Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains

Occurrence and extend of arsenic and fluoride contamination in groundwater in selected districts of the Eastern Ganges Basin

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Table of Contents

1. INTRODUCTION

Arsenic and fluoride contamination in environment is a serious issue worldwide. Numerous researchers studied the occurrences and extend of these elements in the environment and their impact on human health. Arsenic is one of the hazardous elements in the environment its contamination of groundwater is widely reported worldwide, including Argentina, Bangladesh, Bolivia, Brazil, Chile, China, Cambodia, Ghana, Greece, Hungary, India, Japan, Korea, Mexico, Mongolia, Nepal, New Zealand, Poland, Taiwan, Vietnam and the USA (Aiuppa et al. 2003; Bibi et al. 2008; Buschmann et al. 2006; Casentini et al. 2011; Ravenscroft et al. 2009; Sahoo and Kim 2013; Smedley and Kinniburgh 2002; Thakur et al. 2011; Yoshizuka et al. 2010). Arsenic occurrences and its chemical form act as a major role of toxicity to humans. Methylated trivalent arsenic is more toxic than inorganic arsenic (Styblo et al., 2000). Numerous studies documented that arsenic-contaminated drinking water is a major source for the health issues of the peoples who are living in the arsenic-contaminated region. Recent studies implied that food crops are also a major route for arsenic due to the usage of arsenic-contaminated groundwater for irrigation (Rajmohan and exposure Prathapar, 2014).

Arsenic exposure causes serious health issues such as cancer in the skin, lungs, bladder, liver and the kidneys; and cardiovascular, neurological, hematological, renal, and respiratory problems (Adeel 2002; Booth 2009; WHO 2011). Health implications are generally caused due to the consumption of arsenic-enriched water. Earlier studies reported various ways of arsenic exposure, for example, inhalation, ingestion and dermal contact (Mondal and Polya 2008; Pal et al. 2007; Rahman et al. 2006b). Human exposure to arsenic is mainly through drinking water compared to food and air (Kwok 2007; Villaescusa and Bollinger 2008; Yu et al. 2007). Symptoms of acute toxicity caused by arsenic are vomiting, muscle cramps, colicky abdominal pain, tingling of the hands and feet. Chronic (i.e. long-term) exposure to arsenic provokes arsenicosis, cardiovascular diseases, skin lesions etc. (Bissen and Frimmel 2003). List of major diseases identified in arsenic-contaminated areas are hyper pigmentation, keratosis, weaknesses, anemia, burning sensation of the eyes, swelling of legs, liver fibrosis, chronic lung diseases, gangrene of toes, neuropathy, skin cancer, etc. (Government of India 2007). All these diseases are collectively referred to as arsenicosis. Arsenic toxicity to human beings varies with respect to several factors namely chemical and physical form of the arsenic compound, the dosage, duration of exposure, dietary compositions of interacting elements, age and sex of individuals, the route by which it enters the body, nutritional status of the person, immunity level of the individual etc. (DCH 1997; Khan and Ahmed 1997). Arsenic species and their behavior, especially chronic toxicological effects, lead the WHO to lower the regulatory limits of arsenic from 50 µg/L to 10 µg/L in the drinking water (Kapaj et al. 2006; Lubin et al. 2007; Mandal and Suzuki 2002; WHO 2008). The USA (USEPA 2002) and the

European Union (EU 1998) also reduced the arsenic permissible limit from 50 µg/L to 10 µg/L. Arsenic contamination in groundwater and its impact on food chain and health in Eastern Ganges basin is discussed in detail by Rajmohan and Prathapar (2014).

Fluoride generally occurs at low concentration in groundwater and it is a common constituent of groundwater. High fluoride concentration is originated by both natural such as rocks and volcanic activity and man-made activities i.e. phosphate fertilizers usage in agriculture, clays used in ceramic industries, burning of coals, etc. Besides this, other factors like residence time in aquifer, contact times with fluoride minerals, groundwater chemical composition and climate regulate fluoride enrichment in groundwater. Fluoride has significant mitigating effect against dental caries and its presence in drinking water is beneficial if $F \leq 1$ mg/l (WHO, 2010). However, the groundwater with fluoride content greater than 1.5 mg/l is not advisable for drinking as it causes serious health issues such as dental fluorosis, skeletal Fluorosis, etc. WHO recommended limit for fluoride is 1.5 mg/l in drinking water. Mottling of teeth may occur if the groundwater fluoride exceeds 1.5 mg/l. Likewise consumption of groundwater with high fluoride (3 to 6 mg/l) may cause skeletal fluorosis (WHO 2004). Further, continuous usage of groundwater with 10 mg/l of fluoride can result in crippling fluorosis.

Like arsenic, fluoride contamination is also a serious issue worldwide. Fawell et al (2006) reported that groundwater with high fluoride content occur in many areas of the world. High fluoride is identified in 28 countries such as Argentina, Brazil, Canada, China Eritrea, Ethiopia, Germany, India, Indonesia, Israel, Japan, Kenya, Mexico, Niger Nigeria, Norway, Pakistan, Saudi Arabia, Senegal, South Africa, Spain, Sri Lanka, Sudan, Thailand, Turkey, Uganda, United Republic of Tanzania and United States of America.

In this study, the primary objective is to evaluate the occurrence and extend of arsenic and fluoride contamination in groundwater, soil and food chain in the selected districts of Eastern Ganges basin and to suggest the suitable recommendations to manage the valuable groundwater resources. Districts selected for this study are distributed in India (Madhubani in Bihar; Cooch Bihar District in West Bengal) and Nepal (Saptari District). The review is based on the analysis and compilation of published literature, publically available water quality data and grey literature. This study will help for better planning and management of groundwater in the study region

2. STUDY AREAS

2.1 Bihar

Madhubani

Madhubani district lies between the north latitudes of 25º-59' to 26º-39' and east longitudes of 85°43’ and 86°42’. It occupies a total geographical area of 3501 km^2. It is bounded by Darbhanga district in the south, Sitamarhi district in the west, Kosi river in the east and Nepal in the north. Madhubani district has five sub-divisions namely Madhubani, Jaynagar, Benipatti, Jhanjharpur and Phul Paraas and 21 blocks. The district is situated just to the south of Tarai region of Nepal. Total population of this district is 4,476,044 (2011 census). The district Madhubani forms a part of Mid-Ganga basin with Kamla Balan sub-basin. The rivers originating from the Tarai zone with their tributaries are flowing towards south and meeting major rivers in India. Paddy is major crop in this district. Pisciculture is known to be one of the main sources of revenue in the district. In this district, total cropped area is 218381 hectar and 36.85% of the total agricultural land is used for paddy cultivation. Shallow tube wells, tanks and canals are the main water sources for irrigation. Groundwater usage for irrigation indicates that 38.01% of the total irrigated area is served by groundwater. The district has 868 deep tube wells and 13685 shallow tube wells. Water extraction from shallow tube wells is mainly by diesel engines.

Madhubani district experiences a sub-tropical climate and the maximum and minimum daily temperature during May is 24°C and 36°C, respectively. Occasionally, maximum temperature reaches 43°C. During winter, it varies from 10°C to 24°C. Annual rainfall varies from 900 to 1300 mm and average annual rainfall in this district is 1273.2 mm. The maximum rainfall occurs between July and August.

Geologically, Madhubani district is a plain tract situated to the south of Nepal. The northern parts of Madhubani are in touch with the Nepal Tarai zone. Madhubani district can be sub-divided into three geomorphological units namely (i) Newer Flood Plain, (ii) Older flood plain and (iii) Older alluvial plain. Flood plains noticed all along the river courses which are comprised of sand, silt and clay having largely low-lying water logged areas. Soils are classified into three categories: i) Newer Aluvium (Khadar) ii) Sandy Alluvium soil having alkaline reaction and iii) Calcareous soil. The soils in Madhubani fall in the class of largely entisols.

In Madhubani district, the quaternary alluvium is the main repository of groundwater. Granular and mixed zones are found with different thicknesses starting from the depth of 15 m bgl (below ground level) to the explored depth of 398 m bgl. The dug wells are sustained within 15 m bgl, of the formations of predominantly clay, silt and sand lenses and groundwater is unconfined (free water table). In the northern part of the district, in Ladania, Padma and Harlakhi section, the first potential aquifer exists within 15–50 m bgl (semi-confined to confined). The local farmers mostly employ this to construct shallow tube wells. Other important aquifers are present at depth ranges of 129-146 m bgl, 185-197 m bgl and 305-311 m bgl, respectively. These are artesian with an average discharge of 9.6 m^3/h (free flow discharge). These artesian aquifers have developed due to the thick confining clay layer (50–129 m bgl). The piezometric head of the wells constructed in this zone lies at 1.34–2.77 m above ground level (m agl) with the highest free flow discharge of 18 m^3/h. Places near to the rivers show silty and fine sand layers up to a depth of 20 m bgl and groundwater occurs under water table condition. In general, a thick clay bed from 10–60 m bgl with silt and fine sand bed partings covers the underlying major aquifers within 60-110 m bgl as per the state tube well drilling data. These aquifers are under confined condition. According to CGWB (2009), the yield of the wells constructed in the northern part is up to 180 m^3/h with a safe drawdown of 6–12 m. In the pre-monsoon, the depth to groundwater level varies between 4 and 7 m in south and southwestern parts and <4 m in other parts of districts.

2.2 West Bengal

Cooch Bihar

Cooch Bihar is situated between the latitude 26°32′20″ N to 25°57′40″ and longitude 89°54′35″ E to 88°47′40″ E. Total geographical area of Cooch Bihar is 3387 km^2. Cooch Bihar has 5 sub-divisions which are further divided into 12 blocks. Cooch Bihar is located in the Tista and Torsa basin. Cooch Bihar has a moderate humid climate with heavy rainfall. The minimum and maximum temperatures recorded are 3.9°C and 39.9°C, respectively. Annual average rainfall is 5348.8 mm and receives adequate rainfall from south-west monsoon (http://coochbehar.nic.in/Htmfiles/dist_summaryprofile.html). Total agricultural area of this district is 2530.63 km^2. Agricultural activities mainly depend on groundwater along with surface water from canals, tanks and rivers. Major rivers flowing in this district are Tista, Jaldhaka, Torsa and Raidak.

Cooch Bihar is divided into two geographical units namely Newer alluvium and Older alluvium. Soil in this district is sandy to clayey alluvial soils and acidic in nature. Cooch Bihar is underlain by Quaternary alluvium sediment formed by the south-flowing mountainous streams and rivers. The sediments consist of boulder, pebbles, gravels and coarse to medium sand intercalated with lenses of clay. Aquifers are confined and unconfined and groundwater occurs at depths ranges from 2.5 m to 304 m bgl. The yield of these aquifers generally varies from 80 to 170 liter per minute (lpm) with a maximum value of 350 lpm. The groundwater level fluctuates from 2 to 5 m bgl during pre-monsoon and it is from <2 to 5 m bgl during post-monsoon, respectively.

2.3 Nepal

Saptari

Saptari district is located in Terai region and it covers 1363 km^2. The district has 114 Village Development Committees (VDC) and one municipality. Total population is 639,284 and 51% of them are female (2011 census). There is a large variation in topography and the elevation varies from 61 m to 610 m amsl (above mean sea level). Based on topography, the district is divided in three zones namely Sivalic in the north (350 m to 610 m amsl), Bhanwar in the middle (elevation 150-300m amsl) and Tarai in the South (elevation 60-150m amsl). Fifty percent of the district lies in the Tarai area, which is densely populated. The Saptari district falls under arid and semi-arid hydrological zone. The annual average temperature varies between 7°C and 46°C. The average annual 11rainfall is between 1,589 mm and 2,096 mm, and fall from June to September. In this district, the southern part is covered by alluvial soil with very high fertility whereas Bhanwar and Sivalic ranges are classified by soil mixed with sand, gravel and boulder. In the Saptari district, most of the land is arable and 92817 ha is cultivated. The major crops are rice, wheat, maize, oilseed and potatoes.

3. ARSENIC OCCURRENCE AND TRANSPORT

Arsenic in the environment is originated by both geogenic and anthropogenic sources. Geogenic sources are arsenic minerals such as arsenopyrite, orpiment, realgar, claudetite, arsenolite, pentoxide, scorodite and arsenopalledenite (Smedley and Kinniburgh 2002). Flood deposits are major sources for arsenic in sedimentary formations. Besides this, industrial waste, coal combustion, oil, cement, phosphate, fertilizers, mine tailing, smelting, ore processing, metal extraction, metal purification, chemicals, glass, leather, textiles, alkalis, petroleum refineries, acid mines, alloys, pigments, insecticides, herbicides, fungicides and catalysts contribute to arsenic contamination of the groundwater, soil and air. In India, arsenic occurrences are related to numerous isolated geological sources namely Gondwana coal seams in the Rajmahal Basin in eastern India, Bihar mica belt in eastern India, pyrite-bearing shale from the Proterozoic Vindhyan range in central India, Son River Valley gold belt in eastern India and the isolated outcrops of sulfides in the eastern Himalayas (Bhattacharya et al., 2011). In the Eastern Ganges Basin, arsenic is mostly originated from natural sources, and processes (Rajmohan and Prathapar, 2014). Several studies implied that occurrence and source of arsenic in the Bengal Basin is mainly due to fluvial sediments from the Himalayas (Rajmohan and Prathapar, 2014, reference therein). In Bangladesh, high arsenic concentrations are found in the fine-grained sediments, e.g., gray clay (Hossain, 2006). Further, sulfide and oxide minerals are the original sources for arsenic in groundwater in Bangladesh (BGS, 2000). In Nepal Terai, elevated arsenic concentrations in groundwater (up to 800 μg/l) is correlated with the thickness of organic clays (Brikowski et al., 2013). Gurung et al. (2007) studied the fluvio-lacustrine aquifer sediments in Nepal, and reported that a high amount of arsenic was obtained from the fine sediments. Based on aquifer-sediment studies, Kansakar (2004) concluded that the Siwalik Hills and higher parts of the Himalayas are possible sources of arsenic in the Terai region. According to Williams et al. (2004), alluvium derived from the Siwalik group by erosion is a major source of arsenic in the groundwater of Nepal Terai. Rocks containing arsenic are widespread across the Himalayas, including the flood plain areas of the southern belt of the Terai region (Shrestha et al. 2003; NASC/ENPHO 2004).

Various factors and complex geochemical processes regulate the occurrence and transport of arsenic to the soil, water and air. Four major hypotheses are used to explain the occurrence and transport of arsenic: 1. Oxidation of pyrite, 2; Reductive dissolution of Iron oxyhydroxides; 3. Reduction and reoxidation; and 4. Competitive ion exchange (Bhattacharya et al. 2011; Das et al. 1995; Mandal et al. 1996; Ravenscroft et al. 2009; Rahman et al. 2001; Roy and Saha 2002). Detailed discussions about these mechanisms are reported elsewhere (Rajmohan and Prathapar, 2014).

4. EXTEND OF ARSENIC CONTAMINATION

4.1 Bihar

Madhubani

Groundwater in Madhubani district is generally suitable for both domestic as well as irrigation purposes and most of the elements in the groundwater are within the permissible limits of international standards (Table 1; CGWB 2009). In this district, groundwater quality varies with depth and shallow aquifer has high electrical conductivity (EC), chloride, sodium and potassium compared to deeper aquifer (Table 1). Further, excessive iron is encountered in this aquifer, which exceeds the drinking water standards. Ministry of Drinking Water and Sanitation is monitoring the groundwater quality in India through National Rural Drinking Water Program (NRDWP, 2014). They collected 4227 groundwater samples from Madhubani district and analyzed them for selected parameters. They analyzed arsenic and iron contents in 253 and 4225 samples, respectively. Data indicate that arsenic is absent/below detection limit in all samples. Iron content varies from 0.10 mg/l to 0.79 mg/l with a mean value of 0.24 mg/l and 98% of samples are within desirable limit (Fe < 0.3 mg/l) of the Indian drinking water standards (Table 2). Highest average concentration of iron in drinking water is recorded in the Madhwapur (0.35 mg/l) and Babubarthi blocks (0.28 mg/l).

Table 1: Ground water quality in Madhubani District (CGWB, 2009)

Chemical constituents*	Deeper Aquifer	Shallow Aquifer	Drinking Water Standard (As per BIS norms)	
			Highest desirable	Maximum Permissible
pH	7.0	7.42 – 8.91	6.5 – 8.5	No relaxation
EC (μS/cm)	564 - 734	500 - 2000	500	2000
Total Hardness ($CaCO_3$)	235 - 280	110 - 380	300	600
Bicarbonate	378 - 445	177 - 476	200	600
Calcium	52 - 80	12 - 44	75	200
Magnesium	16 - 35	12 - 66	30	100
Chloride	3.55 – 10.60	14 - 263	250	1000
Sulphate	< 1.0	-	200	400 if Mg<30
Nitrate	< 1.0	-	45	100
Fluoride	0.2 – 0.25	0.41 – 0.76	0.6 – 1.2	1.5
Iron	<0.1 – 3.20	-	0.30	1.0
Sodium	22 - 45	75 - 246		
Potasium	1.40	2.70	1.90 - 50	

*Unit-mg/l except EC and pH

Table 2: Descriptive statistics of Iron concentration in groundwater in Madhubani district

Blocks	Fe (mg/l)				No. of Samples Fe>0.3 mg/l	Total samples
	Min	Max	Mean	STD		
Andharathari	0.15	0.64	0.24	0.06	3	97
Babubarthi	0.12	0.78	0.28	0.10	23	162
Basopatti	0.21	0.78	0.24	0.08	2	66
Benipatti	0.10	0.62	0.21	0.07	1	142

Bisfi	0.10	0.59	0.24	0.05	2	85
Ghoghardiha	0.12	0.66	0.27	0.08	13	91
Harlakhi	0.10	0.28	0.25	0.01	0	440
Jainagar	0.10	0.29	0.23	0.03	0	124
Jhanjharpur	0.10	0.30	0.22	0.05	0	359
Kaluahi	0.21	0.29	0.25	0.01	0	195
Khajauli	0.15	0.78	0.25	0.04	4	534
Khutauna (Laukaha)	0.24	0.26	0.25	0.00	0	440
Ladania	0.12	0.66	0.27	0.08	9	83
Lakhanaur	0.00	0.28	0.25	0.00	0	451
Laukahi	0.12	0.52	0.26	0.06	2	38
Madhepur	0.20	0.27	0.25	0.00	0	147
Madhwapur	0.16	0.79	0.35	0.16	22	76
Pandaul	0.21	0.78	0.27	0.08	10	187
Phulparas	0.11	0.47	0.22	0.07	3	59
Rahika	0.12	0.22	0.12	0.01	0	195
Rajnagar	0.14	0.28	0.25	0.01	0	254
Total	*0.10*	*0.79*	*0.24*	*0.06*	*94*	*4225*

MPA (2012) carried out a water quality tests in 22 panchayats of the five districts namely Supaul, Saharsa, Khagaria, Madhubani and West Champaran in North Bihar. In Madhubani, they collected 250 water samples from handpumps, dug wells, ponds, and chaurs from five selected panchyats namely Baliya, Luckhnour, Gangapur, Hardi, Harna and analyzed for physical, chemical and biological parameters. They reported that water from handpumps have high iron content compared to dugwells and 83% of samples in Luckhnour, 73% in Harna, 70% in Baliya, 56% in Hardi and 50% in Gangapur exceeded the desirable limit of iron for drinking (Fe > 0.3 mg/l). In the case of arsenic, 21% samples collected from handpumps in Baliya panchayats exceed the drinking water limit of arsenic (As>50 μg/l). In addition, 10% of samples collected from Hardi and <3% of samples from Gangapur, Harna panchayats exceeded the drinking water standards of arsenic. This study is not correlating well with the NRDWP (2014) study. Moreover, earlier studies reported that there is a strong positive correlation between iron and arsenic occurrence (Rajmohan and Prathapar, 2014 and reference therein). High iron concentrations in groundwater indicate that the aquifer is in anaerobic conditions which enhances reduction of Fe(III) to aqueous Fe(II) an mobilization of arsenic bound to Fe(III) leading to the enrichment of iron and arsenic in the groundwater. Anaerobic conditions are favorable for arsenic release to groundwater and its mobilization. Therefore, detailed study is necessary for groundwater arsenic in the blocks where high iron concentrations is encountered in groundwater. In addition, there is no data available to assess the arsenic contamination of soil and food chain in this district.

4.1 West Bengal

Cooch Bihar

In Cooch Bihar, groundwater quality is generally good and suitable for both domestic and agricultural usage (CGWB, 2009). In this district, groundwater is slightly acidic to alkaline in nature. Electrical conductivity ranges from 66 to 599 μS/cm and chloride varies from 35 to 105 mg/l (Table 3). Groundwater in Cooch Bihar has high iron content, which ranges from 0.04 to 10.2 mg /l. Excess iron, identified in some blocks, causes quality issues, and appropriate treatment is necessary before its consumption for domestic and agricultural purposes.

Table 3: Ground water quality in Cooch Bihar district (CGWB, 2009)

Parameters	Shallow Aquifer	Drinking Water Standard (As per BIS norms)	
		Highest desirable	Maximum Permissible
pH	6.5 – 7.8	6.5 – 8.5	No relaxation
EC (μS/cm)	66-599	500	2000
Bicarbonate	40-510	200	600
Chloride	35-105	250	1000
Fluoride	0.12 – 0.37	0.6 – 1.2	1.5
Iron	0.04 – 10.2	0.30	1.0

Similarly, NRDWP (2014) also reported high iron content in groundwater in Cooch Bihar. They analyzed 8217 groundwater samples for iron content collected from 12 blocks in Cooch Bihar. Results suggest that 65% of samples have Fe > 1 mg/l and 85% of samples contain Fe >0.3 mg/l, respectively (Figure 1). Especially, groundwater samples collected from Mathabhanga-I&II, Mekliganj and Sitalkuchi blocks have high iron content (Fe > 1 mg/l) in more than 90% of the samples (Table 4).

Table 4: Distribution of Iron in groundwater in Cooch Bihar district

Blocks	% samples having Fe content (mg/l)				Total samples
	≤0.3	0.3 < Fe ≤ 1	1< Fe ≤ 4	Fe > 4	
Cooch Bihar-II	15	32	44	10	177
Cooch Bihar-I	16	32	42	9	310
Dinhata-I	12	33	50	5	1532
Dinhata-II	6	32	55	7	1231

Matha Bhanga-II	5	2	91	1	806
Matha Bhanga-I	5	6	88	2	1016
MekliganJ	3	6	90	1	214
Sitai	17	53	29	1	233
Sitalkuchi	2	5	92	1	738
Tufanganj-I	35	22	39	4	1262
Tufanganj-II	35	20	42	4	695
Total	*14*	*21*	*61*	*4*	*8217*

Based on groundwater arsenic concentration, Sengupta et al. (2009) classified Cooch Bihar district as mildly affected district since 460 out of 474 samples had As < 10 μg/l (Table 5). However, they studied only 5 blocks out of 12 in this district and the study was carried out in 2005. NRDWP (2014) screened 1549 samples for arsenic concentration collected from deep tube wells in Cooch Bihar-I block, and reported that arsenic concentration is less than 10 μg/l. As mentioned earlier, high iron content in groundwater expresses that there is a high possibility for arsenic enrichment in groundwater. Hence, detailed study is necessary to evaluate the groundwater quality for arsenic contamination. Further, there is no data available to determine arsenic contamination in soil and food chain in this district.

Table 5: Arsenic distribution in hand tube wells in Malda and Cooch Bihar districts (After Sengupta et al., 2009)

Districts	NBS (TNB)	NBS with As >10 μg/L	NBS with As >50 μg/L	n	Distribution of total samples in different arsenic concentration (μg/L) ranges						Max. As (μg/L)
					<10	11-50	51-100	101-300	301-1000	> 1000	
Malda	14(15)	13	9	4449	2127	810	488	742	260	22	1904
Cooch Bihar	5(12)	4	1	474	460	13	1				54

TNB – Total number of block, NBS – Number of block surveyed, n – number of samples analysed.

4.2 Nepal

Saptari

In the joint study carried out by NASC and ENPHO, 570 groundwater samples from various groundwater wells in Saptari district were collected and analyzed for arsenic (NASC/ENPHO 2004). They reported that 86.3% of the samples in Saptari contain less than 10 μg/l of arsenic

(Table 6). According to NASC/ENPHO (2004), population and households exposed to arsenic contamination (As>10 μg/l) in Saptari district are 1.5% and 1.9%, respectively (Table 7). Based on a review, Yadav et al. (2011) reported that 15% of groundwater samples, collected from Saptari districts, respectively, have arsenic content greater than 10 μg/l and exceeds WHO guideline value (Table 8). However, this conclusion is not very reliable since the number samples collected from these districts are very low compared to the NASC/UNICEF (2007) study. Data is not available to evaluate the arsenic enrichment in soil and food chain.

Table 6: Classification of Arsenic concentration in groundwater collected from Dhanusha, Saptari and Sunsari districts, Nepal Terai (Shrestha et al., 2003)

District	As Range (μg/l)						Total	% of TW > 10 μg/l	Min	Max	Mean	STD
	0 -10		11-50		> 50							
	No	%	No	%	No	%						
Dhanusha	238	83.5	39	13.7	8	2.8	285	16.5	0	106	7.8	14.6
Saptari	492	86.3	71	12.5	7	1.2	570	13.7	0	98	6.1	10.6
Sunsari	159	92.4	13	7.6	0	0.0	172	7.6	0	50	3.3	6.1

Table 7: Classification of population and households using arsenic tested tube wells and percentage of arsenic exposed population and households in selected districts in Nepal Terai (Shrestha et al., 2003)

District	Population using arsenic tested tube wells				% of arsenic exposed population based on		Households using arsenic tested tube wells				% of arsenic exposed household based on	
	0 - 10 μg/l	11 - 50 μg/l	> 50 μg/l	Total	WHO Guideline	Nepal Interim Standard	0 - 10 μg/l	11 - 50 μg/l	> 50 μg/l	Total	WHO Guideline	Nepal Interim Standard
Dhanusha	15,887	2,017	386	18,290	0.9	0.6	2,422	350	59	2,831	1.1	0.7
Saptari	45,981	3,890	306	50,177	1.5	0.4	6,513	646	56	7,215	1.9	0.7
Sunsari	9,071	492	-	9,563	0.2	-	849	59	-	908	0.2	-

Table 8: Status of arsenic contamination in Terai districts of the Nepal. (After Yadav et al., 2011)

District	As (μg/l)			Total test	Max. As (μg/l)	% of sample above WHO guideline value	% of sample above As>50 μg/l
	0–10	10–50	>50				
Dhanusha	157	43	9	209	106	25	4
Saptari	532	82	14	628	98	15	2
Sunsari	303	67	2	372	—	19	1

5. FLUORIDE OCCURRENCE AND TRANSPORT

Fluorine is the most reactive element in the halogen group and has a strong tendency to acquire a negative charge, and in solution forms F^- ions (Hem, 1989). Fluoride has same charge and radius as hydroxide ions. In groundwater, fluoride is a common constituent and mostly occurs at low concentration. Fluoride concentration in seawater is 1 mg/l and it is <0.5 mg/l in most rivers and lakes. It generally originates from various types of rocks and volcanic activity. In addition, usage of phosphatic fertilizers in agricultural practices and clays in ceramic industries also can result in high fluoride concentrations in groundwater. In the earth's crust, fluorite, apatite and micas are common fluorine bearing minerals and groundwater in formations containing these minerals generally have high fluoride concentrations. Fluorite (CaF_2) is a common fluoride mineral of low solubility occurring in both igneous and sedimentary rocks. The fluorine concentration in the rocks are vary with rock types; i.e. igneous (100 mg/kg (ultramafic) - >1000 mg/kg (alkali)); sedimendary (200 mg/kg (limestone) – 1000 mg/kg (shale)) and metamorphic (100 mg/kg (regional) - >5000 mg/kg (contact)) (Vasak, 1992). High fluoride groundwater is encountered in hard rock terrains, especially those with granitic (alkaline) and gneissic rocks as it has been reported from India, Pakistan, West Africa, Thailand, China, Sri Lanka, and Southern Africa (Fawell et al., 2006).

The fluoride concentration in groundwater has a strong relation with flow velocity and residence time in the aquifer. Generally, deep aquifers have elevated fluoride concentrations compared to shallow aquifer. Fluoride occurrence and transport are regulated by the solubility of CaF_2. Lowering of pH and Ca concentration in groundwater will enhance the solubility of fluorite followed by enhancement of fluoride in groundwater. In addition, cation exchange of sodium for calcium may also increase fluoride concentration in groundwater (Edmunds and Smedley, 1996). According to Vasak (1992), fluoride content will increase in groundwater during evaporation if the groundwater remains in equilibrium with calcite and alkalinity is greater than hardness. Fluoride is also derived from dissolution of evaporative salts on the surface. According to Fawell et al. (2006), high fluoride groundwater in India is a result of dissolution of fluorite, apatite and topaz from the local bedrock and it has also been reported that there is a negative correlation between fluoride and calcium concentrations in Indian groundwater.

6. EXTEND OF FLUORIDE CONTAMINATION

6.1 Bihar

Madhubani

In Bihar, groundwater in 9 districts namely Aurangabad, Banka, Buxar, Jamui, Kaimur, Munger, Nawada, Rohtas, Supaul are affected by fluoride contamination and Madhubani and Purnia are free from fluoride contamination (SOE, 2009). In Madhubani district, NRDWP (2014) screened 4227 groundwater samples for fluoride concentration collected from difference sources. Table 9 indicates that fluoride ranges from 0.11 to 1.30 mg/l with a mean value of 0.70 mg/l and within the permissible limit of drinking water standards (F<1.5 mg/l). The average concentration of fluoride varies from 0.22 mg/l (Rahika block) to 0.84 mg/l (Khajauli block) and maximum concentration is recorded in Harlakhi block in Madhubani district.

Table 9: Blockwise distribution of Fluoride concentration in groundwater in Madhubani district

Blocks	F (mg/l)				Count
	Minimum	Maximum	Mean	STD	
Andharathari	0.24	0.78	0.52	0.08	97
Babubarthi	0.25	1.11	0.55	0.09	162
Basopatti	0.41	0.95	0.56	0.12	67
Benipatti	0.22	0.72	0.45	0.18	142
Bisfi	0.40	1.12	0.54	0.10	85
Ghoghardiha	0.22	0.88	0.46	0.16	91
Harlakhi	0.11	1.30	0.81	0.12	440
Jainagar	0.30	0.80	0.59	0.09	124
Jhanjharpur	0.36	1.05	0.66	0.13	359
Kaluahi	0.45	1.04	0.83	0.11	195
Khajauli	0.22	1.11	0.84	0.14	534
Khutauna (Laukaha)	0.44	1.20	0.82	0.10	440
Ladania	0.22	0.85	0.43	0.16	83
Lakhanaur	0.46	1.03	0.82	0.11	451
Laukahi	0.32	0.72	0.57	0.08	38
Madhepur	0.46	0.99	0.78	0.12	147
Madhwapur	0.25	0.66	0.56	0.05	76
Pandaul	0.22	0.99	0.78	0.14	187
Phulparas	0.23	0.75	0.59	0.11	59
Rahika	0.22	0.22	0.22	0.00	196
Rajnagar	0.46	1.02	0.77	0.11	254
Total	*0.11*	*1.30*	*0.70*	*0.20*	*4227*

6.2 West Bengal

Cooch Bihar

The Ministry of Water Resources (2008) and SOE (2009) reported that groundwater in Bankura, Bardhhman, Birbhum, Dakhin, Dinajpur, Malda, Nadia, Purulia, Uttar Dinajpur districts is enriched in fluoride. In this assessment, Cooch Bihar is not listed. In Cooch Bihar, fluoride in groundwater varies from 0.12–0.37 mg/l (CGWB, 2009) which does not create any hazard.

6.3 Nepal

Saptari

Existing literature highlights that very limited studies have been carried out on groundwater quality monitoring in Nepal's Terai and Kathmandu valley. These studies concentrated mostly on major ions, arsenic, nutrients and bacteria in groundwater and nothing has been reported regarding fluoride. Currently there is no data available to explain the fluoride status in groundwater, soil and food chain in the Nepal, especially not in these districts.

7. RESEARCH GAPS AND RECOMMENDATIONS

This review has identified the following the research gaps:

- Data scarcity is a major issue in these districts.
- Existing literature indicates that very limited studies carried out on groundwater arsenic in these districts.
- There is no data available to evaluate arsenic contamination in soil and food chain in these districts except one or two studies in Bangladesh.
- Most of the existing studies concentrated only on arsenic not on fluoride contamination in groundwater. In Nepal, literature/data is not available to explore fluoride occurrence in groundwater, soil and food chain.
- Studies carried out by private and government sector is not correlating very well, which may be due to sampling methods, storage time, analysis procedure, etc.
- In this report, iron occurrence and distribution in groundwater is also discussed with arsenic content.
- Iron contamination in groundwater is very common in all districts and this observation highlights that the aquifer is in anaerobic condition, which enhances content of metals

and metalloids in groundwater by reduction process, especially arsenic if it is associated with iron hydroxides.

- A detailed comprehensive study is necessary to explore arsenic and fluoride occurrence in groundwater, soil and food chain in these districts as base for developing suitable groundwater management and mitigation of the arsenic and fluoride problems.

8. CONCLUSIONS

Arsenic and fluoride contamination are prominent issues worldwide. In this study, a review was carried out to explore the arsenic and fluoride occurrence in groundwater, soil and food chain in the selected districts namely Madhubani, Cooch Bihar and Saptari districts in Eastern Ganges Basin. In addition to arsenic and fluoride, iron concentrations in groundwater have been evaluated since iron and arsenic occurrence are interrelated. There is no data to evaluate the arsenic and fluoride enrichment in soil and food chain.

In India, the groundwater in the studied districts contains high iron concentrations and exceeds desirable (Fe > 0.3 mg/l) or permissible (Fe > 1 mg/l) limit of drinking water standards. In Nepal, data or literature is not available to discuss groundwater iron concentrations in Saptari districts. Existing studies reveal that groundwater arsenic contamination is encountered in all the three districts. However, severity is not even in the studied districts. In Madhubani and Cooch Bihar districts, the groundwater arsenic is not studied well. In Nepal Terai, most of the studies reported that 90% of the groundwater samples have As<10 μg/l.

Studies related to fluoride in groundwater are very limited. Fluoride concentration in groundwater in Madhubani and Cooch Bihar districts are generally lower than the drinking water standards (F < 1.5 mg/l). In Nepal Terai, data is not available to discuss fluoride concentration in groundwater and existing studies concentrated mostly on major ions, nutrients and some biological parameters in groundwater.

In summary, data scarcity is a major issue in the studied districts to explore the arsenic and fluoride contamination in groundwater, soil and food chain. High iron contents observed in groundwater in all the districts suggest that aquifer is in anaerobic condition, which favours for reduction process and subsequent release metals and metalloids to groundwater, especially arsenic if it is in the soil or aquifer sediment. Hence, detailed studies are recommended before going to do any groundwater management activities in these districts.

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