

Freshwater Quality at Risk: Global Evidence of Potentially Toxic Element Contamination

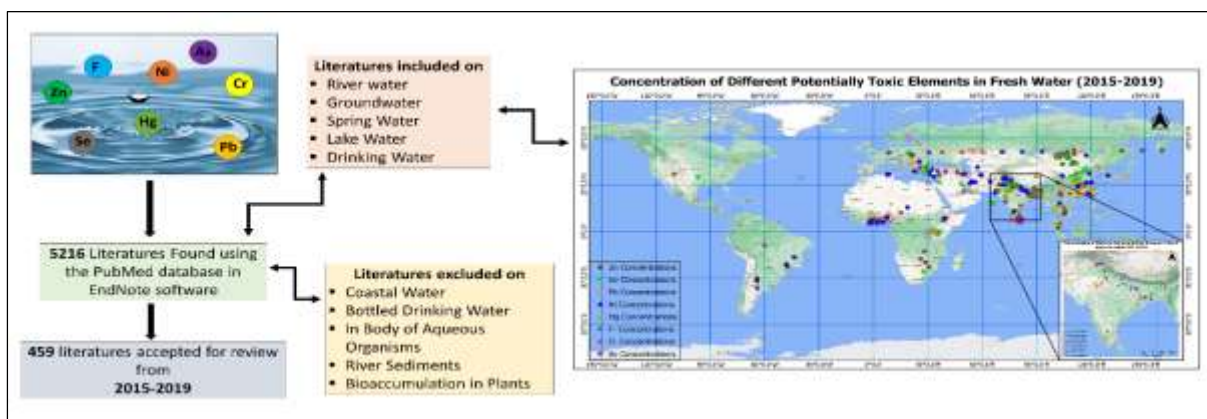
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Abstract

Water is an essential element of our lives. In natural water, several chemical and inorganic elements are present. Some of which are toxic in nature, referred to as potentially toxic elements. The presence of potentially toxic elements in fresh water exceeding the required permissible limit may cause adverse health effects if used for drinking purposes. In the present study PubMed database using EndNote software has been used for collecting data on eight potentially toxic elements i.e., Selenium, Arsenic, Lead, Fluoride, Mercury, Chromium, Nickel and Zinc. A total number of 6186 literatures have been found based on the literature search for all the elements. Among which 19 literatures for Selenium, 67 literatures for Arsenic, 142 literatures for Lead, 8 literatures for Fluoride, 43 literatures for Mercury, 74 literatures for Chromium, 49 literatures for Nickel and 88 literatures for Zinc have been selected. The major aim of the study is to find out the spatial concentration of these potentially toxic elements in fresh water at a global level. Only those studies have been selected for the purpose of the study which are available on natural water i.e., groundwater from wells and bore holes, river water, spring water, lake water, water from wetlands and drinking water. The studies based on coastal water, sea water, river sediments, bottled drinking water have not been included. The spatial distribution of all the elements in fresh water shows wide variations. In countries like the USA, Greece, Bangladesh, Mongolia, Benin and Italy, very high concentrations of these elements are found exceeding the permissible limit recommended by the WHO.

Keywords: Fresh Water; Potentially Toxic Elements; Selenium; Lead; Mercury; Chromium; Zinc; Nickel; Arsenic; Fluoride.



Graphical Abstract

1. Introduction

There are different types of biological, physical, chemical and radiological contaminants present in water in various quantities. Among the various kinds of chemical contaminants, heavy metals are playing a vital role in deteriorating the quality of drinking water. By the term ‘heavy metals’, we refer the group of those physical and chemical miscellaneous and heterogeneous elements which are both biologically and environmentally essential inorganic contaminants [1]. It generally consists of a large number of toxic metals and metalloids. For example, As, Pb, Hg, Zn, Cd, Fe, Cr, Ni, Ag, Cu, etc. In scientific literature the term heavy metal is usually replaced by the term ‘potentially toxic elements’ [1]. The term refers to those commonly known heavy metals which are toxic in nature with regard to their concentration and exposure limits for a particular organism varying from species to species in different ecosystems [1]. These potentially toxic elements enter our food chain via consumption of drinking water. Their non-degradable nature and accumulation through the trophic levels cause detrimental biological effects. The concentration of these potentially toxic elements in water is caused naturally as well as anthropogenically i.e., by various anthropogenic activities like the dumping of solid wastes, mining, untreated waste effluents from different industries, use of toxic elements containing fertilizers and pesticides in an unjustified way, etc. The commonly found potentially toxic elements are Selenium (Se), Lead (Pb), Mercury (Hg), Chromium (Cr), Zinc (Zn), Nickel (Ni), Arsenic (As), Fluoride (F⁻), etc. Some of these potentially toxic elements even in low concentrations are very essential for sustaining human lives but, elements like Pb, Hg, As, Cd are non-essential and very toxic for living organisms as well as for human lives[2]. The major objective of the study is to find out the spatial concentration of these potentially toxic elements in fresh water at a global level with the help of a systematic literature review. By careful examination of the spatial distribution of these potentially toxic elements, we can identify the source points of each of these elements from where they have entered the water source and eventually to our food chain.

2. Methodology for Data Search:

2.1. Relevant studies have been identified through a systematic search using the PubMed database in EndNote software. The studies on heavy metal or potentially toxic element concentration in water published from 2015 to 2019 have been searched using some keywords from ‘any field’. For searching the literature related to Selenium concentration in water, the selected keywords are ‘Heavy Metals’, ‘Water’ and ‘Selenium’; for Lead, the selected keywords are ‘Heavy Metals’, ‘Water’ and ‘Lead’; for Mercury, the keywords are ‘Heavy Metals’, ‘Water’ and ‘Mercury’; for Chromium, the keywords are ‘Heavy Metals’, ‘Water’ and ‘Chromium’; for Zinc, the keywords are ‘Heavy Metals’, ‘Water’ and ‘Zinc’; for Nickel, the keywords are ‘Heavy Metals’, ‘Water’ and ‘Nickel’; for Arsenic, the keywords are ‘Heavy Metals’, ‘Water’ and ‘Arsenic’; and for Fluoride, the keywords are ‘Heavy Metals’, ‘Water’ and ‘Fluoride’. The details of the literatures selected for the study are given in [Table.1](#).

Table.1. Details of Literature Review

Potentially Toxic Element	Total No. of Literature found using EndNote (PubMed)
Arsenic	678
Chromium	769
Fluoride	34
Lead	1433
Mercury	751
Nickel	574
Selenium	91
Zinc	886

2.2. Inclusion of literature: For the present study on the review of literature, only the studies available on natural water i.e., groundwater from wells and bore holes, river water, spring water, lake water, water from wetlands, and drinking water have been included. The studies mentioning the elements’ concentration (only the above-mentioned elements) in water and the amount of concentration in specific locations have been considered for this study. In the case of some studies, the average concentration for different seasons or for different samples or for a range value have been calculated by the authors for getting one single value of concentration in water for one location [3-5]. Some studies regarding a particular metal have been found using the keyword of another metal, not that particular metal. For instance, Pb concentrations in water have been found in the studies, which have been found using the keyword for another metal like Se, but not using that particular keyword i.e., Pb metal (Fig.1).

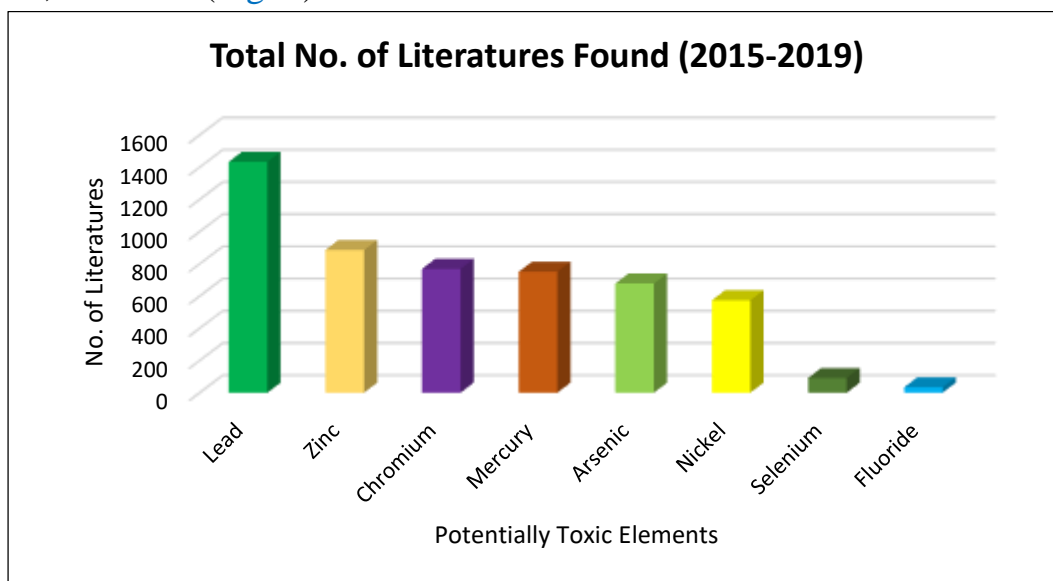


Fig.1. Total No. of Literature found using EndNote (PubMed) for 8 Potentially Toxic Elements

2.3. Exclusion of Literature: The search results using the above-mentioned keywords, showed various results like the heavy metal concentration in coastal water [6], in water from coastal lagoons [7], in bottled drinking water[8, 9], in body of aqueous organisms like pond turtles [10], in oysters [11], fishes and shrimp species [12-14], in the river sediments [15-17], bioaccumulation in plant species[18, 19], etc. These studies have not been considered for the present study. The papers in different languages rather than English have also been excluded from the present study [20, 21].

3. Concentration of Different Potentially Toxic Elements Present in Fresh Water

3.1. Arsenic (As) Concentration in Water: As is a potentially toxic element found in both organic and inorganic form in water. It has carcinogenic properties and normally found in the form of oxides or sulphides or salt with iron, sodium, copper, etc. Its inorganic forms (Arsenite and arsenate) are very much fatal to every living creature including human beings. The inorganic As are 10 to 60 times more toxic than the organic As compounds[43].

The WHO guideline value for the maximum permissible limit of As concentration in drinking water is 10 µg/l[44, 45]. If the As concentration in drinking water is 10 to 100 times higher than the permissible limit, it can cause severe health effects.

Drinking water is contaminated by As in more than 30 countries around the world. The reasons behind As concentration in water may be geological or anthropogenic. The man-made or anthropogenic sources of As include mining and ore processing activities, which indirectly affect the quality of water through soil and air pollution; use of As containing fertilizers and pesticides; use of As containing soap, paints, dyes, metals, drugs, etc. [43]. The geological source of As contamination in water is the presence of As rich pyrites in the sediments (mainly in the Gangetic plain of West Bengal, India and Bangladesh). Pyrite oxidation and iron oxyhydroxide-reduction processes are mainly responsible for As poisoning in water [46].

A total number of 678 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Arsenic (As) is given in Fig.2.

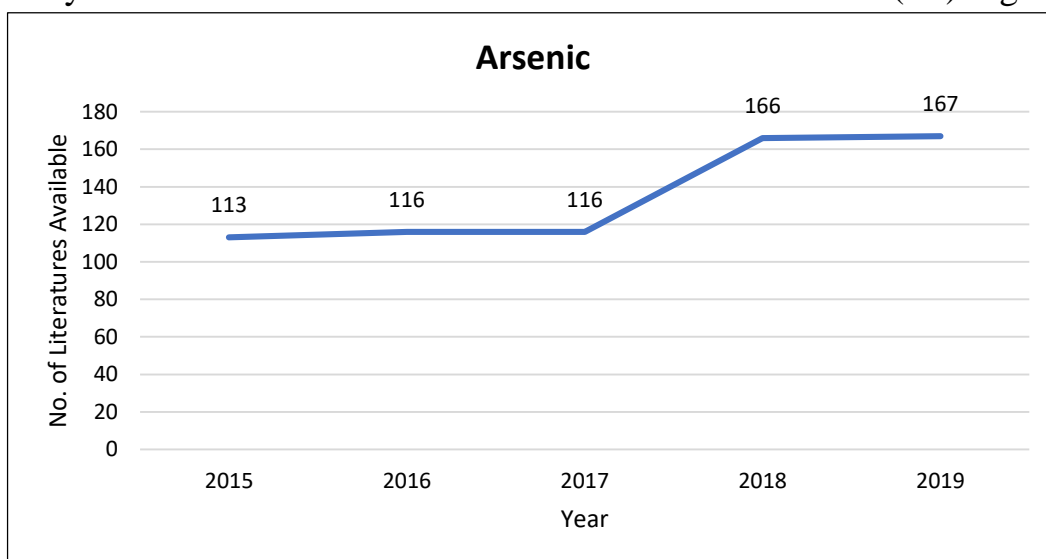


Fig.2. Total No. of Literatures Available for Arsenic (As)

Among these 678 literatures only 67 literatures have been selected for the purpose of this study which are related to the concentration of As in fresh water (Fig.3.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of As is found in Balikhora of Ghior Upazila, Manikganj District of Bangladesh (6690 $\mu\text{g/l}$) and the lowest concentration is found in the water of Xiaoqing River, China (0.00192 $\mu\text{g/l}$).

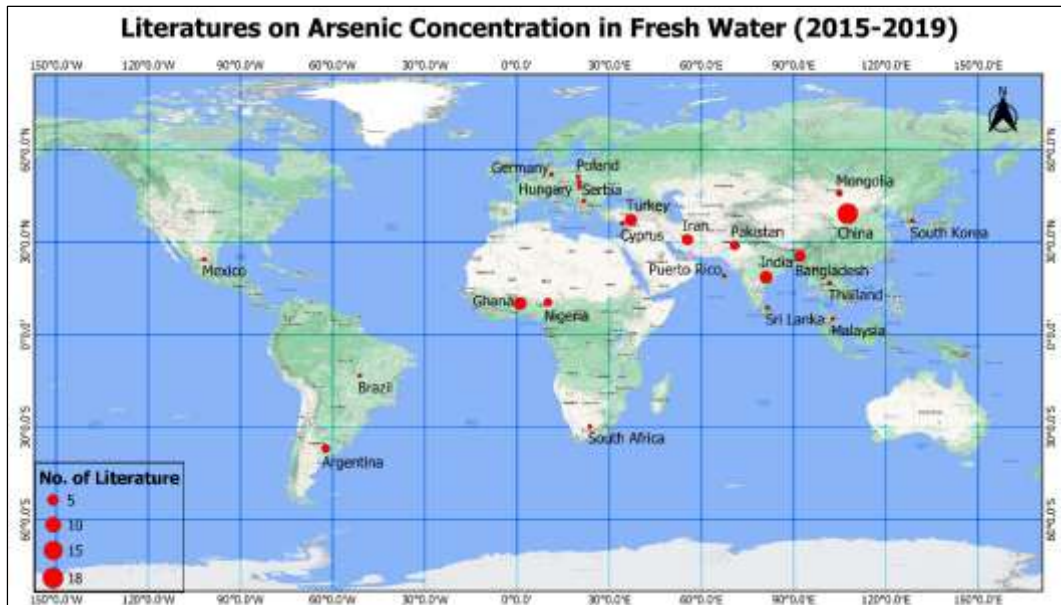


Fig.3. Literatures on Arsenic Concentration in Fresh Water (2015-2019)

The average values have also been calculated for similar sources of water in the same location. In China Zn concentrations are found in several locations (Table.2.). Zn concentrations in the water of Ma Tian and Zhu Dui of Suxian District of Chenzhou City, Hunan Province, Southern China are 2227 and 316 $\mu\text{g/l}$ [47]; in the water of Dongting lake of China is 4.2 $\mu\text{g/l}$ [48]; in the water of Taihu Lake, China is 0.07 $\mu\text{g/l}$ [49]; in lake water samples of Tai Lake, China (40 $\mu\text{g/l}$) [50]; in lake water samples of Kampar Lake, Malaysia (3.44 $\mu\text{g/l}$) [51]; and Caohai Wetland, China (1.95 $\mu\text{g/l}$) [52]; in Wen Rui Tang River Watershed, China (1.71 $\mu\text{g/l}$) [53]; in water samples from China (0.012 $\mu\text{g/l}$) [54]; and and Caohai Wetland, China (1.95 $\mu\text{g/l}$) [52]; in Yangzong Lake (50 $\mu\text{g/l}$) and Datun Lake (1,140 $\mu\text{g/l}$), China [55]; in water samples from Wei River of Shaanxi region, China (28.48 $\mu\text{g/l}$) [56]; in surface water samples of Honghu Lake, China (0.99 $\mu\text{g/l}$) [57]; in Xiaoqing River, China (0.00476 $\mu\text{g/l}$) [58]. Du Y. et al., 2018, found As concentration of 2.49 $\mu\text{g/l}$ in natural water in Lower Cambrian, Southern Shaanxi, China[33]. Nong, et al., 2019, showed As concentration in the surface water of different places of China [35]. Fang T. et al., 2019 showed As concentration in water of different lakes of China i.e., Chaohu, Taihu, Caizi, Dongting, Hulun, and Honghu Lake and Los Molinos Lake of Argentina [59]. Shao, T., et al., 2017 has found As concentrations in East Liaohe River (0.037 $\mu\text{g/l}$), Hunhe River (0.045 $\mu\text{g/l}$), Liaohe River (0.006 $\mu\text{g/l}$), Taizihe River (0.038 $\mu\text{g/l}$) and West Liaohe River (0.016 $\mu\text{g/l}$) in Liaohe River watershed, China [60]. Li, L., et al., 2018 has found As concentrations in river water downstream (15 $\mu\text{g/l}$) and in river water of mine area (185 $\mu\text{g/l}$) of Karstic river system, China [61].

Table.2. Arsenic (As) Concentration in Different Locations in China

Location	As Concentration (µg/l)	Reference
Yangzong Lake	50	Chen, G., et al., 2015
Datun Lake	1140	Chen, G., et al., 2015
Chenzhou City	1271.5	Huang X., et al., 2015
Dongting lake	4.2	Liu, J., et al., 2015
Wei River	31.425	Yang, X., et al., 2015
Tai Lake	4.5	Fu, Z., et al., 2016
Three Gorges River	2.1	Zhen, G., et al., 2016
Upper Han River	14.16	Zhen, G., et al., 2016
Xijiang River	2.533333	Zhen, G., et al., 2016
Beijiang River	19.53	Zhen, G., et al., 2016
Dongjiang River	0.46	Zhen, G., et al., 2016
Caohai Wetland	1.95	Hu, J., et al., 2017
Caohai Wetland	1.9499	Hu, J., et al., 2017
Honghu Lake	0.99	Li, F., et al., 2017
Liaohe River Watershed	0.0284	Shao, T., et al., 2017
Shaanxi	2.49	Du, Y., et al., 2018
Taihu Lake	0.07	Bi, B., et al., 2018
Karstic River System	100	Li, L., et al., 2018
Xiaoqing River	0.00476	Li, Q., et al., 2018
Wen Rui Tang River Watershed	1.71	Qu, L., et al., 2018
Chaohu Lake	0.33	Fang, T., et al., 2019
Caizi Lake	3.21	Fang, T., et al., 2019
Taihu Lake	1.37	Fang, T., et al., 2019
Dongting Lake	3.62	Fang, T., et al., 2019
Hulun Lake	132.68	Fang, T., et al., 2019
Honghu Lake	0.99	Fang, T., et al., 2019
Danjiangkou Reservoir	0.86	Nong, et al., 2019
Dongting Lake	0.9	Nong, et al., 2019

Saleh H.N., et al., 2019, showed Arsenic concentration in water at different sites of Iran [62]. Zn concentrations are found in the lake water of Shadegan Wetland, Iran (2.7 µg/l) [36]; in well water samples from Iranian Market (6.3 µg/l) [9]; in drinking water in Mashhad city, Iran (0.18 µg/l) [63] (Table.3.).

Table.3. Arsenic (As) Concentration in Different Locations in Iran

Location	As Concentration (µg/l)	Reference
Iranian Market	6.3	Hadiani, M.R., et al., 2015
Haraz River	55.35	Zhen, G. et al., 2016
Mashhad City	0.18	Alidadi, H., et al., 2019
Neyshabur	1.07	Saleh, H.N., et al., 2019
Chakaneh	3.87	Saleh, H.N., et al., 2019
Kharv	0.52	Saleh, H.N., et al., 2019
Ghadangah	3.07	Saleh, H.N., et al., 2019
Darrood	2.75	Saleh, H.N., et al., 2019
Shadegan Wetland	2.7	Yavar Ashayeri, N. & Keshavarzi B., 2019

Kose E. et al., 2015, showed As concentration in different places along the Porsuk Stream of Turkey[64]. Durmaz E, et al., 2016 found As concentration in water in four sites i.e., Isikh (6.7µg/l), Saraykay (6.9µg/l), Soke (8.6µg/l), and Tasburun (1.4µg/l) on Buyuk Menderes River in Turkey [30]; in the water of Bogacayi River at Antalaya in Turkey is 0.43 µg/l[65] (Table.4.).

Table.4. Arsenic (As) Concentration in Different Locations in Turkey

Location	As Concentration (µg/l)	Reference
Porsuk Stream	15.75	Kose, E., et al., 2015
Tigris River	0.63	Zhen, G., et al., 2016
Buyuk Menderes River	5.9	Durmaz, E., et al., 2017
Bogacayi River	0.43	Cengiz, M.F., et al., 2017
Dil Deresi	50	Nong, et al., 2019

As concentrations in water in different regions of China, Iran and Turkey are depicted in Fig.4.

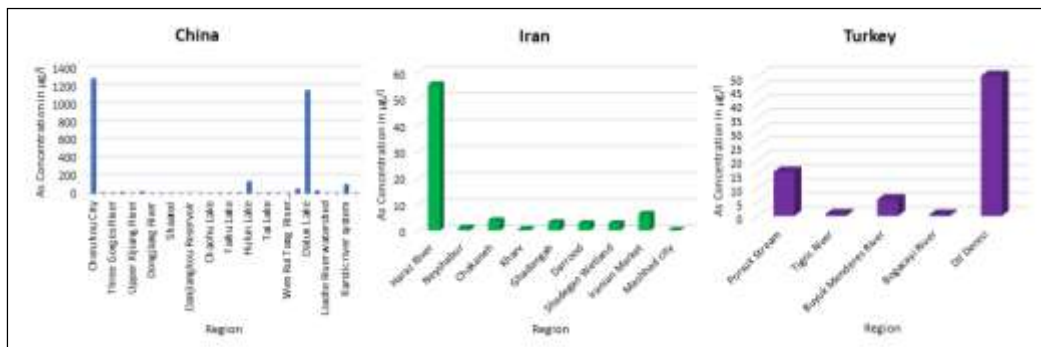


Fig.4. Arsenic (As) Concentration in Fresh Water in China, Iran and Turkey

Rasool et al., 2016 found the concentration in the drinking water of Sargana and Mailsi area of Pakistan [66]. As concentrations are found in drinking water samples in Lahore (51 µg/l), Jhang (22 µg/l), Multan (24 µg/l), Vehari (50.4 µg/l) and Swabi (0.35 µg/l) regions of Pakistan [67]; in lake water samples of Manchar Lake, Pakistan (96.6 µg/l), Manga Mandi (672 µg/l), Waran Piranwala (681 µg/l), Kalanwala (1889 µg/l), Jamshoro (59.5 µg/l) and Hyderabad (7.25 µg/l) regions of Pakistan [68]; in drinking water samples collected from tap water and hand pumps (30 µg/l) and surface water samples collected from the Chenab river and canals i.e., Jhang Branch Upper Canal, Rakh Branch Canal, Gugera Branch Canal (10 µg/l) in Faisalabad, Pakistan [39] (Table.5.).

Table.5. Arsenic (As) Concentration in Different Locations in Pakistan

Location	As Concentration (µg/l)	Reference
Sargana	165.82	Rasool, et al., 2016
Mailsi	145.6	Rasool, et al., 2016
Manchar Lake	96.6	Rehman, K., et al., 2018
Manga Mandi	672	Rehman, K., et al., 2018
Waran Piranwala	681	Rehman, K., et al., 2018
Kalanwala	1889	Rehman, K., et al., 2018
Jamshoro	59.5	Rehman, K., et al., 2018
Hyderabad	7.25	Rehman, K., et al., 2018
Punjab and Khyber Pakhtunkhwa Province	29.55	Hussain, S., et al., 2019
Faisalabad	20	Mahfooz, Y., et al., 2019

As concentrations are found in Charigram, Talibpur, Singair, Jamsha, Joy Mantop, Jamirta, Saista villages of Singair Upazila; Balla, Gala, Chala, Balara, Harukandi, Ramkrishnapur, Boyra of Harirampur Upazila; Katla Hat, Nali, Baniajuri, Balikhora of Ghior Upazila, Manikganj District of Bangladesh [69]. As concentration is 9.88 $\mu\text{g/l}$ in the water of Pasur River, Khulna city, Bangladesh [70]. The concentration of As in the water of Buriganga River at both Rayer Bazar and Pagla of Bangladesh is 134 $\mu\text{g/l}$, in the water of Karatoa River is 41.5 $\mu\text{g/l}$, in the water of Pasur River at Mongla is 52.5 $\mu\text{g/l}$ [71]. Rahman et al., 2015 showed the concentration in the water of different places of the Gangetic Plain in India and Bangladesh [72] (Table.6.).

Table.6. Arsenic (As) Concentration in Different Locations in Bangladesh

Location	As Concentration ($\mu\text{g/l}$)	Reference
Singair Upazila, Manikganj District	880	Aktar, et. al., 2015
Harirampur Upazila, Manikganj District	2574.286	Aktar, et. al., 2015
Ghior Upazila, Manikganj District	3100	Aktar, et. al., 2015
Noakhali	297.5	Rahman, et al., 2015
Korotoa River	41.5	Zhen, G. et al., 2016
Pasur River	9.88	Ali, M.M., 2018
Buriganga River	134	Islam, M.M., et al., 2018
Karatoa River	41.5	Islam, M.M., et al., 2018
Pasur River	52.5	Islam, M.M., et al., 2018

As concentrations are found in the water samples, collected from different sources (bore holes, streams, and dug-outs) in Nangodi and Tinga of Ghana are 2 and 31 $\mu\text{g/l}$ respectively[73]; in River Tano in Bono, Bono East, and Ahafo Regions, Ghana (12 $\mu\text{g/l}$) [74]. Hadzi G. Y., et al., 2015, showed As concentration in different river waters in different places[75]. The As concentration in the water of Prestea Huni District of Ghana is 170 $\mu\text{g/l}$ [4]. As is concentrated (8.81 $\mu\text{g/l}$) in the groundwater near the gold mine area of Obuasi, Ghana[76]. Hadzi G.Y., 2018 has found As concentrations in Nyam River (208 $\mu\text{g/l}$), Subri River (6.5 $\mu\text{g/l}$), Birim River (12 $\mu\text{g/l}$), Bonsa River (3 $\mu\text{g/l}$), Atewa Forest River (5 $\mu\text{g/l}$), Ankasa River (2.5 $\mu\text{g/l}$) and Bosomkese Forest River (2.5 $\mu\text{g/l}$) in Ghana [77]. As

concentrations are found in borehole drinking water samples in Tarkwa, Ghana (0.63 µg/l) [78] (Table.7.).

Table.7. Arsenic (As) Concentration in Different Locations in Ghana

Location	As Concentration (µg/l)	Reference
Tarkwa	0.63	Bortey-Sam, N., et al., 2015
Tinga	31	Cobbina, S., et al., 2015
Nangodi	2	Cobbina, S., et al., 2015
Tarkwa	2	Hadzi, G.Y., et al., 2015
Atewa	2	Hadzi, G.Y., et al., 2015
Kenyasi	3	Hadzi, G.Y., et al., 2015
Bosomkese	3	Hadzi, G.Y., et al., 2015
Bekwai	3	Hadzi, G.Y., et al., 2015
Obuasi	8.81	Bempah, C.K., & Ewusi A., 2016
Prestea Huni District	170	Obiri, S., et al., 2016
Nyam River	208	Hadzi, G.Y., et al., 2018
Subri River	6.5	Hadzi, G.Y., et al., 2018
Birim River	12	Hadzi, G.Y., et al., 2018
Bonsa River	3	Hadzi, G.Y., et al., 2018
Atewa Forest River	5	Hadzi, G.Y., et al., 2018
Atewa Forest River	2.5	Hadzi, G.Y., et al., 2018
Bosomkese Forest River	2.5	Hadzi, G.Y., et al., 2018
River Tano	12	Nyantakyi, A.J., et al., 2019

As concentrations in water in different regions of Pakistan, Bangladesh and Ghana are depicted in Fig.5.

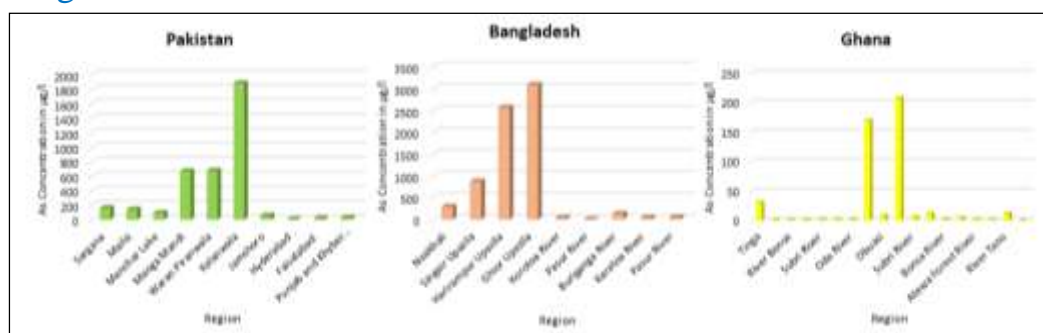


Fig.5. Arsenic (As) Concentration in Fresh Water in Pakistan, Bangladesh and Ghana
 As Concentration in the water of El Comredo Dam on the San Lorenzo River is 21.27 $\mu\text{g/l}$ [79]. As concentration in the water of Biala Przemsza River is 3.36 $\mu\text{g/l}$ [80]; in the water of Ugljesnica River of Serbia is 1.1625 $\mu\text{g/l}$ [81]. Zhen G. et al., 2016, showed As concentration in some rivers of different countries[82]. Arsenic Concentration in the water of Gonyeli Lake, Cyprus is 56.7 $\mu\text{g/l}$ [83]. Tabelin C. B., 2018, found that the development and utilization of geothermal fields for power generation have caused dramatic increases in the concentrations of As (up to 240 $\mu\text{g/l}$) in groundwater and surface water, which are utilised for drinking and irrigation purposes [31]. Golubkina N., et al., 2018, showed As concentration in the water of different sites of Mongolia[32]. Griboff J. et al., 2018 showed As concentration of 1.225 $\mu\text{g/l}$ in the water of Los Molinos lake, Cordoba, Argentina [34]. As has been noticed to be concentrated in the river water of Asejire River near Asejire town, Eleyele River in Ibadan, in Erinle River at Ede, Osun State and Dandaru River of Orita-Mefa, Ibadan, Nigeria[84]. H.M.A., et al., 2018 showed As concentration in well water of different districts of Sri Lanka [85]. The concentration of As in the groundwater and surface water of Ado-Odo Ota in Osun State, Nigeria is 45.26 $\mu\text{g/l}$ [86]; in the water of Hyeongsan River and its tributaries in Pohang City, South Korea is 1.856 $\mu\text{g/l}$ [87]. Fang T. et al., 2019 showed As concentration in water of Los Molinos Lake of Argentina [59]. As concentrations are found in drinking water samples of La Pampa, Argentina (2652 $\mu\text{g/l}$) [68]; in river water of Vieira River, Montes Claros, Brazil (1.3 $\mu\text{g/l}$) [88] (Fig.6.).

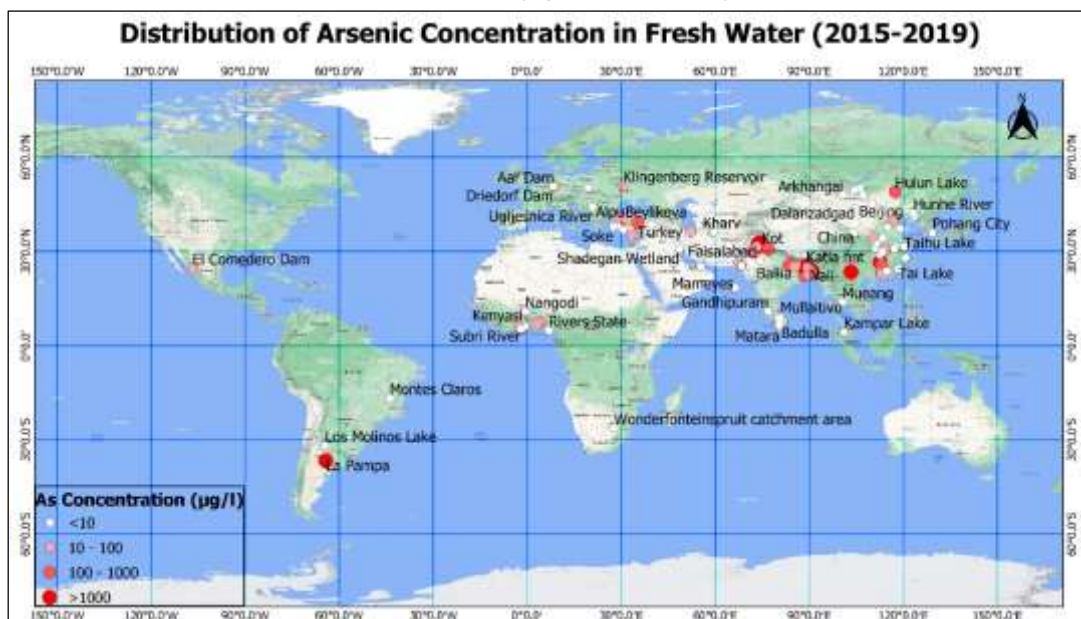


Fig.6. Spatial Distribution of Arsenic (As) Concentration in Fresh Water (2015-2019)
 As concentrations are found in WonderfonteinSpruit catchment area, South Africa (2.264 $\mu\text{g/l}$) [37]. Nagy, A.S., et al., 2016 has found As concentration of 7.03 $\mu\text{g/l}$ in water samples from Danube River located near Hungarian and Slovakian border [89]. Ortiz-Colón, A.I., et al., 2016 has found As concentrations of in river water samples from Mameyes (less than 0.150 $\mu\text{g/l}$), Rio Piedras (0.563 $\mu\text{g/l}$ to 0.928 $\mu\text{g/l}$) and La Plata (0.796 $\mu\text{g/l}$ to 1.717 $\mu\text{g/l}$) Rivers in Puerto Rico [38]. As concentrations are found in borehole water samples from Rivers State, Nigeria (0.06 $\mu\text{g/l}$ to 0.2 $\mu\text{g/l}$) [90]; in river water samples from Selenga River

basin, Mongolia (7.53 $\mu\text{g/l}$) [91]. Hahn, J., et al., 2018 has found As concentrations in pore water samples from Aar Dam (22.2 $\mu\text{g/l}$), Driedorf Dam (0.9 $\mu\text{g/l}$) and Klingenberg Reservoir (13.6 $\mu\text{g/l}$) in Germany [92]. As concentrations are found in drinking groundwater from Mueang district in the Ubon Ratchathani province, Thailand (1.584 $\mu\text{g/l}$) [93].

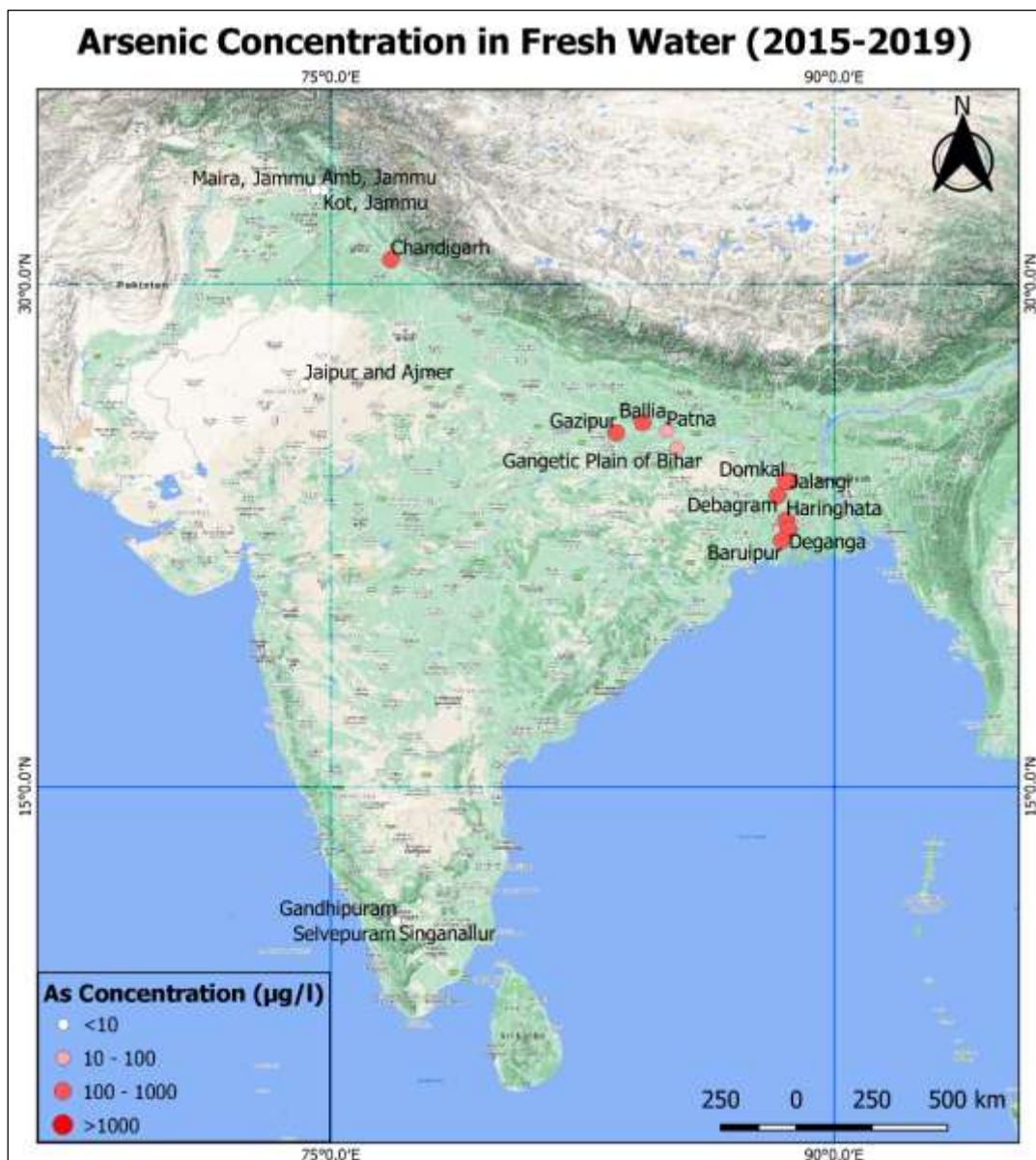


Fig.7. Spatial Distribution of Arsenic (As) Concentration in Fresh Water in Different Regions of India

In India (Fig.7.), As concentrations are found in the ground water of Debagram, Nadia District of India is 266 $\mu\text{g/l}$ [40]; in the water of different places of Coimbatore District, Tamil Nadu, India[94]; in the drinking water of Ballia (32.14 $\mu\text{g/l}$) and Gazipur Districts (52 $\mu\text{g/l}$) of Uttar Pradesh; and Maner Block of Patna District of Bihar (331 $\mu\text{g/l}$)[95]; in drinking water samples in Jaipur and Ajmer districts, Rajasthan, India (0.10 $\mu\text{g/l}$ to 5.36 $\mu\text{g/l}$) [42]; in water samples form handpumps in Gangetic plain of Bihar, India (27.5 $\mu\text{g/l}$) [96]; in groundwater in Chandigarh, India (136 $\mu\text{g/l}$) [97]. Rahman et al., 2015 showed the concentration in the water of different places of Gangetic Plain in India and Bangladesh i.e.,

Jalangi, Domkal of Murshidabad District; Deganga of North 24 Parganas; Haringhata of Nadia; and Baruipur of South 24 Parganas District in West Bengal, India [72]. Kumar A. et al., 2016, showed As concentration in the drinking water of Amb, Kot, Maira of Jammu District (presently the UT of Jammu and Kashmir), India as 0.46, 0.23, and 0.08 µg/l respectively [98]. The concentration values of As in different parts of India are depicted in Fig.8.

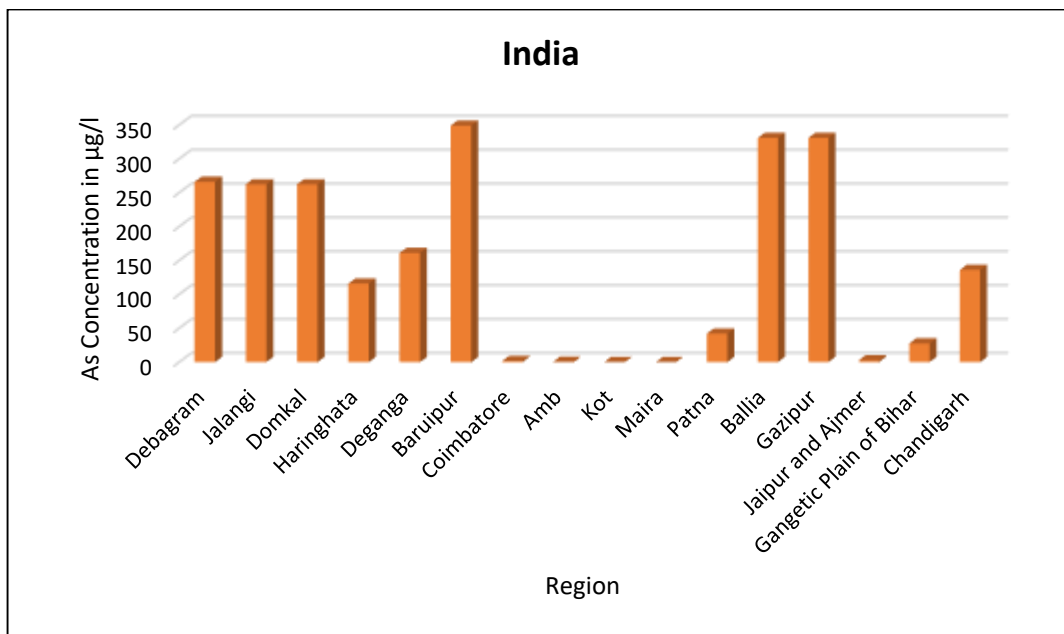


Fig.8. Arsenic (As) Concentration in Different Regions of India

The country wise As concentration in fresh water shows that highest mean and SD of As concentration i.e., 1491.6352 µg/l and 1694.290735 µg/l respectively are found for Bangladesh. It is followed by Argentina and Pakistan. In these countries the average As concentrations are more than 100 µg/l. In Germany, Nigeria, Mexico, Ghana, Turkey, Cyprus, India and China, the average As concentrations are from 10 to 100 µg/l. The average As concentrations in Puerto Rico, Sri Lanka, Serbia, Brazil, Thailand, South Korea, South Africa, Mongolia, Poland, Malaysia, Hungary and Slovakia and Iran are within the permissible limit i.e., 10 µg/l as directed by the WHO (Table.8.).

Table.8. Country Wise Average Arsenic (As) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
Cyprus	56.7	-
Germany	12.23333	8.749222
Hungary and Slovakia	7.03	-
Poland	3.36	-
Developing Countries		
Argentina	884.8183	1249.586
Bangladesh	1491.635	1694.291
Brazil	1.3	-

China	89.47231	354.6861
Ghana	26.49666667	58.20530846
India	87.89133	115.9107
Iran	8.423333	16.6848
Malaysia	3.43875	-
Mexico	21.27	-
Mongolia	2.552556	2.515099
Nigeria	16.23167	13.87854
Pakistan	260.3013333	485.5330765
Puerto Rico	0.717333	0.452166
Serbia	1.1625	-
South Africa	2.264286	3.122233
South Korea	1.856	-
Sri Lanka	0.958333	1.69507
Thailand	1.584	-
Turkey	27.54125	56.04277

3.2. Chromium (Cr) Concentration in Water: Chromium (Cr) is the 7th most abundant element presents on the Earth., The most common forms of Cr are Chromium trivalent (Cr^{+3}) and Chromium hexavalent (Cr^{+6}), being both are toxic (though Cr^{+6} is extremely toxic) for human being and animals. Cr is insoluble in water in its reduced form (Cr^{+3}), whereas, the oxidized form (Cr^{+6}) is soluble and thus mobile in water. The major sources of Cr are petroleum from ferro chromate refractory material, pigment oxidants, catalyst, chromium steel, fertilizers, oil well drilling, and metal plating tanneries and are released in the environment through sewage and fertilizers. The industries like metallurgy, electroplating, paints and pigments, tanning, wood preservation, chemical production, paper and pulp, etc. play an important role in the production of Cr. The WHO standard limit for Cr concentration in water is 50 $\mu\text{g}/\text{l}$. Different studies show Cr concentration in water at different locations. A total number of 769 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Chromium (Cr) is given in [Fig.9](#).

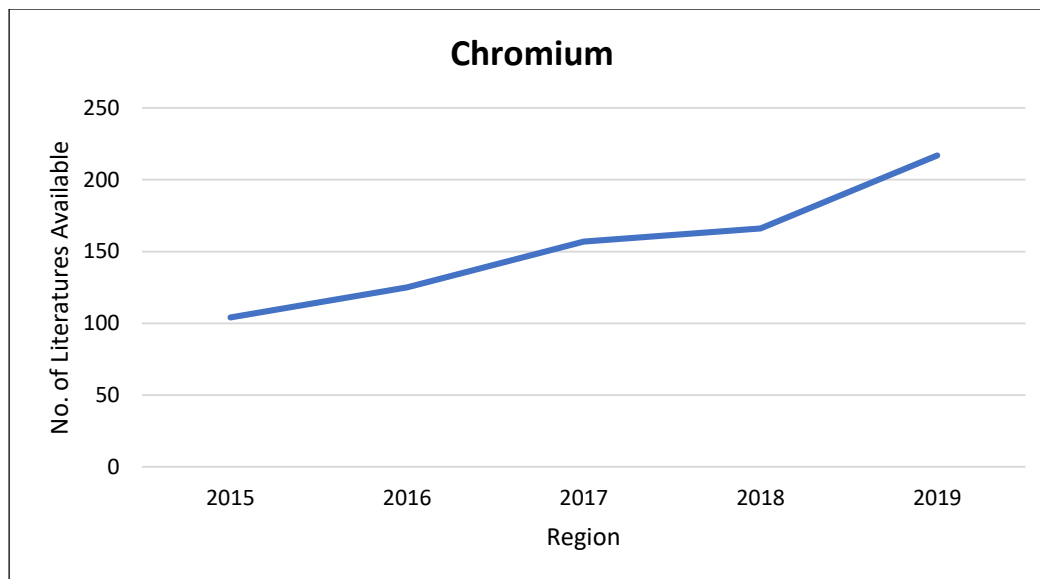


Fig.9. Total No. of Literatures Available for Chromium (Cr)

Among these 769 literatures only 74 literatures have been selected for the purpose of this study which are related to the concentration of Cr in fresh water (Fig.10.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of Cr is found in Brownfield, China (93060 $\mu\text{g/l}$) and the lowest concentration is found in Taizihe River, China (0.004 $\mu\text{g/l}$).



Fig.10. Literatures on Chromium Concentration in Fresh Water (2015-2019)

The average values have also been calculated for similar sources of water in the same location. Nong et al., 2019, showed Cr concentration in water (Table.9.) from 29 fixed stations of Middle Route (MR) of the South-to-North Water Diversion Project of China (SNWDPC) in four places i.e., Henan Province, Hubei Province, Tianjin Municipality and Beijing capital, and calculated an average Cr concentration of 4.009 $\mu\text{g/l}$ and also found Cr concentration in the water of Danjiangkou Reservoir, Dongting Lake of China [35]. Cr concentration in the water of Dongting Lake, China is 4 $\mu\text{g/l}$ [48]; in the water of Caohai Wetland of China is 3.884 $\mu\text{g/l}$ [106]; in the groundwater of Lower Cambrian, southern Shanxi, China is 3.06 $\mu\text{g/l}$ [33]; in the water of Taihu, Chaohu, and Poyang Lakes in China are 0.88, 1.63 and 2.21 $\mu\text{g/l}$ [49]; in Tai Lake, China (40 $\mu\text{g/l}$) [50]; in Caohai Wetland, China

(3.84 $\mu\text{g/l}$) [52]; in Wen Rui Tang River Watershed, China (5.32 $\mu\text{g/l}$) [53]. Fang T., et al., 2019 showed the concentration in the water of five different lakes of China[59]. Cr concentrations are found in groundwater in Brownfield, China (93060 $\mu\text{g/l}$) and surface water of Xiangjiang River (112.94 $\mu\text{g/l}$) [105]; in Diaojiang River (0.2–2.0 $\mu\text{g/l}$) [205]; in water samples from China (19.9 $\mu\text{g/l}$) [54]; in water samples from Wei River of Shaanxi region, China (23.92 $\mu\text{g/l}$) [56]; in river water samples from Selenga River basin, Mongolia (4.21 $\mu\text{g/l}$) [91]; in surface water samples of Honghu Lake, China (1.63 $\mu\text{g/l}$) [57]. Shao, T., et al., 2017 has found Cr concentrations in East Liaohe River (0.102 $\mu\text{g/l}$), Hunhe River (0.0084 $\mu\text{g/l}$), Liaohe River (0.005 $\mu\text{g/l}$), Taizihe River (0.004 $\mu\text{g/l}$) and West Liaohe River (0.007 $\mu\text{g/l}$) in Liaohe River watershed, China [60].

Table.9. Chromium (Cr) Concentration in Different Locations in China

Location	Cr Concentration ($\mu\text{g/l}$)	Reference
Dongting lake	4	Liu, J., et al., 2015
Wei River	23.92	Yang, X., et al., 2015
Tai Lake	40	Fu, Z., et al., 2016
Caohai Wetland	3.844	He, J., et al., 2017
Caohai Wetland	3.844	Hu, J., et al., 2017
Brownfield	93060	Li, F., et al., 2017
Honghu Lake	1.63	Li, F., et al., 2017
Liaohe River Watershed	0.02528	Shao, T., et al., 2017
Taihu Lake	0.88	Bi, B., et al., 2018
Chaohu Lake	1.63	Bi, B., et al., 2018
Poyang Lake	2.21	Bi, B., et al., 2018
Shaanxi	3.06	Du Y, et al., 2018
Wen Rui Tang River Watershed	5.32	Qu, L., et al., 2018
Diaojiang River	0.875	Wang, J. et al., 2018
Chaohu Lake	0.51	Fang, T., et al., 2019
Caizi Lake	66.7	Fang, T., et al., 2019
Taihu Lake	1.39	Fang, T., et al., 2019
Dongting Lake	0.62	Fang, T., et al., 2019

Hulun Lake	21.43	Fang, T., et al., 2019
Honghu Lake	1.63	Fang, T., et al., 2019
Danjiangkou Reservoir	0.26	Nong, et al., 2019
Three Gorges Reservoir	10.12	Nong, et al., 2019
Dongting Lake	0.89	Nong, et al., 2019
Henan	4.009	Nong, et al., 2019
Hebei	4.009	Nong, et al., 2019
Tianjin	4.009	Nong, et al., 2019
Beijing	4.009	Nong, et al., 2019

Cr concentration in the water of Pasur River in Khulna City, Bangladesh is 48.9 $\mu\text{g/l}$ [70]. Rahman et al., showed Cr concentration at Noakhali of Bangladesh (0.8 mg/l) [72]. Islam M. M., et al., 2018, showed Cr concentration in the water of different rivers at various locations of Bangladesh [71]. Asaduzzaman, M., et al., 2016 found Cr concentration of 118848 $\mu\text{g/l}$ in water samples collected from Buriganga River, Bangladesh [108] (Table.10.).

Table.10. Chromium (Cr) Concentration in Different Locations in Bangladesh

Location	Cr Concentration ($\mu\text{g/l}$)	Reference
Noakhali	0.8	Rahman, et al., 2015
Buriganga River	118848	Asaduzzaman, M., et al., 2016
Pasur River	48.9	Ali, M.M., 2018
Rayer Bazaar	114	Islam, M.M., et al., 2018
Pagla	114	Islam, M.M., et al., 2018
Balughat	587	Islam, M.M., et al., 2018
Faridabad	587	Islam, M.M., et al., 2018
Tongi	39	Islam, M.M., et al., 2018
Kalurghat	25	Islam, M.M., et al., 2018
Bogra	78	Islam, M.M., et al., 2018
Mongla	52.5	Islam, M.M., et al., 2018
Chilmari	37	Islam, M.M., et al., 2018
Kawtail	177	Islam, M.M., et al., 2018
Postagola	177	Islam, M.M., et al., 2018
Sodorghat	177	Islam, M.M., et al., 2018
Modinanagar	177	Islam, M.M., et al., 2018

Saleh H.N., et al., 2019, showed Cr concentration in the drinking water of different places in Iran[62]. Cr concentration is found in drinking water in Mashhad city, Iran (4.94 µg/l) [63]. Cr concentrations are also found in well water samples in Abarkouh (3.06 µg/l), Meybod (4.48 µg/l), Bafgh (3.12 µg/l), Behabed (3.76 µg/l) and Ardakan (5.48 µg/l) regions [155] (Table.11.).

Table.11. Chromium (Cr) Concentration in Different Locations in Iran

Location	Cr Concentration (µg/l)	Reference
Abarkouh	3.06	Fallahzadeh, R. A., et al., 2017
Meybod	4.476	Fallahzadeh, R. A., et al., 2017
Bafgh	3.118	Fallahzadeh, R. A., et al., 2017
Behabed	3.764	Fallahzadeh, R. A., et al., 2017
Ardakan	5.482	Fallahzadeh, R. A., et al., 2017
Neyshabur	5.3	Saleh, H.N., et al., 2019
Chakaneh	4.66	Saleh, H.N., et al., 2019
Kharv	1.5	Saleh, H.N., et al., 2019
Ghadangah	0.003	Saleh, H.N., et al., 2019
Darrood	1.094	Saleh, H.N., et al., 2019
Mashhad City	4.94	Alidadi, H., et al., 2019

Cr concentrations are found in the water of Eleyele Lake of Nigeria is 2.575µg /l[5]; in the groundwater of Bwari, Kuje, Gwagwalda and Azhatta of Nigeria are 30, 20, 600, and 2 µg/l respectively[147]; in the water of Asejire River at Asejire, Eleyele River at Ibadan, Erinle River at Ede and Dandarou River at Orita-Mefa in Nigeria, the concentration of Cr are 50, 54, 41 and 63 µg/l respectively [84]. Titilawo, Y. et al., 2018 has found Cr concentrations in Erinle-Ede (53 µg/l), Ido Osun (37µg/l), Osun-Osogbo (47 µg/l), Oba-Iwo (73 µg/l), Ejigbo (90 µg/l), Ilobu-Okinni (90 µg/l), Asejire-Ikire (93 µg/l), Shasha (1350 µg/l), Ila-Oke Ila (40 µg/l) and Inisha-Okuku (50 µg/l) regions in Nigeria [206] (Table.12.).

Table.12. Chromium (Cr) Concentration in Different Locations in Nigeria

Location	Cr Concentration (µg/l)	Reference
Eleyele Lake	2.575	Olayinka, O. O., et al., 2017
Bwari	30	Sawyerr, H. O., et al., 2017
Kuje	20	Sawyerr, H. O., et al., 2017
Gwagwalda	600	Sawyerr, H. O., et al., 2017
Azhatta	2	Sawyerr, H. O., et al., 2017
Asejire River	50	Adesiyani, I. M., 2018
Eleyele River	54	Adesiyani, I. M., 2018
Erinle River	41	Adesiyani, I. M., 2018
Dandaru River	63	Adesiyani, I. M., 2018
Erinle-Ede	53	Titilawo, Y., et al., 2018
Ido Osun	37	Titilawo, Y., et al., 2018
Osun-Osogbo	47	Titilawo, Y., et al., 2018
Oba-Iwo	73	Titilawo, Y., et al., 2018
Ejigbo	90	Titilawo, Y., et al., 2018
Ilobu-Okinni	90	Titilawo, Y., et al., 2018
Asejire-Ikire	93	Titilawo, Y., et al., 2018
Shasha	1350	Titilawo, Y., et al., 2018
Ila-Oke Ila	40	Titilawo, Y., et al., 2018
Inisha-Okuku	50	Titilawo, Y., et al., 2018

Cr concentrations in water in different regions of Iran and Nigeria are depicted in Fig.11.

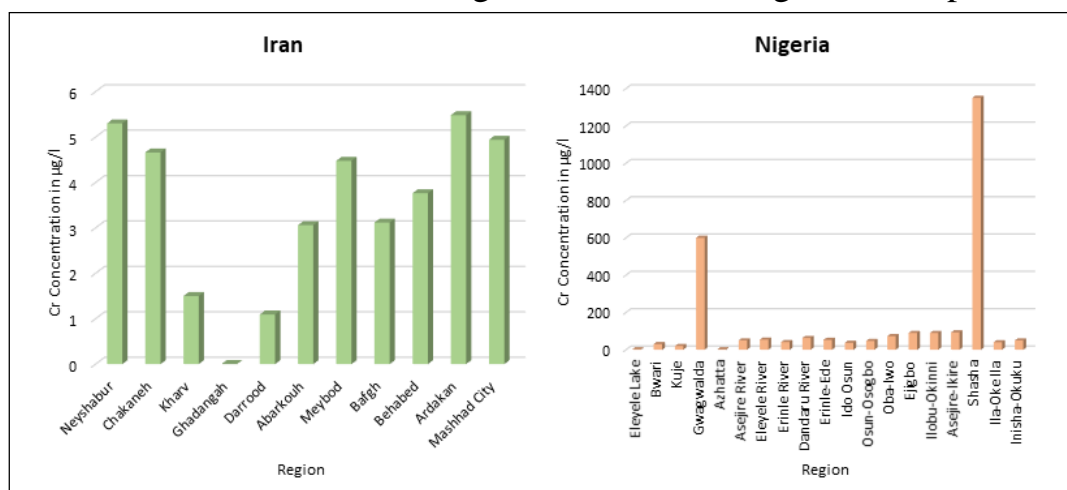


Fig.11. Chromium (Cr) Concentration in Fresh Water in Iran and Nigeria

Hadzi G. Y. et al., 2015, found Cr concentration in the water of different rivers at different sites in Ghana[75]. Bempah C.K., & Ewusi A., 2016, showed Cr concentration of 1 µg/l in the groundwater of the gold mine area of Obuasi, Ghana [76]. Hadzi G.Y. et al., 2018 has found Cr concentrations in Nyam River (14.5 µg/l), Subri River (9.5 µg/l), Birim River (48.5 µg/l), Bonsa River (11.5 µg/l) and Ankasa River (2 µg/l), Ghana [77]. Cr concentration is also found in River Tano in Bono, Bono East, and Ahafo Regions, Ghana (266 µg/l) [74] (Table.13.).

Table.13. Chromium (Cr) Concentration in Different Locations in Ghana

Location	Cr Concentration (µg/l)	Reference
Tarkwa	10	Hadzi, G.Y., et al., 2015
Atewa	2	Hadzi, G.Y., et al., 2015
Obuasi	14	Hadzi, G.Y., et al., 2015
Ankasa	23	Hadzi, G.Y., et al., 2015
Bosomkese	12	Hadzi, G.Y., et al., 2015
Bekwai	8	Hadzi, G.Y., et al., 2015
Obuasi	1	Bempah, C.K., & Ewusi A., 2016
Nyam River	14.5	Hadzi, G.Y., et al., 2018
Subri River	9.5	Hadzi, G.Y., et al., 2018
Birim River	48.5	Hadzi, G.Y., et al., 2018
Bonsa River	11.5	Hadzi, G.Y., et al., 2018
Ankasa River	2	Hadzi, G.Y., et al., 2018
River Tano	266	Nyantakyi, A.J., et al., 2019

Kose E. et al., 2015, found Cr concentration in the water of Porsuk River at different sites along the river in Turkey [64]. Cr concentrations are found in the water of Buyuk Menderes River at four sites i.e., Isikh, Saraykay, Soke, and Tasburun in Turkey are 0.1, 0.5, 0.9, and 1.5 µg/l respectively[30]; in the water of Bogacayi River in Antalaya, Turkey is 3.2 µg /l[65]. Nong et al., 2019, showed Cr concentration in the water of Dil Deresi of Turkey[35] (Table.14.).

Table.14. Chromium (Cr) Concentration in Different Locations in Turkey

Location	Cr Concentration (µg/l)	Reference
Eymir	24	Kose, E. et al., 2015
Agagkoy	24	Kose, E. et al., 2015
Kutahya	25	Kose, E. et al., 2015
Eskigehe	21	Kose, E. et al., 2015
Alpu	28	Kose, E. et al., 2015
Beylikova	26	Kose, E. et al., 2015
Yunusemre	26	Kose, E. et al., 2015
Sakarya	24	Kose, E. et al., 2015
Bogacayi River	3.2	Cengiz, M.F., et al., 2017
Isikh	0.1	Durmaz E, et al., 2017
Saraykay	0.5	Durmaz E, et al., 2017
Soke	0.9	Durmaz E, et al., 2017
Tasburun	1.9	Durmaz E, et al., 2017
Dil Deresi	42	Nong, et al., 2019

Cr concentrations in water in different regions of Ghana and Turkey are depicted in Fig.12.

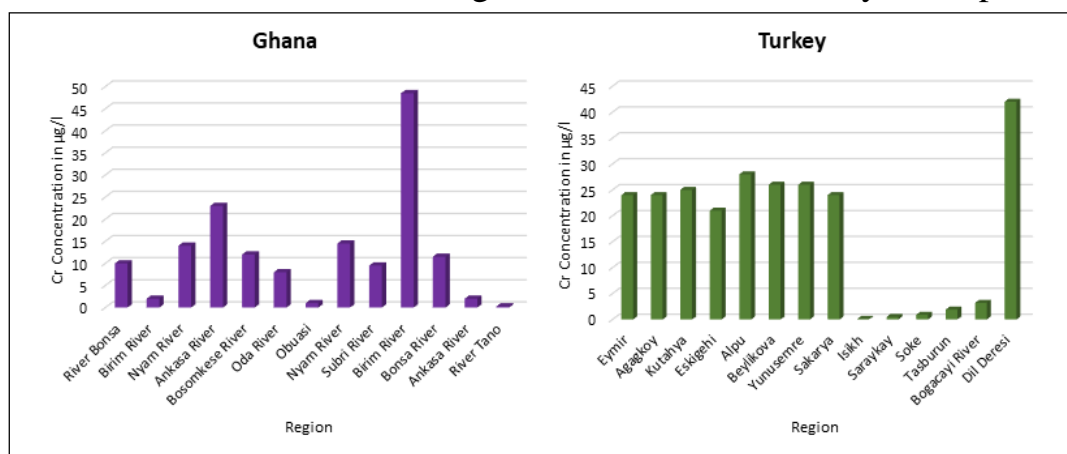


Fig.12. Chromium (Cr) Concentration in Fresh Water in Ghana and Turkey

Nyairo W. N., et al., 2015, showed Cr concentration in the water of different sites on Nyangores tributary and Amala tributary and a site on the confluence of the both the tributaries in Kenya [29]. Cr concentration in the water of Sarno River in San Marzano and Scafati are 17970 and 9050 µg/l respectively[134]; in the water of Nakivubo Channel and Lake Victoria at Kampala in Uganda are 60 and 4 µg /l[135]. Cr concentration in the water of Biala Przemsza River of Poland is 2.96 µg/l[80]. The Cr concentration in the water of Gonyeli Lake of Cyprus is 20.8 µg /l[83]; in the surface water of Annaba, Lake Tonga and Seybouse Watershed of Algeria are 2130, 115 and 80 µg/l respectively [145]; Golubkina N. et al., 2018, showed Cr concentration in the water of different places of Mongolia[32]; The

concentration in the water of Hyeongsan River and its tributaries in Pohang City, South Korea is 0.803 $\mu\text{g/l}$ [87]; in the water of Tenango Dam, Puebla, Mexico is 144 $\mu\text{g/l}$ [149]. The Cr concentration in the water of the catchment area of Nakivubo Channel in Kampala, Uganda is 105.4 $\mu\text{g/l}$ [150]. De Melo, W. A et al., 2017 found Cr concentrations of 880 $\mu\text{g/l}$ and 950 $\mu\text{g/l}$ in Acude and Maria Lucinda Streamlet and Santa Rosa Streamlet in Brazil respectively [154]. Cr concentrations are found in Jaboticabal Watershed, Brazil (35.25 $\mu\text{g/l}$) [158]; in Asopos River, Greece (8270 $\mu\text{g/l}$) [157]; in Kampar Lake, Malaysia (3.104 $\mu\text{g/l}$) [51]; in river water of Guaribas River, Brazil (36 $\mu\text{g/l}$) [207]; Vongdala N., et al., 2018 has found Cr concentration of 120 $\mu\text{g/l}$ in surface water in Vientiane, Laos [156] (Fig.13.).



Fig.13. Spatial Distribution of Chromium (Cr) Concentration in Fresh Water (2015-2019)

Nambatingar, N. et al., 2017 has found Cr concentration of 10 to 130 $\mu\text{g/l}$ in different locations in Chari River, Chad [196]. Cr concentrations are found in boreholes in Richmond Suburb, Zimbabwe (33.83 $\mu\text{g/l}$) [159]; in boreholes at Muledane village (0.005 to 0.15 $\mu\text{g/l}$) [160]; Yusta-García, R. et al., 2017 has found Cr concentrations in Capahuari South Pastaza (5.05 $\mu\text{g/l}$), Capah. North Capahuari River (3.2 $\mu\text{g/l}$), Dorissa Macusari River (1.25 $\mu\text{g/l}$), Pucacuro River (2.38 $\mu\text{g/l}$), Chambira Chambira/Maranon (6.91 $\mu\text{g/l}$), Huayurí Corrientes River (315300 $\mu\text{g/l}$), Huayuri River (1.75 $\mu\text{g/l}$), Jibarito Corrientes River (0.58 $\mu\text{g/l}$), Pucacun–gayacu River (0.84 $\mu\text{g/l}$), Nueva Esperanza Corrientes (13.83 $\mu\text{g/l}$), Capirona Corrientes (9.78 $\mu\text{g/l}$), Trompeteros 1&2 Corrientes (4.36 $\mu\text{g/l}$), Pavayacu Tigre River (9.26 $\mu\text{g/l}$), Forestal Tigre River (3.51 $\mu\text{g/l}$), San Jacinto Tigre River (1.7 $\mu\text{g/l}$), Piedra Negra River (9.2 $\mu\text{g/l}$), Bartra Tigre River (16.1 $\mu\text{g/l}$), Montano River (2 $\mu\text{g/l}$), Yanayacu Maranon River (5.1 $\mu\text{g/l}$) and Huisto Yana-yaquillo River (8.6 $\mu\text{g/l}$) [162]. Cr concentrations are found in Wonderfontein spruit catchment area, South Africa (0.62 $\mu\text{g/l}$) [37]; in different locations from Leyole River, Ethiopia (880.43 $\mu\text{g/l}$) [161]; in Assopos–Thiva Basin (less than 2 to 850 $\mu\text{g/l}$) and Central Evia (less than 2 to 360 $\mu\text{g/l}$) [208]. Cr concentrations are found in drinking water samples in Lahore (2593 $\mu\text{g/l}$), Jhang (5 $\mu\text{g/l}$), Multan (11.6 $\mu\text{g/l}$), Vehari (8.03 $\mu\text{g/l}$), Peshwar (5.79 $\mu\text{g/l}$) and Swabi (4.13 $\mu\text{g/l}$) regions of Pakistan [67].

Cr concentrations are found in pore water samples from Aar Dam (2.09 $\mu\text{g/l}$), Driedorf Dam (1.65 $\mu\text{g/l}$) and Klingenberg Reservoir (1.73 $\mu\text{g/l}$) in Germany [92]; in drinking water samples collected from tap water and hand pumps (5 $\mu\text{g/l}$) and surface water samples collected from the Chenab river and canals i.e., Jhang Branch Upper Canal, Rakh Branch Canal, Gugera Branch Canal (240 $\mu\text{g/l}$) in Faisalabad, Pakistan [39]. Nagy, A.S., et al., 2016 has found Cr concentration of 9.86 $\mu\text{g/l}$ in water samples from the Danube River located near Hungarian and Slovakian border [89]. Ortiz-Colón, A.I., et al., 2016 has found Cr concentrations of in river water samples from Mameyes (1.843-1.893 $\mu\text{g/l}$), Rio Piedras (1.663-1.927 $\mu\text{g/l}$) and La Plata (1.747-2.203 $\mu\text{g/l}$) Rivers in Puerto Rico [38].

In India (Fig.14.) Cr concentrations are found in fresh water in several locations. Bhowmick S., et al., showed Cr concentration of 5.6 $\mu\text{g/l}$ in the groundwater of Nadia, West Bengal, India[40]. Gautam et al., 2015, showed an average Cr concentration in the Subarnarekha basin area i.e., 10.7 $\mu\text{g/l}$. Other sites are at Hatia bridge (6.37 $\mu\text{g/l}$), Khuddi village (12.29 $\mu\text{g/l}$), Tatanagar (10.89 $\mu\text{g/l}$), Adityapur (11.14 $\mu\text{g/l}$), Sakchi (11.03 $\mu\text{g/l}$), Govindpur (10.39 $\mu\text{g/l}$), Mango (12.70 $\mu\text{g/l}$), Jugsalai (10.49 $\mu\text{g/l}$), Jaduguda (10.08 $\mu\text{g/l}$), Mushabani (10.44 $\mu\text{g/l}$), Maubhandar (9.81 $\mu\text{g/l}$), Ghatsila (12.05 $\mu\text{g/l}$), Chakulia (11.60 $\mu\text{g/l}$), Chandil (10.78 $\mu\text{g/l}$), Kandra (10.31 $\mu\text{g/l}$), Saraikela (9.87 $\mu\text{g/l}$), Chaibasa (9.67 $\mu\text{g/l}$), Chkradharpur (10.16 $\mu\text{g/l}$), and Chakulia (14.05 $\mu\text{g/l}$) [183]. Kumar A., et al., 2016, analysed the drinking water and found Cr concentration in the water at different places of Jammu District (presently the UT of Jammu and Kashmir), India[98]. Very low concentration of Cr is found in the water of the Ghaghara River at Ayodhya, Faizabad of Uttar Pradesh (0.007 mg/l), Ghaghara River at Chhapra, Bihar (0.005 mg/l)[184].



Fig.14. Spatial Distribution of Chromium (Cr) Concentration in Fresh Water in Different Regions of India

Cr concentration in the water of Yamuna River at Maznu Ka Tila, Kashmiri Gate, Sarai Kale Khan, Okhla Barrage and Najagarh drain of Delhi, India are 80, 380, 60, 90 and 940 $\mu\text{g/l}$ respectively.[185]; in the water (surface water and groundwater) of Reasi District, Jammu and Kashmir (presently the UT of Jammu and Kashmir), India is 100 $\mu\text{g/l}$ [186]. Singh A.K., et al., 2019, showed Cr concentration in the drinking water of four districts of Sikkim, India[41]. Cr concentrations are also found in river water of Yamuna River at Delhi (50 $\mu\text{g/l}$) [182]; in groundwater in Kanpur, India (24 $\mu\text{g/l}$) [179]; in Koleru Lake, India (8.6 $\mu\text{g/l}$) [209] ; in groundwater of Ropar Wetland, Punjab, India (50 to 100 $\mu\text{g/l}$) [180]; in the water of Talcher Gauge Station on Brahmani River, is 104.935 $\mu\text{g/l}$ [177]; in groundwater in Chandigarh, India (0.21 $\mu\text{g/l}$) [97]. Shankar B.S., 2019, showed Cr concentration of 812.3 $\mu\text{g/l}$ in the groundwater of Peenya industrial area of Bangalore, India[187]. The concentration values of Cr in different parts of India are depicted in Fig.15.

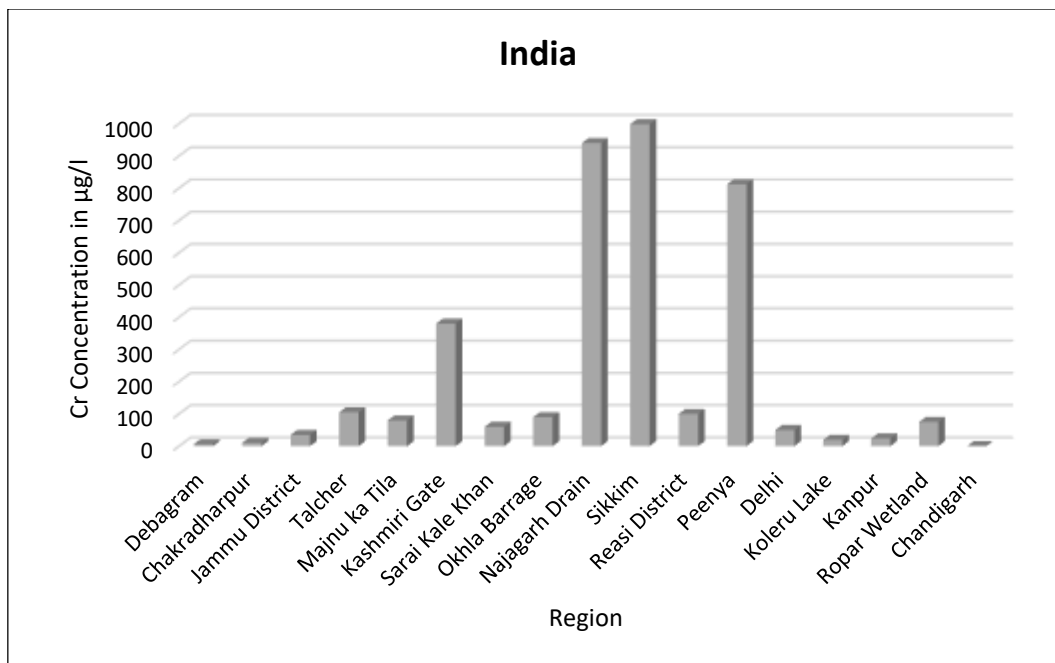


Fig.15. Chromium (Cr) Concentration in Different Regions of India

The country wise Cr concentration in fresh water shows that the highest mean and SD of Cr concentration i.e., 13510 µg/l and 4460µg/l are found for Italy. It is followed by Greece. In these countries, the average Cr concentrations are more than 1000 µg/l. In China, Ghana, Peru, Turkey, Cyprus, Uganda, Laos, Mexico, Bangladesh, India, Nigeria, Pakistan, Brazil, Ethiopia and Algeria, the average Cr concentrations are from 10 to 1000 µg/l. In South Africa, South Korea, Kenya, Germany, Puerto Rico, Mongolia, Poland, Malaysia, Iran, Hungary and Slovakia, the average Cr concentrations are from 0.05 to 10 µg/l. In Zimbabwe and Chad, the average Cr concentration is within 0.05 µg/l (Table.15.).

Table.15. Country Wise Average Chromium (Cr) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
Cyprus	20.8	-
Germany	1.823333	0.191369
Greece	2959	3756.776
Hungary and Slovakia	9.86	-
Poland	2.96	-
Developing Countries		
Algeria	775	958.2362
Bangladesh	8082.56	29603.81243
Brazil	466.3229	449.5316
Chad	50	-
China	2915.338294	16190.46501
Ethiopia	622.15	602.65
Ghana	32.46153846	68.43538826

India	190.1289487	367.8083965
Iran	3.399727	1.754386
Italy	13510	4460
Kenya	1.745	0.346157
Laos	120	-
Malaysia	3.10356	-
Mexico	144	-
Mongolia	2.19	0.931498
Nigeria	282	622.1865
Pakistan	328.4744	855.9177
Peru	15770.27	68716.83296
Puerto Rico	1.879333	0.07392
South Africa	0.349464	0.271964
South Korea	0.803	-
Turkey	17.61429	12.9979
Uganda	56.46667	41.4717
Zimbabwe	33.83333333	-

3.3. Fluoride (F⁻) Concentration in Water: Fluoride (F⁻) is the 13th most abundant element presents on the Earth’s surface, combining with other substances. Coal combustion, use of fertilizers, and generation of industrial wastes with phosphate fertilizers are the important sources of fluoride in the environment. It is an essential element for the animals and human beings as in low levels of concentration, it provides protection against dental cariosity, especially in children. The minimum concentration of fluoride required to protect is approximately 0.5 mg/l [188]. According to the WHO, the highest desirable limit of F⁻ is 0.6-0.9 mg/l or 600-900 µg/l whereas, the highest permissible limit is 0.8 – 1.7 mg/l[189]. A total number of 34 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Fluoride (F⁻) is given in [Fig.16](#).

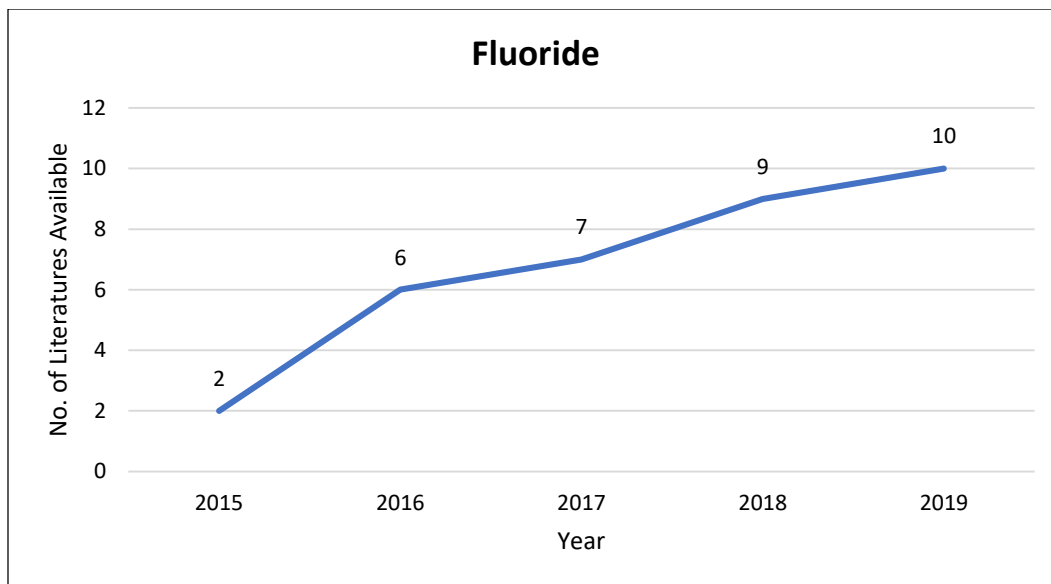


Fig.16. Total No. of Literatures Available for Fluoride (F⁻)

Among these 34 literatures only 8 literatures have been selected for the purpose of this study which are related to the concentration of F⁻ in fresh water (Fig.17.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of F⁻ is found in Khatanbulag, Mongolia (4700 µg/l) and the lowest concentration is found in the water of Ropar wetland, Punjab, India (0.33 µg/l).

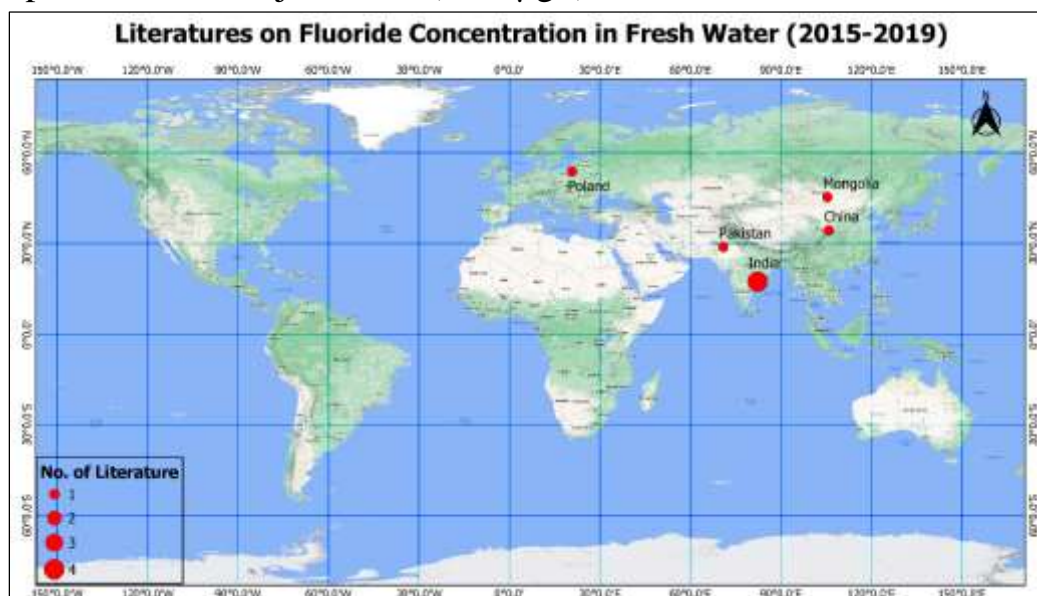


Fig.17. Literatures on Fluoride Concentration in Fresh Water (2015-2019)

The average values have also been calculated for similar sources of water in the same location (Table.16.).

Table.16. Details of Fluoride (F⁻) Concentration in Fresh Water

Location	Country	Source	F ⁻ Concentration (µg/l)	Reference
Mongolia	Mongolia	Drinking water	1015.1875	Golubkina, N. et al., 2018

Sikkim	India	Drinking water	37	Singh, A K, et al., 2019
Brownfield	China	Groundwater	5000	Li, F., et al., 2017
Sindh	Pakistan	Groundwater	1000	Ali, W., et al., 2019
Punjab	Pakistan	Groundwater	1000	Ali, W., et al., 2019
Ropar Wetland	India	Groundwater	330	Sharma, S., et al., 2019
Sattal Lake	India	Lake water	472	Inaotombi, & Gupta, 2017
Biala Przemsza River	Poland	River water	400	Jablonska-Czapla, M., et al., 2016
Tangra, Cossipore, Dhapa, Inside leather complex, Topsia, Garia, Behala, Central Kolkata	India	Water sample	0.426	Chakrobarty, D., et al., 2017

Hoque, Khaliquzzaman, Hossain, & Khan, 2003, showed F⁻ concentration in the water samples from tube well in different cities i.e., Barisal, Bogra, Chittagong, Comilla, Dhaka, Dinajpur, Faridpur, Gazipur, Jamalpur, Jessore, Khulna, Kishoregong, Kustia, Mymensingh, Pabna, Rajsahi, Rangpur, Sylhet, Tangail and in the water samples from city water supplies in different cities of Bangladesh i.e., Barisal, Bogra, Chittagong, Comilla, Dhaka, Dinajpur [190]. Fluoride concentration in the water of Biala Przemsza River in Poland is 400 µg/l [80]. Golubkina N., et al., 2018 found F⁻ concentration in the drinking water of different places of Mongolia i.e., Sainshand (1500 µg/l), Zuun Bayan (1270 µg/l), Ulaanbadrakh (1800 µg/l), Khatanbulag (4700 µg/l), Zamin-Ude (2340 µg/l), Bayan (920 µg/l), Selenge (440 µg/l), Shaamar (410 µg/l), Barunkhara (350 µg/l), Omno Gobi (310 µg/l), Dalanzadgad (313 µg/l), Arkhangai (350 µg/l), Ulaanbaatar (340 µg/l), Gachuurt (500 µg/l), Tuul Valley of Ulaanbaatar (300 µg/l) and Erdenet (400 µg/l) [32]. F⁻ concentrations are also found in groundwater in Brownfield, China (5000 µg/l) [105]. F⁻ concentrations of 68.53 µg/l and 72.71 µg/l are found in the groundwater of Sindh and Punjab in Pakistan respectively [191] (Fig.18.).



Fig.18. Spatial Distribution of Fluoride (F^-) Concentration in Fresh Water (2015-2019)
 In India (Fig.19.), Fluoride has been found to be concentrated in different places i.e., Hanumangarh town, Hanumangarh junction, Satipura, Rorhawali, Sureshia, Tibbi, Masitawali, Tilwara Jheel, Meharwala, Silwala, Rampura, Chahuwali, Shergarh, Rawatsar, Goluwala, Paka Saharna, Lalgargh Jatan, Nohar, Pilbanga of Rajasthan [189]. Studies show the concentration of F^- at different locations of Kolkata i.e., Tangra, Topsia, Dhapa, Garia, Behala, Cossipore, Central Kolkata and inside Kolkata Leather Complex [192]. F^- is also concentrated in the drinking water of four districts i.e., East ($38 \mu\text{g/l}$), West ($36 \mu\text{g/l}$), North ($36 \mu\text{g/l}$) and South ($38 \mu\text{g/l}$) of Sikkim, India[41]. F^- is also concentrated in the eastern and western wing of Sattal Lake in Central Himalaya, India ($472 \mu\text{g/l}$) [193]; and in groundwater of Ropar Wetland, Punjab, India ($330 \mu\text{g/l}$) [180].

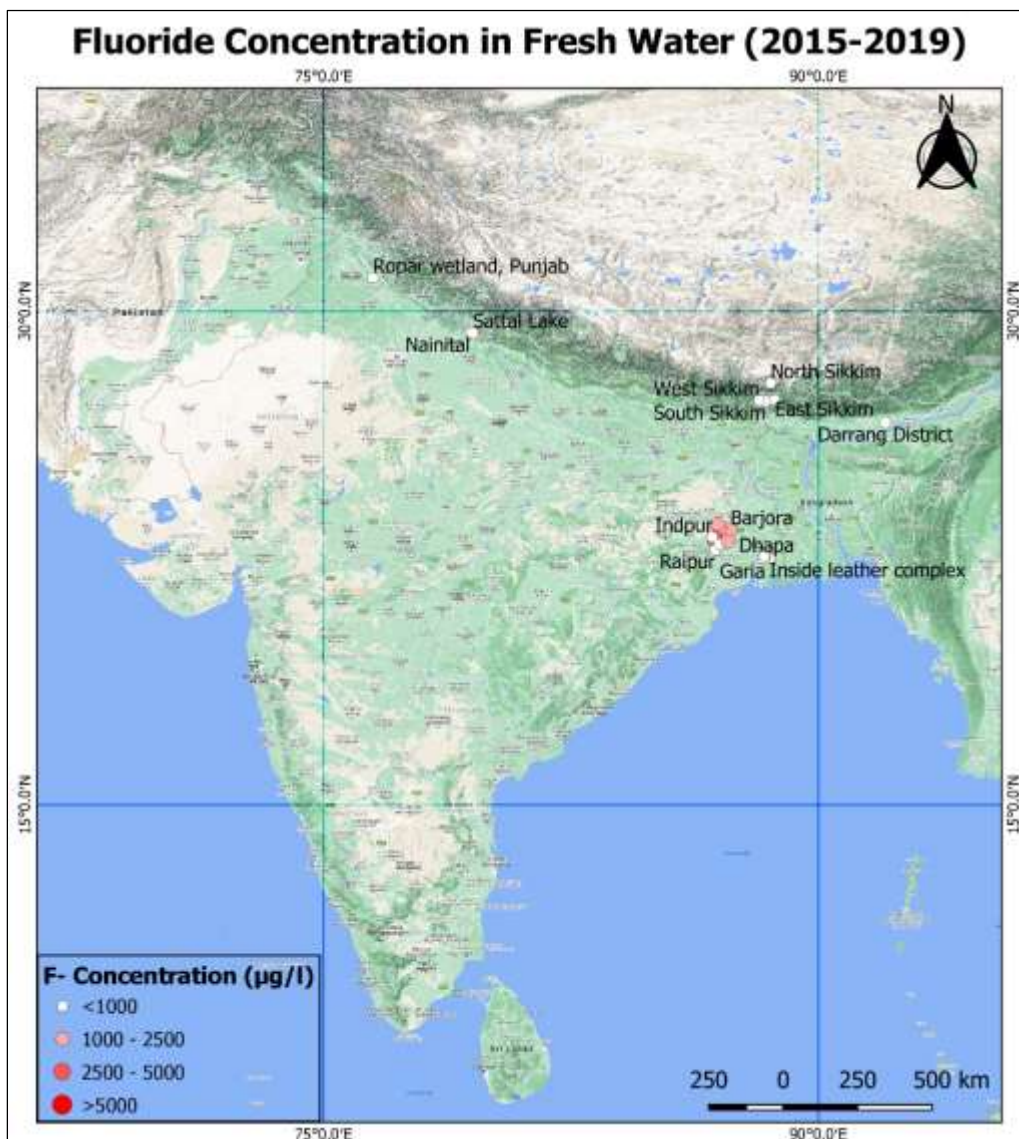


Fig.19. Spatial Distribution of Fluoride (F⁻) Concentration in Fresh Water in Different Regions of India

The country wise F⁻ concentration in fresh water shows that the highest mean of F⁻ concentration i.e., 5000 µg/l is found for China. It is followed by Mongolia. In Pakistan, Poland and India, the average F⁻ concentrations are within the permissible limit i.e., 1000 µg/l as directed by the WHO (Table.17.).

Table.17. Country Wise Average Fluoride (F⁻) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
Poland	400	-
Developing Countries		
China	5000	-
India	312.6667	179.955
Mongolia	1015.188	1130.309
Pakistan	1000	0

3.4. Lead (Pb) Concentration in water: Lead is a natural element found to be present as a major constituent in Galena and hydrothermal mineral veins. Lead can be produced through ore processing, from motor vehicle exhaust smokes and from the decay of lead pipework [99]. Other sources of Pb are gasoline, paints, storage batteries, cosmetics, industrial emissions, household dust, toys, pitchers made of bell-metal, etc. [43]. The concentration of Pb in water is determined by the presence of $PbCO_3$ and a low level of alkalinity[99]. The solubility of Pb in drinking water (Plumbosolvency) is strongly affected by pH and alkalinity. The pH value above 7 markedly reduces the solubility of Pb in water. In the least plumbosolvent water the alkalinity ranges between 10 and 80 mg/l and pH is more than 8.5[100]. Pb contamination causes various health effects [43]. Different literature shows Lead (Pb) concentration in water in different countries. The standard limit for Pb concentration in water according to WHO (2011) is 0.01 $\mu\text{g/l}$, US EPA (2009) is 0.015 $\mu\text{g/l}$, and BIS (2012) is 0.01 $\mu\text{g/l}$, beyond which the drinking water gets contaminated [101]. A total number of 1433 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Lead (Pb) is given in Fig.20.

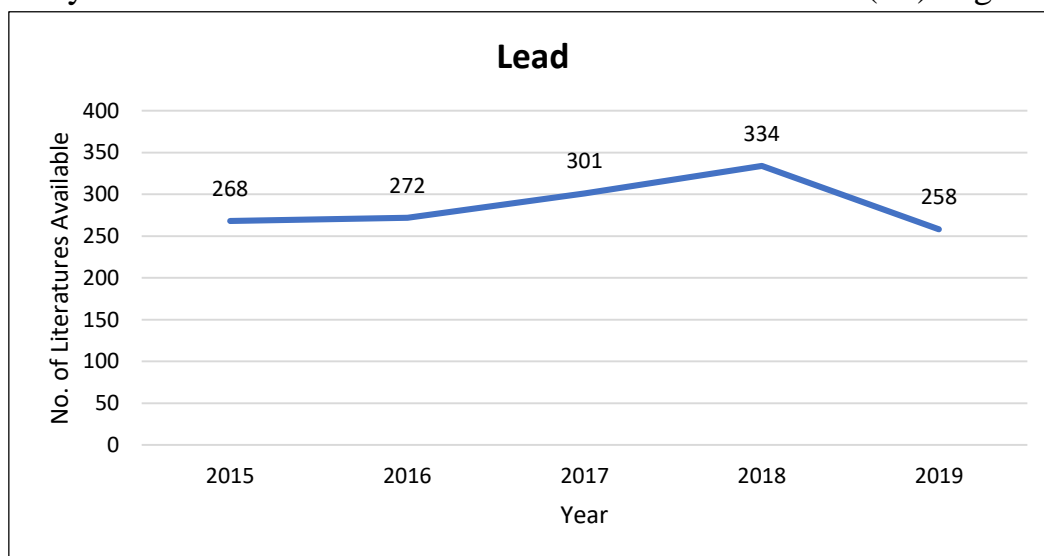


Fig.20. Total No. of Literatures Available for Lead (Pb)

Among these 1433 literatures only 116 literatures have been selected for the purpose of this study which are related to the concentration of Pb in fresh water (Fig.21.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of Pb is found in the water of Lake Victoria, Kenya (50300 $\mu\text{g/l}$) and the lowest concentration is found in drinking water samples from San Marzano, Italy (0.01 $\mu\text{g/l}$). The average values have also been calculated for similar sources of water in the same location.



Fig.21. Literatures on Lead Concentration in Fresh Water (2015-2019)

Bi B. et al., 2018, showed lead concentration in the water of three lakes i.e., Taihu, Chaohu and Poyang Lakes of China [49]. Pb concentration in the water of Saopaulo River, Brazil is 2.61 $\mu\text{g/l}$ [103]; in Caohai Wetland, China (3.65 $\mu\text{g/l}$) [52]; and Wen Rui Tang River Watershed, China (4.23 $\mu\text{g/l}$) [53]. Du Y. et al., 2018, showed Pb concentration of 0.03 $\mu\text{g/l}$ in the water of Lower Cambrian, Southern Shaanxi, China[33]. Fang T. et al., 2019, showed Pb concentration in water of five lakes of China [59]. Nong et al., 2019, showed concentration in the water of different lakes, reservoirs, and places of China [104]. Pb concentrations are found in Tai Lake, China (17 $\mu\text{g/l}$) [50]. in groundwater in Brownfield, China (90 $\mu\text{g/l}$) [105]; in water samples from China (5.2 $\mu\text{g/l}$) [54]. [91]; in surface water samples of Honghu Lake, China (3.42 $\mu\text{g/l}$) [57]; in river water downstream (1 $\mu\text{g/l}$) and in river water of mine area (34 $\mu\text{g/l}$) of Karstic river system, China [61]; in the water of Ma Tian, in Suxian District of Chenzhou City, Hunan Province, Southern China is 824 $\mu\text{g/l}$ [47]; in the water of Cahoi wetland, China is 3.654 $\mu\text{g/l}$ [106] (Table.18.).

Table.18. Lead (Pb) Concentration in Different Locations in China

Location	Pb Concentration ($\mu\text{g/l}$)	Reference
Three Gorges River	0.07	Zhen, G., et al., 2016
Upper Xijiang River	5.56	Zhen, G., et al., 2016
Middle Xijiang River	8.62	Zhen, G., et al., 2016
Lower Xijiang River	7.01	Zhen, G., et al., 2016
Beijiang River	2.24	Zhen, G., et al., 2016

Dongjiang River	1.11	Zhen, G., et al., 2016
Caohai Wetland	3.654	He, J., et al., 2017
Honghu Lake	3.42	Li, F., et al., 2017
Brownfield	90	Li, F., et al., 2017
Taihu Lake	0.019	Bi, B., et al., 2018
Chaohu Lake	2.08	Bi, B., et al., 2018
Poyang Lake	0.81	Bi, B., et al., 2018
Wen Rui Tang River Watershed	4.23	Qu, L., et al., 2018
Chaohu Lake	0.44	Fang, T., et al., 2019
Caizi Lake	2.42	Fang, T., et al., 2019
Taihu Lake	0.76	Fang, T., et al., 2019
Dongting Lake	1.49	Fang, T., et al., 2019
Hulun Lake	0.28	Fang, T., et al., 2019
Honghu Lake	3.42	Fang, T., et al., 2019
Danjiangkou Reservoir	0.76	Nong, et al., 2019
Three Gorges Reservoir	3.244	Nong, et al., 2019
Dongting Lake	1	Nong, et al., 2019

Asaduzzaman, M., et al., 2016 found Pb concentration of 2854 µg/l in water samples collected from Buriganga River, Bangladesh [108]. Concentration in the water of Pasur River, in Khulna City, Bangladesh is 23.35 µg/l[70]. Islam M.M. et al., 2018 examined and found Pb concentration in the water of different rivers of different places in Bangladesh[71]. Pb is also concentrated in the groundwater of Gangetic plain area of India and Bangladesh and Noakhali (0.2 µg/l) in Bangladesh [72] (Table.19.).

Table.19. Lead (Pb) Concentration in Different Locations in Bangladesh

Location	Pb Concentration (µg/l)	Reference
Buriganga River, Chilmari	2.854	Asaduzzaman, M., et al., 2016
Buriganga River	72.45	Gogoi, A., et al., 2016

Korotoa River	31	Zhen, G., et al., 2016
Pasur River, Khulna City	23.35	Ali, M.M., 2018
Buriganga River, Rayer Bazaar	119	Islam, M.M., et al., 2018
Buriganga River, Pagla	119	Islam, M.M., et al., 2018
Buriganga River, Balughat	65	Islam, M.M., et al., 2018
Buriganga River, Faridabad	65	Islam, M.M., et al., 2018
Turag River, Tongi	73	Islam, M.M., et al., 2018
Karnaphuli River, Kalurghat	14	Islam, M.M., et al., 2018
Karatoa River, Bogra	31	Islam, M.M., et al., 2018
Pasur River, Mongla	55.36	Islam, M.M., et al., 2018
Kurigram, Brahmaputra River	37	Islam, M.M., et al., 2018

Pb concentration in the groundwater of Vehari of Pakistan is 310 µg/l [111]. in drinking water samples collected from tap water and hand pumps (1 µg/l) in Faisalabad, Pakistan [39]. Masood, N., et al., 2019 has found Pb concentrations in groundwater in different regions of Gujrat, Pakistan (100 µg/l) [112]. Rehman K., et al., 2018 has found Pb concentrations in Khyber Pakhtunkhwa, Punjab and Sindh Provinces of Pakistan [68]. Pb concentrations are found in drinking water samples in Lahore (15 µg/l), Jhang (10.31 µg/l), Multan (1.18 µg/l), Vehari (31 µg/l), Peshwar (1.84 µg/l) and Swabi (2.03 µg/l) regions of Pakistan [67] (Table.20.).

Table.20. Lead (Pb) Concentration in Different Locations in Pakistan

Location	Source	Pb Concentration (µg/l)	Reference
Hasan Abdal	Drinking water	30	Rehman, K., et al., 2018
Lahore	Drinking water	2	Rehman, K., et al., 2018
Kasur	Drinking water	3	Rehman, K., et al., 2018

Sialkot	Drinking water	810	Rehman, K., et al., 2018
Korangi	Drinking water	240	Rehman, K., et al., 2018
Nawabshah	Drinking water	29.5	Rehman, K., et al., 2018
Karachi	Drinking water	6	Rehman, K., et al., 2018
Peshwar	Drinking water	380	Rehman, K., et al., 2018
Charsadda	Drinking water	375	Rehman, K., et al., 2018
Risalpur	Drinking water	375	Rehman, K., et al., 2018
Hattar	Drinking water	1170.5	Rehman, K., et al., 2018
Hattar Industrial Estate	Drinking water	260	Rehman, K., et al., 2018
Jhang	Drinking water	10.31	Hussain, S., et al., 2019
Multan	Drinking water	1.18	Hussain, S., et al., 2019
Vehari	Drinking water	31	Hussain, S., et al., 2019
Peshwar	Drinking water	1.84	Hussain, S., et al., 2019
Swabi	Drinking water	2.03	Hussain, S., et al., 2019
Faisalabad	Drinking water samples	1	Mahfooz, Y., et al., 2019
Vehari	Ground water	310	Khalid, S., et al., 2017
Keenjhar Lake	Lake water	2.925	Bilal, M., et al., 2017
Gadap Lake	Lake water	59.15	Bilal, M., et al., 2017
Lahore	Water sample	15	Hussain, S., et al., 2019

Gujrat district	Water sample	100	Masood, N., et al., 2019
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Pb concentration in Titiwangsa Lake, Selangor District, Malaysia is 0.73 µg/l[119]. Pb concentration in the groundwater of Ampar Tenang, Sepang District, Malaysia is 61.25 µg/l[122]. The quantity of Pb in the irrigation water of Dashte Mashaad is 2.61 µg/l[125]; in the water of Kenyir Lake, Malaysia is 1 µg/l[126]; in the drinking water of mining area Kitwe, Zambia is 50 µg/l[127]. Nyairo W. N. et al., 2015, showed Pb concentration in the water of different sites along Nyangores and Amala tributary, Kenya [29]. Pb in water of Tiga Dam, Nigeria is 330 µg/l[104]; Pb in San Marzano River and Scafati in Italy, are 0.01 and 850 µg/l respectively[134]; in the water of Nakivudo Channel and of Victoria Lake at Kampala are 1600 and 1250 µg/l respectively[135]. The concentration of Pb in the water of El Comedero Dam, San Lorenzo River is only 0.4 µg/l[79]; in the water of Pearl River at Nansa, Southeast Guangzhou city is 1030 µg/l[136].

The average concentration in the water of Prestea Huni district, Ghana is 61.085 µg/l[4]; in the groundwater and surface water of Tinga and Nangodi of Ghana are 250 and 31 µg/l respectively [73]; in River Tano in Bono, Bono East, and Ahafo Regions, Ghana (381 µg/l) [74]. Hadzi G.Y., 2018 has found Pb concentrations in Nyam River (2.5 µg/l), Subri River (1 µg/l), Birim River (22.5 µg/l), Bonsa River (13 µg/l) and Bosomkese Forest River (5 µg/l), Ghana [77] ([Table.21.](#)).

Table.21. Lead (Pb) Concentration in Different Locations in Ghana

Location	Source	Pb Concentration (µg/l)	Reference
Tarkwa	Drinking water	0.381	Nyantakyi, A.J., et al., 2019
Nyam River	River water	31	Cobbina S., et al., 2015
Subri River	River water	2.5	Hadzi, G.Y., 2018
Birim River	River water	1	Hadzi, G.Y., 2018
Bonsa River	River water	22.5	Hadzi, G.Y., 2018
Bosomkese Forest River	River water	13	Hadzi, G.Y., 2018
River Tano	River water	381	Hadzi, G.Y., 2018
Nangodi	Surface water	250	Cobbina, S., et al., 2015

Prestea Huni	Water sample	61.085	Obiri S., et al., 2016
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Kose E., et al., 2015, showed Pb concentration in the water of different sites along Porsuk Stream, Turkey[64]. Durmaz E., et al., 2017, found Pb concentration at different sites, in the water of Buyuk Menderes River, Turkey [30]. Nong et al., 2019, showed concentration in the water of different lakes, reservoirs, and places at Dil Deresi of Turkey [104]. Kukrer, S. & Mutlu, E., 2019 found the concentration of only 0.8 µg/l in the water of Sarayduzu Dam, Turkey[140] (Table.22.).

Table.22. Lead (Pb) Concentration in Different Locations in Turkey

Location	Pb Concentration (µg/l)	Reference
Porsuk Stream	20.75	Kose, E. et al., 2015
Sakarya River	1786	Gogoi, A., et al., 2016
Tigris River	0.22	Gogoi, A., et al., 2016
Tigris River	2.82	Zhen, G., et al., 2016
Menderes River	1.198	Zhen, G., et al., 2016
Riva Stream	41.67	Zhen, G., et al., 2016
Buyuk Menderes River	3.225	Durmaz, E., et al., 2017
Sarayduzu Dam	0.8	Kukrer, S. & Mutlu, E., 2019
Dil Deresi	120	Nong, et al., 2019

Ngwoke et al. 2015 showed Pb concentration in the groundwater of different villages of Agulu, Nigeria, namely Amaatutu (147 µg/l), Amaezike (95 µg/l), Ifiteani (7 µg/l), Nneogidi (170 µg/l), Nneoha (23µg/l), Nnkitako (77 µg/l), Nwanchi (57 µg/l), Obeagu (83 µg/l), Obe (117 µg/l), Odidama (117 µg/l, Okpu Agulu (83 µg/l), Okpu Ifite(127 µg/l), Ukunu (3 µg/l), Umuiifite (1 µg/l)[141]. The Pb concentration in the water of Baleh River at Sarawak, Malaysia is 30 µg/l [142]. Gogoi A., et al., 2016 and Zhen G. et al., 2016, showed Pb concentration in the water of different rivers worldwide [143]. The Quantity of Pb in the water of Biala Przemsza River, Poland 56.63 µg/l[80]; in the water of Ugljesnica River, Serbia is 582 µg/l[81]; in the water of Koka Dam and Sire Robi, Ethiopia are 3.37 and 4.24 µg/l respectively[144]. Alkas F.B., et al., 2017, found Pb concentration of 0.914 µg/l in the water of Goyneli Lake, Cyprus[83]. Belabed B.E. et al., 2017, showed Pb concentration in water of Mariout Lake of Egypt, Lake Victoria of Kenya, and Annaba, Lake Tonga and Seybouse Watershed of Algeria[145]. The concentration of Pb in the water of Keenjhar Lake and Gadap Lake are 2.925 and 59.125µg/l respectively[146] and in the water of Eleyele Lake, Nigeria is 1845 µg/l[5]; in the groundwater of Bwari, Kuje, Gwagwalda and Azhatta of Nigeria are 200, 100, 100 and 2 µg/l respectively[147]. Golubkina N. et al., 2017, found Pb concentration in the water of different locations of Mongolia [32]. Griboff J. et al., 2018,

found Pb concentration of 0.65 $\mu\text{g/l}$ in the water of Los Molinos Lake, Cordoba, Argentina [34]. Adesian I.M., 2018, showed Pb concentration in the river water from different places of Nigeria [84]. Afolayan A.O. et al., 2018 showed Pb concentration in the water of Ori-Ile Stream at Odolo, Omilende Area, Nigeria[148]. HMA, et al., 2018 showed Pb concentration in the water of 25 districts of Sri Lanka[85]. The concentration in the water of Tenango Dam, Puebla, Mexico is 1320 $\mu\text{g/l}$ [149]; in the water from Ado-Odo Ota, Osun state, Nigeria is 2.6 $\mu\text{g/l}$ [86]; in the river water (Hyeongsan River and its tributaries) of Pohang city, South Korea is 0.028 $\mu\text{g/l}$ [87]. Tabelin C. B. et al. 2018, showed Pb concentration (100 $\mu\text{g/l}$) in the marshes with slightly acidic pH in Canada [31]. Dietler D. et al., showed Pb concentration in the water from the catchment area of Nakivudo Channel, at Kampala, Uganda[150]. Ezemonye, L.I., et al., 2019, showed Pb concentration (180 $\mu\text{g/l}$) in the water of Benin River in Koko Town, Nigeria [151]. Kasozi K. I. et al., 2019, showed the Pb concentration (23.54 $\mu\text{g/l}$) in the water of Bushenyi District, Uganda [152]. Saleh H. N. et al., 2019, showed Pb concentration in water of different locations of Iran [62]. Skalny A. V. et al., 2019, showed Pb concentration in the water of different districts of Russia [153]. De Melo, W. A et al., 2017 found Pb concentrations of 160 and 180 $\mu\text{g/l}$ in Acude and Maria Lucinda Streamlet and Santa Rosa Streamlet in Brazil respectively [154]. Pb concentrations are also found in well water samples in Behabad (1.39 $\mu\text{g/l}$) and Ardakan (0.48 $\mu\text{g/l}$) regions [155]. Vongdala N., et al., 2018 has found Pb concentration of 95 $\mu\text{g/l}$ in surface water in Vientiane, Laos [156]. Charalampous N. et al., 2015 has found Pb concentration of more than 1500 $\mu\text{g/l}$ in Asopos River, Greece [157]. Pb concentrations are found in Kampar Lake, Malaysia (3.35 $\mu\text{g/l}$) [51]. Pb concentrations are found in lake water samples of Shadegan Wetland, Iran (1.11 $\mu\text{g/l}$) [36]. Saran L. M. et al., 2018 has found Pb concentration of 13.8 $\mu\text{g/l}$ in Jaboticabal Watershed, Brazil [158] (Fig.22.).

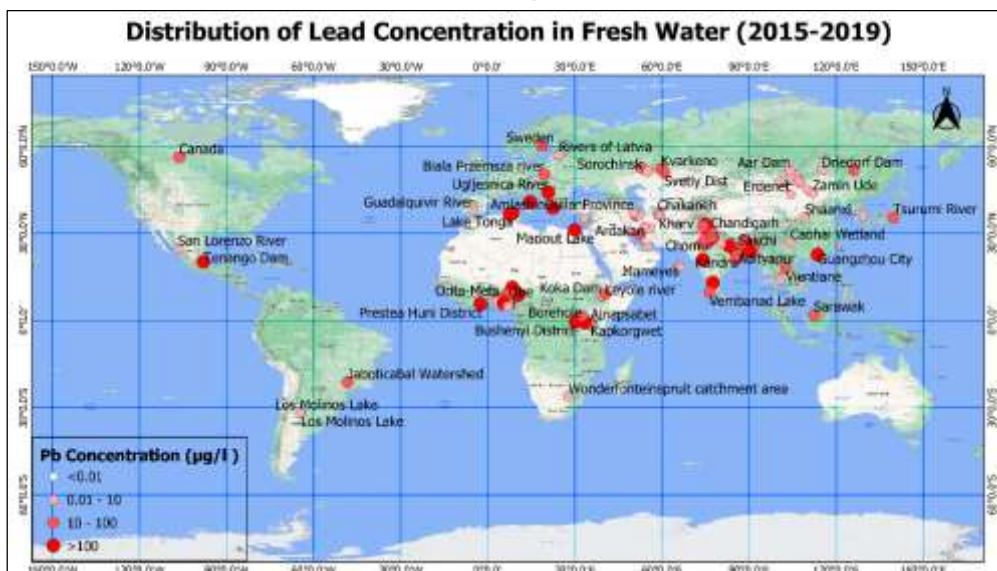


Fig.22. Spatial Distribution of Lead (Pb) Concentration in Fresh Water (2015-2019)
 Pb concentrations are also found in boreholes in Richmond Suburb, Zimbabwe (147.83 $\mu\text{g/l}$) [159]; boreholes at Muledane village (0.002 to 0.026 $\mu\text{g/l}$) [160]. Pb concentrations are found in Wonderfonteinspruit catchment area, South Africa (8.19 $\mu\text{g/l}$) [37]; in different locations from Leyole River, Ethiopia (12.67 $\mu\text{g/l}$) [161]. Yusta-García, R. et al., 2017 has

found Pb concentrations in Capahuari South Pastaza (8.9 $\mu\text{g/l}$), Capah. North Capahuari River (7.6 $\mu\text{g/l}$), Dorissa Macusari River (7.3 $\mu\text{g/l}$), Pucacuro River (7.3 $\mu\text{g/l}$), Chambira Chambira/Maranon (15.1 $\mu\text{g/l}$), Huayurí Corrientes River (77.2 $\mu\text{g/l}$), Huayuri River (7.4 $\mu\text{g/l}$), Jibarito Corrientes River (7.5 $\mu\text{g/l}$), Pucacun–gayacu River (7 $\mu\text{g/l}$), Nueva Esperanza Corrientes (5.7 $\mu\text{g/l}$), Capirona Corrientes (10.6 $\mu\text{g/l}$), Trompeteros 1&2 Corrientes (6 $\mu\text{g/l}$), Pavayacu Tigre River (9.9 $\mu\text{g/l}$), Forestal Tigre River (53.8 $\mu\text{g/l}$), San Jacinto Tigre River (7.7 $\mu\text{g/l}$), Piedra Negra River (8.1 $\mu\text{g/l}$), Bartra Tigre River (13.8 $\mu\text{g/l}$), Montano River (13.8 $\mu\text{g/l}$), Yanayacu Maranon River (7.4 $\mu\text{g/l}$) and Huisto Yana-yaquillo River (7.1 $\mu\text{g/l}$) [162].

Pb concentrations are found in water samples from Danube River located near Hungarian and Slovakian border (6.58 $\mu\text{g/l}$) [89]; in river water samples from Mameyes (0.213-0.261 $\mu\text{g/l}$), Rio Piedras (less than 0.130 $\mu\text{g/l}$) and La Plata (less than 0.130-0.276 $\mu\text{g/l}$) Rivers in Puerto Rico [38]; in the water of Baleh River at Sarawak, Malaysia (30 $\mu\text{g/l}$) [163]; in borehole water samples from Rivers State, Nigeria (0.1 $\mu\text{g/l}$ to 0.22 $\mu\text{g/l}$) [90]; in river water samples from Selenga River basin, Mongolia (1.64 $\mu\text{g/l}$) in well water samples of Amlashin Guilan Province, Iran (0.337 $\mu\text{g/l}$) [164]; in pore water samples from Aar Dam (0.8 $\mu\text{g/l}$), Driedorf Dam (2.3 $\mu\text{g/l}$) and Klingenberg Reservoir (22.6 $\mu\text{g/l}$) in Germany [92]; in drinking groundwater from Mueang district in the Ubon Ratchathani province, Thailand (6.902 $\mu\text{g/l}$) [93]; in drinking water in Mashhad city, Iran (0.58 $\mu\text{g/l}$) [63].

In India (Fig.23.), Pb concentration is found (127.2 $\mu\text{g/l}$) in the drinking water of tea garden belt, Darrang district, Assam [165]; in the water of Binjhole pond (20 $\mu\text{g/l}$), Panipat, Haryana[166]; in the groundwater of Nainital District (23 $\mu\text{g/l}$), India [167]. Pb concentration of 165 $\mu\text{g/l}$ is also found in the water of Twin lakes i.e., upper and lower lakes of Bhopal, Madhya Pradesh[171]. Pb concentration in Pallikaranai wetland, Tamil Nadu, India is 580 $\mu\text{g/l}$ [173]; in the lake of Latipada , Maharashtra, India is 12510 $\mu\text{g/l}$ [175]; in the water of Lilour Lake of Uttar Pradesh, India is 990 $\mu\text{g/l}$ [176]; in the water of Talcher Gauge station on Brahmani River, Talcher, India is 50.9 $\mu\text{g/l}$ [177]; in Vembanad Lake, India (55.27 $\mu\text{g/l}$) [178]; in groundwater in Kanpur, India (4 $\mu\text{g/l}$) [179]; in groundwater of Ropar Wetland, Punjab, India (4 to 40 $\mu\text{g/l}$) [180]; in drinking water samples in Jaipur and Ajmer districts, Rajasthan, India (0.63 $\mu\text{g/l}$ to 40.27 $\mu\text{g/l}$) [42]; in the groundwater of Debagaram, Nadia, India is 2.9 $\mu\text{g/l}$ [40]; in the water of Damodar River near Bokaro steel plant, Bokaro, Jharkhand, India is 59 $\mu\text{g/l}$ [181]; and in groundwater in Chandigarh, India (19 $\mu\text{g/l}$) [97]. Bhattacharya A., et al., 2015 has found Pb concentration of 100 $\mu\text{g/l}$ in Delhi, India [182].

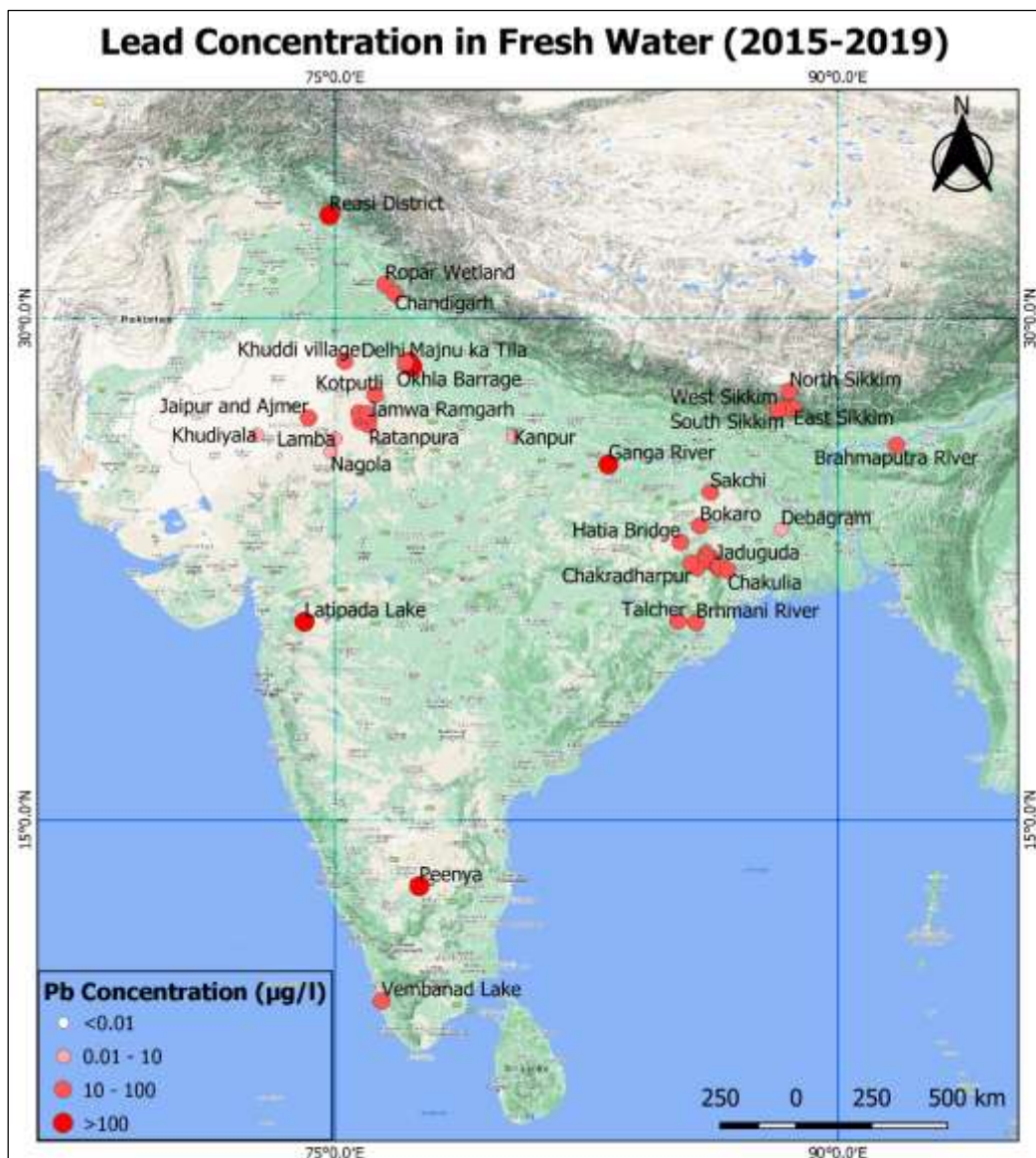


Fig.23. Spatial Distribution of Lead (Pb) Concentration in Fresh Water in Different Regions of India

Pb has been found to be concentrated in different areas of Subarnarekha basin, Jharkhand such as at Hatia Bridge, Khuddi village, Tatanagar, Adityapur, Sakchi, Govindpur, Mango, Jugsalai, Jaduguda, Mushabani, Maubhandar, Ghatsila, Chakulia, Chandil, Kandra, Saraikela, Chaibasa, Chakradharpur [183]. Singh et al., 2016, showed the Pb concentration in the water of Ghaghara River at different surrounding sites of the River in Uttar Pradesh and Bihar, India [184]. Jakhu R. and Mehra R., 2018, found Pb concentration in the drinking water of different places of Jaipur and Ajmer district of Rajasthan, India [42]. Rahman Z. and Singh, V. P., 2018, showed Pb concentration in water at different places along Yamuna River in Delhi [185]. Singh A.K. et al., 2019 showed Pb concentration in the water of four districts of Sikkim, India [41]. Kaur M. et al., 2019, found Pb concentration of 200 $\mu\text{g/l}$ in the water (surface and groundwater) of the Reasi District, India [186]. Shankar B.S., 2019, examined the Pb concentration of 145.3 $\mu\text{g/l}$ in the surface water of Peenya, Bangalore, India [187]. Pb is also concentrated in the groundwater of Gangetic plain area of India and Bangladesh i.e., Jalangi (1.6 $\mu\text{g/l}$), Domkal (1.6 $\mu\text{g/l}$), Haringhata (2.8 $\mu\text{g/l}$), Deganga (1.9 $\mu\text{g/l}$), and Baruipur (9.6 $\mu\text{g/l}$) area in West Bengal, India [72].

The country wise Pb concentration in fresh water shows that the highest mean and SD of Pb concentration ($\mu\text{g/l}$) i.e., 3358.3 $\mu\text{g/l}$ and 12545.7 $\mu\text{g/l}$ respectively are found for Kenya. It is followed by Greece, Uganda, Algeria, Mexico, Serbia, Italy, India, Bangladesh, Egypt, Pakistan, Nigeria, Brazil and Turkey. In all of these countries the average Pb concentration is more than 100 $\mu\text{g/l}$. In Iran, Peru, Russia, Malaysia, Japan, Sweden, Poland, China, Ghana, Laos and Canada the average Pb concentrations are from 10 to 100 $\mu\text{g/l}$. In Ethiopia, Thailand, South Africa and Germany the average Pb concentrations are from 1 to 10 $\mu\text{g/l}$. The average Pb concentrations in South Korea, Latvia, Sri Lanka, Zimbabwe, Spain, Puerto Rico, Argentina, Mongolia and Cyprus are within 1 $\mu\text{g/l}$ ([Table.23.](#)).

Table.23. Country Wise Average Lead (Pb) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
Canada	100	-
Cyprus	0.914	-
Germany	8.566667	9.941943
Greece	1500	-
Italy	425.005	424.995
Japan	38	-
Latvia	0.1	-
Poland	56.63	-
Spain	0.178	-
Sweden	40	-
Developing Countries		
Algeria	688.3333	126.1172
Argentina	0.36	0.29
Bangladesh	273.78153846154	745.51637520937
Brazil	117.933333333333	74.084696275427
China	63.70584375	224.96750708576
Egypt	220	-
Ethiopia	6.76047619	4.1947382539693
Ghana	76.8195	124.11678110654
India	320.51415384615	1712.6144437087
Iran	11.9634	25.212333584445
Kenya	3358.3	12545.7
Laos	95	-
Malaysia	30	0
Mexico	660.2	659.8
Mongolia	0.911111	0.66184
Pakistan	183.2797826087	288.71115117723

Nigeria	147.752	323.80164815722
Peru	14.46	17.59805103
Puerto Rico	0.212556	0.059972
Russia	16.8	6.177378
Serbia	582	-
South Africa	8.191428571	-
South Korea	0.028	-
Sri Lanka	0.136	0.149345
Thailand	6.902	-
Turkey	112.18989473684	395.40282576019
Uganda	801.644708	580.8049674774
Zimbabwe	0.147833333	-

3.5. Mercury (Hg) Concentration in Water: The study of the concentration of Mercury in water is of great concern as it has neurological effects even at its lower levels of concentration. Hg is present in the environment in three forms i.e., as metallic elements, inorganic salts, and organic compounds. All three forms have different levels of toxicity. These forms are present in the surface water of rivers, lakes, and oceans and after taken up by the microorganisms, they transform into methylmercury and eventually undergo through biomagnification, causing disturbances to the aquatic animals[43]. Thus, the major source of mercury exposure to humans is the intake of contaminated fish as food[198]. Mercury is also released into the environment from different industries like paper and pulp, pharmaceuticals, chlorine, and caustic soda industry, etc. The Environment Protection Agency has considered Hg (methylmercury and mercury chloride) as highly cancer-causing metal. Due to severe health effects, the WHO has set a standard value of 1 µg/l for the concentration of Hg in drinking water.

A total number of 751 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Mercury (Hg) is given in Fig.24.

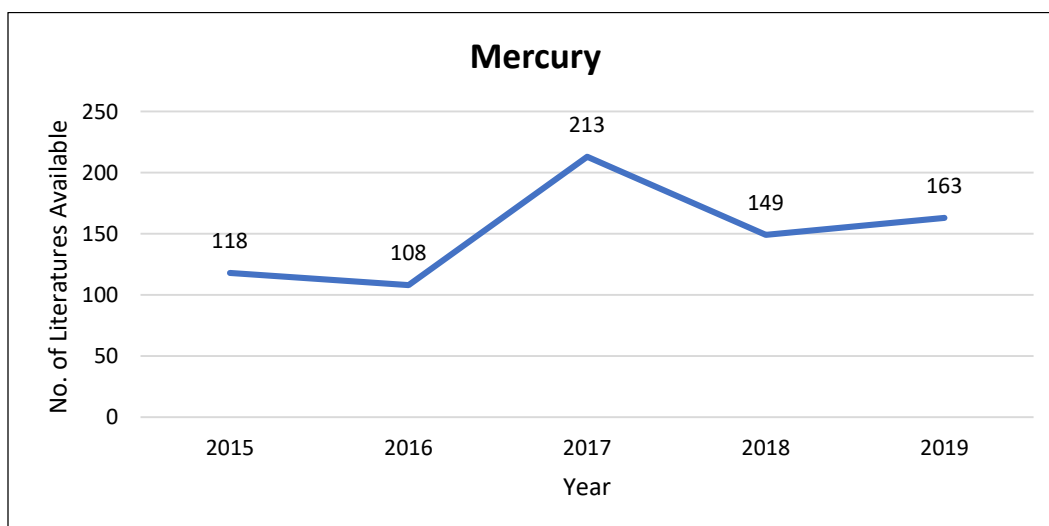


Fig.24. Total No. of Literatures Available for Mercury (Hg)

Among these 751 literatures only 43 literatures have been selected for the purpose of this study which are related to the concentration of Hg in fresh water (Fig.25.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of Hg is found in Prestea Huni District, Ghana (499 µg/l) and the lowest concentration is found in the water of Vembanad Lake, India (0.00001425 µg/l).

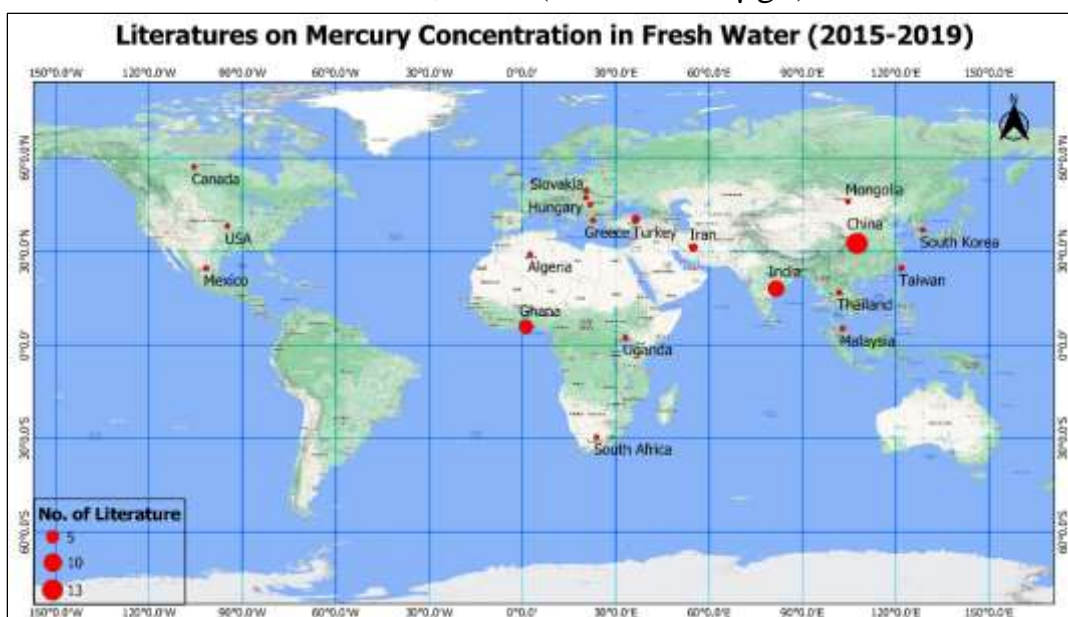


Fig.25. Literatures on Mercury Concentration in Fresh Water (2015-2019)

The average values have also been calculated for similar sources of water in the same location. The details of the places having Hg concentration in fresh water are given in Table.24.

Table.24. Details of Mercury (Hg) Concentration in Fresh Water

Location	Country	Source	Hg Concentration (µg/l)	Reference
Tinga	Ghana	Drinking water	38	Cobbina, S., et al., 2015
Nangodi	Ghana	Drinking water	64	Cobbina, S., et al., 2015
Sainshand	Mongolia	Drinking water	0.5	Golubkina, N., et al., 2018
Bayan	Mongolia	Drinking water	0.6	Golubkina, N., et al., 2018
Mashhad City	Iran	Drinking water	0.01	Alidadi, H., et al., 2019
Mueang District	Thailand	Groundwater	0.05	Wongsasuluk, P., et al., 2017

Indian Lake	Canada	Lake water	0.96	Stuyt, S. S., et al., 2015
Upper Rideau Lake	Canada	Lake water	1.17	Stuyt, S. S., et al., 2015
Newboro Lake	Canada	Lake water	1.48	Stuyt, S. S., et al., 2015
Kampar Lake	Malaysia	Lake water	2.425188	Ahmed, M., et al., 2017
Sarayduzu Dam	Turkey	Lake water	0.001	Kukrer, S. & Mutlu, E., 2019
Asopos River	Greece	River water	300	Charalampous, N., et al., 2015
Ankasa River	Ghana	River water	2	Hadzi, G.Y., et al., 2015
Bosomkese River	Ghana	River water	2	Hadzi, G.Y., et al., 2015
Oda River	Ghana	River water	2	Hadzi, G.Y., et al., 2015
San Lorenzo River	Mexico	River water	0.131	Paez-Osuna F., et al., 2015
Ugljesnica River	Serbia	River water	0.825	Milivojevic, J., et al., 2016
Mississippi River	USA	River water	0.0058	Zhen, G. et al., 2016
Buyuk Menderes River	Turkey	River water	0.105	Durmaz, E., et al., 2017
Ankorba River Basin	Ghana	River water	0.98	Gbogbo, F., et al., 2017
Densu River Basin	Ghana	River water	1.16	Gbogbo, F., et al., 2017, F., et al., 2017
Volta River Basin	Ghana	River water	0.77	Gbogbo, F., et al., 2017
Hyeongsan River	South Korea	River water	0.2	Bailon, M.X., et al, 2018
Nakivubo Channel	Uganda	River water	8.6	Dietler, D., et al., 2019
River Tano	Ghana	River water	45	Nyantakyi, A.J., et al., 2019

Danube River	Hungaria n and Slovakia n border	Water sample	0.43	Nagy, A.S., et al., 2016
Prestea Huni District	Ghana	Water sample	499	Obiri, S., et al., 2016
Seybouse Watershed	Algeria	Water sample	135.5	Belabed, B. E., et al, 2017
Wonderfonte inspruit catchment area	South Africa	Water sample	0.17	Jordaan, K., et al., 2019
Bao-Shan Reservoir	Taiwan	Water sample	0.009	Wang, Y. L., et al., 2019
Siangshan Wetland	Taiwan	Water sample	0.031	Wang, Y. L., et al., 2019
Iranian Market	Iran	Well water	0.6	Hadiani, M.R., et al., 2015

Hg remains present in its different forms in the surface water. Different literature showed different locations for mercury concentration in water. Hg concentrations are found in the water from different drinking water sources in Nangodi and Tinga of Ghana are 64 and 38 $\mu\text{g/l}$ respectively [73]; in the water of El Comedero Dam on San Lorenzo River in Mexico is 0.131 $\mu\text{g/l}$ [79]. Hadzi G.Y., et al., 2015, showed Hg concentration in the water of different rivers in different places in Ghana[75]. Hg concentration in the water of Indian Lake, Upper Rideau Lake and Newboro Lake of Canada are 0.96, 1.17 and 1.48 $\mu\text{g/l}$ respectively [199]; in the water of Ugljesnica River of Serbia is 0.825 $\mu\text{g/l}$ [81]; in the water of Prestea-Huni District is 499 $\mu\text{g/l}$ [4]. Zhen G. et al., 2016 analysed the water quality of Mississippi River of USA and showed Hg concentration of 0.0058 $\mu\text{g/l}$ [82]. Bempah, C.K., & Ewusi A., 2016, showed Hg concentration in groundwater near gold mines at Obuasi, Ghana[76]. Dumraz E. et al., 2017, showed Hg concentration in the water of four sites on Buyuk Menderes River in Turkey, among which Isikh and Saraykay have Hg level below the detection limit and Soke and Tasburun have Hg limit of 0.2 and 0.01 $\mu\text{g/l}$ [30]. Belabed B. E., et al., 2017 showed Hg concentration (135.5 $\mu\text{g/l}$) in the water of Seybouse watershed in Algeria [145]. Gbogbo F., et al., 2017 showed Hg concentration in Ankorba, Densu and Volta River Basin of Ghana[200]. Hg concentration in the water of Bogacayi River in Antalaya, Turkey is below the detection limit [65]; in the water of Sainshand and Bayan of Mongolia are 0.5 and 0.6 $\mu\text{g/l}$ respectively [32]. The concentration of Hg in the water of Hyeongsan River in Pohang City, South Korea is 0.2 $\mu\text{g/l}$ [87]. The Hg concentration in the water of Sarayduzu Dam, Turkey is 0.001 $\mu\text{g/l}$ [140]; in the water of Bao-Shan Reservoir and Shianshan Wetland in Taiwan are 0.009 and 0.031 $\mu\text{g/l}$ respectively[201] (Fig.26.).

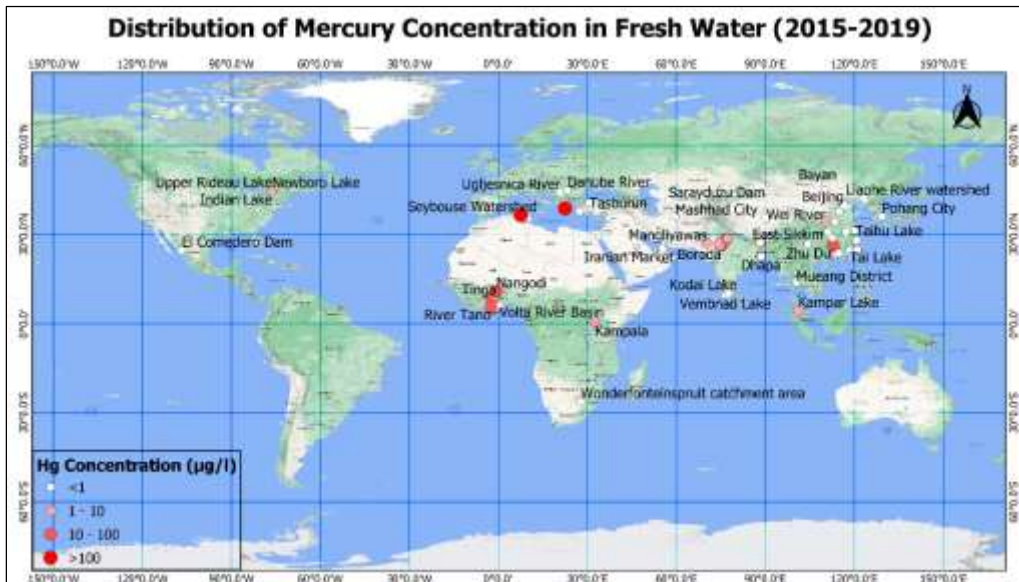


Fig.26. Spatial Distribution of Mercury (Hg) Concentration in Fresh Water (2015-2019)
 Charalampous N. et al., 2015 has found Hg concentration of more than $300\ \mu\text{g/l}$ in Asopos River, Greece [157]. Hg concentrations are found in Kampar Lake, Malaysia ($2.43\ \mu\text{g/l}$) [51]; in the water of Nakivudo Channel, Kampala, Uganda ($8.6\ \mu\text{g/l}$) [135]. Hg concentrations are found in Wonderfonteinspruit catchment area, South Africa ($0.17\ \mu\text{g/l}$) [37]; and in River Tano in Bono, Bono East, and Ahafo Regions, Ghana ($45\ \mu\text{g/l}$) [74]. Hg concentrations are found in well water samples from Iranian Market ($0.6\ \mu\text{g/l}$) [9]; in drinking groundwater from Mueang district in the Ubon Ratchathani province, Thailand ($0.05\ \mu\text{g/l}$) [93]; in drinking water in Mashhad city, Iran ($0.01\ \mu\text{g/l}$) [63]. Nagy, A.S., et al., 2016 has found Hg concentration of $0.43\ \mu\text{g/l}$ in water samples from the Danube River located near Hungarian and Slovakian border [89].

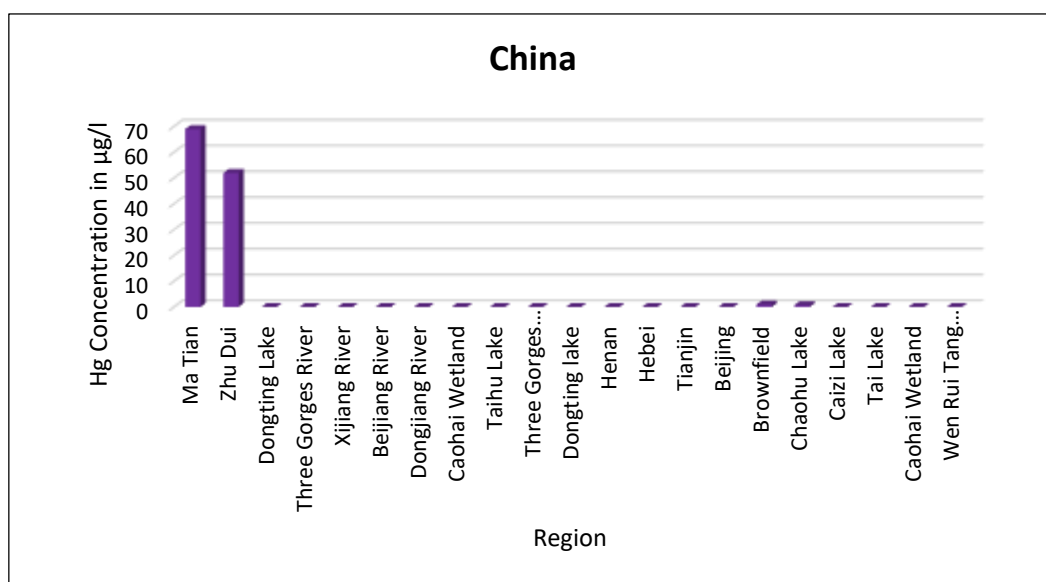


Fig.27. Hg Concentration in Different Regions of China
 Nong et al., 2019, showed Hg concentration (Fig.27.) in water from 29 fixed stations of Middle Route (MR) of the South-to-North Water Diversion [202] Project of China (SNWDPC) in four places i.e., Henan Province, Hubei Province, Tianjin Municipality and Beijing capital, and calculated average Hg concentration of $0.16\ \mu\text{g/l}$; in the water of Three

Gorges Reservoir it is 0.015 $\mu\text{g/l}$ and in the water of background, Dongting Lake, China is 0.025 $\mu\text{g/l}$ [35]. Wen Rui Tang River Watershed, China (0.03 $\mu\text{g/l}$) [53]. Zhen G. et al., 2016 analysed the water quality of three Gorges River, Upper Xixiang, Middle Xixiang, Lower Xixiang River, Beijiang River and Dongjiang River of China and showed Hg concentration of 0.05, 0.02, 0.02, 0.01, 0.02 and 0.01 respectively [82]. in the water of Cahoi wetland, China is 0.065 $\mu\text{g/l}$ [106]; in the water of Dongting Lake is 0.02 $\mu\text{g/l}$ [48]; in the water of Taihu Lake is 0.021 $\mu\text{g/l}$ [49]; in the water of Ma Tian and Zhu Dui, Suxian District of Chenzhou City, Hunan Province, Southern China are 52 and 69 $\mu\text{g/l}$ respectively [47]; in Caohai Wetland, China (0.065 $\mu\text{g/l}$) [52]; in groundwater in Brownfield, China (1 $\mu\text{g/l}$) [105]; and in water samples from Wei River of Shaanxi region, China (9.88 $\mu\text{g/l}$) [56]. Fang T. et al., 2019, showed Hg concentration in the water of Chaohu Lake (0.74 $\mu\text{g/l}$) and Caihu Lake (0.04 $\mu\text{g/l}$) in China [59]. Shao, T., et al., 2017 has found Hg concentrations in East Liaohe River (0.023 $\mu\text{g/l}$), Hunhe River (0.12 $\mu\text{g/l}$), Liaohe River (0.013 $\mu\text{g/l}$), Taizihe River (0.019 $\mu\text{g/l}$) and West Liaohe River (0.003 $\mu\text{g/l}$) in Liaohe River watershed, China [60].

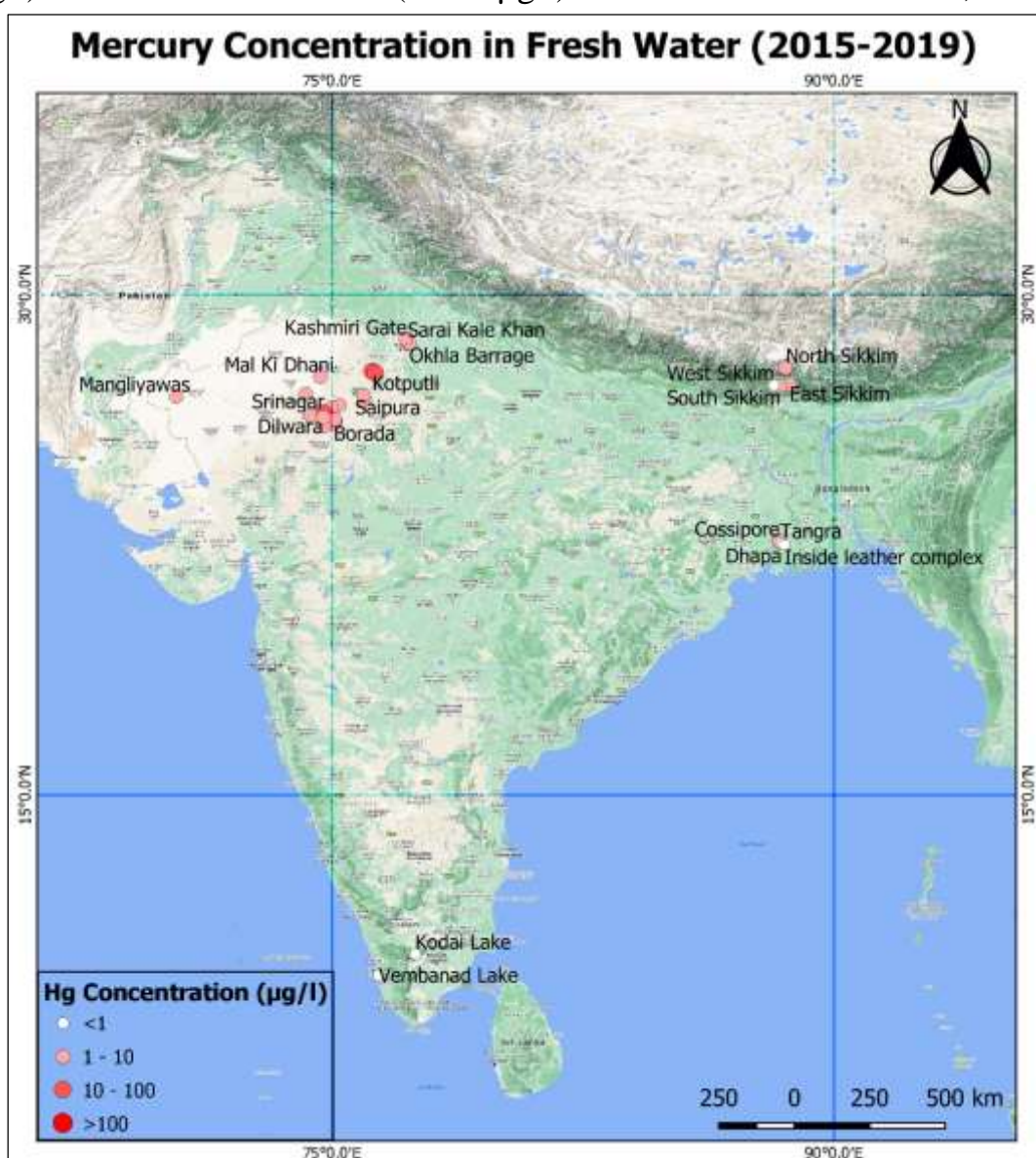


Fig.28. Spatial Distribution of Mercury (Hg) Concentration in Fresh Water in Different Regions of India

In India (Fig.28.) Hg concentrations are found in fresh water in several locations. Hg concentrations are found in the drinking water of different sites of Kolkata e.g. Tangra (3.649 mg/l), Cossipore (1.755 mg/l), Dhapa (0.932 mg/l) and Inside Kolkata Leather Complex (0.719 mg/l) [203]. Singh A.K., et al., showed the Hg concentration in potable water in the four districts of Sikkim, India, in their study [41]. Hg concentrations are found in Vembanad Lake, India (0.00001425 µg/l) [178]; and Kodai Lake, India (0.415 µg/l) [202]; in the water of Vembanad Lake, India is 0.0318 µg/l[204]. Jakhu R. and Mehra R., 2018 showed Hg concentration in the drinking water at different places of Jaipur and Ajmer districts of Rajasthan[42]. The concentration values of Hg in different parts of India are depicted in Fig.29.

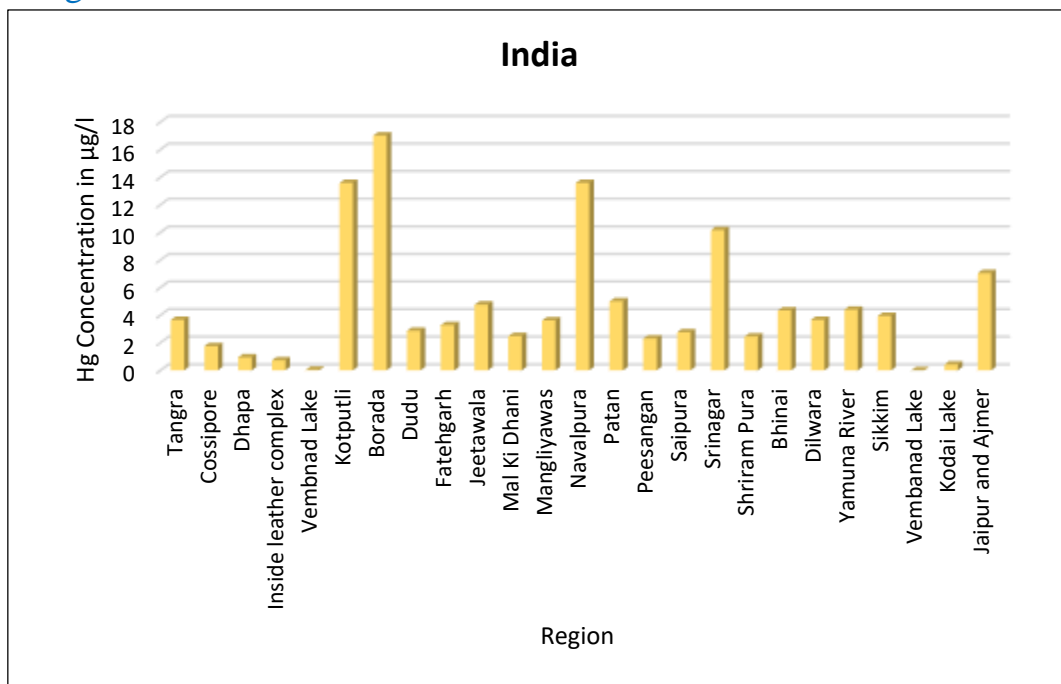


Fig.29. Mercury (Hg) Concentration in Different Regions of India

The country wise Hg concentration in fresh water shows that the highest mean of Hg concentration (µg/l) i.e., 300 µg/l is found for Greece. It is followed by Algeria and Ghana. In these countries the average Hg concentration is more than 50 µg/l. In Canada, Malaysia, India, China and Uganda, the average Hg concentrations are from 1 to 10 µg/l. In the USA, Taiwan, Thailand, Turkey, Mexico, South Africa, South Korea, Iran, Hungary and Slovakia, Mongolia and Serbia the average Hg concentrations are from 0.005 to 1 µg/l which is the permissible limit as directed by the WHO (Table.25.).

Table.25. Country Wise Average Mercury (Hg) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
Canada	1.203333	0.213594
Greece	300	-
Hungary and Slovakia	0.43	-
USA	0.0058	-

Developing Countries		
Algeria	135.5	-
China	4.935091358	15.99375586
Ghana	59.75454545	140.5540816
India	4.503963	3.996331
Iran	0.305	0.295
Malaysia	2.425188	-
Mexico	0.131	-
Mongolia	0.55	0.05
Serbia	0.825	-
South Africa	0.17	-
South Korea	0.2	-
Taiwan	0.02	0.011
Thailand	0.05	-
Turkey	0.070333	0.091762
Uganda	8.6	-

3.6. Nickel (Ni) Concentration in Water: Human exposure to a high level of Nickel concentration, associated with nickel refining, electroplating, and welding, has the potential to produce a variety of paranormal health effects[194]. Gowd and Govil, in their study, mentioned municipal sewage sludge, sewage treatment plants, and landfill sites, industries like ceramics, steel and alloys, electroplating, and refractory as the major sources of Ni in water. Some other anthropogenic sources include fuel combustion or waste released from industries, where Ni is extracted from ore [195]. The WHO (WHO, 1996) guideline value of Ni concentration in drinking water is 20 µg/l and it is generally found to remain in association with Lead (Pb) and Copper (Cu). An increase in the level of Ni concentration is associated with an increased level of Cu and Pb [195].

A total number of 574 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Nickel (Ni) is given in Fig.30.

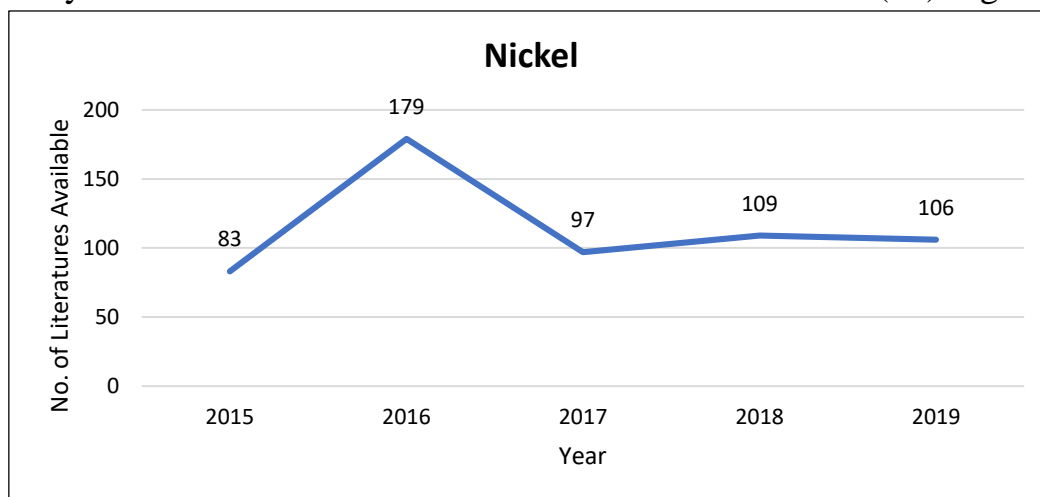


Fig.30. Total No. of Literatures Available for Nickel (Ni)

Among these 574 literatures only 49 literatures have been selected for the purpose of this study which are related to the concentration of Ni in fresh water (Fig.31.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of Ni is found in Asopos River, Greece (10100 µg/l) and the lowest concentration is found in Xiaoqing River, China (0.00661 µg/l). The average values have also been calculated for similar sources of water in the same location.

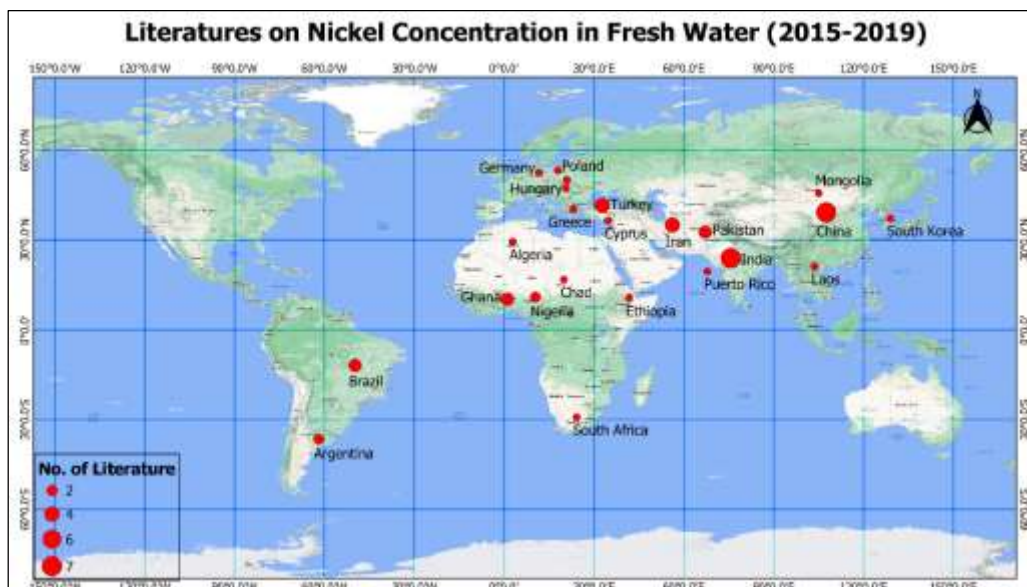


Fig.31. Literatures on Nickel Concentration in Fresh Water (2015-2019)

De Melo, W. A et al., 2017 found Ni concentrations of 775 µg/l and 850 µg/l in Acude and Maria Lucinda Streamlet and Santa Rosa Streamlet in Brazil respectively [154]. Ni concentrations are found in Jaboticabal Watershed, Brazil (15.4 µg/l) [158] and in river water of Vieira River, Montes Claros, Brazil (33.8 µg/l) [88] (Table.26.).

Table.26. Nickel (Ni) Concentration in Different Locations in Brazil

Location	Ni Concentration (µg/l)	Reference
Acude and Maria Lucinda Streamlet	775	De Melo, W. A., et al., 2017
Santa Rosa Streamlet	850	De Melo, W. A., et al., 2017
Jaboticabal Watershed	15.4	Saran, L.M., et al., 2018
Vieira River	33.8	Reis, M.M., 2019

Du Y., et al., 2018, showed Ni concentration of 3.99 µg/l in the groundwater of Lower Cambrian, south Shanxi, China [33]. Bi B et al., 2018 found Ni concentration of 1.92 µg/l in the water of Chaohu Lake, China [49]. Fang T., et al., 2019 found Ni concentration in the water of different lakes of China and Sarayduzu Dam of Turkey [59]. Ni concentrations are found in Tai Lake, China (20 µg/l) [50]; in groundwater in Brownfield, China (1 µg/l) [105];

in water samples from China (3.61 µg/l) [54]; in Xiaoqing River, China (0.00661 µg/l) [58] (Table.27.).

Table.27. Nickel (Ni) Concentration in Different Locations in China

Location	Ni Concentration (µg/l)	Reference
Tai Lake	20	Fu, Z., et al, 2016
Brownfield	1	Li, F., et al., 2017
Chaohu Lake	1.92	Bi, B., et al., 2018
Shaanxi	3.99	Du, Y., et al., 2018
Xiaoqing River	0.00661	Li, Q., et al., 2018
Chaohu Lake	1.51	Fang, T., et al., 2019
Taihu Lake	2.04	Fang, T., et al., 2019
Dongting Lake	1.51	Fang, T., et al., 2019
Hulun Lake	4.39	Fang, T., et al., 2019

Ni concentrations in water in different regions of China and Brazil are depicted in Fig.32.

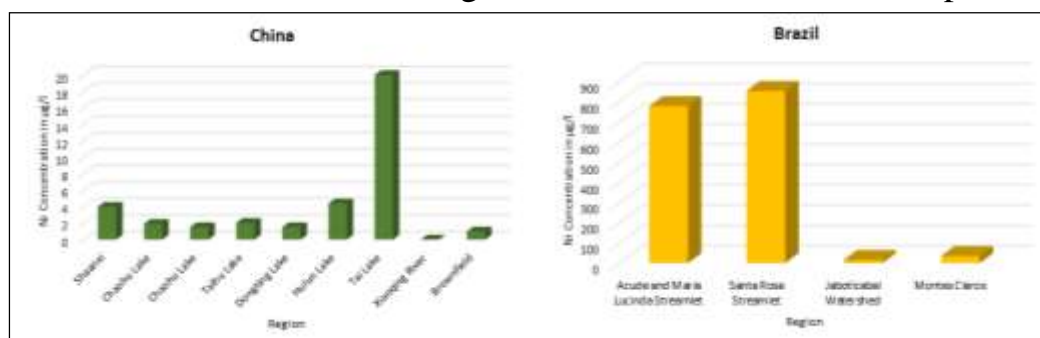


Fig.32. Nickel (Ni) Concentration in Fresh Water in China and Brazil

Kose E. et al., 2015 found Ni in the water of the Porsuk stream at different sites of Turkey[64]. Ni concentration in the water of Bogacayi River at Antalya, Turkey is 3.47 µg/l[65]; in the water of Buyuk Menderes River at four different sites i.e., Isikh, Saraykay, Soke, and Tasburun are 4.4 µg /l, 13.2 µg /l, 8.2 µg /l, and 5.5 µg/l respectively[30]. Kukrer, S. & Mutlu, E., 2019 found the concentration of only 1.6 µg/l in the water of Sarayduzu Dam, Turkey[140] (Table.28.).

Table.28. Nickel (Ni) Concentration in Different Locations in Turkey

Location	Ni Concentration (µg/l)	Reference
Porsuk Stream	30.125	Kose, E., et al., 2015
Bogacayi River	3.47	Cengiz, M.F., et al., 2017
Buyuk Menderes River	4.4	Durmaz, E., et al., 2017

Sarayduzu Dam	1.6	Kukrer, S. & Mutlu, E., 2019
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Ni concentrations are found in drinking water samples in Lahore (1306 µg/l), Jhang (15.32 µg/l), Multan (5.98 µg/l), Vehari (24.22 µg/l), Peshwar (0.94 µg/l) and Swabi (1.1 µg/l) regions of Pakistan [67]. Ni concentrations are found in Khyber Pakhtunkhwa, Punjab and Sindh Provinces of Pakistan [68]; in drinking water samples collected from tap water and hand pumps (40 µg/l) in Faisalabad, Pakistan [39]. Masood, N., et al., 2019 has found Ni concentrations in groundwater in different regions of Gujrat, Pakistan (212 µg/l) [112] (Table.29.).

Table.29. Nickel (Ni) Concentration in Different Locations in Pakistan

Location	Ni Concentration (µg/l)	Reference
Punjab province	71.75	Rehman, K., et al., 2018
Sindh Province	248.17	Rehman, K., et al., 2018
Khyber Pakhtunkhwa	1074.75	Rehman, K., et al., 2018
Lahore	1306	Hussain, S., et al., 2019
Jhang	15.32	Hussain, S., et al., 2019
Multan	5.98	Hussain, S., et al., 2019
Vehari	24.22	Hussain, S., et al., 2019
Peshwar	0.94	Hussain, S., et al., 2019
Swabi	1.1	Hussain, S., et al., 2019
Faisalabad	40	Mahfooz, Y., et al., 2019
Gujrat	212	Masood, N., et al., 2019

Ni concentrations in water in different regions of Turkey and Pakistan are depicted in Fig.33.

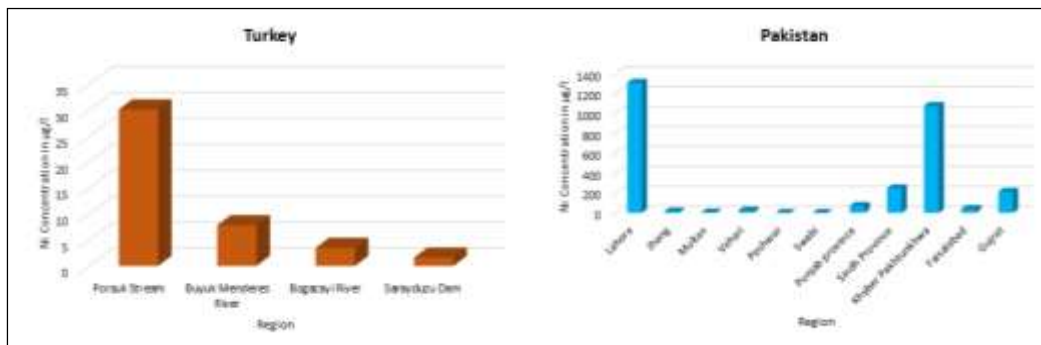


Fig.33. Nickel (Ni) Concentration in Fresh Water in Turkey and Pakistan

The Ni concentration in the water of Gonyeli Lake, Cyprus is 19.6 µg /l[83]; in the surface water of Annaba, Lake Tonga and Seybouse Watershed are 1081, 500 and 470 µg /l[145]; in the groundwater of Bwari and Kuje of Nigeria, it is 10 and 20 µg/l respectively[147]; Ni concentrations in the water of Biala Przemsza River of Poland is 7.68 µg/l[80]; in the water of Koka Dam, and Sire Robi are 4.67 and 5.97 µg/l respectively[133]; in the water near the gold mine of Obuasi, Nigeria is 7.31 µg /l[76]. Golubkina N., et al., 2018 showed Ni concentration in the water (well, spring and river) from different places of Mongolia[32]. The concentration in the water of Los Molinos Lake, Cordoba, Argentina is 0.56 µg /l[34]; in the water of Ado-Odo Ota, Osun state of Nigeria, is 2.6 µg /l[86]; in the water of Hyeongsan River, in Pohang City of South Korea is 11.77 µg /l[87].

Ezemonye L.I., et al., 2019 showed Ni concentration of 420 µg/l in the water of Benin River in Koko Town, Nigeria[151]. Ni concentrations are also found in river water of Yamuna River at Delhi (50 µg/l) [182]; in Asopos River, Greece (10100 µg/l) [157]; and in the water of Koka Dam and Sire Robi of Ethiopia are 4.67 µg/l and 5.97 µg/l respectively[144]. Ni concentrations are also found in well water samples in Abarkouh (1.07 µg/l), Meybod (3.49 µg/l), Bafgh (1.09 µg/l) and Behabed (3.65 µg/l) regions [155]. Vongdala N., et al., 2018 has found Ni concentration of 25 µg/l in surface water in Vientiane, Laos [156]. Ni concentrations are found in lake water samples of Shadegan Wetland, Iran (26.32 µg/l) [36]; Hadzi G.Y., 2018 has found Ni concentrations in Nyam River (10.5 µg/l), Subri River (10 µg/l), Birim River (21 µg/l), Bonsa River (7.5 µg/l), Atewa Forest River (5 µg/l), Bosomkese Forest River (2 µg/l) and Oda River (3.5 µg/l) in Ghana [77]. Ni concentrations are found in Wonderfonteinspruit catchment area, South Africa (12.035 µg/l) [37]; Nambatingar, N. et al., 2017 has found Ni concentration of 80 to 650 µg/l in different locations in Chari River, Chad [196] (Fig.34.).



Fig.34. Spatial Distribution of Nickel (Ni) Concentration in Fresh Water (2015-2019)
 Ni concentrations are found in borehole drinking water samples in Tarkwa, Ghana (2.8 $\mu\text{g/l}$) [78]; in water samples from Danube River located near Hungarian and Slovakian border (5.83 $\mu\text{g/l}$) [89]; in river water samples from Mameyes (2.513-3.183 $\mu\text{g/l}$), Rio Piedras (2.500-2.643 $\mu\text{g/l}$) and La Plata (1.993-4.360 $\mu\text{g/l}$) Rivers in Puerto Rico [38]; in river water samples from Selenga River basin, Mongolia (3.86 $\mu\text{g/l}$) [91]; in well water samples of Amlashin Guilan Province, Iran (4.421 $\mu\text{g/l}$) [164]; in pore water samples from Aar Dam (2.25 $\mu\text{g/l}$), Driedorf Dam (7.31 $\mu\text{g/l}$) and Klingenberg Reservoir (112 $\mu\text{g/l}$) in Germany [92]; and in drinking water in Mashhad city, Iran (1.69 $\mu\text{g/l}$) [63].

Table.30. Nickel (Ni) Concentration in Different Locations in India

Location	Ni Concentration ($\mu\text{g/l}$)	Reference
Delhi	50	Bhattacharya, A., et al., 2015
Debagram	8.3	Bhowmick, S., et al., 2015
Bokaro	140	Kumar, A. & Samaddar, S. R., 2015
Katerniaghat	17	Singh, et al., 2016
Colonelganj	12	Singh, et al., 2016
Ayodhya	18	Singh, et al., 2016
Dohrihat	7	Singh, et al., 2016
Chhapra	14	Singh, et al., 2016
Neeru stream	5.32	Kumar, R., et al., 2019
Chandigarh	2.1	Ravindra, K. and Mor, S., 2019
Peenya	87.67	Shankar, B.S., 2019

In India (Table.30.) Ni concentrations are found in fresh water in several locations. Ni concentration in the groundwater of Debagram of Nadia, West Bengal, India, is $8.3 \mu\text{g/l}$ [40]; The Ni concentration in the water of Damodar River near Bokaro Thermal Plant, Jharkhand, India is $140 \mu\text{g/l}$ [181]; Ni is concentrated in the river water in some sites of the Subarnarekha River Basin Area (average concentration is $19.7 \mu\text{g/l}$). These are at Hatia bridge ($14.69 \mu\text{g/l}$), Khuddi village ($11.90 \mu\text{g/l}$), Tatanagar ($17.85 \mu\text{g/l}$), Adityapur ($13.22 \mu\text{g/l}$), Sakchi ($13.52 \mu\text{g/l}$), Govindpur ($16.65 \mu\text{g/l}$), Mango ($14.75 \mu\text{g/l}$), Jugsalai ($14.39 \mu\text{g/l}$), Jaduguda ($10.96 \mu\text{g/l}$), Mushabani ($11.55 \mu\text{g/l}$), Maubhandar ($11.24 \mu\text{g/l}$), Ghatsila ($72.58 \mu\text{g/l}$), Chakulia ($75.41 \mu\text{g/l}$), Chandil ($15.68 \mu\text{g/l}$), Kandra ($12.04 \mu\text{g/l}$), Saraikela ($11.17 \mu\text{g/l}$), Chaibasa ($13.14 \mu\text{g/l}$), Chkradharpur ($11.54 \mu\text{g/l}$), Chakulia ($12.47 \mu\text{g/l}$) [183] (Fig.35.).

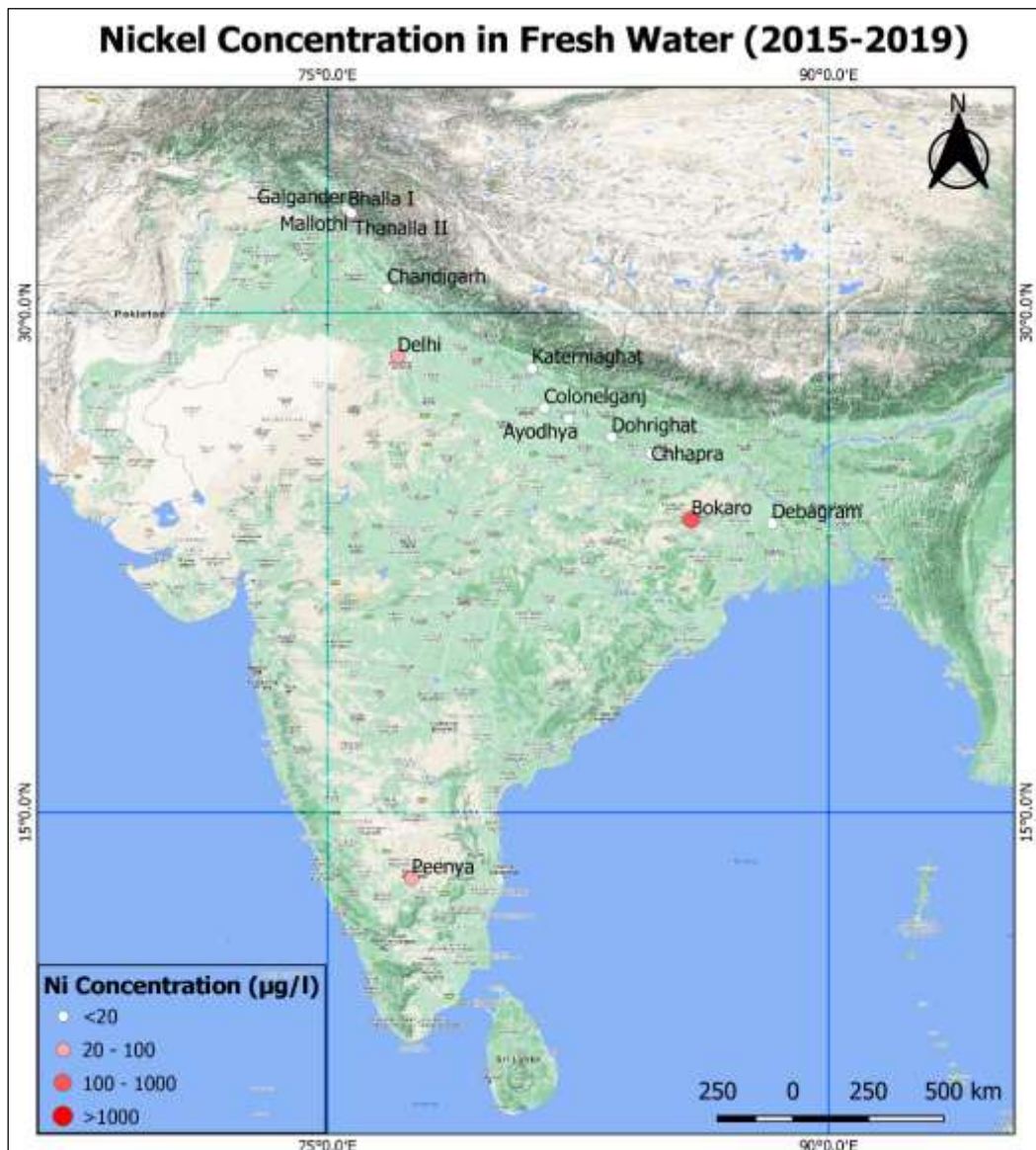


Fig.35. Spatial Distribution of Nickel (Ni) Concentration in Fresh Water in Different Regions of India

Singh, et al., 2016, showed Ni concentration in the water of the Ghaghara River at various locations of Katerniaghat, Colonelganj, Dohrihat, and Ayodhya of Uttar Pradesh and at Chhapra of Bihar, India [184]. Shankar B. S., 2019, showed the concentration of $87.67 \mu\text{g/l}$ in the groundwater of Peenya, Bangalore, India [187]; Kumar, R., et al., 2019 found Ni

concentrations of 5.32 $\mu\text{g/l}$ in different locations of River water of Neeru stream, Jammu and Kashmir (presently the UT of Jammu and Kashmir), India [197]. groundwater in Chandigarh, India (2.1 $\mu\text{g/l}$) [97]. The concentration values of Ni in different parts of India are depicted in Fig.36.

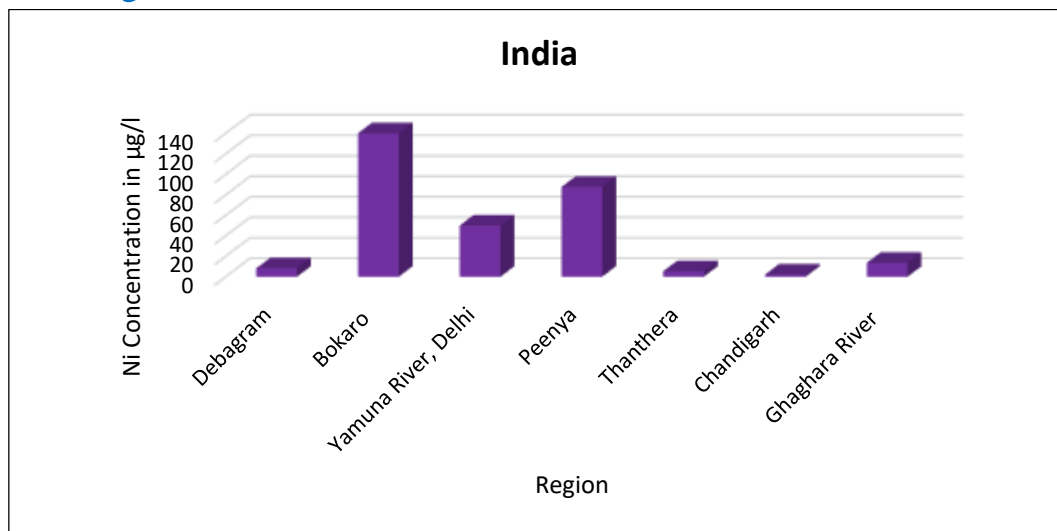


Fig.36. Ni Concentration in Water in Different Regions of India

The country wise Ni concentration in fresh water shows that the highest mean of Ni concentration ($\mu\text{g/l}$) i.e., 10100 $\mu\text{g/l}$ is found for Greece. It is followed by Algeria, Brazil, Pakistan, Chad and Nigeria. In these countries the average Ni concentration is more than 100 $\mu\text{g/l}$. In Laos and Germany, the average Ni concentrations are from 20 to 100 $\mu\text{g/l}$. In Argentina, Puerto Rico, Mongolia, China, Ethiopia, Hungary and Slovakia, Iran, Poland, Ghana, South Korea, South Africa, India, Cyprus and Turkey, the average Ni concentration is within the permissible limit i.e., 20 $\mu\text{g/l}$ as directed by the WHO (Table.31.).

Table.31. Country Wise Average Nickel (Ni) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
Cyprus	19.6	-
Germany	40.52	50.58619
Greece	10100	-
Hungary and Slovakia	5.84	-
Poland	7.68	-
Developing Countries		
Algeria	683.6667	281.2239
Argentina	0.56	0
Brazil	418.55	394.895
Chad	326	220.8257231
China	3.997661	5.493811145
Ethiopia	5.32	0.65
Ghana	7.734444	5.493748

India	13.97343	26.84132
Iran	5.960286	8.40302
Laos	25	-
Mongolia	3.86	-
Nigeria	113.15	177.2675
Pakistan	338.4373913	542.1440309
Puerto Rico	2.865333	0.247294
South Africa	12.03429	16.77268
South Korea	11.77	-
Turkey	19.81214	13.72536

3.7. Presence of Selenium (Se) in Water: Selenium is present in the earth's crust in the sulphur-containing minerals. Water is not a major source of Selenium, but it is important to determine a guideline value for Se in drinking water to achieve a balance between recommended guideline value and undesirable value of intake. The Se level in surface water as well as in groundwater varies from 0.06 – 400 mg/l. In some areas, it reaches to 6000 µg/l, whereas the WHO (World Health Organisation) permissible limit is 10 µg/l¹. Both the deficiency (<40 µg/day) and excessiveness or toxicity (>400 µg/day) of Se can cause severe health effects [22]. The permissible concentration of Se in drinking water varies over different parts of the world. For example, the permissible concentration of Se is 1 µg/l in Russia, 8 µg/l in Germany; 10 µg/l in Egypt, the USA, Australia, Canada, India, Poland, Japan, New Zealand, Thailand, and European Union (EU) countries and 50 µg/l in the Czech Republic. Relatively higher upper limits of 30 µg/l have been mentioned by California Environmental Protection Agency; 50 µg/l by U.S. Environmental Protection Agency and 40 µg/l by World Health Organization (WHO, 2011) [23]. Wide variations in the permissible Se levels in drinking water across different countries and agencies are difficult to comprehend because Se in water exists as inorganic selenate or selenite species [23]. Selenium concentration in natural water (surface water or the water from rivers, lakes, or other wetlands and groundwater) is found in various below-mentioned places in the world either in deficiency or in excess amount. A total number of 152 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Selenium (Se) is given in [Fig.37](#).

¹https://www.who.int/water_sanitation_health/dwq/chemicals/selenium.pdf

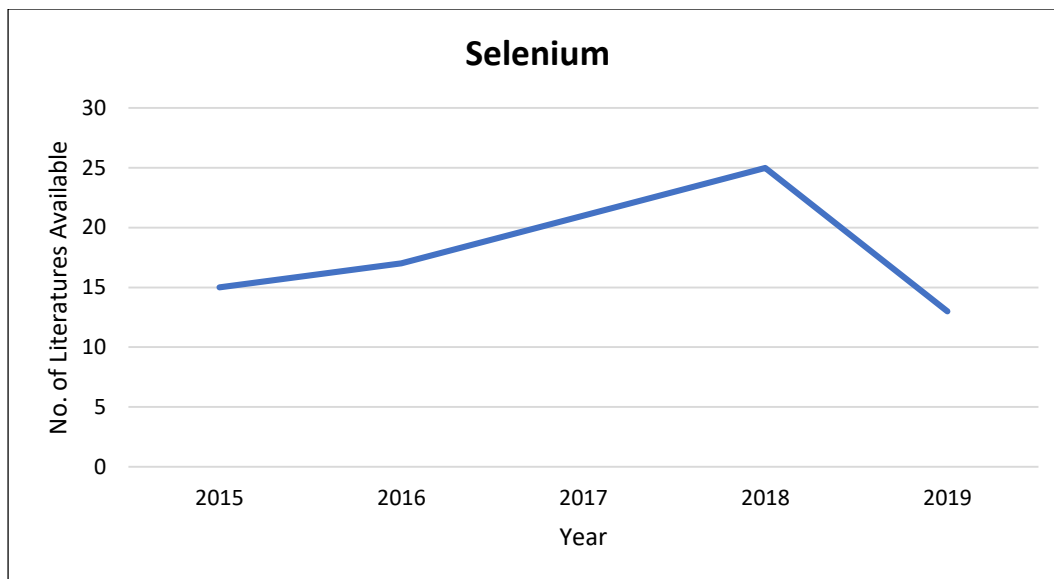


Fig.37. Total No. of Literatures Available for Selenium (Se)

Among these 91 literatures only 14 literatures have been selected for the purpose of this study which are related to the concentration of Se in fresh water (Fig.38.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of Se is found in groundwater of Makarba Lake, India (641.4 $\mu\text{g/l}$) and the lowest concentration is found in the water of the central water supply in Erdenet, Mongolia (0.022 $\mu\text{g/l}$).

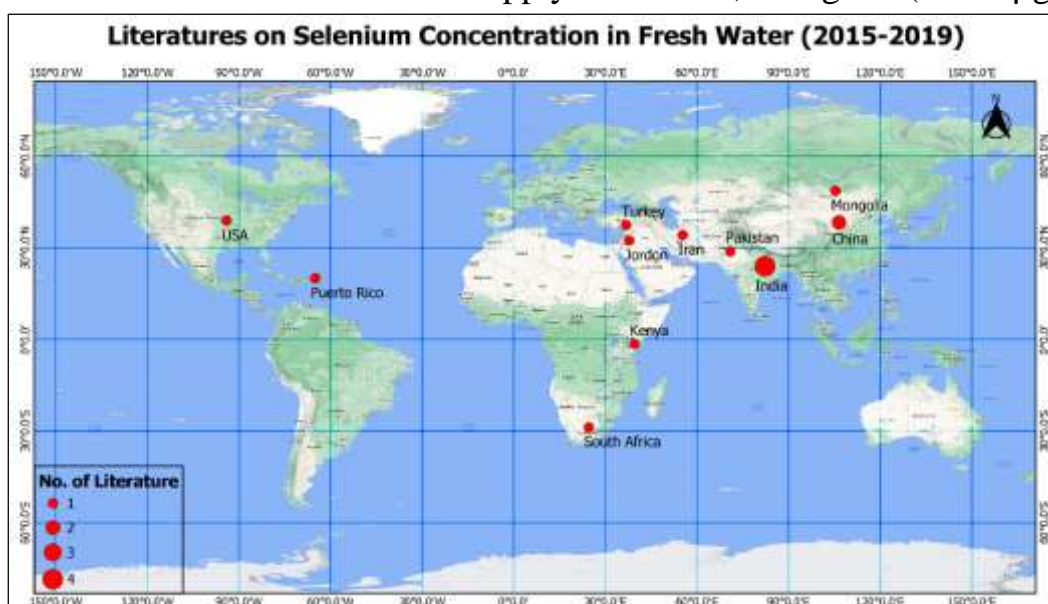


Fig.38. Literatures on Selenium Concentration in Fresh Water (2015-2019)

The average values have also been calculated for similar sources of water in the same location. The details of the places having Se concentration in fresh water are given in Table.32.

Table.32. Details of Selenium (Se) Concentration in Fresh Water

Location	Country	Source	Se Concentration (µg/l)	Reference
East Sikkim	India	Drinking water	644	Singh, A. K., et al., 2019
South Sikkim	India	Drinking water	578	Singh, A. K., et al., 2019
North Sikkim	India	Drinking water	686	Singh, A. K., et al., 2019
West Sikkim	India	Drinking water	526	Singh, A. K., et al., 2019
Erdenet	Mongolia	Central water supply	0.022	Golubkina, N., et al., 2018
Dornogobi Aimag	Mongolia	Drinking water	9.9	Golubkina, N., et al., 2018
Central Aimag	Mongolia	Drinking water	1.435	Golubkina, N., et al., 2018
Selenge	Mongolia	Drinking water	0.325	Golubkina, N., et al., 2018
Omnogobi	Mongolia	Drinking water	0.465	Golubkina, N., et al., 2018
Jaipur and Ajmer	India	Drinking water	8.47	Jakhu, R. and Mehra, R., 2018
Muzaffarnagar	India	Drinking water	27	Paikaray, S., 2016
Shaanxi	China	Groundwater	5.43	Du, Y., et al., 2018

Zarqa Basin	Jordon	Groundwater	742	Tabelin, C.B., et al., 2018
Arkansas River	USA	Groundwater	45.5	Tabelin, C.B., et al., 2018
Ambli Lake	India	Groundwater	395.4	Paikaray, S., 2016
Makarba Lake	India	Groundwater	641.4	Paikaray, S., 2016
Nazarpur	India	Groundwater	69.5	Paikaray, S., 2016
Jainpur	India	Groundwater	341	Paikaray, S., 2016
Nawanshahr	India	Groundwater	65.5	Paikaray, S., 2016
Chennai	India	Groundwater	10	Paikaray, S., 2016
Ulaanbatar	Mongolia	Groundwater and surface water	0.51	Golubkina, N., et al., 2018
Shadegan Wetland	Iran	Lake Water	26.32	Yavar Ashayeri, N. & Keshavarzi B., 2019
Sites on Nyangores tributary	Kenya	River water	1.07	Nyairo, W N., et al., 2015
Sites on Amala Tributary	Kenya	River water	1.18	Nyairo, W N., et al., 2015
Confluence of Nyangorres and Mara River	Kenya	River water	1.05	Nyairo, W N., et al., 2015
Confluence of Amala and Mara River	Kenya	River water	2.37	Nyairo, W N., et al., 2015

Mameyes	Puerto Rico	River water	<0.360	Ortiz-Colón, A.I., et al., 2016
Rio Piedras	Puerto Rico	River water	0.417-0.583	Ortiz-Colón, A.I., et al., 2016
La Plata	Puerto Rico	River water	0.504-3.210	Ortiz-Colón, A.I., et al., 2016
Sites on Buyuk Menderes River	Turkey	River water	41.91	Durmaz, E., et al., 2017
Wonderfontein Spruit catchment area	South Africa	River water	0.64	Jordaan, K. et al., 2019
Arkhangai	Mongolia	Spring water	0.12	Golubkina, N., et al., 2018
Faisalabad	Pakistan	Surface water samples collected from the Chenab river and canals	210	Mahfooz, Y., et al., 2019
Danjiangkou Reservoir	China	Water Diversion Project	0.13	Nong, et al., 2019
Henan	China	Water Diversion Project	0.302	Nong, et al., 2019
Hebei	China	Water Diversion Project	0.302	Nong, et al., 2019
Tianjin	China	Water Diversion Project	0.302	Nong, et al., 2019

Beijing	China	Water Diversion Project	0.302	Nong, et al., 2019
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Different studies show the presence of Se in natural water in various locations of different countries across the world (Fig.39.). Se is present in the water of Zhoukaudian area, Beijing, China (0.017 µg/l); Sweden; drinking water in the USA (0.13 µg/l); drinking water in Italy (7 µg/l); domestic water supply and drinking water in China (105 µg/l) [24]; spring water in New Mexico, well waters in South Dakota (1600 µg/l), Colorado and groundwater in Utah, USA (6000 µg/l) [24]. Nyairo W N., et al., 2015, studied Se concentration in water, collected from different sites of Nyangores and Amala tributary in Kenya[29]. Durmaz E., et al., 2017 showed Se concentration in water from four sites i.e., Isikh, Saraykay, Soke and Tasburun of Buyuk Menderes River, Turkey[30]. Tabelin C. B, et al., 2018, in their study, mentioned Se concentration in groundwater near Arkansas River in Colorado, USA (45.5 µg /l) and in Amman Zarqa basin, Amman, Jordon (742 µg /l) [31]. Golubkina N., et al., 2018 in their study showed the concentration of Se in well, spring and river water in different regions of Mongolia [32].

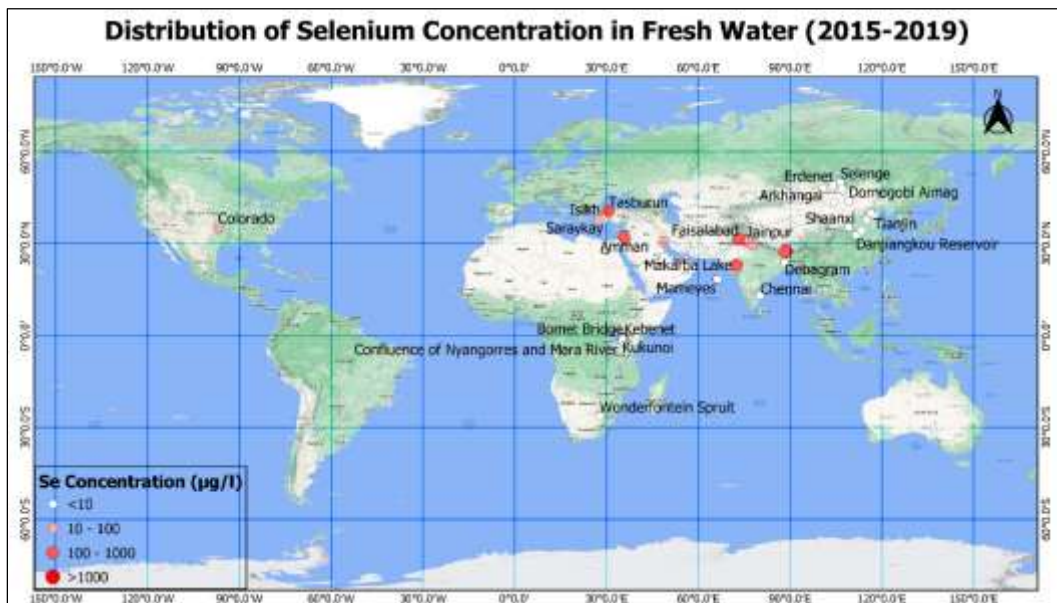


Fig.39. Spatial Distribution of Selenium (Se) Concentration in Fresh Water (2015-2019) Griboff J., et al., 2018, analysed the water quality of Los Molinos Lake, Cordoba, Argentina, and found a very low level of Se concentration i.e., below the detection limit [34]. Nong et al., 2019, showed Se concentration in water from 29 fixed stations of Middle Route (MR) of the South-to-North Water Diversion Project of China (SNWDPC) in four places i.e., Henan Province, Hubei Province, Tianjin Municipality and Beijing capital, and calculated average Se concentration of 0.302 µg /l[35]. Se concentration of 26.32 µg/l is found in the lake water of Shadegan Wetland, Iran [36]; and in Wonderfonteinspruit catchment area, South Africa (0.64 µg/l) [37]. Ortiz-Colón, A.I., et al., 2016 has found As concentrations of in river water samples from Mameyes (less than 0.360µg/l), Rio Piedras (0.417µg/l to 0.583µg/l) and La Plata (0.504 µg/l to 3.210 µg/l) Rivers in Puerto Rico [38]. Se concentration

is found in surface water samples collected from the Chenab river and canals i.e., Jhang Branch Upper Canal, Rakh Branch Canal, Gugera Branch Canal (210 $\mu\text{g/l}$) in Faisalabad, Pakistan [39].

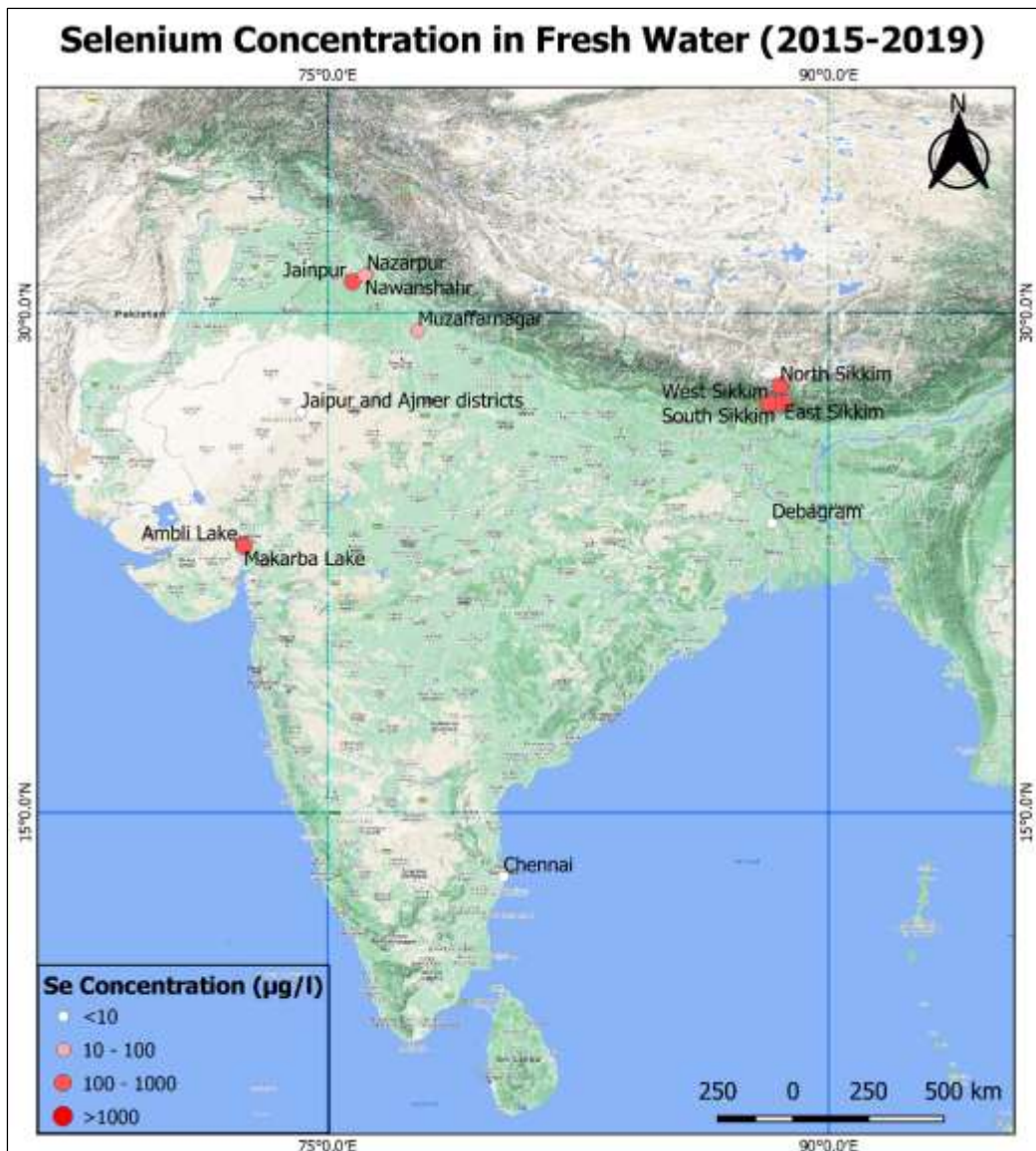


Fig.40. Spatial Distribution of Selenium (Se) Concentration in Fresh Water in Different Regions of India

In India (Fig.40.) Se concentration of 0.6 $\mu\text{g/l}$ has been found in the groundwater of Debagram, Nadia district of West Bengal, [40]. Very high concentration of Se has been found in the western and southern parts of India i.e., Ambli Lake (395.4 $\mu\text{g/l}$) and Makarba Lake (641.4 $\mu\text{g/l}$) of Gujarat; in the groundwater of Nazarpur (69.5 $\mu\text{g/l}$), Jainpur (341 $\mu\text{g/l}$), Nawanshahr (65.5 $\mu\text{g/l}$) of Punjab; Chennai city of Tamil Nadu (more than 10 $\mu\text{g/l}$); and western part of Muzaffarnagar (27 $\mu\text{g/l}$), Uttar Pradesh; [22]. Se has also been found in drinking water of four districts of Sikkim, India (608.5 $\mu\text{g/l}$) [41]. Se concentrations are also found in drinking water samples in Jaipur and Ajmer districts, Rajasthan, India (0.31 $\mu\text{g/l}$ to 16.63 $\mu\text{g/l}$) [42]. The concentration values of Se in different parts of India are depicted in Fig.41.

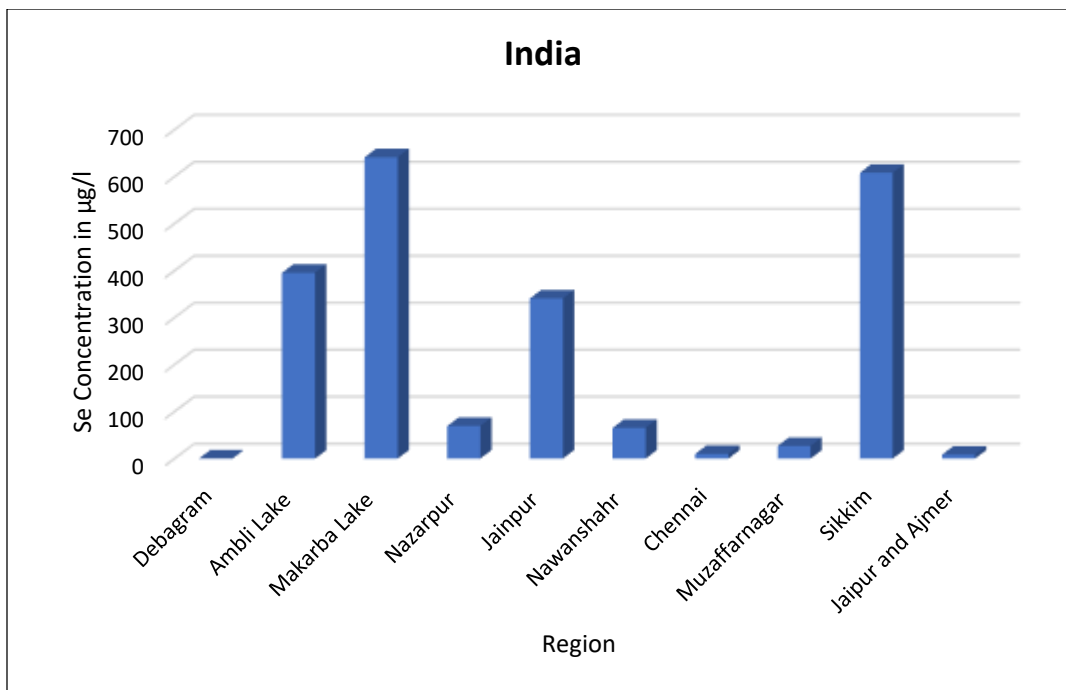


Fig.41. Selenium (Se) Concentration in Different Regions of India

The country wise Se concentration in fresh water shows that the highest mean 742 µg/l is found for Jordan. It is followed by India, Pakistan, the USA, Turkey and Iran. In these countries the average Se concentration is more than the permissible limit. The average Se concentrations in South Africa, Puerto Rico, China, Kenya and Mongolia are within the permissible limit i.e., 10 µg/l as directed by the WHO (Table.33.).

Table.33. Country Wise Average Selenium (Se) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
USA	45.5	-
Developing Countries		
China	1.128	1.924938
India	307.144	272.2759
Iran	26.32	-
Jordon	742	-
Kenya	1.20929	0.630878
Mongolia	1.825286	3.324033
Pakistan	210	-
Puerto Rico	0.905667	0.67512
South Africa	0.64286	0.03731
Turkey	41.9125	48.1151

3.8. Zinc (Zn) Concentration in Water: The process of smelting of Zinc ores, municipal wastes, use of pesticides and fungicides having zinc sulphates, automobiles, etc. are the major sources of zinc pollution in water. It is a very essential micro-nutrient for human beings and becomes harmful only at its high level of concentration[210]. According to the

WHO, the maximum permissible limit is 5000 $\mu\text{g/l}$. There are several literatures available on the concentration of Zn in water.

A total number of 886 literatures have been found using the PubMed database in EndNote software. The year wise distribution of literature available for Zinc (Zn) is given in Fig.42.

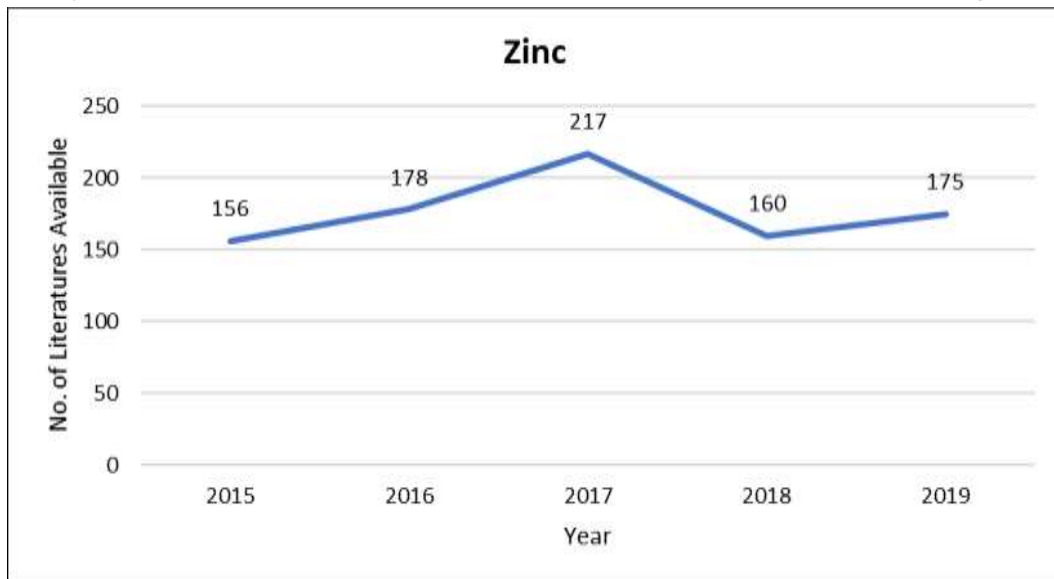


Fig.42. Total No. of Literatures Available for Zinc (Zn)

Among these 886 literatures only 88 literatures have been selected for the purpose of this study which are related to the concentration of Zn in fresh water (Fig.43.). For instance, river water, lake water, groundwater and drinking water samples. The highest concentration of Zn is found in Asopos River, Greece (103330 $\mu\text{g/l}$) and the lowest concentration is found in Xiaoqing River, China (0.0182 $\mu\text{g/l}$). The average values have also been calculated for similar sources of water in the same location.



Fig.43. Literatures on Arsenic Concentration in Fresh Water (2015-2019)

Gogoi A., et al., 2016 showed Zn concentration in water of Khosk River of Iran [143]. Zn concentrations are found in lake water of Shadegan Wetland, Iran (5.9 $\mu\text{g/l}$) [36]; in Yazd province, Iran (46.13 $\mu\text{g/l}$) [155]; in well water samples of Amlashin Guilan Province, Iran (3.57 $\mu\text{g/l}$) [164]. Saleh H.N., et al., 2019 showed Zn concentration in the groundwater from

different places of Neyshabur Plain, Iran[62]. Zhen G. et al., 2016, showed Zn concentration in some rivers of different countries[82] (Table.34.)

Table.34. Zinc (Zn) Concentration in Different Locations in Iran

Location	Zn Concentration (µg/l)	Reference
Khoshk River	70	Gogoi, A., et al., 2016
Siahroud River	89	Zhen, G., et al., 2016
Haraz River	52.75	Zhen, G., et al., 2016
Neyshabur	11.01	Saleh, H.N., et al., 2019
Chakaneh	0.27	Saleh, H.N., et al., 2019
Kharv	0.68	Saleh, H.N., et al., 2019
Ghadangah	0.1	Saleh, H.N., et al., 2019
Darrood	3.83	Saleh, H.N., et al., 2019
Yazd Province	46.1306	Fallahzadeh, R. A., et al., 2017
Amlashin Guilan Province	3.57	Naghipour, D., et al., 2018
Shadegan Wetland	5.9	Yavar Ashayeri, N. & Keshavarzi, B., 2019

Bempah C.K., & Ewusi A., 2016 showed the concentration of 81.5 µg/l in the water near the gold mine area of Obuasi, Ghana [76]. Zn concentrations in the water (samples collected from different sources of drinking water like streams, borehole, and dug-outs) of Tinga and Nangodi of Ghana are 34 and 6 µg/l[73]; in river water in Ghana i.e., Nyam River (59.5 µg/l); Subri River (28 µg/l); Birim River (93.5 µg/l); Bonsa River (27.5 µg/l); Atewa Forest River (27.5 µg/l); Ankasa River (18.5 µg/l); Bosomkese Forest River (22 µg/l); Oda River (20.5 µg/l); Kalakpa River (3.5 µg/l); Kakum River (15.5 µg/l); Mole River (14 µg/l) [77]; in borehole drinking water samples in Tarkwa, Ghana (52.7 µg/l) [78]; in River Tano in Bono, Bono East, and Ahafo Regions, Ghana (149 µg/l) [74]. Hadzi G.Y., et al., 2015, showed Zn concentration in the water of different rivers at different locations of Ghana [75] (Table.35.).

Table.35. Zinc (Zn) Concentration in Different Locations in Ghana

Location	Zn Concentration (µg/l)	Reference
Tarkwa	52.7	Bortey-Sam, N., et al., 2015
Tinga	34	Cobbina S., et al., 2015

Nangodi	2	Cobbina S., et al., 2015
Tarkwa	15	Hadzi, G.Y., et al., 2015
Atewa	10	Hadzi, G.Y., et al., 2015
Kenyasi	12	Hadzi, G.Y., et al., 2015
Obuasi	33	Hadzi, G.Y., et al., 2015
Ankasa	10	Hadzi, G.Y., et al., 2015
Bosomkese	14	Hadzi, G.Y., et al., 2015
Bekwai	15	Hadzi, G.Y., et al., 2015
Obuasi	81.5	Bempah, C.K., & Ewusi A., 2016
Nyam River	59.5	Hadzi, G.Y., et al., 2018
Subri River	28	Hadzi, G.Y., et al., 2018
Birim River	93.5	Hadzi, G.Y., et al., 2018
Bonsa River	27.5	Hadzi, G.Y., et al., 2018
Atewa Forest River	27.5	Hadzi, G.Y., et al., 2018
Ankasa River	18.5	Hadzi, G.Y., et al., 2018
Bosomkese Forest River	22	Hadzi, G.Y., et al., 2018
Oda River	20.5	Hadzi, G.Y., et al., 2018
Kalakpa River	3.5	Hadzi, G.Y., et al., 2018
Kakum River	15.5	Hadzi, G.Y., et al., 2018
Mole River	14	Hadzi, G.Y., et al., 2018
River Tano	149	Nyantakyi, A.J., et al., 2019

Zn concentrations in water in different regions of Iran and Ghana are depicted in Fig.44.

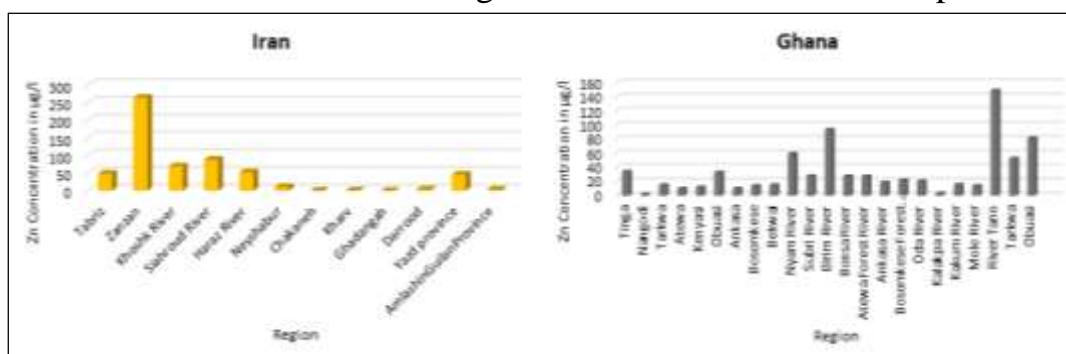


Fig.44. Zinc (Zn) Concentration in Fresh Water in Iran and Ghana

Kose E., et al., 2015, showed Zn concentration in the water of the Porsuk River at different sites in Turkey[64]. Kukrer, S. & Mutlu, E., 2019 showed a concentration of 7.47 µg/l in the water of Sarayduzu Dam, Turkey[140]. Zn concentration in the water of Buyuk Menderes River at Isikh, Saraykay, Soke and Tasburun of Turkey are 11.4, 30.4, 36.3 and

33.7 µg/l respectively [30]. Gogoi A., et al., 2016 showed Zn concentration in water of Sakarya River and Tigris River of Turkey [143]. Zhen G. et al., 2016, showed Zn concentration in some rivers of different countries[82] ([Table.36.](#)).

Table.36. Zinc (Zn) Concentration in Different Locations in Turkey

Location	Zn Concentration (µg/l)	Reference
Porsuk Stream	54.375	Kose, E. et al., 2015
Sakarya River	1786	Gogoi, A., et al., 2016
Tigris River	0.22	Gogoi, A., et al., 2016
Tigris River	12.01	Zhen, G., et al., 2016
Menderes River	126.81	Zhen, G., et al., 2016
Riva Stream	709.89	Zhen, G., et al., 2016
Buyuk Menderes River	27.95	Durmaz, E., et al., 2017
Sarayduzu Dam	7.47	Kukrer, S. & Mutlu, E., 2019

Zn concentrations are found in Acude and Maria Lucinda Streamlet (3750 µg/l) and Santa Rosa Streamlet (4315 µg/l) in Brazil [154]; in Jaboticabal Watershed, Brazil (83.05 µg/l) [158]; in river water of Guaribas River, Brazil (104 µg/l) [207] ([Table.37.](#)).

Table.37. Zinc (Zn) Concentration in Different Locations in Brazil

Location	Zn Concentration (µg/l)	Reference
Guaribas River	104	De Castro, E., Sousa J. M., et al., 2017
Acude and Maria Lucinda Streamlet	3750	De Melo, W. A., et al., 2017
Santa Rosa Streamlet	4315	De Melo, W. A., et al., 2017
Jaboticabal Watershed	83.05	Saran, L.M., et al., 2018

Nadmitov B., et al., 2015 has found Zn concentration in the river water of Russia i.e., Selenga River (41 µg/l); Temnik River (11 µg/l); Chikoy River (9.7); Khilok River (6.4 µg/l); and Goosinoe Lake (8.9 µg/l) [211]. Skalny A. V., et al., 2019 showed the concentration in the groundwater of five districts i.e., Solochinsk, Sakmara, Sol-Iletsk, Kvarkeno and Svetly District of 1178, 1232, 1144, 4690 and 4618 µg/l respectively[153] ([Table.38.](#)).

Table.38. Zinc (Zn) Concentration in Different Locations in Russia

Location	Zn Concentration (µg/l)	Reference
Selenga River	41	Nadmitov, B., et al., 2015
Temnik River	11	Nadmitov, B., et al., 2015
Chikoy River	9.7	Nadmitov, B., et al., 2015
Khilok River	6.4	Nadmitov, B., et al., 2015
Goosinoe Lake	8.9	Nadmitov, B., et al., 2015
Sorochinsk	1178	Skalny, A. V., et al., 2019
Sakmara	1232	Skalny, A. V., et al., 2019
Sol Iletsk	1144	Skalny, A. V., et al., 2019
Kvarkeno	4690	Skalny, A. V., et al., 2019
Svetly Dist	4618	Skalny, A. V., et al., 2019

Zn concentrations in water in different regions of Turkey, Pakistan, Brazil and Russia are depicted in Fig.45.

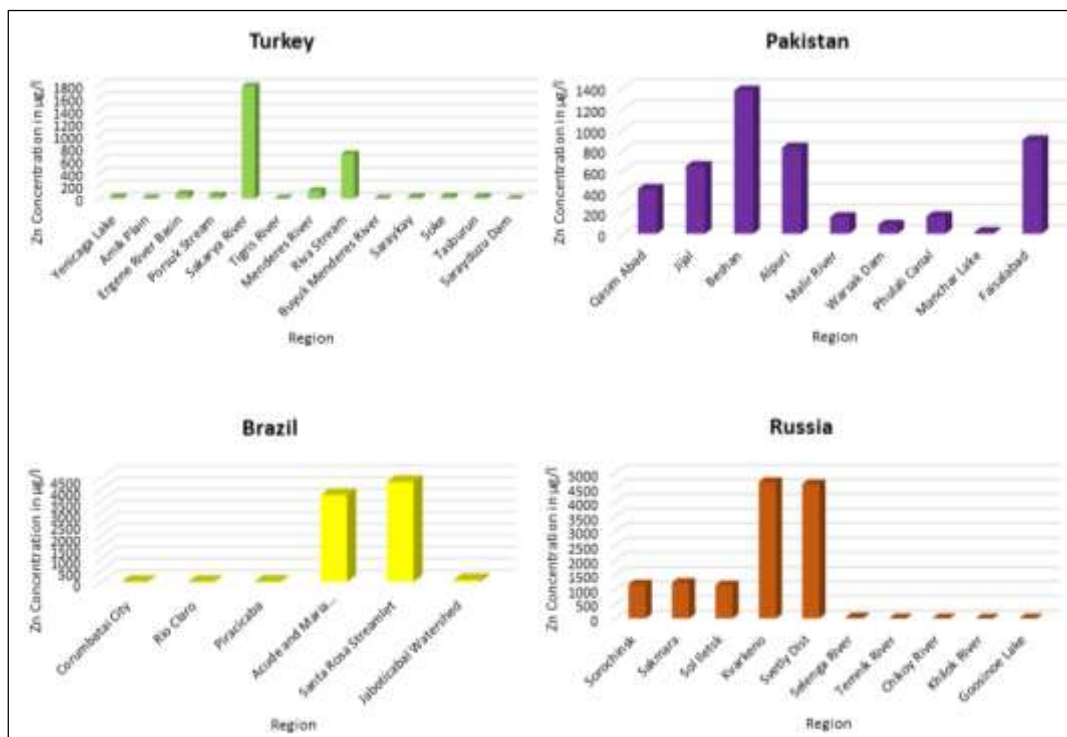


Fig.45. Zinc (Zn) Concentration in Fresh Water in Turkey, Pakistan, Brazil and Russia

Rehman, I.U., et al., 2018 has found Zn concentrations of 1060 µg/l in Pakistan [212]. Zn concentration in drinking water samples collected from tap water and hand pumps is 900 µg/l in Faisalabad, Pakistan [39]. Nyairo W. N., et al., 2015 showed Zn concentration in the river water at different sites of Nyangores and Amala tributary in Kenya [29]. The concentration in the water of Tiga Dam of Nigeria is 10 µg/l[104]; in the water of San Marzano River and Scafati are 29940 and 46760 µg/l[134]; in the water of Nakivudo Channel and Lake Victoria are 1400 and 300 µg/l respectively[135]. Paez-Osuna F., et al., 2015 showed the concentration in the water of El-Comedero Dam on San Lorenzo River is 583 µg/l[79]. Squadrone S., et al., 2016, found a concentration of 50 µg/l in the water of Baleh River in Sarawak, Malaysia and of 3000 µg/l in the water of Sweden[142]. Zn concentration in the water of Al Asfar Lake of Saudi Arabia is 18 µg/l[213]; in the water of Biala Przemsza River in Poland is 438.63 µg/l[80]; in the water of Ugljesnica River in Serbia is 346 µg/l[81]; in the water of Koka Dam and Sire Robi of Ethiopia are 126.62 and 137.85 µg/l respectively[144]. Zhen G. et al., 2016, showed Zn concentration in the water of different rivers of different countries[82]. The concentration of Zinc in the water of Mariout Lake (Egypt), Victoria Lake (Kenya), Tonga lake (Algeria)and Seybouse Watershed are 18300, 75000, 1050 and 370 µg/l respectively[145]; in the water of Eleyele Lake, Nigeria is 3170 µg/l[5]; in the groundwater of Bwari, Kuje, Gwagwalda and Ajhatta are 3145, 2900, 2100 and 9000 µg/l respectively[147]. The Zn concentration in the water of Los Molinos Lake, Cordoba, Argentina is 3.75 µg/l[34]; in the water of Ado-Odo Ota of Osun State, Nigeria, is 323.16 µg/l[86]; in the water of Hyeongsan River and its tributaries in Pohang City of South Korea is 18.46 µg/l[87]; in the water of Benin River in Koko Town of Nigeria is 10 µg/l[151]; in the drinking water of Bushyeni District is 4462.3 µg/l[152]. Fang T. et al., 2019 showed the concentration in the water of Los Molinos Lake (3.75 µg/l) of

Argentina[59]. The Zn concentration of 37093 $\mu\text{g/l}$ has been found in the groundwater of Monument valley site (a former Uranium tailing mill) in Navajo Nation in north-eastern Arizona, Mexican Hat, USA [27]. Zn concentrations are also found in Asopos River, Greece (103330 $\mu\text{g/l}$) [157]; and Mbaa River in Imo State, Nigeria (650 $\mu\text{g/l}$) [214]. Zn concentrations are also found in groundwater of Agbor Town, Nigeria (20 $\mu\text{g/l}$) [215]; in Kampar Lake, Malaysia (24.62 $\mu\text{g/l}$) [51] (Fig.46.).



Fig.46. Spatial Distribution of Zinc (Zn) Concentration in Fresh Water (2015-2019)

Nambatingar, N. et al., 2017 has found Zn concentration of 161 $\mu\text{g/l}$ in different locations in Chari River, Chad [196]. Titilawo, Y. et al., 2018 has found Zn concentrations in Erinle-Ede (223 $\mu\text{g/l}$), Ido Osun (247 $\mu\text{g/l}$), Osun-Osogbo (273 $\mu\text{g/l}$), Oba-Iwo (307 $\mu\text{g/l}$), Ejigbo (387 $\mu\text{g/l}$), Ilobu-Okinni (350 $\mu\text{g/l}$), Asejire-Ikire (403 $\mu\text{g/l}$), Shasha (367 $\mu\text{g/l}$), Ila-Oke Ila (150 $\mu\text{g/l}$) and Inisha-Okuku (390 $\mu\text{g/l}$) regions in Nigeria [206]. Zn concentrations are found in Wonderfontein spruit catchment area, South Africa (1.51 $\mu\text{g/l}$) [37]; in different locations from Leyole River, Ethiopia (248.286 $\mu\text{g/l}$) [161]; in borehole water samples at Muledane village (less than 5.0 to 3.0 $\mu\text{g/l}$) [160]. Kasozi K. I. et al., 2019, has found Zn concentrations in borehole (14.5 $\mu\text{g/l}$), open well (5.338 $\mu\text{g/l}$), spring (28.76 $\mu\text{g/l}$) and tap water (446.7 $\mu\text{g/l}$) in Uganda [152]. Zn concentrations are found in water samples from Danube River located near Hungarian and Slovakian border (51.5 $\mu\text{g/l}$) [89]; in river water samples from Mameyes (5.137-9.733 $\mu\text{g/l}$), Rio Piedras (less than 3.600 $\mu\text{g/l}$) and La Plata (less than 3.600-7.830 $\mu\text{g/l}$) Rivers in Puerto Rico [38]; in the water of Baleh River at Sarawak, Malaysia (50 $\mu\text{g/l}$) [163]; in pore water samples from Aar Dam (76.9 $\mu\text{g/l}$), Driedorf Dam (963 $\mu\text{g/l}$) and Klingenberg Reservoir (3281 $\mu\text{g/l}$) in Germany [92]. Zn concentration in the water of Ma Tian and Zhu Dui of Suxian District, Hunan Province, China are 45 and 26 $\mu\text{g/l}$ respectively [47]; in the water of Caohai wetland of China is 41.341 $\mu\text{g/l}$ [106]; in the water of Taihu Lake, Chaohu Lake, and Pohang Lake are 10.96, 20.67 and 28.82 $\mu\text{g/l}$ respectively [49]; in the water of Lower Cambrian, southern Shanxi Province of China is 9.65 $\mu\text{g/l}$ [33]. Zn concentrations are also found in Caohai Wetland, China (1.95 $\mu\text{g/l}$) [52]; Wen Rui Tang River Watershed, China (72.1 $\mu\text{g/l}$) [53]; in groundwater in

Brownfield, China (2140 µg/l) and surface water of Xiangjiang River (0.25 µg/l) [105]; in drinking water samples from China (48.5 µg/l) [54]; in surface water samples of Honghu Lake, China (20.45 µg/l) [57]; in Xiaoqing River, China (0.02415 µg/l) [58]; in river water downstream (450 µg/l) and in river water of mine area (1465 µg/l) of Karstic river system, China [61]; and in Tai Lake, China (40 µg/l) [50]. Fang T. et al., 2019 showed the concentration in the water of Chaohu (29.74 µg/l), Caizi (34.33 µg/l), Taihu (6.41 µg/l), Dongting (20.91 µg/l), Hulun (8.79 µg/l) and Honghu Lake (20.45 µg/l) of China [59] (Table.39.).

Table.39. Zinc (Zn) Concentration in Different Locations in China

Location	Zn Concentration (µg/l)	Reference
Ma Tian	45	Huang, X., et al., 2015
Zhu Dui	26	Huang, X., et al., 2015
Tai Lake	40	Fu, Z., et al., 2016
Xijiang River	27.78666667	Zhen, G., et al., 2016
Beijiang River	16.36	Zhen, G., et al., 2016
Dongjiang River	36.32	Zhen, G., et al., 2016
Caohai Wetland	41.341	He, J., et al., 2017
Caohai Wetland	1.95	Hu, J., et al., 2017
Brownfield	2.14	Li, F., et al., 2017
Xiangjiang River	0.25	Li, F., et al., 2017
Honghu Lake	20.45	Li, F., et al., 2017
Shaanxi	9.65	Du, Y., et al., 2018
Taihu Lake	10.96	Bi, B., et al., 2018
Chaohu Lake	20.67	Bi, B., et al., 2018
Poyang Lake	28.82	Bi, B., et al., 2018
Karstic River System	957.5	Li, L., et al., 2018
Xiaoqing River	0.02415	Li, Q., et al., 2018
Wen Rui Tang River Watershed	72.1	Qu, L., et al., 2018
China	48.5	Zhong, W., et al., 2018
Chaohu Lake	29.74	Fang, T., et al., 2019
Caizi Lake	34.33	Fang, T., et al., 2019
Taihu Lake	6.41	Fang, T., et al., 2019
Dongting Lake	20.91	Fang, T., et al., 2019
Hulun Lake	8.79	Fang, T., et al., 2019
Honghu Lake	20.45	Fang, T., et al., 2019

Golubkina N et al., 2018 found the concentration of Zn in the drinking water from different sites of Mongolia [32] (Table.40.). Nadmitov B., et al., 2015 has found Zn concentration in the river water of Mongolia i.e., Kharaa River (110 µg/l); Khangal River (19 µg/l); Sharin Gol River (20 µg/l); Selenga River (240 µg/l); Ere River (11 µg/l); Delger River (8.3 µg/l); Egiyn River (6.5 µg/l); Tuul River (99 µg/l); Orkhon River (75 µg/l); Selenga & Uda River (19 µg/l); Modonkul River (100 µg/l); Dzhuda River (8.7 µg/l); in groundwater of Boroo Gold mine area (18 µg/l); well water in Ulaanbataar (345.05 µg/l); river water of Tuul and Orkhon River (4.4 µg/l) [211]. Zn concentration is also found in river water samples from Selenga River basin, Mongolia (0.02 µg/l) [91].

Table.40. Zinc (Zn) Concentration in Different Locations in Mongolia

Location	Zn Concentration (µg/l)	Reference
Kharaa River	110	Nadmitov, B., et al., 2015
Khangal River	19	Nadmitov, B., et al., 2015
Sharin Gol River	20	Nadmitov, B., et al., 2015
Selenga River	240	Nadmitov, B., et al., 2015
Ere River	11	Nadmitov, B., et al., 2015
Delger River	8.3	Nadmitov, B., et al., 2015
Egiyn River	6.5	Nadmitov, B., et al., 2015
Tuul River	99	Nadmitov, B., et al., 2015
Orkhon River	75	Nadmitov, B., et al., 2015
Selenga & Uda River	19	Nadmitov, B., et al., 2015
Modonkul River	100	Nadmitov, B., et al., 2015
Dzhuda River	8.7	Nadmitov, B., et al., 2015
Boroo Gold mine area	18	Nadmitov, B., et al., 2015
Ulaanbataar	345.05	Nadmitov, B., et al., 2015

Tuul and Orkhom River	4.4	Nadmitov, B., et al., 2015
Selenga River basin	0.02	Batbayar, G., et al., 2017
Sainshand	290	Golubkina, N., et al., 2018
Zamin Ude	50	Golubkina, N., et al., 2018
Shaamar	20	Golubkina, N., et al., 2018
Bayan	20	Golubkina, N., et al., 2018
Dalanzadgad	20	Golubkina, N., et al., 2018
Arkhangai	10	Golubkina, N., et al., 2018
Gachuurt	30	Golubkina, N., et al., 2018
Erdenet	863.33	Golubkina, N., et al., 2018

Zn concentrations in water in different regions of China and Mongolia are depicted in Fig.47.

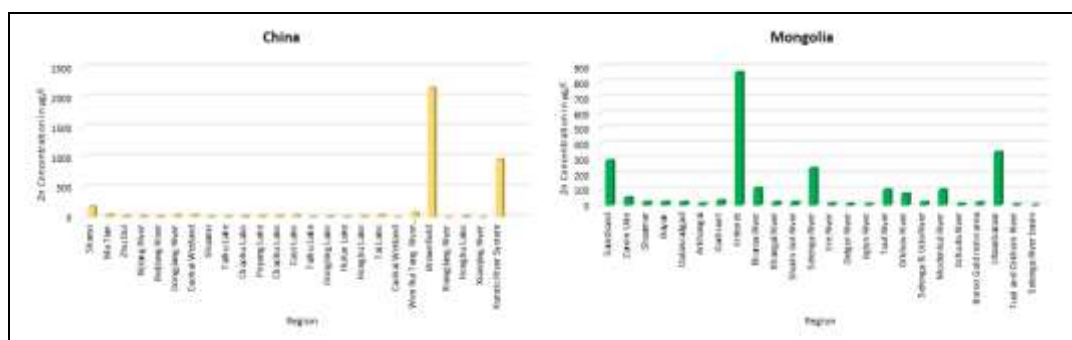


Fig.47. Zinc (Zn) Concentration in Fresh Water in China and Mongolia

In India (Fig.48.) Zn concentrations are found in fresh water in several locations. Gautam et al., 2015, showed Zn concentration in water of different parts of Subarnarekha River Basin area i.e., Hatia bridge (50.20 µg/l), Khuddi village (1116.71 µg/l), Tatanagar (43.63 µg/l), Adityapur (34.93 µg/l), Sakchi (169.44 µg/l), Govindpur (25.15 µg/l), Mango (47.11 µg/l), Jugsalai (90.04 µg/l), Jaduguda (42.70 µg/l), Mushabani (74.29 µg/l), Maubhandar (31.81 µg/l), Ghatsila (102.23 µg/l), Chakulia (103.91 µg/l), Chandil (9060.42 µg/l), Kandra (3554.73 µg/l), Saraikela (150.97 µg/l), Chaibasa (325.41 µg/l), Chkradharpur (4071.48 µg/l), Chakulia (191.55 µg/l), having an average Zn concentration of 1015 µg/l [183]. Zn concentrations are also found in river water of Yamuna River at Delhi (690 µg/l) [182]; in

the water at Talcher gauge station, Talcher, India is 29.055 $\mu\text{g/l}$ [177]; in the drinking water of four districts of Sikkim i.e., East, South, North and West Sikkim, are 208, 760, 1943, and 403 $\mu\text{g/l}$ respectively [41]; in the surface water and groundwater of Reasi District, Jammu (presently the UT of Jammu and Kashmir), India is 500 $\mu\text{g/l}$ [186]; Koleru Lake, India (19.8 $\mu\text{g/l}$) [209]; Vembanad Lake, India (90.87 $\mu\text{g/l}$) [178]; in the groundwater of Debagram, Nadia District of West Bengal, India is 56 $\mu\text{g/l}$ [40]; in the water of Latipada Lake of Maharashtra, India is 12510 $\mu\text{g/l}$ [175]; in groundwater in Kanpur, India (126 $\mu\text{g/l}$) [179]; in groundwater of Ropar Wetland, Punjab, India (260 to 580 $\mu\text{g/l}$) [180]; in groundwater in Chandigarh, India (9.54 $\mu\text{g/l}$) [97]; in Sattal Lake in Central Himalaya, India (167.5 $\mu\text{g/l}$) [193]. Gogoi A., et al., 2016 showed Zn concentration in water of Ganga and Brahmaputra Rivers of India[143].



Fig.48. Spatial Distribution of Zinc (Zn) Concentration in Fresh Water in Different Regions of India

Bhatia, A., et al., 2015 has found Zn concentration of 0.04 $\mu\text{g/l}$ in groundwater in Delhi Urban Area, Alipur, India [216]. Kumar, R., et al., 2019 found Zn concentrations of 9.17 $\mu\text{g/l}$ in different locations of River water of Neeru stream, Jammu and Kashmir (presently the UT of Jammu and Kashmir), India [197]. Kumar A. & Samaddar S., 2015 found a concentration of 86 $\mu\text{g/l}$ in the water of Damodar River near Bokaro Steel Plant, Jharkhand,

India[181]. Zinc is concentrated (very low concentration) at different locations in river water of Ghaghara River i.e., at Katerniaghat (0.018 mg/l), Colonelganj (0.021 mg/l), Ayodhya (0.028 mg/l), Dohrightat (0.017 mg/l) of Uttar Pradesh and at Chhapra (0.020 mg/l) of Bihar, India [184]. Kumar A., et al., 2016 showed the concentration in groundwater and surface water of different places of Jammu District (presently the UT of Jammu and Kashmir), India[98]. The concentration values of Zn in different parts of India are depicted in Fig.49.

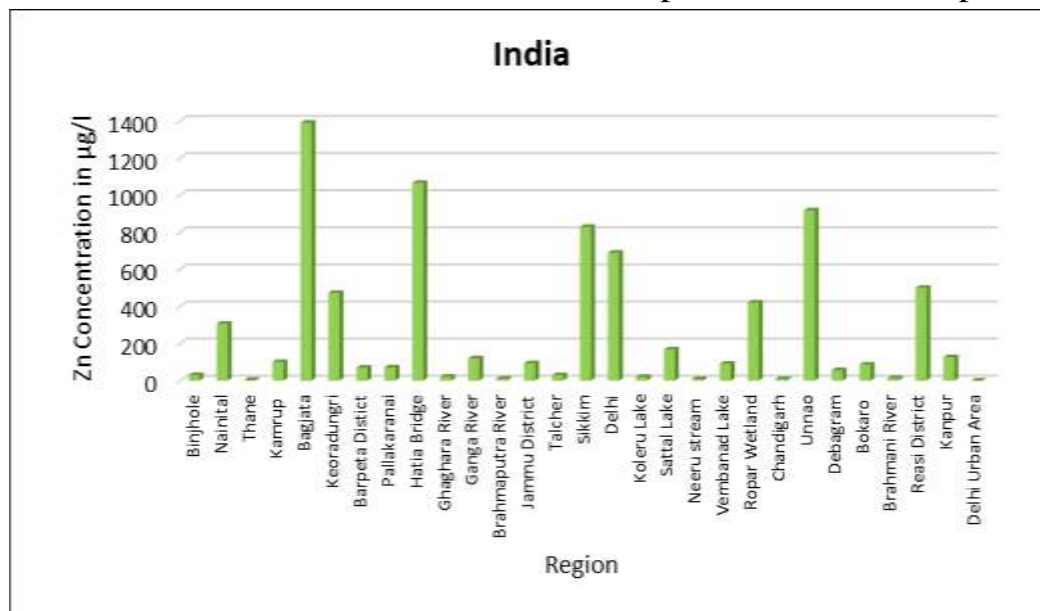


Fig.49. Zinc (Zn) Concentration in Different Regions of India

The country wise Zn concentration in fresh water shows that the highest mean and SD of Zn concentration i.e., 52816.24 µg/l and 50513.76 µg/l is found for Greece. It is followed by Italy, USA, Egypt, Kenya, Sweden, Germany, Russia, Brazil and Nigeria. In these countries the average Zn concentration is more than 1000 µg/l. In Taiwan, Ethiopia, Poland, Chad, China, Turkey, Serbia, India, Pakistan, Mexico, Algeria, Bangladesh and Uganda, the average Zn concentrations are from 100 to 1000 µg/l. In Puerto Rico, Saudi Arabia, South Korea, Slovakia, Iran, Ghana, Hungary and Slovakia, Thailand, Malaysia, Zambia and Mongolia, the average Zn concentrations are from 5 to 100 µg/l. In South Africa, Spain, Latvia, Argentina and Zimbabwe, the average Zn concentration is within 5 µg/l (Table.41.).

Table.41. Country Wise Average Zinc (Zn) Concentration in Fresh Water

Country	Mean	SD
Developed Countries		
Germany	1440.3	1350.907
Greece	52816.24	50513.76
Hungary and Slovakia	51.5	-
Italy	38350	8410
Latvia	3.35	-
Poland	148.7767	204.9696

Slovakia	20	-
Spain	1.58	-
Sweden	3000	-
USA	37093	-
Developing Countries		
Algeria	710	340
Argentina	3.75	0
Bangladesh	950	-
Brazil	1179.496	1811.116
Chad	161	63.63175308
China	162.193505	454.3899405
Egypt	18300	-
Ethiopia	112.96	89.70742
Ghana	34.51942308	33.47718409
India	431.7987397	1433.273784
Iran	46.01253	64.86219
Kenya	5018.86	18703.25
Malaysia	88.27396667	133.2478723
Mexico	583	-
Mongolia	99.47083	184.0098
Nigeria	1092.342	1979.821
Pakistan	567.436	442.8762343
Puerto Rico	5.583333	1.568398
Russia	1293.9	1754.894
Saudi Arabia	18	-
Serbia	346	-
South Africa	1.51	-
South Korea	18.46	-
Taiwan	100.63	-
Thailand	63.4	-
Turkey	172.2211	409.2861
Uganda	951.0854286	1503.841919
Zambia	95	15
Zimbabwe	4	-

4. Conclusion

Natural water present on the earth's surface is a source of various physical elements and minerals essential for life. Each element has its own role to play in our food chain. The amount of these elements varies for different sources of water as well as from place to place. In some areas they may occur in very high quantities, in others only meagre quantity is

found. Some of the elements are toxic in nature if consumed in excess amounts. The water should contain a definite amount of these potentially toxic elements, exceeding which may cause adverse health effects. International organizations, such as the World Health Organization (WHO) recommends a guideline value for each of the elements along with various water quality parameters present in the water to be classified as fit for drinking or any other household uses. The permissible limit for Nickel (Ni) is 20 $\mu\text{g/l}$, for Selenium (Se) and Arsenic (As) is 10 $\mu\text{g/l}$, for Zinc (Zn) is 5000 $\mu\text{g/l}$, for Fluoride (F^-) is 1000 $\mu\text{g/l}$, for Chromium (Cr) is 50 $\mu\text{g/l}$, for Lead (Pb) is 0.01 $\mu\text{g/l}$ and for Mercury (Hg) is 1 $\mu\text{g/l}$. The variations in limit indicates that the harmful effects that may be caused by drinking the water containing these elements also varies. The available literature suggests that researchers are considering the importance of fresh water and stress has been given on pollution free water. The total available number of literatures suggests that the highest number of publications are for Pb. It is followed by Zn, Cr, Hg, As and Ni. The least number of publications are found for Se and F^- . The year wise trends in available literature shows increasing trends for As, Cr, F^- , decreasing trend for Pb and Se, and fluctuating trend for Hg, Ni and Zn. Overall, the rising trend shows increasing scientific investigation on these potentially toxic elements. There are wide variations found for the potentially toxic elements present in different parts of the world. It was found that a very high concentration of Se i.e., more than 742 $\mu\text{g/l}$ is found in the groundwater of Zarqa Basin in Jordan. On the other hand, countries like South Africa, Puerto Rico, China, Kenya and Mongolia have Se concentration of less than 10 $\mu\text{g/l}$. In Balikhora of Ghior Upazila and Harirampur Upazila of Manikganj District in Bangladesh, Datun Lake and Chenzhou City in China, Kalanwala region in Pakistan, the As concentration are found to be more than 1000 $\mu\text{g/l}$ whereas countries like Puerto Rico, Sri Lanka, Serbia, Brazil, Thailand, South Korea, South Africa, Mongolia, Poland, Malaysia, Hungary and Slovakia and Iran have As concentration of less than 10 $\mu\text{g/l}$. Very high concentrations of Pb i.e., more than 1000 $\mu\text{g/l}$ are found in Lake Victoria in Kenya, Karnataka and Lake of Latipada, Maharashtra in India, in parts of Benin and Uganda. In South Korea, Latvia, Sri Lanka, Zimbabwe, Spain, Puerto Rico, Argentina, Mongolia and Cyprus, the concentration of Pb is within 1 $\mu\text{g/l}$. In Brownfield in China, Buriganga River in Bangladesh and San Marzano in Italy the Cr concentration is more than 10000 $\mu\text{g/l}$. In countries like Cyprus, Hungary and Slovakia, Poland, South Korea, Chad, Kenya, Malaysia, Ghana, Iran, Mongolia, Germany, Puerto Rico, South Africa, Turkey and Zimbabwe, the Cr concentrations are within 50 $\mu\text{g/l}$.

In Khatanbulag in Mongolia, Sindh and Punjab region in Pakistan, parts of China and Mongolia, the F^- concentrations are more than 1000 $\mu\text{g/l}$ whereas in India and Poland, the F^- concentrations are within 1000 $\mu\text{g/l}$. In Prestea Huni District in Ghana, Asopos River in Greece and Seybouse Watershed in Algeria, the Hg concentrations are more than 100 $\mu\text{g/l}$. In USA, Taiwan, Thailand, Turkey, Mexico, South Africa, South Korea, Iran, Hungary and Slovakia, Mongolia and Serbia the average Hg concentrations are from 0.005 to 1 $\mu\text{g/l}$. In Greece, Italy, Egypt and Kenya, the Zn concentrations are more than 5000 $\mu\text{g/l}$. Asopos River in Greece, Khyber Pakhtunkhwa and Lahore in Pakistan have Ni concentrations of

more than 1000 µg/l. In Argentina, Puerto Rico, Mongolia, China, Ethiopia, Hungary and Slovakia, Iran, Poland, Ghana, South Korea, South Africa, India, Cyprus and Turkey, the average Ni concentrations are within 20 µg/l. There are several developed countries which contain higher amounts of these elements. In most of the developing countries both higher and moderate amounts of these elements are found.

These regional variations show that the available fresh water contains a large number of potentially toxic elements due to which the quality of the water is gradually compromised. It indirectly creates the problem related to the acceptability of this water for drinking purposes. The water containing these elements above the required permissible limits leads to severe health problems if used directly without removing or treating the contaminants. In regions with very high content of these elements in the fresh water, the water should not be used directly without proper treatment. The literature review of the above mentioned potentially toxic elements can be used for further investigation on finding the link between pollution load and development of countries. It may be used for further research.

References:

1. Bhat, U.N. and A.B. Khan, *Heavy metals: An ambiguous category of inorganic contaminants, nutrients and toxins*. Research Journal of Environmental Sciences, 2011. **5**(8): p. 682-690.
2. Shakir, S.K., et al., *Toxic Metal Pollution in Pakistan and Its Possible Risks to Public Health*. Rev Environ Contam Toxicol, 2017. **242**: p. 1-60.
3. Dsikowitzky, L., et al., *Assessment of heavy metals in water samples and tissues of edible fish species from Awassa and Koka Rift Valley Lakes, Ethiopia*. Environ Monit Assess, 2013. **185**(4): p. 3117-31.
4. Obiri, S., et al., *Human Health Risk Assessment of Artisanal Miners Exposed to Toxic Chemicals in Water and Sediments in the Prestea Huni Valley District of Ghana*. Int J Environ Res Public Health, 2016. **13**(1).
5. Olayinka, O.O., et al., *Assessment of the Pollution Status of Eleyele Lake, Ibadan, Oyo State, Nigeria*. J Health Pollut, 2017. **7**(15): p. 51-62.
6. Al Rashdi, S., et al., *Distribution of heavy metals in the coastal area of Abu Dhabi in the United Arab Emirates*. Mar Pollut Bull, 2015. **97**(1-2): p. 494-498.
7. Arcega-Cabrera, F., et al., *Impacts of geochemical and environmental factors on seasonal variation of heavy metals in a coastal lagoon Yucatan, Mexico*. Bull Environ Contam Toxicol, 2015. **94**(1): p. 58-65.
8. Fakhri, Y., et al., *Assessment of carcinogenic and non-carcinogenic risk lead in bottled water in different age groups in Bandar Abbas Ciry, Iran*. Glob J Health Sci, 2015. **7**(4): p. 286-94.
9. Hadiani, M.R., et al., *Trace elements and heavy metals in mineral and bottled drinking waters on the Iranian market*. Food Addit Contam Part B Surveill, 2015. **8**(1): p. 18-24.

10. Adel, M., et al., *Mercury, lead, and cadmium in tissues of the Caspian Pond Turtle (Mauremys caspica) from the southern basin of Caspian Sea*. Environ Sci Pollut Res Int, 2017. **24**(4): p. 3244-3250.
11. Mok, J.S., et al., *Bioaccumulation of heavy metals in oysters from the southern coast of Korea: assessment of potential risk to human health*. Bull Environ Contam Toxicol, 2015. **94**(6): p. 749-55.
12. Giri, S., et al., *Risk assessment due to intake of heavy metals through the ingestion of groundwater around two proposed uranium mining areas in Jharkhand, India*. Environ Monit Assess, 2012. **184**(3): p. 1351-8.
13. Geng, J.J., et al., *Nutrients and contaminants in tissues of five fish species obtained from Shanghai markets: Risk-benefit evaluation from human health perspectives*. Sci Total Environ, 2015. **536**: p. 933-945.
14. Levesque, B., et al., *Seasonal variations of contamination and exoskeletal malformations in the white shrimps Palaemon longirostris in the Gironde estuary, France*. Environ Sci Pollut Res Int, 2018. **25**(23): p. 22689-22701.
15. Devarajan, N., et al., *Hospital and urban effluent waters as a source of accumulation of toxic metals in the sediment receiving system of the Cauvery River, Tiruchirappalli, Tamil Nadu, India*. Environ Sci Pollut Res Int, 2015. **22**(17): p. 12941-50.
16. Dvorak, P., et al., *Concentration of heavy and toxic metals in fish and sediments from the Morava river basin, Czech Republic*. Neuro Endocrinol Lett, 2015. **36 Suppl 1**: p. 126-32.
17. Niu, Y., et al., *Assessment of Heavy Metal Pollution in Sediments of Inflow Rivers to Lake Taihu, China*. Bull Environ Contam Toxicol, 2015. **95**(5): p. 618-23.
18. Alia, N., et al., *Toxicity and Bioaccumulation of Heavy Metals in Spinach (Spinacia oleracea) Grown in a Controlled Environment*. Int J Environ Res Public Health, 2015. **12**(7): p. 7400-16.
19. Chowdhury, R., et al., *Accumulation of Trace Metals by Mangrove Plants in Indian Sundarban Wetland: Prospects for Phytoremediation*. Int J Phytoremediation, 2015. **17**(9): p. 885-94.
20. Li, F., et al., *[Bioaccumulation of Heavy Metals in Twigs and Leaves of Abies fabri at Mount Gongga in China: A Comparison Study Between 1999 and 2014]*. Huan Jing Ke Xue, 2017. **38**(7): p. 3045-3053.
21. Li, L.F., et al., *[Accumulation Characteristics of Heavy Metals in Greenhouse Soil and Vegetables in Siping City, Jilin Province]*. Huan Jing Ke Xue, 2018. **39**(6): p. 2936-2943.
22. Paikaray, S., *Origin, mobilization and distribution of selenium in a soil/water/air system: a global perspective with special reference to the Indian scenario*. CLEAN–Soil, Air, Water, 2016. **44**(5): p. 474-487.
23. Dhillon, K.S. and S.K. Dhillon, *Selenium in groundwater and its contribution towards daily dietary Se intake under different hydrogeological zones of Punjab, India*. Journal of Hydrology, 2016. **533**: p. 615-626.

24. Gore, F., J. Fawell, and J. Bartram, *Too much or too little? A review of the conundrum of selenium*. Journal of water and health, 2009. **8**(3): p. 405-416.
25. Rossiter, H.M., et al., *Chemical drinking water quality in Ghana: water costs and scope for advanced treatment*. Sci Total Environ, 2010. **408**(11): p. 2378-86.
26. Masresha, A.E., et al., *Speciation of selected trace elements in three Ethiopian Rift Valley Lakes (Koka, Ziway, and Awassa) and their major inflows*. Sci Total Environ, 2011. **409**(19): p. 3955-70.
27. Miao, Z., et al., *Transport and Fate of Ammonium and Its Impact on Uranium and Other Trace Elements at a Former Uranium Mill Tailing Site*. Appl Geochem, 2013. **38**.
28. Cao, S., et al., *Health risks from the exposure of children to As, Se, Pb and other heavy metals near the largest coking plant in China*. Sci Total Environ, 2014. **472**: p. 1001-9.
29. Nyairo, W.N., P.O. Owuor, and F.O. Kengara, *Effect of anthropogenic activities on the water quality of Amala and Nyangores tributaries of River Mara in Kenya*. Environ Monit Assess, 2015. **187**(11): p. 691.
30. Durmaz, E., et al., *Metal pollution in biotic and abiotic samples of the Buyuk Menderes River, Turkey*. Environ Sci Pollut Res Int, 2017. **24**(5): p. 4274-4283.
31. Tabelin, C.B., et al., *Arsenic, selenium, boron, lead, cadmium, copper, and zinc in naturally contaminated rocks: A review of their sources, modes of enrichment, mechanisms of release, and mitigation strategies*. Sci Total Environ, 2018. **645**: p. 1522-1553.
32. Golubkina, N., et al., *Selenium and drinking water quality indicators in Mongolia*. Environ Sci Pollut Res Int, 2018. **25**(28): p. 28619-28627.
33. Du, Y., et al., *Selenium and hazardous elements distribution in plant-soil-water system and human health risk assessment of Lower Cambrian, Southern Shaanxi, China*. Environ Geochem Health, 2018. **40**(5): p. 2049-2069.
34. Griboff, J., et al., *Bioaccumulation and trophic transfer of metals, As and Se through a freshwater food web affected by anthropic pollution in Cordoba, Argentina*. Ecotoxicol Environ Saf, 2018. **148**: p. 275-284.
35. Nong, X., et al., *Spatio-temporal Characterization Analysis and Water Quality Assessment of the South-to-North Water Diversion Project of China*. Int J Environ Res Public Health, 2019. **16**(12).
36. Yavar Ashayeri, N. and B. Keshavarzi, *Geochemical characteristics, partitioning, quantitative source apportionment, and ecological and health risk of heavy metals in sediments and water: A case study in Shadegan Wetland, Iran*. Mar Pollut Bull, 2019. **149**: p. 110495.
37. Jordaan, K., et al., *An integrated insight into the response of bacterial communities to anthropogenic contaminants in a river: A case study of the Wonderfonteinspruit catchment area, South Africa*. PLoS One, 2019. **14**(5): p. e0216758.
38. Ortiz-Colon, A.I., et al., *Assessment of Concentrations of Heavy Metals and Phthalates in Two Urban Rivers of the Northeast of Puerto Rico*. J Environ Anal Toxicol, 2016. **6**(2).

39. Mahfooz, Y., et al., *Investigating the drinking and surface water quality and associated health risks in a semi-arid multi-industrial metropolis (Faisalabad), Pakistan*. Environ Sci Pollut Res Int, 2019. **26**(20): p. 20853-20865.
40. Bhowmick, S., et al., *Assessment of toxic metals in groundwater and saliva in an arsenic affected area of West Bengal, India: A pilot scale study*. Environ Res, 2015. **142**: p. 328-36.
41. Singh, A.K., et al., *Physicochemical Parameters and Alarming Coliform Count of the Potable Water of Eastern Himalayan State Sikkim: An Indication of Severe Fecal Contamination and Immediate Health Risk*. Front Public Health, 2019. **7**: p. 174.
42. Jakhu, R. and R. Mehra, *Risk estimation and multivariate statistical analysis of the heavy metal content of drinking water samples*. Toxicol Ind Health, 2018. **34**(10): p. 714-725.
43. Jaishankar, M., et al., *Toxicity, mechanism and health effects of some heavy metals*. Interdisciplinary toxicology, 2014. **7**(2): p. 60-72.
44. Chakraborti, D., et al., *Status of groundwater arsenic contamination in the state of West Bengal, India: A 20-year study report*. Molecular nutrition & food research, 2009. **53**(5): p. 542-551.
45. Shrivastava, A., et al., *Arsenic contamination in shallow groundwater and agricultural soil of Chakdaha block, West Bengal, India*. Frontiers in Environmental Science, 2014. **2**: p. 50.
46. Roychowdhury, T., H. Tokunaga, and M. Ando, *Survey of arsenic and other heavy metals in food composites and drinking water and estimation of dietary intake by the villagers from an arsenic-affected area of West Bengal, India*. Science of the Total Environment, 2003. **308**(1-3): p. 15-35.
47. Huang, X., et al., *Different Choices of Drinking Water Source and Different Health Risks in a Rural Population Living Near a Lead/Zinc Mine in Chenzhou City, Southern China*. Int J Environ Res Public Health, 2015. **12**(11): p. 14364-81.
48. Liu, J., et al., *An integrated model for assessing heavy metal exposure risk to migratory birds in wetland ecosystem: A case study in Dongting Lake Wetland, China*. Chemosphere, 2015. **135**: p. 14-9.
49. Bi, B., et al., *Occurrence and risk assessment of heavy metals in water, sediment, and fish from Dongting Lake, China*. Environ Sci Pollut Res Int, 2018. **25**(34): p. 34076-34090.
50. Fu, Z., et al., *Copper and zinc, but not other priority toxic metals, pose risks to native aquatic species in a large urban lake in Eastern China*. Environ Pollut, 2016. **219**: p. 1069-1076.
51. Ahmed, M., et al., *Microwave assisted digestion followed by ICP-MS for determination of trace metals in atmospheric and lake ecosystem*. J Environ Sci (China), 2017. **55**: p. 1-10.
52. Hu, J., et al., *Assessment of the distribution, bioavailability and ecological risks of heavy metals in the lake water and surface sediments of the Caohai plateau wetland, China*. PLoS One, 2017. **12**(12): p. e0189295.

53. Qu, L., et al., *Risk analysis of heavy metal concentration in surface waters across the rural-urban interface of the Wen-Rui Tang River, China*. Environ Pollut, 2018. **237**: p. 639-649.
54. Zhong, W., et al., *Health risk assessment of heavy metals in freshwater fish in the central and eastern North China*. Ecotoxicol Environ Saf, 2018. **157**: p. 343-349.
55. Chen, G., et al., *Industrial arsenic contamination causes catastrophic changes in freshwater ecosystems*. Sci Rep, 2015. **5**: p. 17419.
56. Yang, X., et al., *Heavy metal pollution and health risk assessment in the Wei River in China*. Environ Monit Assess, 2015. **187**(3): p. 111.
57. Li, F., et al., *Spatial Distribution and Fuzzy Health Risk Assessment of Trace Elements in Surface Water from Honghu Lake*. Int J Environ Res Public Health, 2017. **14**(9).
58. Li, Q., et al., *Risk ranking of environmental contaminants in Xiaoqing River, a heavily polluted river along urbanizing Bohai Rim*. Chemosphere, 2018. **204**: p. 28-35.
59. Fang, T., et al., *An overview of heavy metal pollution in Chaohu Lake, China: enrichment, distribution, speciation, and associated risk under natural and anthropogenic changes*. Environ Sci Pollut Res Int, 2019.
60. Shao, T., et al., *Influence of environmental factors on absorption characteristics of suspended particulate matter and CDOM in Liaohe River watershed, northeast China*. Environ Sci Pollut Res Int, 2017. **24**(23): p. 19322-19337.
61. Li, L., H. Liu, and H. Li, *Distribution and migration of antimony and other trace elements in a Karstic river system, Southwest China*. Environ Sci Pollut Res Int, 2018. **25**(28): p. 28061-28074.
62. Saleh, H.N., et al., *Carcinogenic and Non-carcinogenic Risk Assessment of Heavy Metals in Groundwater Wells in Neyshabur Plain, Iran*. Biol Trace Elem Res, 2019. **190**(1): p. 251-261.
63. Alidadi, H., et al., *Health risk assessments of arsenic and toxic heavy metal exposure in drinking water in northeast Iran*. Environ Health Prev Med, 2019. **24**(1): p. 59.
64. Kose, E., et al., *Heavy metal accumulations in water, sediment, and some cyprinid species in Porsuk Stream (Turkey)*. Water Environ Res, 2015. **87**(3): p. 195-204.
65. Cengiz, M.F., et al., *Evaluation of heavy metal risk potential in Bogacayi River water (Antalya, Turkey)*. Environ Monit Assess, 2017. **189**(6): p. 248.
66. Rasool, A., et al., *Arsenic in groundwater and its health risk assessment in drinking water of Mailsi, Punjab, Pakistan*. Human and Ecological Risk Assessment: An International Journal, 2016. **22**(1): p. 187-202.
67. Hussain, S., et al., *Health Risk Assessment of Different Heavy Metals Dissolved in Drinking Water*. Int J Environ Res Public Health, 2019. **16**(10).
68. Rehman, K., et al., *Prevalence of exposure of heavy metals and their impact on health consequences*. J Cell Biochem, 2018. **119**(1): p. 157-184.
69. Akter, A., M. Mia, and H. Zakir, *Arsenic contamination in surface and groundwater in major parts of Manikganj district, Bangladesh*. Journal of the Bangladesh Agricultural University, 2015. **13**(1): p. 47-54.

70. Ali, M.M., et al., *Assessment of toxic metals in water and sediment of Pasur River in Bangladesh*. Water Sci Technol, 2018. **77**(5-6): p. 1418-1430.
71. Islam, M.M., et al., *Heavy Metal and Metalloid Pollution of Soil, Water and Foods in Bangladesh: A Critical Review*. Int J Environ Res Public Health, 2018. **15**(12).
72. Rahman, M.M., Z. Dong, and R. Naidu, *Concentrations of arsenic and other elements in groundwater of Bangladesh and West Bengal, India: potential cancer risk*. Chemosphere, 2015. **139**: p. 54-64.
73. Cobbina, S.J., et al., *Comparative Assessment of Heavy Metals in Drinking Water Sources in Two Small-Scale Mining Communities in Northern Ghana*. Int J Environ Res Public Health, 2015. **12**(9): p. 10620-34.
74. Nyantakyi, A.J., O. Akoto, and B. Fei-Baffoe, *Seasonal variations in heavy metals in water and sediment samples from River Tano in the Bono, Bono East, and Ahafo Regions, Ghana*. Environ Monit Assess, 2019. **191**(9): p. 570.
75. Hadzi, G.Y., D.K. Essumang, and J.K. Adjei, *Distribution and Risk Assessment of Heavy Metals in Surface Water from Pristine Environments and Major Mining Areas in Ghana*. J Health Pollut, 2015. **5**(9): p. 86-99.
76. Bempah, C.K. and A. Ewusi, *Heavy metals contamination and human health risk assessment around Obuasi gold mine in Ghana*. Environ Monit Assess, 2016. **188**(5): p. 261.
77. Hadzi, G.Y., D.K. Essumang, and G.A. Ayoko, *Assessment of contamination and health risk of heavy metals in selected water bodies around gold mining areas in Ghana*. Environ Monit Assess, 2018. **190**(7): p. 406.
78. Bortey-Sam, N., et al., *Health risk assessment of heavy metals and metalloid in drinking water from communities near gold mines in Tarkwa, Ghana*. Environ Monit Assess, 2015. **187**(7): p. 397.
79. Paez-Osuna, F., et al., *Heavy metals in waters and suspended sediments affected by a mine tailing spill in the upper San Lorenzo River, Northwestern Mexico*. Bull Environ Contam Toxicol, 2015. **94**(5): p. 583-8.
80. Jablonska-Czapla, M., et al., *Impact of the Pb and Zn ore mining industry on the pollution of the Biala Przemsza River, Poland*. Environ Monit Assess, 2016. **188**(5): p. 262.
81. Milivojevic, J., et al., *Assessment of Heavy Metal Contamination and Calculation of Its Pollution Index for Ugljesnica River, Serbia*. Bull Environ Contam Toxicol, 2016. **97**(5): p. 737-742.
82. Zhen, G., et al., *Temporal variation and regional transfer of heavy metals in the Pearl (Zhujiang) River, China*. Environ Sci Pollut Res Int, 2016. **23**(9): p. 8410-20.
83. Alkas, F.B., et al., *Monitoring and assessment of heavy metal/metalloid concentration by inductively coupled plasma mass spectroscopy (ICP-MS) method in Gonyeli Lake, Cyprus*. Environ Monit Assess, 2017. **189**(10): p. 516.
84. Adesiyan, I.M., et al., *Concentrations and Human Health Risk of Heavy Metals in Rivers in Southwest Nigeria*. J Health Pollut, 2018. **8**(19): p. 180907.

85. HMA, S.H., et al., *Arsenic, cadmium, lead, and chromium in well water, rice, and human urine in Sri Lanka in relation to chronic kidney disease of unknown etiology*. J Water Health, 2018. **16**(2): p. 212-222.
86. Samuel, O.A., et al., *Computation of human health risk in surface water in Ado-Odo Ota, Ogun State, Nigeria*. Data Brief, 2018. **19**: p. 1574-1583.
87. Bailon, M.X., et al., *Total mercury, methyl mercury, and heavy metal concentrations in Hyeongsan River and its tributaries in Pohang city, South Korea*. Environ Monit Assess, 2018. **190**(5): p. 274.
88. Reis, M.M., et al., *Metal Contamination of Water and Sediments of the Vieira River, Montes Claros, Brazil*. Arch Environ Contam Toxicol, 2019. **77**(4): p. 527-536.
89. Nagy, A.S., J. Szabo, and I. Vass, *Evaluation of trace metal levels in surface water and sediments of the Hungarian upper section of the Danube River and its tributaries*. J Environ Sci Health A Tox Hazard Subst Environ Eng, 2016. **51**(14): p. 1248-1261.
90. Ejike, C.E., C.O. Eferibe, and F.O. Okonkwo, *Concentrations of some heavy metals in underground water samples from a Nigerian crude oil producing community*. Environ Sci Pollut Res Int, 2017. **24**(9): p. 8436-8442.
91. Batbayar, G., et al., *Chemical water quality gradients in the Mongolian sub-catchments of the Selenga River basin*. Environ Monit Assess, 2017. **189**(8): p. 420.
92. Hahn, J., et al., *Impacts of dam draining on the mobility of heavy metals and arsenic in water and basin bottom sediments of three studied dams in Germany*. Sci Total Environ, 2018. **640-641**: p. 1072-1081.
93. Wongsasuluk, P., et al., *Using urine as a biomarker in human exposure risk associated with arsenic and other heavy metals contaminating drinking groundwater in intensively agricultural areas of Thailand*. Environ Geochem Health, 2018. **40**(1): p. 323-348.
94. Mohankumar, K., V. Hariharan, and N.P. Rao, *Heavy Metal Contamination in Groundwater around Industrial Estate vs Residential Areas in Coimbatore, India*. J Clin Diagn Res, 2016. **10**(4): p. BC05-7.
95. Kumar, M., et al., *Arsenic and other elements in drinking water and dietary components from the middle Gangetic plain of Bihar, India: health risk index*. Science of the Total Environment, 2016. **539**: p. 125-134.
96. Satyapal, G.K., et al., *Possible bioremediation of arsenic toxicity by isolating indigenous bacteria from the middle Gangetic plain of Bihar, India*. Biotechnol Rep (Amst), 2018. **17**: p. 117-125.
97. Ravindra, K. and S. Mor, *Distribution and health risk assessment of arsenic and selected heavy metals in Groundwater of Chandigarh, India*. Environ Pollut, 2019. **250**: p. 820-830.
98. Khachatryan, V., et al., *Measurement of Long-Range Near-Side Two-Particle Angular Correlations in pp Collisions at $\sqrt{s}=13$ TeV*. Phys Rev Lett, 2016. **116**(17): p. 172302.

99. Edmunds, W. and P. Smedley, *Groundwater geochemistry and health: an overview*. Geological Society, London, Special Publications, 1996. **113**(1): p. 91-105.
100. Ratnayaka, D., M. Brandt, and K. Johnson, *Specialized and advanced water treatment processes*. Water Supply, 2009: p. 365-423.
101. Rahman, Z. and V.P. Singh, *Assessment of heavy metal contamination and Hg-resistant bacteria in surface water from different regions of Delhi, India*. Saudi journal of biological sciences, 2018. **25**(8): p. 1687-1695.
102. Wang, Y., et al., *Heavy metal concentrations in water, sediment, and tissues of two fish species (*Triplophysa pappenheimi*, *Gobio hwanghensis*) from the Lanzhou section of the Yellow River, China*. Environ Monit Assess, 2010. **165**(1-4): p. 97-102.
103. Ren, T., et al., *Determination of lead, cadmium, copper, and nickel in the tonghui river of beijing, china, by cloud point extraction-high resolution continuum source graphite furnace atomic absorption spectrometry*. J Environ Qual, 2013. **42**(6): p. 1752-62.
104. Abalaka, S.E., *Heavy metals bioaccumulation and histopathological changes in *Auchenoglanis occidentalis* fish from Tiga dam, Nigeria*. J Environ Health Sci Eng, 2015. **13**: p. 67.
105. Li, F., et al., *Investigation, Pollution Mapping and Simulative Leakage Health Risk Assessment for Heavy Metals and Metalloids in Groundwater from a Typical Brownfield, Middle China*. Int J Environ Res Public Health, 2017. **14**(7).
106. He, J., Y. Song, and J.P. Chen, *Development of a novel biochar/PSF mixed matrix membrane and study of key parameters in treatment of copper and lead contaminated water*. Chemosphere, 2017. **186**: p. 1033-1045.
107. Ahmad, J.U. and M.A. Goni, *Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh*. Environ Monit Assess, 2010. **166**(1-4): p. 347-57.
108. Asaduzzaman, M., et al., *Impact of tannery effluents on the aquatic environment of the Buriganga River in Dhaka, Bangladesh*. Toxicol Ind Health, 2016. **32**(6): p. 1106-13.
109. Ul Haq, N., et al., *Drinking water: A major source of lead exposure in Karachi, Pakistan*. 2011.
110. Sehar, S., et al., *Analysis of elemental concentration using ICP-AES and pathogen indicator in drinking water of Qasim Abad, District Rawalpindi, Pakistan*. Environ Monit Assess, 2013. **185**(2): p. 1129-35.
111. Khalid, S., et al., *Influence of groundwater and wastewater irrigation on lead accumulation in soil and vegetables: Implications for health risk assessment and phytoremediation*. Int J Phytoremediation, 2017. **19**(11): p. 1037-1046.
112. Masood, N., A. Farooqi, and M.I. Zafar, *Health risk assessment of arsenic and other potentially toxic elements in drinking water from an industrial zone of Gujrat, Pakistan: a case study*. Environ Monit Assess, 2019. **191**(2): p. 95.
113. Waseem, A., et al., *Pollution status of Pakistan: a retrospective review on heavy metal contamination of water, soil, and vegetables*. Biomed Res Int, 2014. **2014**: p. 813206.

114. Siwela, A.H., C.B. Nyathi, and Y.S. Naik, *A comparison of metal levels and antioxidant enzymes in freshwater snails, Lymnaea natalensis, exposed to sediment and water collected from Wright Dam and Lower Mguza Dam, Bulawayo, Zimbabwe*. *Ecotoxicol Environ Saf*, 2010. **73**(7): p. 1728-32.
115. Nikolaidis, C., et al., *Heavy metal pollution associated with an abandoned lead-zinc mine in the Kirki region, NE Greece*. *Bull Environ Contam Toxicol*, 2010. **85**(3): p. 307-12.
116. Teijon, G., et al., *Occurrence of emerging contaminants, priority substances (2008/105/CE) and heavy metals in treated wastewater and groundwater at Depurbaix facility (Barcelona, Spain)*. *Sci Total Environ*, 2010. **408**(17): p. 3584-95.
117. Brazova, T., et al., *Perch and its parasites as heavy metal biomonitors in a freshwater environment: the case study of the Ruzin water reservoir, Slovakia*. *Sensors (Basel)*, 2012. **12**(3): p. 3068-81.
118. Palacios, J., D. Roman, and F. Cifuentes, *Exposure to low level of arsenic and lead in drinking water from Antofagasta city induces gender differences in glucose homeostasis in rats*. *Biol Trace Elem Res*, 2012. **148**(2): p. 224-31.
119. Said, K.S., M. Shuhaimi-Othman, and A.K. Ahmad, *The evaluation of water quality and metal concentrations of Titiwangsa Lake, Selangor, Peninsular Malaysia*. *Pak J Biol Sci*, 2012. **15**(10): p. 459-68.
120. Taghipour, H., et al., *Corrosion and scaling potential in drinking water distribution system of tabriz, northwestern iran*. *Health Promot Perspect*, 2012. **2**(1): p. 103-11.
121. Zamani, A.A., M.R. Yaftian, and A. Parizanganeh, *Multivariate statistical assessment of heavy metal pollution sources of groundwater around a lead and zinc plant*. *Iranian J Environ Health Sci Eng*, 2012. **9**(1): p. 29.
122. Ashraf, M.A., et al., *Study of contaminant transport at an open-tipping waste disposal site*. *Environ Sci Pollut Res Int*, 2013. **20**(7): p. 4689-710.
123. Khan, M.U., R.N. Malik, and S. Muhammad, *Human health risk from heavy metal via food crops consumption with wastewater irrigation practices in Pakistan*. *Chemosphere*, 2013. **93**(10): p. 2230-8.
124. Koumolou, L., et al., *Health-risk market garden production linked to heavy metals in irrigation water in Benin*. *C R Biol*, 2013. **336**(5-6): p. 278-83.
125. Mousavi, S.R., et al., *Concentrations of mercury, lead, chromium, cadmium, arsenic and aluminum in irrigation water wells and wastewaters used for agriculture in Mashhad, northeastern Iran*. *Int J Occup Environ Med*, 2013. **4**(2): p. 80-6.
126. Yen Nhi, T.T., N.A. Mohd Shazili, and F. Shaharom-Harrison, *Use of cestodes as indicator of heavy-metal pollution*. *Exp Parasitol*, 2013. **133**(1): p. 75-9.
127. Ndilila, W., et al., *Environmental and toenail metals concentrations in copper mining and non mining communities in Zambia*. *Int J Hyg Environ Health*, 2014. **217**(1): p. 62-9.
128. Aparecida Maranho, L., et al., *Dissolved heavy metal determination and ecotoxicological assessment: a case study of the corumbatai river (sao paulo, Brazil)*. *Arh Hig Rada Toksikol*, 2014. **65**(3): p. 319-28.

129. Chen, Y.M., et al., *Some selected heavy metal concentrations in water, sediment, and oysters in the Er-Ren estuary, Taiwan: chemical fractions and the implications for biomonitoring*. Environ Monit Assess, 2014. **186**(11): p. 7023-33.
130. Igwe, O., et al., *Risks associated with the mining of Pb-Zn minerals in some parts of the Southern Benue trough, Nigeria*. Environ Monit Assess, 2014. **186**(6): p. 3755-65.
131. Michalec, B.K., et al., *The evaluation of heavy metal content in water and sediments of small reservoirs in light of various environmental quality regulations*. J Environ Sci Health A Tox Hazard Subst Environ Eng, 2014. **49**(7): p. 827-32.
132. Ossai, E.K., C.M. Iwegbue, and G.E. Nwajei, *Trace elements in water, soil, earthworm and fishes from Otokutu end of Warri River, Delta State, Nigeria*. Pak J Biol Sci, 2014. **17**(10): p. 1136-40.
133. Wongsasuluk, P., et al., *Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agricultural area in Ubon Ratchathani province, Thailand*. Environ Geochem Health, 2014. **36**(1): p. 169-82.
134. Basile, A., et al., *Effects of heavy metals on ultrastructure and Hsp70 induction in Lemna minor L. exposed to water along the Sarno River, Italy*. Ecotoxicol Environ Saf, 2015. **114**: p. 93-101.
135. Fuhrmann, S., et al., *Microbial and chemical contamination of water, sediment and soil in the Nakivubo wetland area in Kampala, Uganda*. Environ Monit Assess, 2015. **187**(7): p. 475.
136. Pei, N., B. Chen, and S. Liu, *Pb and Cd Contents in Soil, Water, and Trees at an Afforestation Site, South China*. Bull Environ Contam Toxicol, 2015. **95**(5): p. 632-7.
137. Obiri-Danso, K., M.G. Adonadaga, and J.N. Hogarh, *Effect of agrochemical use on the drinking water quality of Agogo, a tomato growing community in Ashanti Akim, Ghana*. Bull Environ Contam Toxicol, 2011. **86**(1): p. 71-7.
138. Saygi, Y. and S.A. Yigit, *Heavy metals in Yenicaga Lake and its potential sources: soil, water, sediment, and plankton*. Environ Monit Assess, 2012. **184**(3): p. 1379-89.
139. Arkoc, O., *Heavy metal concentrations of groundwater in the east of Ergene Basin, Turkey*. Bull Environ Contam Toxicol, 2014. **93**(4): p. 429-33.
140. Kukrer, S. and E. Mutlu, *Assessment of surface water quality using water quality index and multivariate statistical analyses in Sarayduzu Dam Lake, Turkey*. Environ Monit Assess, 2019. **191**(2): p. 71.
141. Ngwoke, K.G., et al., *Levels of lead and arsenic in groundwater and blood of residents of Agulu, Nigeria*. Pol J Environ Stud, 2015. **24**(4): p. 1717-1721.
142. Squadrone, S., et al., *Sex- and age-related variation in metal content of penguin feathers*. Ecotoxicology, 2016. **25**(2): p. 431-8.
143. Gogoi, A., et al., *Influence of ligands on metal speciation, transport and toxicity in a tropical river during wet (monsoon) period*. Chemosphere, 2016. **163**: p. 322-333.
144. Woldemichael, G., T. Tulu, and G.U. Flechsig, *Solar UV-treatment of water samples for stripping-voltammetric determination of trace heavy metals in Awash river, Ethiopia*. Heliyon, 2016. **2**(3): p. e00091.

145. Belabed, B.E., et al., *Modeling seasonal and spatial contamination of surface waters and upper sediments with trace metal elements across industrialized urban areas of the Seybouse watershed in North Africa*. Environ Monit Assess, 2017. **189**(6): p. 265.
146. Bilal, M., et al., *A new tunable dispersive liquid-liquid micro extraction method developed for the simultaneous preconcentration of lead and cadmium from lakes water: a multivariate study*. Spectrochim Acta A Mol Biomol Spectrosc, 2017. **183**: p. 417-424.
147. Sawyerr, H.O., et al., *Impact of Dumpsites on the Quality of Soil and Groundwater in Satellite Towns of the Federal Capital Territory, Abuja, Nigeria*. J Health Pollut, 2017. **7**(14): p. 15-22.
148. Afolayan, A.O., *Accumulation of Heavy Metals from Battery Waste in Topsoil, Surface Water, and Garden Grown Maize at Omilende Area, Olodo, Nigeria*. Glob Chall, 2018. **2**(3): p. 1700090.
149. Munoz-Najera, M.A., et al., *Heavy metal bioaccumulation in Oreochromis niloticus from Tenango Dam, Puebla, Mexico*. Environ Monit Assess, 2018. **190**(5): p. 280.
150. Dietler, D., et al., *Daily variation of heavy metal contamination and its potential sources along the major urban wastewater channel in Kampala, Uganda*. Environ Monit Assess, 2019. **191**(2): p. 52.
151. Ezemonye, L.I., et al., *Potential health risk consequences of heavy metal concentrations in surface water, shrimp (Macrobrachium macrobrachion) and fish (Brycinus longipinnis) from Benin River, Nigeria*. Toxicol Rep, 2019. **6**: p. 1-9.
152. Kasozi, K.I., et al., *Safety of Drinking Water from Primary Water Sources and Implications for the General Public in Uganda*. J Environ Public Health, 2019. **2019**: p. 7813962.
153. Skalny, A.V., et al., *Zinc, copper, cadmium, and lead levels in cattle tissues in relation to different metal levels in ground water and soil*. Environ Sci Pollut Res Int, 2019. **26**(1): p. 559-569.
154. de Melo, W.A., C.A. Braga, and L.C. Carneiro, *Occurrence of heavy metals and contaminants on the surface of adjacent rivers*. J Water Health, 2017. **15**(1): p. 50-57.
155. Fallahzadeh, R.A., et al., *Spatial analysis and health risk assessment of heavy metals concentration in drinking water resources*. Environ Sci Pollut Res Int, 2017. **24**(32): p. 24790-24802.
156. Vongdala, N., et al., *Heavy Metal Accumulation in Water, Soil, and Plants of Municipal Solid Waste Landfill in Vientiane, Laos*. Int J Environ Res Public Health, 2018. **16**(1).
157. Charalampous, N., et al., *A Multidisciplinary Assessment of River Surface Water Quality in Areas Heavily Influenced by Human Activities*. Arch Environ Contam Toxicol, 2015. **69**(2): p. 208-22.
158. Saran, L.M., et al., *Land use impact on potentially toxic metals concentration on surface water and resistant microorganisms in watersheds*. Ecotoxicol Environ Saf, 2018. **166**: p. 366-374.

159. Teta, C. and T. Hikwa, *Heavy Metal Contamination of Ground Water from an Unlined Landfill in Bulawayo, Zimbabwe*. J Health Pollut, 2017. **7**(15): p. 18-27.
160. Edokpayi, J.N., et al., *Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa*. Chem Cent J, 2018. **12**(1): p. 2.
161. Zinabu, E., et al., *Monitoring river water and sediments within a changing Ethiopian catchment to support sustainable development*. Environ Monit Assess, 2019. **191**(7): p. 455.
162. Yusta-Garcia, R., et al., *Water contamination from oil extraction activities in Northern Peruvian Amazonian rivers*. Environ Pollut, 2017. **225**: p. 370-380.
163. Sim, S.F., et al., *Baseline trace metals in water and sediment of the Baleh River-a tropical river in Sarawak, Malaysia*. Environ Monit Assess, 2016. **188**(9): p. 537.
164. Naghipour, D., S.D. Ashrafi, and K. Taghavi, *Data of heavy metals in soil and groundwater at Kiwi gardens of Amlash in Guilan Province, Iran*. Data Brief, 2018. **18**: p. 1556-1561.
165. Borah, K.K., B. Bhuyan, and H.P. Sarma, *Lead, arsenic, fluoride, and iron contamination of drinking water in the tea garden belt of Darrang district, Assam, India*. Environ Monit Assess, 2010. **169**(1-4): p. 347-52.
166. Dubey, S.K., et al., *Contamination of ground water as a consequence of land disposal of dye waste mixed sewage effluents: a case study of Panipat district of Haryana, India*. Bull Environ Contam Toxicol, 2010. **85**(3): p. 295-300.
167. Jain, C.K., A. Bandyopadhyay, and A. Bhadra, *Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India*. Environ Monit Assess, 2010. **166**(1-4): p. 663-76.
168. Bhagure, G.R. and S.R. Mirgane, *Heavy metal concentrations in groundwaters and soils of Thane Region of Maharashtra, India*. Environ Monit Assess, 2011. **173**(1-4): p. 643-52.
169. Chakrabarty, S. and H.P. Sarma, *Heavy metal contamination of drinking water in Kamrup district, Assam, India*. Environ Monit Assess, 2011. **179**(1-4): p. 479-86.
170. Cumar, S.K. and B. Nagaraja, *Environmental impact of leachate characteristics on water quality*. Environ Monit Assess, 2011. **178**(1-4): p. 499-505.
171. Gupta, B., et al., *Dynamics of toxic heavy metals in different compartments of a highly urbanized closed aquatic system*. J Environ Monit, 2012. **14**(3): p. 916-24.
172. Haloi, N. and H.P. Sarma, *Heavy metal contaminations in the groundwater of Brahmaputra flood plain: an assessment of water quality in Barpeta District, Assam (India)*. Environ Monit Assess, 2012. **184**(10): p. 6229-37.
173. Karpagavalli, M.S., P. Malini, and A. Ramachandran, *Analysis of heavy metals in drying wetland Pallikaranai, Tamil Nadu, India*. J Environ Biol, 2012. **33**(4): p. 757-61.
174. Dwivedi, A.K. and P.S. Vankar, *Source identification study of heavy metal contamination in the industrial hub of Unnao, India*. Environ Monit Assess, 2014. **186**(6): p. 3531-9.

175. Waykar, B. and R. Petare, *Studies on monitoring the heavy metal contents in water, sediment and snail species in Latipada reservoir*. J Environ Biol, 2016. **37**(4): p. 585-9.
176. Singh, R., A. Singh, and R. Bhadouria, *Water Quality Assessment Using Physico-Chemical Parameters and Heavy Metals of Lilour Lake, Bareilly, Uttar Pradesh (India)*. Int. J. Pure App. Biosci, 2017. **5**(6): p. 278-285.
177. Swain, R. and B. Sahoo, *Mapping of heavy metal pollution in river water at daily time-scale using spatio-temporal fusion of MODIS-aqua and Landsat satellite imageries*. J Environ Manage, 2017. **192**: p. 1-14.
178. ShyleshChandran, M.S., et al., *Distribution and risk assessment of trace metals in multifarious matrices of Vembanad Lake system, Peninsular India*. Mar Pollut Bull, 2019. **145**: p. 490-498.
179. Dotaniya, M.L., et al., *Geo-Accumulation Indices of Heavy Metals in Soil and Groundwater of Kanpur, India Under Long Term Irrigation of Tannery Effluent*. Bull Environ Contam Toxicol, 2017. **98**(5): p. 706-711.
180. Sharma, S., A.K. Nagpal, and I. Kaur, *Appraisal of heavy metal contents in groundwater and associated health hazards posed to human population of Ropar wetland, Punjab, India and its environs*. Chemosphere, 2019. **227**: p. 179-190.
181. Kumar, A. and S.R. Samadder, *Analysis of the leaching behavior of elements from coal combustion residues for better management*. Environ Monit Assess, 2015. **187**(6): p. 370.
182. Bhattacharya, A., et al., *Assessment of Yamuna and associated drains used for irrigation in rural and peri-urban settings of Delhi NCR*. Environ Monit Assess, 2015. **187**(1): p. 4146.
183. Gautam, S.K., et al., *Evaluation of groundwater quality in the Chotanagpur plateau region of the Subarnarekha river basin, Jharkhand State, India*. Sustainability of Water Quality and Ecology, 2015. **6**: p. 57-74.
184. Khachatryan, V., et al., *Search for direct pair production of supersymmetric top quarks decaying to all-hadronic final states in pp collisions at [Formula: see text]*. Eur Phys J C Part Fields, 2016. **76**(8): p. 460.
185. Rahman, Z. and V.P. Singh, *Assessment of heavy metal contamination and Hg-resistant bacteria in surface water from different regions of Delhi, India*. Saudi J Biol Sci, 2018. **25**(8): p. 1687-1695.
186. Kaur, M., et al., *Quantitative assessment of exposure of heavy metals in groundwater and soil on human health in Reasi district, Jammu and Kashmir*. Environ Geochem Health, 2019.
187. Shankar, B.S., *A critical assay of heavy metal pollution index for the groundwaters of Peenya Industrial Area, Bangalore, India*. Environ Monit Assess, 2019. **191**(5): p. 289.
188. Chouhan, S. and S. Flora, *Arsenic and fluoride: two major ground water pollutants*. 2010.
189. Suthar, S., et al., *Fluoride contamination in drinking water in rural habitations of Northern Rajasthan, India*. Environmental monitoring and assessment, 2008. **145**(1-3): p. 1-6.
190. Hoque, A., et al., *Fluoride levels in different drinking water sources in Bangladesh*. Fluoride, 2003. **36**(1): p. 38-44.

191. Ali, W., et al., *Unraveling prevalence and public health risks of arsenic, uranium and co-occurring trace metals in groundwater along riverine ecosystem in Sindh and Punjab, Pakistan*. Environ Geochem Health, 2019. **41**(5): p. 2223-2238.
192. Chakraborti, D., et al., *Arsenic in groundwater of the Kolkata Municipal Corporation (KMC), India: Critical review and modes of mitigation*. Chemosphere, 2017. **180**: p. 437-447.
193. Inaotombi, S. and P.K. Gupta, *Fate of Metals in Relation to Water and Sediment Properties in a Subtropical Lake in Central Himalaya, India*. Arch Environ Contam Toxicol, 2017. **72**(3): p. 391-401.
194. Kasprzak, K.S., F.W. Sunderman Jr, and K. Salnikow, *Nickel carcinogenesis*. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 2003. **533**(1-2): p. 67-97.
195. Gowd, S.S. and P.K. Govil, *Distribution of heavy metals in surface water of Ranipet industrial area in Tamil Nadu, India*. Environmental monitoring and assessment, 2008. **136**(1-3): p. 197-207.
196. Nambatingar, N., et al., *Heavy Metal Pollution of Chari River Water during the Crossing of N'Djamena (Chad)*. Toxics, 2017. **5**(4).
197. Kumar, R., A. Raina, and N. Sharma, *Dataset on water quality characteristics of a hill stream in Bhandarwah, Jammu and Kashmir*. Data Brief, 2019. **26**: p. 104462.
198. Eckley, C.S. and H. Hintelmann, *Determination of mercury methylation potentials in the water column of lakes across Canada*. Science of the Total Environment, 2006. **368**(1): p. 111-125.
199. Stuyt, S.S., E.E. Chapman, and L.M. Campbell, *Lake and watershed influences on the distribution of elemental contaminants in the Rideau Canal System, a UNESCO world heritage site*. Environ Sci Pollut Res Int, 2015. **22**(15): p. 11558-73.
200. Gbogbo, F., et al., *High levels of mercury in wetland resources from three river basins in Ghana: a concern for public health*. Environ Sci Pollut Res Int, 2017. **24**(6): p. 5619-5627.
201. Wang, Y.L., et al., *Distribution of mercury and methylmercury in surface water and surface sediment of river, irrigation canal, reservoir, and wetland in Taiwan*. Environ Sci Pollut Res Int, 2019. **26**(17): p. 17762-17773.
202. Bhave, P. and R. Shrestha, *Total mercury status in an urban water body, Mithi River, Mumbai and analysis of the relation between total mercury and other pollution parameters*. Environ Monit Assess, 2018. **190**(12): p. 711.
203. Singh, R.B., M.S. Haque, and A. Grover, *Drinking water, sanitation and health in Kolkata metropolitan city: Contribution towards urban sustainability*. Geography, Environment, Sustainability, 2015. **8**(4): p. 64-81.
204. Ramasamy, E.V., et al., *Total and methyl mercury in the water, sediment, and fishes of Vembanad, a tropical backwater system in India*. Environ Monit Assess, 2017. **189**(3): p. 130.
205. Wang, J., et al., *Temporal-spatial variation and partitioning of dissolved and particulate heavy metal(loid)s in a river affected by mining activities in Southern China*. Environ Sci Pollut Res Int, 2018. **25**(10): p. 9828-9839.
206. Titilawo, Y., et al., *Determination of levels of some metal contaminants in the freshwater environments of Osun State, Southwest Nigeria: A risk assessment approach to predict health threat*. Chemosphere, 2018. **211**: p. 834-843.

207. de Castro, E.S.J.M., et al., *Physico-chemical and genotoxicity analysis of Guaribas river water in the Northeast Brazil*. Chemosphere, 2017. **177**: p. 334-338.
208. Megremi, I., et al., *Spatial diversity of Cr distribution in soil and groundwater sites in relation with land use management in a Mediterranean region: The case of C. Evia and Assopos-Thiva Basins, Greece*. Sci Total Environ, 2019. **651**(Pt 1): p. 656-667.
209. Das Sharma, S. and D. Sujatha, *Characterization of the water chemistry, sediment (13)C and (18)O compositions of Kolleru Lake-a Ramsar wetland in Andhra Pradesh, India*. Environ Monit Assess, 2016. **188**(7): p. 409.
210. Silambarasan, K., P. Senthilkumaar, and K. Velmurugan, *Studies on the distribution of heavy metal concentrations in River Adyar, Chennai, Tamil Nadu*. European Journal of Experimental Biology, 2012. **2**(6): p. 2192-2198.
211. Nadmitov, B., et al., *Large-scale monitoring and assessment of metal contamination in surface water of the Selenga River Basin (2007-2009)*. Environ Sci Pollut Res Int, 2015. **22**(4): p. 2856-67.
212. Rehman, I.U., et al., *Enrichment, spatial distribution of potential ecological and human health risk assessment via toxic metals in soil and surface water ingestion in the vicinity of Sewakht mines, district Chitral, Northern Pakistan*. Ecotoxicol Environ Saf, 2018. **154**: p. 127-136.
213. Hussein, A.H., A.S. El Mahmoudi, and A.A. Al Naeem, *Assessment of the Heavy Metals in Al Asfar Lake, Al-Hassa, Saudi Arabia*. Water Environ Res, 2016. **88**(2): p. 142-51.
214. Ajima, M.N., et al., *Bioaccumulation of heavy metals in Mbaa River and the impact on aquatic ecosystem*. Environ Monit Assess, 2015. **187**(12): p. 768.
215. Oyem, H.H., I.M. Oyem, and A.I. Usese, *Iron, manganese, cadmium, chromium, zinc and arsenic groundwater contents of Agbor and Owa communities of Nigeria*. Springerplus, 2015. **4**: p. 104.
216. Bhatia, A., S. Singh, and A. Kumar, *Heavy Metal Contamination of Soil, Irrigation Water and Vegetables in Peri-Urban Agricultural Areas and Markets of Delhi*. Water Environ Res, 2015. **87**(11): p. 2027-34.

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