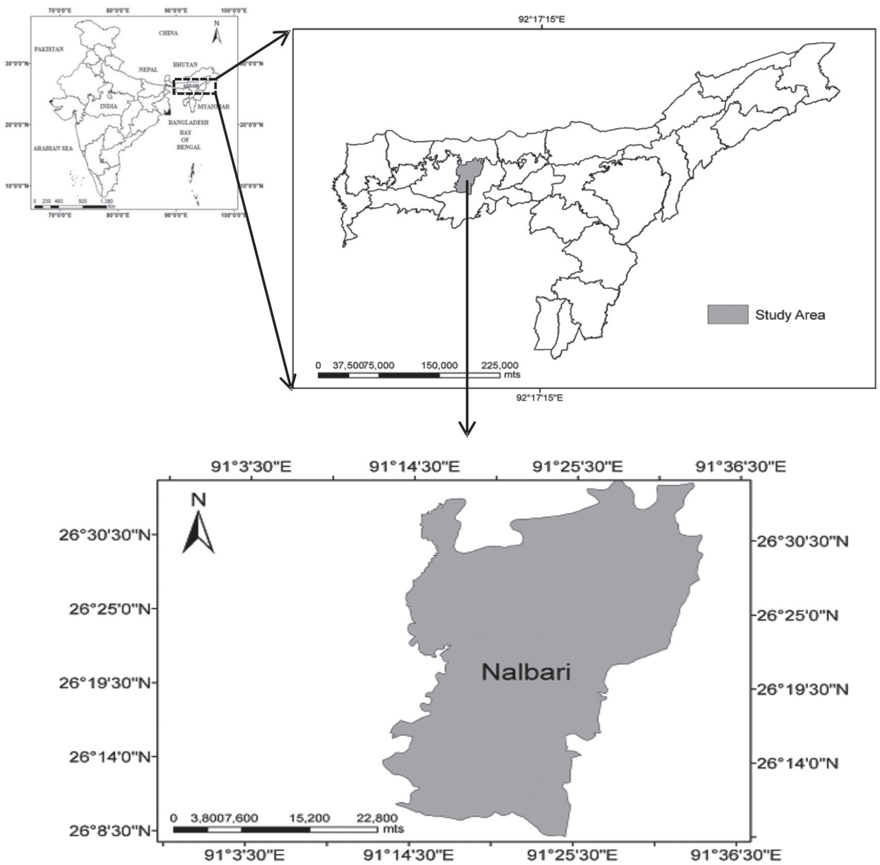

Fig. 1. Map of the study area.

samples were analyzed for 7 heavy metals: arsenic (As), iron (Fe), cadmium (Cd), copper (Cu), manganese (Mn), lead (Pb), and zinc (Zn) using Atomic Absorption Spectrophotometer. The sampling locations were mapped with the help of hand held Global Positioning system (GPS) receiver and are reported in Universal Transverse Mercator (UTM) coordinates.

Human health risk assessment is an effective approach to determine health risk levels posed by various contaminant.The Heavy metal Pollution Index (HPI) represents the total quality of water with respect to heavy metals. The proposed HPI is based on weighted arithmetic quality mean method and is developed on two basic steps: Firstly, by establishing a rating scale for each selected parameter giving weightage to selected parameter (heavy metal) and, secondly, by selecting the pollution parameter on which the index is to be based. Rating system is an arbitrary value between 0 and 1, and its selection depends upon the importance of individual quality considerations in a comparative way, or it can be assessed by making values inversely proportional to the recommended standard for the corresponding parameter. The HPI method was developed by assigning a rating or weightage (Wi) for each chosen parameter. The rating is an arbitrary value between zero and one and its selection reflects the relative importance of individual quality considerations. It can be defined as inversely proportional to the standard permissible value (Si) for each parameter (Horton, 1965; Mohan *et al*., 1996; Reddy, 1995; Prasanna *et al.*, 2012; Prasad *et al.*, 2014).

In this study, the concentration limits (i.e., the standard permissible value (Si) and highest desirable value (Ii) for each parameter) were taken from the WHO standard. The uppermost permissive value for drinking water (Si) refers to the maximum allowable concentration in drinking water in absence of any alternate water source. The desirable maximum value (Ii) indicates the standard limits for the same parameters in drinking water. Significance of the presence of heavy metals has been considered in framing the criteria for recommended limits in drinking water (BIS 2003).

The HPI, assigning a rating or weightage (Wi) for each selected parameter, is determined using the expression below (Mohan *et al*., 1996):

$$HPI=\frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi}$$

where Qi and Wi are the sub-index and unit weight of the ith parameter, respectively, and n is the number of parameters considered. The sub-index (Qi) is calculated by

$$Q_i=\sum_{i=1}^{n}\frac{\{Mi(-)Ii\}}{Si-Ii}\times 100$$

where Mi,Ii and Si are the monitored metal, ideal and standard values of the ith parameter, respectively. The sign (-) indicates numerical difference of the two values, ignoring the algebraic sign.

RESULTS AND DISCUSSION

The range and mean concentrations of the heavy metals (Fe, As, Cd, Cu, Mn, Ni and Zn in the groundwater samples of the study area are given in Table 1. The analytical results indicate that mean concentration of heavy metals in the study area followed the order Fe>Cd>As>Mn. The concentrations of Cu, Zn and Pb were found within permissible limit for drinking water quality at all sites which indicated that they were not significant source of pollution in this area.

Fe was detected in the range of 100 ppb to 6200 ppb, which exceeded the WHO permissible limit in 93% of the samples. Available literature also shows that groundwater of Assam valleys is highly ferruginous (Aowal, 1981, Singh *et al*., 2004). The source of iron in the study area may be due to leaching from ferromagnesian silicates, such as hornblende and pyroxenes. (Kortatsi *et al*., 2008). Hornblende and pyroxene is reported in the basement rock of the region (CGWB, 1995). In greater part of the Brahmaputra and Barak River valleys, iron concentration exceeds the permissible limit at shallow depths (CGWB, 2010). Excessive intake of iron may result in gastrointestinal effects like constipation, nausea, vomiting and diarrhea. Cardiaovascular and cancer risk is also associated with increased body iron stores (Dooley, 1997).

Cd in the study area varied from BDL to 38 ppb with a mean of 6.26 ppb, with 63% of the samples exceeding the permissible limit. Cadmium is highly toxic, producing symptoms such as nausea, vomiting, respiratory difficulties, cramps, and loss of consciousness at high doses. Chronic exposure to metal can lead to anemia, anosmia (loss of sense of smell), cardiovascular diseases, renal problems, and hypertension (Mielke *et al*., 1991; Robards and Worsfold, 1991). Even though the exact possibility of its origin and source cannot be ascertained, however the use of PVC plastic and electrical batteries and their unscientific disposal might have released this toxic chemical into the groundwater (Chakraborty and Sarma, 2010).

Arsenic concentration in the study area varies between 4 ppb to 100 ppb with a mean of 55.86ppb. It is seen that As is present beyond the permissible limit in 43% of the samples. Arsenic being classied as a Class 1 carcinogen; consumption of water with elevated arsenic levels can lead to a variety of chronic human illnesses including skin lesions such as keratosis, hyperkeratosis, melanosis, leucomelanosis and cancer of lung, bladder and kidney (Smith *et al*. 2003; Kapaj *et al*. 2006). It has been estimated that parts of all the states and countries surveyed in the Ganges–Brahmaputra–Meghna flood plain (GBM), which has an area of approximately 500,000 km^2, are at a risk of groundwater arsenic contamination (Chakraborti *et al*. 2004). High As concentration in the study area is

Table 1. Heavy metal concentration of groundwater in the study area

Parameter	Minimum (ppb)	Maximum (ppb)	Mean (ppb)	MAC (BIS 2012)	% sample above MAC (BIS 2012)
Arsenic	4	100	55.86	50	43.33
Iron	100	6200	2436.66	300	93.33
Manganese	70	800	370	300	43.33
Copper	2.5	100	24.45	1500	None
Lead	BDL	6	1.33	10	None
Cadmium	BDL	38	6.26	3	63.33
Zinc	2	270	46.91	15000	None

MAC: Maximum Allowable Concentration

reported is related to its geogenic nature. Hydrogeochemical study had revealed that the reductive dissolution of MnOOH and FeOOH represents an important mechanism of arsenic release in the study area along with major cations playing an important role in leaching of As into the groundwater (Choudhury *et al.*, 2014).

Manganese concentration in the study area varied between 70 ppb to 800 ppb with a mean value of 370. Mn concentration in the study area exceeded the permissible limit in 43.33% of the samples. Fe and Mn are common metallic elements found in the earth's crust (Kumar *et al*., 2010). High concentration of Mn in the Brahmaputra Flood plain is earlier reported (Chaudhary *et al.*, 2014, Chakraborty and Sharma, 2010). It is suggested that Mn could be released by incongruent or disproportionation reactions from silicate or oxide minerals (Edmunds and Smedley, 2000; Edmunds *et al.*, 2002). Numerous pathologic conditions could occur as a consequence of excess persistent intake of manganese including behavioral changes and other nervous system disorders (Elster *et al*., 1988; ATSDR, 2008).

Cu, Zn and Pb is not detected in the water samples hence the risk associated with these metals does not arise. Overdoses of copper can lead to neurological complications, hypertension, and liver and kidney dysfunctions (Rao *et al*., 2001; Krishna and Govil, 2004). The primary anthropogenic sources of Zn in the environment are metal smelters and mining activities. Lead is a commutative poison and a possible human carcinogen (Bakare-Odunola, 2005). Lead and Mercury can cause irreversible brain damage (Momodu and Anyakora, 2010). Lead is toxic, when accumulated in the body can cause nervous and kidney damage (Mugica *et al*., 2002). Lead is also reported to be a possible human carcinogen (Bakare-Odunola, 2005).

Heavy metal Pollution Index

Though comparing the determined concentration of an ion in groundwater used for drinking with the national and international standards ascertains their suitability for drinking, sometimes this alone does not stand sufficient to establish the risk of drinking groundwater as the quantity of water consumed by human is not fully taken into account. At such times, HPI gives an idea of the estimated risk of that concentration in the area.

The computational method for calculating HPI is given in the Table 2. Qi is the sub-index of the ith parameter; Wi is the unit weightage of the ith parameter; n is the number of parameters; Mi is the monitored value of heavy metal of ith parameter; Ii is the ideal value of ith parameter; Si is the standard value of the ith parameter.

The HPI of all the surface waters has also been calculated separately (Table 3) using WHO standards (Siegel, 2002; Prasanna *et al.*, 2012). In each calculation, all the seven metals were considered. This helps us to assess the ground water quality in each sampling points, which can be used to compare the index of each sample. HPI of groundwater ranges from 8.56 (sample no 8) to 269.81 (sample no 29) for the groundwater samples. The mean deviation and percentage deviation were calculated for all the samples (Table 3). Fourteen sampling points (1, 2, 4, 5, 6, 7, 8, 9, 11, 12, 13, 17, 20, 21, 22 and 24) showed that the index values are lower than the mean value and the percentage deviation is also in the negative sign, which indicates a pollution free status of water with respect to metals (Prasad and Bose, 2001). The remaining sampling points (10, 14, 15, 16, 18, 19, 23, 25, 26, 27, 28, 29 and 30) with index values more than the mean HPI value were considered as polluted water. HPI is usually classified into three categories, i.e., low degree of pollution (HPI< 90), medium degree of

Table 2. HPI Calculation for ground water sample

Heavy metal	Mean value (ppb) Mi	Standard Permissible value(ppb) Si	Unit Weightage (Wi)	Sub Index (Qi)	WiQi
Arsenic	55.86	50	0.02	172	3.44
Iron	2436.66	300	0.00333	666.667	2.22
Mn	370	300	0.00333	233.333	0.77
Copper	24.45	1500	0.00067	2	0
Lead	1.33	10	0.1	10	1
cd	6.26	3	0.33333	250	83.3
Zn	46.91	15000	0.000066	0.08	0

Table 3. Sampling points with HPI, Mean deviation and Percentage Deviation

Sample no	HPI	Mean Deviation	% Deviation
1	121.90	-4.10	-3.25
2	51.67	-74.33	-58.99
3	144.86	18.86	14.97
4	48.69	-77.31	-61.36
5	32.42	-93.58	-74.27
6	101.11	-24.89	-19.75
7	55.25	-70.75	-56.15
8	8.56	-117.44	-93.21
9	14.64	-111.36	-88.38
10	139.37	13.37	10.61
11	81.32	-44.68	-35.46
12	73.23	-52.77	-41.88
13	26.50	-99.50	-78.97
14	130.30	4.30	3.41
15	187.62	61.62	48.90
16	181.50	55.50	44.05
17	121.69	-4.31	-3.42
18	145.72	19.72	15.65
19	194.36	68.36	54.25
20	61.91	-64.09	-50.87
21	116.79	-9.21	-7.31
22	97.02	-28.98	-23.00
23	176.02	50.02	39.70
24	114.09	-11.91	-9.45
25	216.45	90.45	71.78
26	217.34	91.34	72.50
27	250.54	124.54	98.84
28	252.68	126.68	100.54
29	269.81	143.81	114.13
30	145.31	19.31	15.33

pollution (90-180), high degree of pollution (HPI >180).

The HPI along with the percentage of samples which fall in different categories is given in Table 4. The present level shows that 36.66 % of samples are within the low HPI zone, 36.67 % fall within the medium zone of pollution while 26.67% falls under the high HPI zone.

CONCLUSION

The present study reveals that the HPI based on the mean concentration level of the seven heavy metals was found to be 125.55 which is above the critical value of 100. It is found in 19 samples which accounts for 63% of the samples. The pollution was found to be maximum (HPI>180) in 27 % of the samples, medium polluted (HPI 90-180) in 36.6% of the samples and low polluted (HPI<90) in 36.6 % of the samples. Under such circumstances, where more than 80% of the population are dependent on ground water for their drinking water source there is a high health risk associated with the consumption of drinking water. In the recent years it is seen that the surface water was inadvertently replaced by groundwater, as a source of drinking water which has exposed the people to various health risks. Further there is every possibility that the heavy metals might enter the food chain. As the district is endowed with reasonable amount of surface water both in the form of rainfall and mighty riverine system, attempt should be made to use these surface water sources rather than depending on the contaminated ground water source for the drinking and agricultural needs.

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Table 4. Evaluation of ground waters quality based on HPI criteria

Index Method	Category	Degree of Pollution	No of samples	% of samples	Samples
HPI	<90	Low	11	36.67	2,4,5,7,8,9,11,12,13,20,22
	90-180	Medium	11	36.67	1,4,6,10,14,17,18,21,23,24,30
	>180	High	8	26.67	15,16,19,25,26,27,28,29

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