

Depthwise Variation of Selenium in Groundwater in Parts of Punjab, India

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ABSTRACT

Selenium is an essential trace element in human diet with carcinogenic effect when consumed in excess. This paper examines the depthwise variation of selenium in the aquifers of northeastern Punjab (India) in the Indo-Gangetic Plains in a piedmont zone. Out of 210 km² hydrogeologically studied area in parts of Hoshiarpur and Nawanshahr districts of Punjab State, about 50% of area was found affected by high selenium concentration problem in groundwater. Three aquifer groups were identified, i.e., aquifer group I, II and III with depth ranges of about 75-95 m (thickness ~90 m), 120-230 m (thickness ~110 m) and beyond 255 m, respectively. A clay horizon of about 15-35 m thickness separates aquifer group of I and II and that of about 15-30 m thickness aquifer group of II and III. Aquifer group I is unconfined, aquifer group II is semi-confined and aquifer group III is confined in nature. High concentrations of selenium is observed in aquifer groups I and II with concentrations decreasing with depth. Aquifer group III is devoid of selenium. The symptoms of high contents of selenium started emerging when people deepened their wells in the 1970s to a depth of 20-45 m in a sandy clay horizon. This, however, is yet to be verified and warrants further investigation.

INTRODUCTION

It was 19 April 2009. Twenty-one polo ponies fell on the ground, dead, just before the onset of the U.S. Polo Championship at Wellington, Florida. Everyone was stunned. Autopsies revealed high dosage of selenium in their blood, 10-20 times higher than the maximum permissible limit (Desta et al. 2012). Selenium was injected into their bodies as a performance enhancing drug just before the competition began.

But this is not for the first time this happened. Even the famous explorer Marco Polo in 13th century once referred in his journals to "a poisonous plant ... which if eaten by (horses) has the effect of causing the hoofs of the animal to drop off." (Horsetalk, 2009). What Marco Polo found 700 years ago is now thought to be a selenium-accumulating plant.

In fact, Selenium is considered both a friend and a foe. Friend because it is an essential immune-boosting trace element needed for all living organisms besides many industrial applications (Burk, 2002; Kieliszek and B³a₂ejak, 2016) and foe because it is a potential toxic

element to the natural ecosystems including the humans and the animals (Tan et al., 2016).

Adult humans need about 26-35 micrograms per day (µg/day) of selenium (WHO 2017), while the upper tolerable intake level is 400 µg/day (FAO/WHO, 2004). While Selenium deficiency affects about 500 - 1100 million people worldwide (White et al., 2012), the population that is exposed to toxic level of this trace element is not well-known. Selenium deficiency causes infertility, cognitive decline, cardiovascular and myodegenerative diseases (Shreenath et al., 2020). Its excesses too have manifold implications not only in humans but also in plants and animals (Terry, 2000; Surai, 2006; Sun et al., 2014; Pilon-Smits, 2015). In humans, typical effects include gastrointestinal disturbances, decayed teeth, loss of hair and dermatitis (WHO, 2011).

During the past 30 years, many researchers have worked on the release mechanism of selenium both in surface water and groundwater (Bassil, 2016). Occurrence of selenium has been reported in groundwater in many countries such as USA (Kulp and Pratt, 2004; Cizdziek and Zhou, 2005; May et al. 2008; Hudak, 2009; Gates et al., 2009; Hudak, 2010; Hay et al., 2016; Linard et al., 2016; Mills et al., 2016; Harte et al., 2018), United Kingdom (Smedley et al., 2002a), Chile (Leybourne and Cameron, 2008), Jordan (Kuisi and Abdel-Fattah, 2009); Nigeria (Etim, 2017), Pakistan (Afzal, 2000); Bangladesh (BGS and DPHE, 2001), Norway (Frengstad et al, 2002), Jordan (Al-Taani et al., 2012), Maldives (Hannigan et al., 2006), China (Chem et al., 2019), Argentina (Smedley, 2002b), France (Bassil et al., 2016), Mongolia (Golubkina et al., 2018) and India (Dhillon and Dhillon, 2003, 2016; Bajaj et al., 2011; Paikaray, 2016). Plant et al. (2014) give the selenium concentrations in many of these countries. Most of these work have highlighted the occurrence, speciation, and genesis of selenium. Depth-wise variation of selenium in aquifers has been poorly studied. This work is an attempt in this direction, and measures the depth-wise variation of selenium in aquifers in an exploratory well site in north-eastern Punjab, India.

Punjab is essentially an agricultural state with high dependency on groundwater that has a stage of development of 165% in the State (CGWB, 2018). Thousands of tubewells are punctured throughout the State for groundwater extraction. This work, therefore, carries special significance as it examines the variation of selenium with depth as the groundwater levels recede downward in depth. The study area for this work covers an area of 210 km² within the latitudes 31°05'00" and 31°12'00" N and longitudes 76°03'00" and 76°17'00" E. It forms

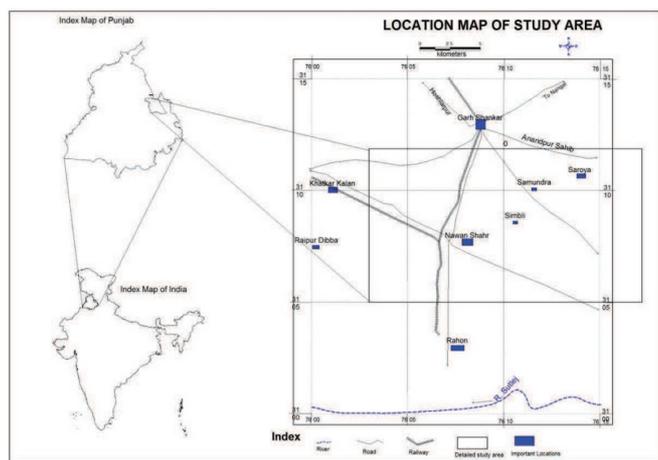


Fig. 1. Location map of the study area and groundwater sampling locations in parts of northeastern Punjab, India.

parts of Hoshiarpur and Nawanshahr districts in the administrative blocks of Garh Shankar, Nawanshahr and Saroya (Fig. 1), where groundwater exploitation has gone up to 131%, 108% and 66%, respectively (CGWB, 2018). Of the 210 km² studied area, an area of 103 km² is found affected by selenium contamination.

Selenium contamination in soil and plants of Punjab (India), especially in its northeastern parts, has been reported by many workers (Dhillon et al., 2005; Yadav et al., 2005, 2008; Dhillon and Dhillon, 2009; Sharma et al., 2009; Chandrasekharan et al., 2009), and more recently in groundwater by Bajaj et al. (2011) and Dhillon and Dhillon (2016). But these work do not give depth-wise variation of selenium in aquifers. Therefore, a defined depth up to which the farmers in the affected areas should drill tubewells is not well-defined. This work satisfies this limitation, and therefore, has special significance not only in the State of Punjab but also elsewhere in the world so that such work could be replicated and the threshold limits for the depth of groundwater structures could be defined in the selenium affected areas.

METHOD

Hydrogeological traverses were made in the study area to understand the aquifer disposition. Many lithological logs of tubewells already drilled in the area were examined to demarcate the extent of various aquifers. Groundwater sampling for selenium was carried out at 14 locations (Fig. 1). About 1 litre of groundwater was collected from each sampled tubewell after about 30 minutes of pumping so that not stored, but fresh groundwaters were collected for chemical analysis.

An exploratory well was constructed at village Simbli in Garh Shankar block of Hoshiarpur district in 2010 to determine the vertical distribution of selenium concentrations in groundwater (Fig. 1). Drill stem tests (packer tests) were conducted at various levels in the borehole. Pumping test was conducted tapping three distinct aquifer

groups. During the course of the field traverses and exploratory drilling, discussions were frequently held with the local farmers and inhabitants about the symptoms of selenium contamination, if any, in their health, soil, plants and animals.

RESULTS AND DISCUSSION

The study area is a part of the vast Indo-Gangetic Alluvial Plain with the Siwalik hills occupying the north and northeastern parts (Fig. 2). The Siwalik Formations have been folded and faulted due to tectonic activities. The transition between the Alluvial Plains and Siwalik hills is marked by a piedmont zone, locally called *Kandi*, which consists of numerous alluvial fans comprising of materials derived from the higher mountains through numerous streams. The East Bein River drains the study area. The Sutlej River flows in the southern part. The soils are loamy to clay-loamy in nature, and are usually decalcified, mildly acidic to neutral in reaction (CGWB, 2012). Paddy is the principal crop; other crops include maize, green fodder, oil seeds, pulses and vegetables.

Hydrogeological Conditions: Multi layered aquifer system exists in the alluvial plains (Fig. 3). There occurs three aquifer groups. Aquifer group I comprises of coarse sand beds, which at places have gravels in them. This group is 90 m thick with a depth range varying between 75-95 m. It is underlain by a regionally extensive clay layer (C-I) of varying thickness (15-35 m), interspersed by thin sand lenses. This clay layer separates aquifer group I from underlying aquifer group II and acts as a semi-confining layer. The semi-confined aquifer group II underlying C-I ranges in depth from 120-230 m with a thickness of about 110 m. It consists of alternating layers of sand and clay with occasional gravels with kankar. The sand layers are generally thick and are separated by the thin clay beds. Aquifer group III too is underlain by a clay layer (C-II) of about 25-30 m thick interspersed by thin lenticular sand layers. Below C-II lies the aquifer group III comprising of alternating layers of sand and clay. Clay layers are very thin in this group, but are extensive. Sediments in this group are

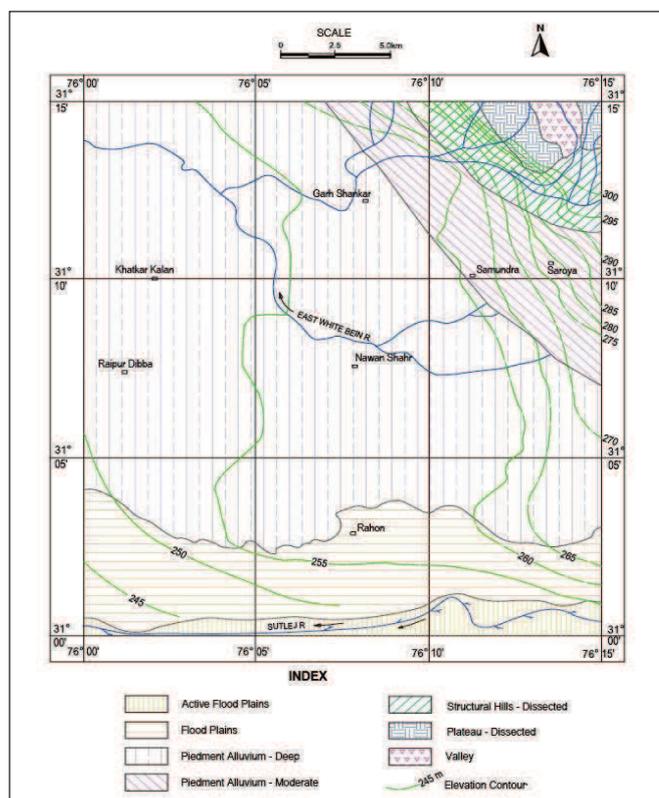


Fig. 2. Geomorphic features in parts of northeastern Punjab, India.

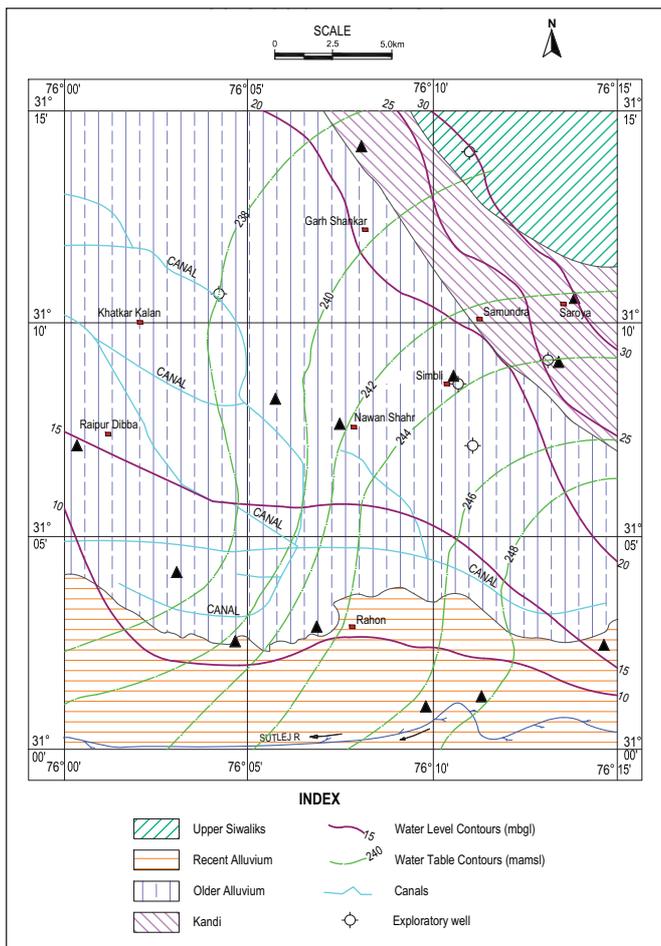


Fig. 3. Hydrogeology in parts of northeastern Punjab, India.

generally finer compared to those in aquifer groups I and II. Aquifer group III is confined in nature.

The depth to water level in unconfined aquifer (Aquifer Group I) ranges between 5.45 and 33.45 m bgl (2010 water level data). Deep water level conditions occur in kandi area, whereas shallow water level occurs in the flood plains along the river Sutlej in southern parts. The exploratory well at village Simbli shows a static water level of 14.80 m below ground level (2010), transmissivity of 739 m²/day, storativity of 2.38 x 10⁻⁴ and hydraulic conductivity of 38 m/day.

Occurrence of Selenium in Groundwater: Out of the 14 groundwater samples collected from tubewells, in 5 samples selenium was not detected. In 9 of them, selenium concentrations varied between 0.0024 and 0.114 mg/L (Table 1). Six samples show higher concentrations than the permissible limit of 0.01 mg/L prescribed by the Bureau of Indian Standards (BIS, 2012). This raises concern about the presence of high amount of selenium in aquifers of the study area.

Vertical groundwater sampling was carried out at the exploratory site at Simbli. No samples were collected at the site up to 40 m depth. However, samples were collected from the adjoining boreholes at two different depth ranges (15-25 m and 35-40 m). The analytical results of the vertical sampling (Table 2) show that groundwater up to 126 m depth has selenium concentrations of more than 0.03 mg/L. This depth limitation may go deeper since the sample number 4 represents a granular zone that has a depth range of about 126 – 172 m. Therefore, it is likely that whole of this zone is affected by selenium. Further downward beyond the depth range of 254 m, there is a drastic decline in selenium concentrations. This shows that selenium is present only in unconfined and semi-confined aquifers, i.e. aquifer groups I and II,

Table 1. Selenium concentrations in groundwater in parts of northeastern Punjab, India

Sam. No.	Location	Geographical Coordinates		Selenium (mg/L)
		East Longitudes	North Latitudes	
1	Digham	76.1589	31.1782	nd
2	Bhagwain	76.05	31.1717	0.0024
3	Naura	76.0853	31.1688	nd
4	Unchi Palli	76.1084	31.1705	nd
5	Basyala	76.1086	31.1655	nd
6	Panam	76.1678	31.1604	0.0107
7	Bhin	76.0956	31.1492	nd
8	Sumundra	76.1878	31.1459	0.0451
9	Kulam	76.1786	31.1298	0.0024
10	Simbli S	76.1786	31.1276	0.1114
11	Simbli M	76.1373	31.1211	0.0606
12	Barwa	76.197	31.1115	0.114
13	Rakkar	76.2231	31.1092	0.1
14	Chankoya	76.2813	31.0819	0.0078

Table 2. Variation of selenium concentrations with depth in parts of northeastern Punjab (India).

Sam. No.	Depth range (m)	Method of collection	Source of water sample	Selenium (mg/L)
1	15-25	Random	Hand pump near bus stop Simbli	0.0529
2	35-40	Random	Irrigation tubewell of Sh Malbir Singh Ex. Sarpanch	0.0511
3	71-74	Zone test	Exploratory well at Simbli	0.0352
4	123-126	Zone test	Exploratory well at Simbli	0.0312
5	254-257	Zone test	Exploratory well at Simbli	0.0051
6	254-300	After 30 min of pumping	Exploratory well at Simbli	0.0071
7	254-300	After 480 min of pumping	Exploratory well at Simbli	0.0021

respectively. In confined aquifer (aquifer group III), selenium concentrations are negligible. Figures 4 give a diagrammatic presentation of the selenium concentrations with depth. To get selenium-free water, therefore, the water supply wells must tap aquifer group III only with complete sealing of the aquifer groups I and II in the affected areas.

Selenium Toxicity: Selenium Toxicity has been noticed in soil, plants as well as in drinking water, posing a serious threat to crops, animals and humans in the study area. High selenium contents are found along ephemeral streamlets descending from the Siwaliks (Prasad and Kar, 2004). It is inferred that sediments brought down by the hilly streams originating from the upper reaches of the Siwaliks may be rich in selenium contents which might have been deposited in the geo-environs of these streams in space and time. The top soil has got enriched with selenium through recycling of selenium-rich groundwater irrigation due to continuous cropping (Dhillon and Dhillon, 2003). Therefore, since the surficial alluvial soil is heavily affected by selenium to the extent of 2.3-11.6 mg/kg (Bajaj et al, 2011), during the time of groundwater percolation, possibly selenium is leaching into the aquifer systems. Some of the villages most affected are Garh Shankar, Nawanshahr, Simbli, Jainpur and Mahindpur (Fig. 1). The villagers of the affected areas report their cattle being sick on consumption of fodder from the selenium-affected areas. The effect is manifested in the form of splitting of hair, deep cracks in the hoofs and horns of the livestock, etc. In case of human, common symptoms of selenium poisoning include loss of hair, malformation

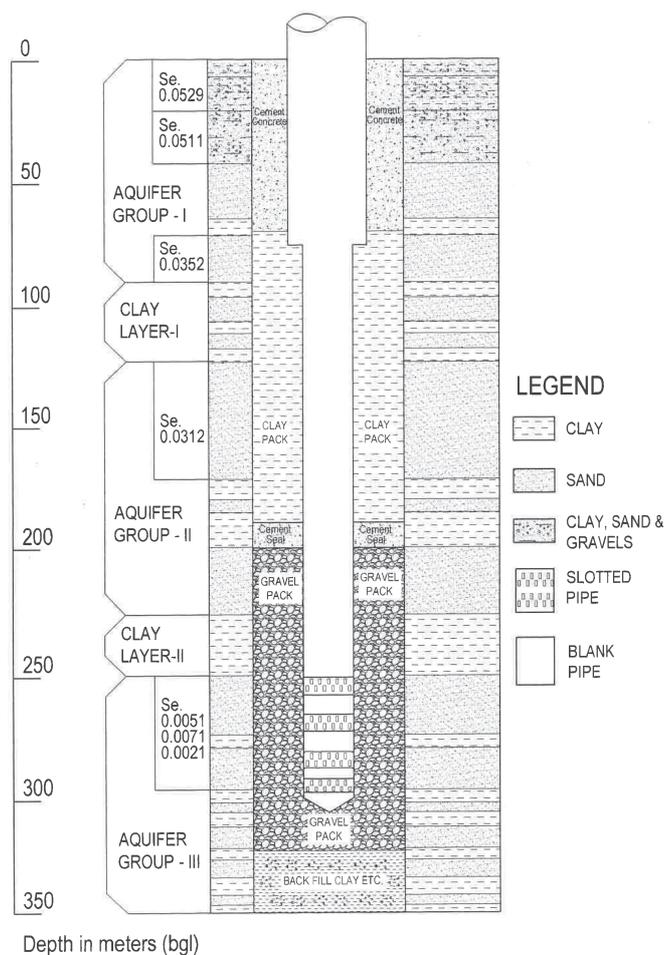


Fig. 4. Vertical distribution of selenium in different aquifer layers in the exploratory well at Simbli (Garh Shamkar), Dist. Hoshiarpur, Punjab, India.

of nails, both of fingers and toes, and progressive deterioration in general health. Typical selenium toxicity symptoms have been reported in wheat, sugarcane and some plants which exhibit papery, snow white chlorosis of leaves with pinkish coloration on the sheath and at the lower surface of leaves (Dhillon and Dhillon, 2003).

Historical Background: Discussions with local people reveal that traditionally the area was under maize and wheat cultivation in the past which required little or no irrigation. Groundwater was withdrawn from shallow aquifers, i.e., less than 20 m deep in those days, and no selenium toxicity was reported. However, after launch of Green Revolution in mid-sixties, high yielding crop varieties were introduced that required huge volumes of irrigation water as well as fertilizers and pesticides. Unregulated withdrawal of groundwater has resulted in sharp decline in water levels and subsequent deepening of tubewells. Symptoms of selenium toxicity started emerging when tubewells tapping aquifers below the sandy clay horizon of 20 m to 45 m were put to use for irrigation and domestic purposes. It is inferred that possibly the use of selenium rich groundwater from this sandy clay horizon has contaminated the surface as well as subsurface soils resulting in high selenium contents in plants as well. With decline in water level, deeper tubewells have been drilled piercing through this selenium rich sandy clay horizon, thus spreading the selenium contamination in the entire region. The exact source of selenium and its provenance could not, however, be established in absence of sufficient data on palaeo-environments and depositional sequences of sediments. More focused research is necessary in this direction by the

scientific community. Punjab recently is witnessing increasing groundwater contamination due to arsenic and uranium as well (CGWB, 2014). Since these elements have strong association with selenium (Hudak, 2010; Etim, 2017; Harte et al., 2018), whether these three elements too have the same provenance in this region is a subject of further investigation.

CONCLUSIONS

An attempt has been made to study the depth-wise variation of selenium in groundwater in northeastern parts of Punjab (India) in an alluvial terrain that forms the western fringe of the Indo-Gangetic Plains. Three aquifer groups have been identified. Aquifer Group I, unconfined in nature, goes up to about 75-95 m from ground surface and ends in a clayey horizon of about 15-35 m thick. Aquifer Group II, semi-confined in nature, occurs below this clayey horizon and goes up to a depth of about 120-230 m ending in a clayey horizon of about 25-30 m thick. Aquifer Group III, confined in nature, exists below this clayey horizon. Selenium contamination is found in Aquifer groups I and II only and decreases with depth. In Aquifer Group III that starts from a depth of about 255 m, selenium concentrations are within the permissible limits. To get selenium-free water, therefore, the water supply wells must tap Aquifer Group III only with complete sealing of the Aquifer Groups I and II in the affected areas. However, extensive study is required for delineation of selenium concentrations both horizontally and vertically.

It is reported that the study area did not have any physical symptom of selenium contamination prior to the green revolution in mid-sixties. As water levels went deeper and deeper post-green revolution in late seventies and groundwater was withdrawn from a sandy-clay horizon at a depth of 20-45 m depth for irrigation purposes, signs of selenium contamination was observed in people. This argument, could not, however, be verified with the limited field work carried out in the present study and needs further investigation.

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References

- Afzal S., Younas, M., Ali, K. (2000) Selenium speciation studies from Soan-Sakesar valley, Salt Range, Pakistan. *Water Internat.* v.25, pp.425-436.
- Al-Taani, A.A., Batayneh, A., El-Radaideh, N., Al-Momani, I., Rawabdeh, A. (2012) Monitoring of Selenium Concentrations in Major Springs of Yarmouk Basin, North Jordan. *World Appl. Sci. Jour.*, v.18(5), pp.704-714.
- Bajaj, M., Eiche, E., Neumann, T., Winter, J., Gallert, C. (2011) Hazardous concentrations of selenium in soil and groundwater in North-West India. *Jour. Hazard. Mater.*, v.189, pp.640-646.
- Ballantyne, C. (2009). Mystery solved: Polo ponies probably died of selenium overdose. *Scientific American*. <https://blogs.scientificamerican.com/news-blog/mystery-solved-polo-ponies-probably-2009-04-30/>. Published on April 30, 2009. Retrieved on October 13, 2020.
- Bassil, J., Naveau, A., Fontaine, C., Grasset, L., Bodin, J., Porel, G., Razack, M., Kazpard, V., Popescu, S-M. (2016) Investigation of the nature and origin of the geological matrices rich in selenium within the Hydrogeological Experimental Site of Poitiers, France. *Comptes Rendus Geosci.*, v.348(8), pp.598-608.
- BGS and DPHE (British Geological Survey, United Kingdom and Department of Public Health Engineering, Bangladesh (2001). Arsenic contamination of groundwater in Bangladesh (four volumes). *In: Kinniburgh, D.G. and Smedley, P.L. (Eds.), BGS Technical Report WC/00/19. Nottingham: British Geological Survey.*

- BIS (Bureau of Indian Standards) (2012). Indian Standard Drinking Water Specification (Second Edition) IS:10500. Indian Standard Institute, New Delhi, pp.1-18.
- Burk, R.F. (2002). Selenium, an Antioxidant Nutrient. *Nutrition in Clinical Care*, v.5(2), pp.75-79. doi:10.1046/j.1523-5408.2002.00006.x
- Chen, Q., Wei, J.C., Jia, C.P., Wang, H.M., Shi, L.Q., Liu, S.L., Ning, F.Z., Ji, Y.H., Dong, F.Y., Jia, Z.W., Hao, D.C. (2019) Groundwater Selenium Level and its Enrichment Dynamics in Seawater Intrusion Area along the Northern Coastal Zones of Shandong Province, China. *Geochem. Internat.*, v.57, pp.1236–1242.
- CGWB (Central Groundwater Board) (2012). Basic data report of exploratory well at Simbli (Garh Shankar) District Hoshiarpur Punjab, Central Groundwater Board, North Western Region, Chandugarh, 16p.
- CGWB (Central Groundwater Board) (2014) Water quality issues and challenges in Punjab, Central Groundwater Board, Ministry of Water Resources, 182p.
- CGWB (Central Groundwater Board) (2018) Groundwater resources of Punjab State, Central Groundwater Board, North Western Region, Chandugarh, 167p.
- Chandrasekaran, K., Ranjit, M., Arunachalam, J. (2009) Determination of inorganic selenium species [Se(IV) and Se(VI)] in tube well water samples in Punjab, India. *Chemical Speciation & Bioavailability*, v.21(1), pp.15-22.
- Cizdziel, J., Zhou, X. (2005) Sources and Concentrations of Mercury and Selenium In Compartments within the Las Vegas Wash During A Period of Rapid Change. *Environ. Monit. Assess.*, v.107, pp.81–99.
- Desta, B., Maldonado, G., Reid, H., Puschner, B., Maxwell, J., Agasan, A., Humphreys, L., Holt, T. (2012) Acute selenium toxicosis in polo ponies. *Jour. Veterinary Diagnostic Investigation*, v.23(3), pp.623–628. doi: 10.1177/1040638711404142 <http://jvd.sagepub.com>.
- Dissanayake, C.B., Rao, C.R.M., Chandrajith, R. (2010) Some Aspects of the Medical Geology of the Indian Subcontinent and Neighbouring Regions. *In: O.Selinus, R.B. Finkelman, J.A. Centeno (Eds.), Medical Geology – A Regional Synthesis*. Springer, London.
- Dhillon, K.S., Dhillon, S.K. (2009). Selenium concentrations of common weeds and agricultural crops grown in the seleniferous soils of northwestern India. *Sci. Total Environ.*, v.407(24), pp.6150-6156.
- Dhillon, K.S., Dhillon, S.K. (2003) Quality of underground water and its contribution towards selenium enrichment of the soil–plant system for a seleniferous region of northwest India. *Jour. Hydrol.*, 272 (1-4):120-130.
- Dhillon, K.S., Dhillon, S.K. (2016) Selenium in groundwater and its contribution towards daily dietary Se intake under different hydrogeological zones of Punjab, India. *Jour. Hydrol.*, v.533, pp.615-626.
- Dhillon, K.S., Dhillon, S.K., Pareek, N. (2005). Distribution and bioavailability of selenium fractions in some seleniferous soils of Punjab, India. *Archives of Agronomy and Soil Sci.*, v.51(6), pp.633-643.
- Etim, E.U. (2017) Occurrence and Distribution of Arsenic, Antimony and Selenium in Shallow Groundwater Systems of Ibadan Metropolis, Southwestern Nigerian. *Jour. Health Pollut.*, v.7(13), pp.32-41. doi:10.5696/2156-9614-7-13.32.
- FAO/WHO (Food and Agriculture Organization and World Health Organization) (2004) Vitamin and mineral requirements in human nutrition, 2nd ed. Report of a Joint FAO/WHO Expert Consultation, Bangkok, Thailand, 21–30 September 1998. Geneva, World Health Organization (<http://whqlibdoc.who.int/publications/2004/9241546123.pdf>).
- Frengstad, B., Banks, D., Aa.M. Skrede, Krog, J.R., Siewers, U. Strand, T. (2002) The hydrochemistry of crystalline bedrock groundwater in Norway. *Norges geologiske undersøkelse Bulletin* 439 pp.87-98.
- Gates, T.K., Cody, B.M., Donnelly, J.P., Herting, A.W., Bailey, R.T., Price, J.M. (2009). Assessing Selenium Contamination in the Irrigated Stream–Aquifer System of the Arkansas River, Colorado. *Jour. Environ. Qual.*, v.38(6), pp.2344-2356.
- Golubkina, N., Erdenetsogt, E., Tarmaeva, I., Brown, O., Tsegmed, S. (2018) Selenium and drinking water quality indicators in Mongolia. *Environ. Sci. Pollut. Res.*, v.25, pp.28619–28627. doi:10.1007/s11356-018-2885-2
- Hannigan, R.E., Bogdevich, O.P., Izmailova, D.N. (2006) Selenium in soils and groundwater of Moldova. *Environ. Geosci.*, v.13(4), pp.267–279.
- Harte, P.T., Blake, J.M., Becher, K.D. (2018) Determination of representative uranium and selenium concentrations from groundwater, 2016, Homestake Mining Company Superfund site, Milan, New Mexico. doi:10.3133/ofr20181055
- Hay, M.B., Leone, G., Partey, F., Wilking, B. (2016). Selenium attenuation via reductive precipitation in unsaturated waste rock as a control on groundwater impacts in the Idaho phosphate patch. *Appl. Geochem.*, v.74, pp.176-193.
- Horsetalk.co.nz (2009) Polo pony selenium levels up to 20 times higher than normal <https://www.horsetalk.co.nz/2009/04/06/polo-pony-selenium-levels-20x-higher/>. Published on April 06, 2009. Retrieved on October 08, 2020.
- Hudak, P.F. (2009) Elevated Fluoride and Selenium in West Texas Groundwater. *Bull. Environ. Contam. Toxicol.*, v.82, pp.39–42. doi:10.1007/s00128-008-9583-6.
- Hudak, P.F. (2010) Nitrate, Arsenic and Selenium Concentrations in The Pecos Valley Aquifer, West Texas, USA. *Internat. Jour. Environ. Res.*, v.4(2), pp.229-236. doi:10.22059/IJER.2010.14
- Kieliszek, M., Blazejak, S. (2016) Current Knowledge on the Importance of Selenium in Food for Living Organisms: A Review. *Molecules*, v.21, pp.609.
- Kuisi, M.A., Abdel-Fattah, A. (2010) Groundwater vulnerability to selenium in semi-arid environments: Amman Zarqa Basin, Jordan. *Environ. Geochem. Health*, v.32, pp.107–128. doi:10.1007/s10653-009-9269-y
- Kulp, T.R., Pratt, L.M. (2004) Speciation and weathering of selenium in upper cretaceous chalk and shale from South Dakota and Wyoming, USA. *Geochim. Cosmochim. Acta*, v.68(18), pp.3687-3701.
- Leybourne, M.I., Cameron, E.M. (2008) Source, transport, and fate of rhenium, selenium, molybdenum, arsenic, and copper in groundwater associated with porphyry–Cu deposits, Atacama Desert, Chile. *Chem. Geol.*, v.247(1–2), pp.208-228. doi:10.1016/j.chemgeo.2007.10.017.
- Linard, J.I., McMahon, P.B., Arnold, L.R., Thomas, J.C. (2016) Response of selenium concentrations in groundwater to seasonal canal leakage, lower Gunnison River Basin, Colorado, 2013. *Scientific Investigations Report 2016-5047*, USGS, Denver, Colorado.
- Marchall, R. (2013). Selenium – poison or miracle? <https://www.horsetalk.co.nz/2013/08/17/selenium-poison-or-miracle/>. Published on August 17, 2013. Retrieved on October 08, 2020.
- May, T.W., Fairchild, J.F., Petty, J.D., Walther, M.J., Lucero, J. Delvaux, M., Manning, J., Armbruster, M. (2008) An evaluation of selenium concentrations in water, sediment, invertebrates, and fish from the Solomon River Basin. *Environ. Monit. Assess.*, v.137, pp.213–232. doi: 10.1007/s10661-007-9742-y
- Mills, T.J., Mast, M.A., Thomas, J., Keith, G. (2016) Controls on selenium distribution and mobilization in an irrigated shallow groundwater system underlain by Mancos Shale, Uncompahgre River Basin, Colorado, USA. *Sci. Total Environ.*, v.566–567, pp.1621-1631. doi:10.1016/j.scitotenv.2016.06.063.
- Paikaray, S. (2016) 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*, v.44(5), pp.474-487.
- Pilon-Smits, E.A.H. (2015) Selenium in Plants. *In: U. Lu'ttge, W. Beyschlag (Ed.), Progress in Botany, Progress in Botany 76*, Springer International Publishing, Switzerland. doi:10.1007/978-3-319-08807-5_4.
- Plant, J.A., Bone, J., Voulvoulis, N., Kinniburgh, D.G., Smedley, P.L., Fordyce, F.M., Klinck, B. (2014) Arsenic and selenium. *In: Holland, H.D. and Turekain, K.K. (Eds.) Environmental Geochemistry*. Oxford, UK, Elsevier, pp.13-57. (Treatise on Geochemistry, 11).
- Prasad, S., Kar, S.K. (2004) Geological control of selenium concentration in the soil of Punjab plain, India. *Proceedings of the Workshop on Medical Geology IGCP-454 held at Nagpur, India, 3–4 February 2004*, Geol. Surv. India, Spec. Publ., No.83, pp.306–313.
- Sharma, N., Prakash, R., Srivastava, A., Sadana, U.S., Acharya, R., Prakash, N.T., Reddy, A.V.R. (2009) Profile of selenium in soil and crops in seleniferous area of Punjab, India by neutron activation analysis. *Jour. Radioanal. Nucl. Chem.*, v.281, pp.59–62.
- Shreenath, A.P., Ameer, M.A., Dooley, J. (2020) Selenium Deficiency. *In: StatPearls [Internet]*. Treasure Island (FL): StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK482260/>. Updated 2020 Aug 24.
- Smedley, P.L., Edmunds, W.M. (2002a). Redox patterns and trace-element behaviour in the East Midlands Triassic sandstone aquifer, UK. *Ground Water*, v.40, pp.44–58.
- Smedley, P.L., Kinniburgh, D.G. (2002b) A review of the source, behaviour

- and distribution of arsenic in natural waters. *Appl. Geochem.*, v.17, pp.517–568.
- Sun Y.C., Chang, Y.C., Su, C.K. (2006). On-Line HPLC-UV/Nano-TiO₂-ICPMS System for the Determination of Inorganic Selenium Species. *Analytical Chem.*, v.78(8), pp.2640-2645. doi: 10.1021/ac051899b.
- Surai, P.F. (2006) Selenium in nutrition and health. University Press, Nottingham, U.K.
- Tan, L.C., Nancharaiah, Y.V., van Hullebusch, E.D., Lens, P.N.L. (2016) Selenium: environmental significance, pollution, and biological treatment technologies. *Biotech. Advan.*, v.34 (5), pp.886-907.
- Terry, N., Zayed, A.M., de Souza, M.P. and Tarun, A.S. (2000) Annual Review of Plant Physiology and Plant Molecular Biology, v.51(1), pp.401-432.
- WHO (2011) Senenium in drinking water. World Health Organization, Geneva, p.22.
- WHO(2017) WHO Guidelines for Drinking Water Quality, fourth ed. incorporating the first addendum. World Health Organization, Geneva, pp.1-631.
- White, P.J., Broadley, M.R., Gregory, P.J. (2012) Managing the Nutrition of Plants and People. *Appl. Environ. Soil Sci.*, pp.1-13, 104826. doi:10.1155/2012/104826.
- Yadav, S.K., Singh, I., Singh, D., Sang-Do Han (2005) Selenium status in soils of northern districts of India (2005) *Jour. Environ. Managmt.*, v.75(2), pp.129-132.
- Yadav, S.K., Singh, I., Sharma, A., Singh, D. (2008) Selenium status in food grains of northern districts of India. *Jour. Environ. Managmt.*, v.88(4), pp.770-774.