Iran J Public Health, Vol. 52, No.1, Jan 2023, pp.64-77

Review Article

Selenium Removal from Water and Wastewater by Different Technologies: A Systematic Review

Abdolmajid Fadaei [1], Abdollah Mohammadian-Hafshejani [2]

1. *Department of Environmental Health Engineering, School of Health, Shahrekord University of Medical Sciences, Shahrekord, Iran*
2. *Department of Epidemiology and Biostatistics, School of Health, Shahrekord University of Medical Sciences, Shahrekord, Iran*

***Corresponding Author:** Email: ali2fadae@yahoo.com

(Received 27 Apr 2022; accepted 18 Jun 2022)

Abstract

Background: Selenium (Se) is an essential element playing a vital role in the metabolism of organisms. Se can generally be discharged in the potable water through natural and anthropogenic activities. Both excess and shortage of Se can cause significant adverse health effects in humans. Excess values of se may **stimulate** toxicity, leading to selenosis and alkali disease in humans and grazing animals, respectively.

Methods: A review search was systematically carried out from the databases Embase, PubMed/MEDLINE, Scopus, PubMed Central (PMC), Google Scholar, as well as medRxiv by using the following keywords: "waste water", "bioremediation", "selenium removal", "adsorption", and "drinking water". This study provides a review of the recent literature covering the period between 2011 and 2021. After screening the full text of the articles, 27 papers were enrolled. This study reviews the reported techniques for Se removal from water and wastewater, including adsorption, biological treatment, microbial reduction, bioreactors, fungal bioreactor, algal treatment, phytoremediation, and photocatalysis.

Results: Biological and bioremediation techniques, such as microbial reduction, biotransformation, and fluidized bed reactor have removal efficiency about 100%. The highest Se concentration of 15-7600 µg/L was achieved in ground waters in Ethiopia and the lowest level of 0.07 µg /L in Finland.

Conclusion: The combination of biological treatment with chemical or physical technologies is envisaged to optimize se elimination and to ensure ecological protection and human health safety.

Keywords: Adsorption; Bioremediation; Selenium (Se) removal; Water and wastewater

Introduction

Release of municipal and industrial wastewater containing hazardous materials and heavy metals into the environment can pose serious threats to humans, animals, plants and urban ecosystems (1). Selenium (Se) is an essential micro-nutrient element at low levels, but toxic when an excessive amount is consumed. The micronutrient benefit of se for human physiological functions is between the concentration of 63 and 135 µg/L, above this limit, Se is considered to be toxic (2). Symptoms of se toxicity were noted to have occurred at a daily intake of more than 800 µg /d, while chronic toxicity results in selenosis. Typical dietary intake of se in the United States is between 80–120 µg/d but varies significantly across other world regions (3). However, the National

Academy of Sciences Institute of Medicine has set 400 µg/d of Se as the tolerable upper safe limit(4). Se generally exists in different oxidation states i.e. Se^{6+} (selenate), Se^{4+} (selenite), Se^{0} (elemental Se), Se^{2-} (selenide), volatile methylated selenides (dimethyl selenide and dimethyl diselenide), and organic forms (selenocysteine and selenomethionine) (5). In water and wastewater, se generally exists as soluble Se oxyanions, selenite ($SeO3^{2-}$) and selenate ($SeO4^{2-}$), corresponding to Se (IV) and Se(VI), respectively. World consumption of Se included electronics (9.1%), pigments (10.3%), chemicals (15.2%), agriculture and other uses (15.7%), metallurgy (23.9%), and glass manufacturing (25.7%) (6).

The major sources of Se are oil refineries, mining of phosphates and wastewater sludge (1). The adverse effects of Se could not be ignored. Se effects on human health appear as dysfunction of the endocrine system, lack of mental alertness, gastrointestinal disturbances, impairment of natural killer cells activity, cardiovascular diseases, selenosis, deformation and loss of nails, and liver damage. Se effects on plants included alteration of protein properties, and reduction of plant biomass. Se also adversely affects animals. Alkali disease and blind staggers are two main syndromes caused by excessive intake of Se in animals (7-9). Therefore, it is very vital to choose a suitable and efficient method for Se removal from water and wastewater.

There are several treatment techniques that can be employed to remove Se from contaminated water and wastewater, including adsorption, bioremediation, photocatalysis, electrocoagulation, advanced oxidation processes (AOPs), reverse osmosis (RO), electrochemical methods, ion-exchange, centrifugation, chemical precipitation, and coagulation (10). Recently, bioremediation through adsorption has been widely investigated as a cost effective alternative because of the possibility of sustainable implementation, including the regeneration and reuse of the adsorbing media (11).

The present study focuses on the evaluation of Se removal by applying several treatment techniques to water and wastewater with emphasis on bioremediation.

Methods

The principal focus of this review is on the Se removal methods and processes. Databases including Google Scholar, Science Direct, PubMed/ MEDLINE, Cochrane, Scopus, medRxiv, and Web of Science were searched to retrieve several papers on the topic. Keywords like "waste water", "bioremediation", "selenium removal", "adsorption", "drinking water", "water treatment", and "ground water" were added to the above mentioned methods to retrieve appropriate papers. As shown in Fig. 1, 91 peer reviewed publications were accessed based on the relevance of titles to the research. These articles were further screened to 56 after reading through their abstracts. Following full text screening of the articles, 27 of them were used for this review, excluding the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reference (12).

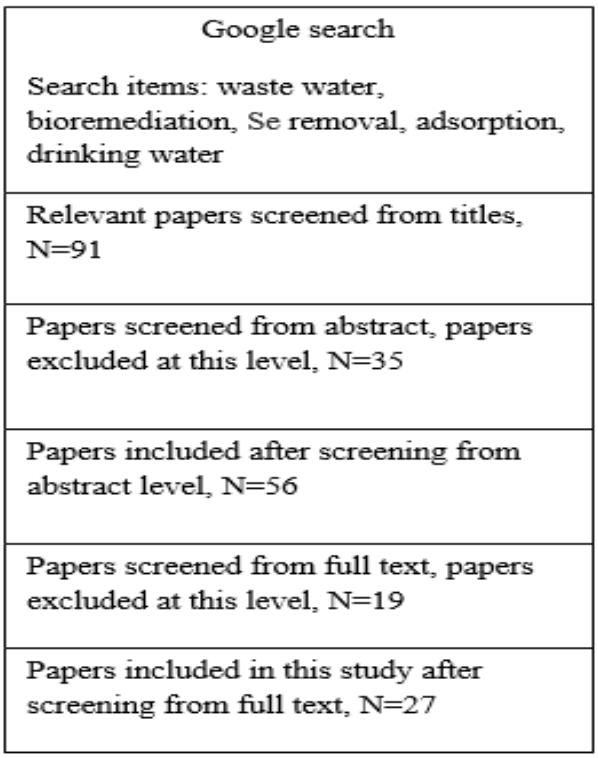

Fig. 1: Chart presentation of the review process

This study provides a review of the recent literature covering the period between 2011 and 2021. The inclusion criteria were access to the original article, English language, and using the type of aqueous solution investigated in this study such as surface water, sea water, ground water, domestic wastewater, mining wastewater, and industrial wastewater were investigated in this study. The exclusion criteria were **unavailability of full text** of the article, review studies, book reviews, guidelines, protocols, letters-to-editors, articles submitted to conferences, theses, white papers, etc.

Statistical analysis

The effect size of the relationship between bioremediation/biological treatment and Se elimination was reported with the 95% confidence interval (CI) for odds ratios (OR). A random-effects meta-analysis model was used to calculate the overall summary estimates. Graphically, the illustration of the individual OR and summary estimates was done in the form of forest plots. Heterogeneity among studies was tested by Cochran's Q test (reported with a $\chi 2$ value and *P*-value, with $P<0.1$ considered as the significance level) and the I2 statistics. I2 with values of 25%, 50%, and 75% demonstrated low, moderate, and high levels of heterogeneity, respectively. Publication bias was assessed using Begg's tests. All statistical analyses were performed using Stata 14.0 software (Stata LLC, College Station, TX, USA). $P<0.05$ was considered as the level of significance.

Results and Discussion

The reviewed articles had used various methods, including adsorption (12), biological and bioremidation (11) technique (i.e. biological treatment, microbial reduction, bioreactors, ABMet@ system, fungal bioreactor, algal treatment, phytoremediation), and photocatalysis process (4).

Adsorption

Adsorption is one of the techniques recommended for the elimination of hazardous elements existing in water and wastewater.

The highest capacity of bimetallic diatom composite adsorbent for Se removal was 227 mg/g, and the lowest removal capacity was 0.009 mg/g for activated alumina adsorbent (Fig.2 and Table 1).

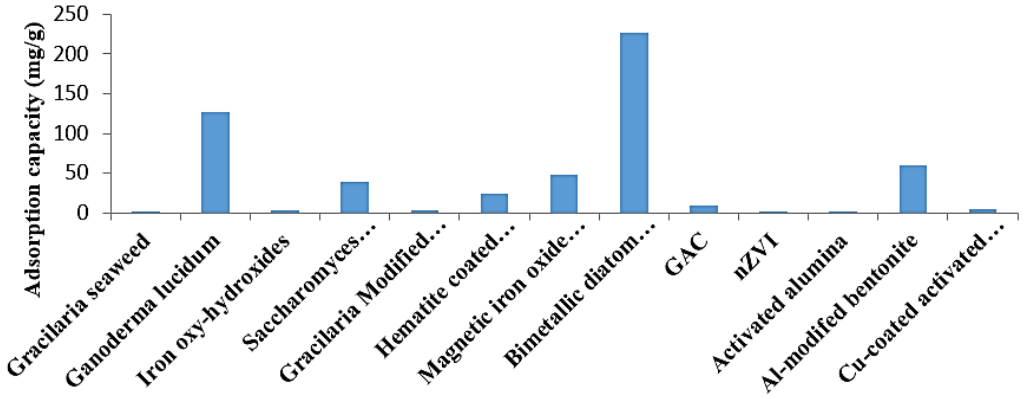

Fig. 2: Comparison of the adsorption capacities of various adsorbents

Table 1: Adsorption method used for Se removal from aqueous phase

Type of adsorbent	*Type of media*	*Reaction time*	*Species of Se*	*pH*	*Removal efficiency*	*Ref*
Gracilaria seaweed	Wastewater	4 h	Se(VI)	2.5 to 8	2.72 mg/g	(13)
Ganoderma lucidum	Artificial water	90 min	Se(VI)	5	126.99 mg/ g	(14)
Iron oxy-hydroxides	Natural waters	-	Se(VI) and Se(IV)	2to9	10 µg Se(VI)/g)and 4.3 mg Se(IV)/g.	(15)
Saccharomyces cerevisiae	Artificial water	30 min	Se(IV)	5	39.0 mg /g (96.1%)	(1)
Gracilaria Modified Biochar	Wastewater	-	Se(VI)	-	3.8 mg/g (98%)	(16)
Hematite coated magnetic nanoparticle	Water	120 min	Se(IV)	4 to 9	25.0 mg/g (97%)	(17)
Magnetic iron oxide nanoparticles	Contaminated water	24 h	Se(IV)	3 and 5	48 mg/g(>99%)	(18)
Bimetallic diatom composite	Artificial water	24 h	Se(IV)	8	227 mg/g	(19)
GAC and nZVI	Artificial wastewater	3 h	Organic Se (Selenomethionine and selenocysteine)	4 to9	GAC: selenocysteine10 mg/g (96.1%) and Selenomethionine 18.9 mg/g (86.7%) nZVI: selenocysteine0.59 mg/g (39.4%) and Selenomethionine < 1.1%	(20)
Activated alumina	Drinking water	70-120 min	Se(VI) and Se(IV)	4 to 9	9.02 µg/ g(80%) and 5.38 µg/ g(72%)	(21)
Al-modified bentonite	Artificial water	-	Se(IV)	3	60.1 mg/ g	(22)
Cu-coated activated carbon	Artificial water	4 h	Se(VI)	6	4.48 mg/g(88%)	(23)

The maximum adsorption capacity of fly ash zeolites for Se (IV) removal from an aqueous solution reported to be 3.93-4.16 mg/g at pH 2, with adsorbent content of 5.0 g/L, and initial concentration of 10 mg/L (24). The adsorption capacity of graphene oxide nanocomposite for Se(IV) removal from contaminated water was 1.62 mg/g at 25°C and pH 4-8 (25). The Se(IV) and Se(VI) removal efficiency by nanocrystalline aluminum oxide(nanocrystalline aluminum oxide) was 97% and 92%, respectively at pH 6.5-7.3, with initial concentration of 10 mg/L(26). Tang et al. reported the Se(VI) removal efficiency by zero-valent iron to be nearly 100% within 16 h, with an addition of 0.2 mM of Fe^{+2} (27). The efficiency of nanoscale zerovalent iron for Se removal from water was 90% at pH 3, with100 mg of the adsorbent (28). The removal efficiency of Se from wastewater by GAC was 78% at pH 7, reaction time 4 h, and 2.5 g /L of the adsorbent (29). Selenite removal efficiency reached above 90% after 6 h adsorption for the initial Se level of 2 mg/L and equilibrium was attained after 48 h(30). The removal efficiency of Se was found from water by oxide/hydroxide nanoparticles to be 95%-98% at pH 4, and 0.01 equilibrium concentration (31). The removal efficiency of Se from aqueous solution was 41%-78% at pH 5 using Al/Si and Fe/Si co-precipitates (32). The removal efficiency of Se from aqueous solution by iron oxide was 100% within 6 h, with an initial concentration of 1 mg/L at pH 6, adsorbent content of 25 mg, and mixing speed of 150 rpm (33). The adsorption capacity of natural goethite for Se(IV) removal from water was found to be 7.740 mg/g within 72 h with an initial level of 150 µg/L at pH 4, and adsorbent content of 0.333 g/L (34).

Biological and bioremediation technique

Biological treatment has emerged over recent years as a leading technology for Se removal from water and wastewater.

Table 2 shows bioremediation and biological treatment for elimination of Se from water and wastewater.

In biological systems, anaerobic and aerobic bacteria, algae, fungi, and plants are capable of catalyzing the Se removal under environmental conditions (35). Bioremediation combines the Se treatment with the potential to remove, recover, and reuse Se in the form of Se biominerals. Microbial reduction is a proven technique for converting soluble Se oxyanions (($SeO4^{2-}$ and $SeO3^{2-}$) to insoluble (Se^{0}) forms to eliminate the pollution from the water (9). The removal efficiency of Se from aqueous solution by using bioreduction was 88%, at pH 6 to 7, with an initial level of 11.6 mM at 30 °C (36). A novel solution was investigated by using a novel bacterial aerobic selenite reductase (*Alishewanella sp.*) for Se (IV) removal (37). *Chlorella vulgaris* was used for treatment (by biological uptake) of Se(IV) and Se(VI). The high elimination efficiency of 89% was observed for the initial Se level of 1580 µg/L(38). Another study was carried out on the use of *C. vulgaris* for Se elimination (by biological uptake) under varying conditions of initial Se level, algal density, temperature and pH. This study has also reported a removal efficiency of about 90% for Se (38). The alga Chlorella vulgaris removed 96% of Se supplied as Se oxyanions (1.58 mg/L) from the wetland water column within 72 h (39). The removal efficiency of se by bioremediation (algal-bacterial biofilm and biofertilizer) was about 65% within 6 d (11). The removal efficiency of Se from soil leachate by plants, such as Lemna minor and Egeria densa was 77% and 60%, respectively at pH 7, initial level of 74 µg/L within7d(40). The removal efficiency of Se (IV) and Se(VI) from environment by fungi(i.e. *Acremonium strictum, Alternaria alternate, Paraconiothyrium sporulosum, Plectosphaerella cucumerina, Pyrenochaeta* sp, and *Stagonospora* sp) was 85%–93% and 20%–30%, respectively, with initial concentration of 0.01 mM, within 10 d (41). The removal efficiency of Se from aqueous solutions by biotransformation was 40.40% after 21 d, with initial level 140-1400 µg/L (42). The adsorption capacity of Se(IV) and Se(VI) from aqueous solution by *Lactobacillus plantarum* was reported to be 700 µg/g, at pH 3-9 and 20–50° C (43). The adsorption capacity of Se(IV) from aqueous solution by *Cladophora hutchinsiae* was 74.9 mg/g, at pH 5 and 20° C (44). The adsorption capacity of Se(IV) from

aqueous solution by *Aspergillus* sp. *J2* was 5.67 mg/g, at pH 4.0-10.7 and temperature 38º C (45). One study used bacterium *Pseudomonas stutzeri NT-I* for bioremediation of selenium-containing refinery wastewater in two different bioreactors (46). The bio-reduction of selenate was reported to elemental Se using aerobic methanotrophs (47). Kieliszek et al. reported the Se removal from environment by yeast cells (*Saccharomyces cerevisiae, Candida utilis,* and *Yarrowia lipolytica*)(48). The removal of selenate was reported from aqueous solution using ethanol-fed fluidized bed reactor via redox potential at ORP-360 mV and pH of 4.0 (49). The efficiency of bioelectrochemical barrier for selenate removal from artificial wastewater was reported to be about 99.5%-99.8% with an initial level of 70 mg/L and voltage of 1.4 V. The selenite removal was reported from activated sludge by bioremediation (*Citrobacter Providencia* sp., and *Citrobacter* sp)(50). The Se removal was investigated from contaminated waters and wastewaters by biomineralization (9).

Table 2: Bioremediation and biological treatment for elimination of Se from water and wastewater

Type of organism	*Selenium species*	*Temperature*	*pH*	*Removal efficiency*	*Ref*
Macroalgae (*Oedogonium* sp)	Se(VI)	20 º C	4	84.14%	(51)
Volatilization(*Pseudomonas stutzeri*)	Se(VI)	38º C	9	82%	(52)
Phytoremediation(Cattail (CT; Typha angustifolia L and muskgrass)	Se(VI) and Se(IV)	-	-	75% and 74%	(53)
Bioreduction (anaerobic granular sludge)	Se(IV)	30°C	7.3	above 92%	
Burkholderia strains	Se(IV)	27 °C	7	75%	(54)
Biotransformation(*Stenotrophomonas maltophilia* SeITE0)	Se(IV)	27 °C	8	100%	(54)
Rhodocyclaceae (*Azospira oryzae* and *Rhizobium* s)	Se(VI)	-	7	99%	(55)
Fungal-pellet bioreactor (*Phanerochaete chrysosporium*)	Se(VI)	30 °C	4.5	70%	(56)
Inverse fluidized bed bioreactor	Se(IV)	30 °C	7	98%	(57)
Fluidized bed reactor	Se(IV) and Se(VI)	-	4.0 -5.0	100%	(58)
Upflow anaerobic sludge blanket (UASB)	Se(IV)	55 °C	7.3	94.4%	(59)
Biological(Cronobacter)	Se(IV)	25 °C	7.5	100%	(60)

Relationship of bioremediation/biological treatment and Se elimination

Considering the adjusted OR from each study in the meta-analysis, the OR of Se elimination with low levels is equal to 66.95% (95% CI=54.29–79.62, $P \leq 0.001$) as compared with the group with high levels of bioremediation/biological treatment, (Fig. 3). There was significant heterogeneity identified in the results during the meta-analysis (chi^2 = 64.94, df = 11, $P \leq 0.001$, I2=83.1%).

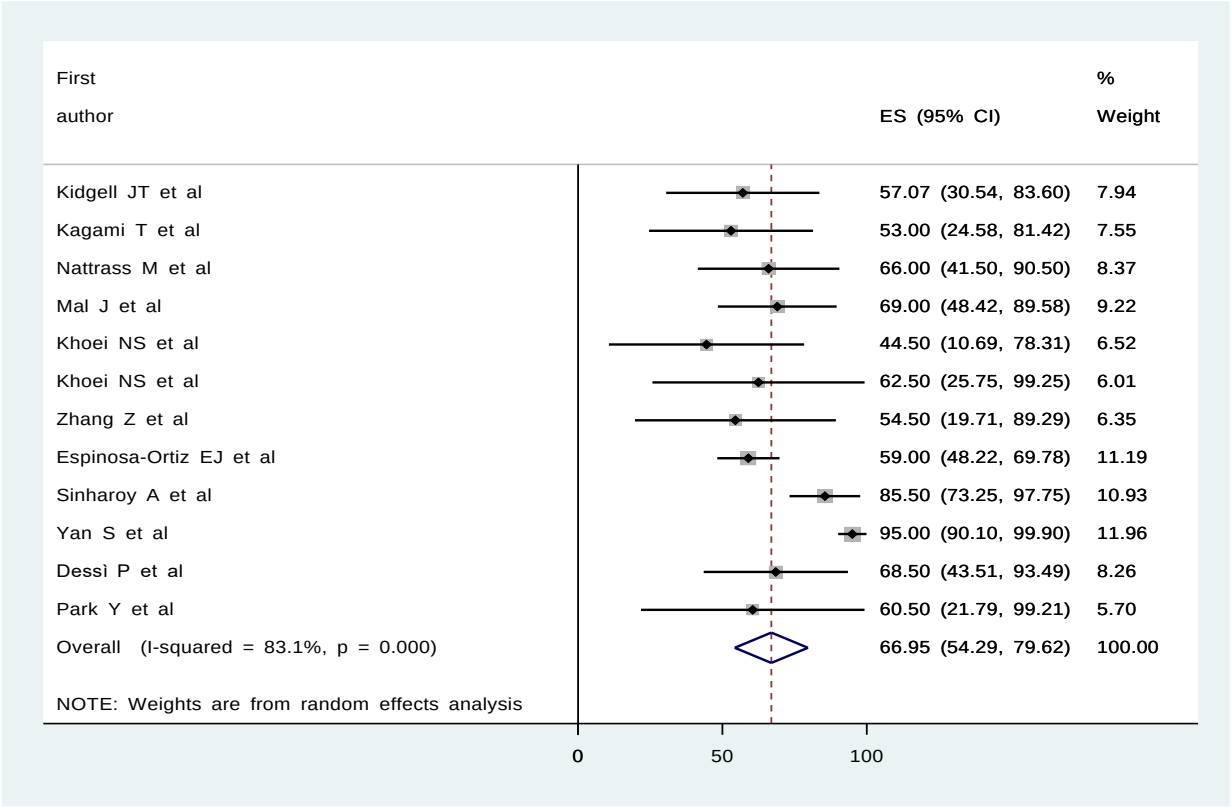

Fig. 3: The forest plot displays the elimination of Se (%) by bioremediation /biological treatment based on the random effects model (CI = 95%) of the average effect size

Evaluation of publication bias related to the relationship of bioremediation/biological treatment and elimination of Se

Evidence of publication bias was suspected upon examining the reported association between the relationship of bioremediation/biological treatment and elimination of Se. Therefore, the statistical tests were undertaken to evaluate potential publication bias in the reported studies. Begg's test (P=0.631) produced no statistically significant results. Therefore, published studies on the relationship of bioremediation/biological treatment and Se elimination are not significantly associated with publication bias, which cannot affect the final results of the meta-analysis.

Photocatalysis process

Recently, photocatalysis has gained wide attention in water and wastewater treatment due to its energy effectiveness and strong redox ability. In addition, it is also advantageous for the recovery of heavy metals from contaminated environments (61). Table 3 shows photocatalytic process for elimination of Se from aqueous phase.

A study demonstrated the photocatalysis (UV_A/TiO_2) for selenate removal from water with an initial level of 0.06 mM, at pH<5 in the presence of 300 mg/L formic acid (62). The removal efficiency of Se from mine water by photocatalysis was reported to be 99.6%, with TiO_2 dose of 0.2 g/L, at pH 3, UV intensity 11.03 mW/cm^2 (UV/TiO_2)(63). The use of photocatalytic reduction for Se(IV) removal was reported from an aqueous solution, at pH 3.5, with TiO_2 dose of 1.5 g/L, initial level of 80 mg/L in the presence of 300 mg/L formic acid (64). The use of photocatalytic reduction for Se(IV) and Se(VI) was demonstrated from aqueous solution, at pH 3.5, with TiO_2 dose of 1.1 g/L, initial level of 20 mg/L in the presence of 300 mg/L formic acid

within 120 min (65). The removal efficiency of total Se from mine water by using photocatalysis (UV/TiO_2) was reported 95.3%, at pH 7, with TiO_2 dose of 1.0 g/L, 15 W UV lamp, within 360 min (66).

Table 3: Photocatalytic process for elimination of Se from aqueous phase

Type of technique	*Environment*	*Removal efficiency*	*comment*	*Ref*
Photocatalytic	Synthetic wastewater	86.7%	Se(VI) and Se(IV) 10 mg/L, pH 4, natural log model	(61)
Solar photocatalytic	Aqueous environment	67%	Se(VI) Se(IV) and selenocyanate10 to 20 mg/L, pH 4, TiO2 =0.25 g/L, at 2 h	(67)
Photocatalytic	Aqueous phase	98%	Se(VI) and Se(IV) 20 mg/L, pH 4,reaction time 3 h, DO= 7 mg/L,T= 26◦C	(68)
Photocatalytic	Wastewater	About 100%	Se(VI) 0.5 mg/L, TiO2 =0.2g/L, reaction time1.5 h, HCOOH 2.0 mM	(69)

Relationship between photocatalysis process and Se elimination

Considering the adjusted OR from each study in the meta-analysis, compared to the group with high levels of photocatalysis process, the OR of Se elimination with low levels is equal to 72.21% (95% CI=49.34-95.08, $P \leq 0.001$) (Fig. 4). A significant heterogeneity was identified in the results during the meta-analysis (chi^2=9.54, df=3, $P \leq 0.001$, I2=68.6%).

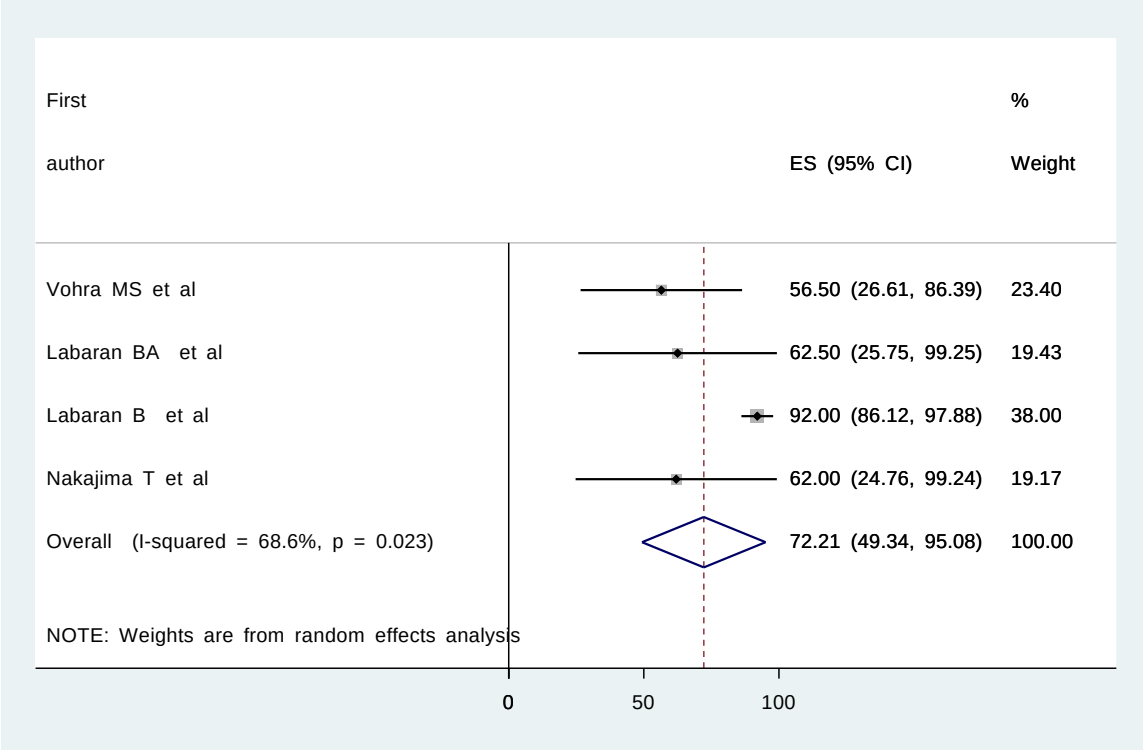

Fig. 4: The forest plot displaying the elimination of Se (%) by photocatalytic process based on the random effects model (CI = 95%) of the average effect size

Evaluation of publication bias related to the relationship of the photocatalysis process and elimination of Se

Evidence of publication bias was suspected upon examining the reported association between the relationship of the photocatalysis process and Se elimination. For this purpose, the statistical tests were undertaken to evaluate potential publication bias in the reported studies. Begg's test (*P*-value=0.734) produced no statistically significant results. Therefore, published studies on the relationship of the photocatalysis process and Se elimination are not significantly associated with publication bias, which cannot affect the final results of the meta-analysis.

Se from global perspective

Regarding ground waters, the highest Se concentration of 15to7600 µg/L was achieved in Ethiopia and the lowest concentration of 0.07 µg/L was found in Finland (Table 4), while in surface waters, the highest Se concentration of 165 to 311µg/L was found in Canada, and the lowest concentration of 0.21µg/L in Brazil (Table 4).

The WHO and EPA recommend that Se in potable water should not exceed 40 and 50 µg/L, respectively (Table 5).

Table 4: Selenium concentration in surface and ground waters from several countries

Regions/countries	*Water sources*	*Selenium concentration*	*Ref*
India (Chandigarh)	Groundwater	0.9 µg/L	(70)
Nigeria	Groundwater	7.33 - 46.3 µg/L	(71)
India(Chennai)	Groundwater	0.15–0.43 µg/L	(70)
Jordan	Groundwater	0.09 - 0.74 µg/L	(72)
Ethiopia	Groundwater	15–7600 µg/l	(73)
Finland	groundwater	0.07 µg/L	(74)
China(Enshi)	groundwater	0.17 µg/L	(74)
Canada(Saskatchewan River)	Surface water	165–311 µg/L	(75)
Australia (Lake Macquarie)	Surface water	50-300 µg/L	(35)
Belgium(Scheldt River)	Surface water	0.23–1.78 µg/L	(76)
Brazil(Amazon River)	Surface water	0.21 µg/L	(76)

Table 5: Summary of guidelines for Se concentration in drinking water

Country/Organization	*Concentration (µg/L)*	*Ref*
European Union	10	(77)
World Health Organization	40	(78)
United State Environmental Protection Agency	50	(79)
Canada	10	(6)
Australian	10	(80)
United States: Oregon	120	(81)
South Africa	20	(82)
New Zealand	10	(74)

Generally, Se concentration in normal water is less than 1 µg/L, while in seawater its content usually ranges from 0.1 to 0.35 µg/L. Global concentration of Se in river water has been reported to be 0.02 to 0.5 µg/L with an average value of 0.07 µg/L. The Se concentration in sur-

face and ground waters has been reported to be up to 0.2, and above 500 µg/L, respectively (83, 84). On Se concentration in natural waters ranges from 0.1 to 400 µg/L and sometimes reaches up to 6000 µg/L(71). In 51 locations in Colorado, New Mexico, and Utah, many of the groundwater samples were found saline with Se concentration of 1000 µg/L(85).

Conclusion

A systematic review of various treatment techniques developed over the last decade for Se (selenite and selenate) removal from water and wastewater was conducted. This study was mainly focused on biological and bioremediation technologies. In spite of the problems with these methods, biological treatment and bioremediation have appeared as the foremost treatment practices for Se removal from wastewater due to their advantages, such as low price, flexibility, lack of chemical waste formation and ability to eliminate Se in a recoverable form. Biological treatment is competently capable of reducing the total effluent Se while allowing for lower operation costs and easier system operation. Techniques, such as microbial reduction, biotransformation, and fluidized bed reactor have removal efficiency about 100%. Commonly, most of the techniques were not effective enough for selenate Se (VI) removal compared to selenite Se (IV). The Se removal efficacy can be enhanced by: 1) Combining biological treatment with chemical or physical methods to optimize Se removal and to ensure environmental protection and human health safety. 2) Removing Se (IV) and Se (VI) from polluted waters and wastewaters in both experimental and real settings.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgements

The author would like to thank Shahrekord University of Medical Sciences.

Conflict of interest

The author declares that there is no conflict of interest.

References

1. Khakpour H, Younesi H, Mohammadhosseini M (2014). Two-stage biosorption of selenium from aqueous solution using dried biomass of the baker's yeast Saccharomyces cerevisiae. *J Environ Chem Eng*, 2:532-542.
2. Albert M, Demesmay C, Rocca J (1995). Analysis of organic and non-organic arsenious or selenious compounds by capillary electrophoresis. *Fresenius' J Anal Chem,* 351:426-432.
3. Spallholz JE, Boylan LM, Rhaman M (2004). Environmental hypothesis: is poor dietary selenium intake an underlying factor for arsenicosis and cancer in Bangladesh and West Bengal, India? *Sci Total Environ,* 323:21-32.
4. Amoako PO, Uden PC, Tyson JF (2009). Speciation of selenium dietary supplements; formation of S-(methylseleno) cysteine and other selenium compounds. *Anal Chim Acta,* 652:315-323.
5. Zhang L, Hu B, Li W, et al (2014). Os PT 2, a phosphate transporter, is involved in the active uptake of selenite in rice. *New Phytologist,* 201:1183-1191.
6. Kumkrong P, LeBlanc KL, Mercier PH, Mester Z (2018). Selenium analysis in waters. Part 1: Regulations and standard methods. *Sci Total Environ,* 640:1611-1634.
7. Fadaei A (2021). Comparison of Water Defluoridation Using Different Techniques. *Int J Chem Engin,* 2021.
8. Ayangbenro AS, Babalola OO (2017). A new strategy for heavy metal polluted environments: a review of microbial

biosorbents. *Int j Environ Res.Public Health,* 14:94.
9. Nancharaiah YV, Lens PN (2015). Selenium biomineralization for biotechnological applications. *Trends Biotechnol,* 33:323-330.
10. Ahmadi D, Khodabakhshi A, Hemati S, Fadaei A (2020). Removal of diazinon pesticide from aqueous solutions by chemical–thermal-activated watermelon rind. *Int J Environ Health Eng,* 9:18.
11. Han W, Mao Y, Wei Y, Shang P, Zhou X (2020). Bioremediation of aquaculture wastewater with algal-bacterial biofilm combined with the production of selenium rich biofertilizer. *Water,* 12:2071.
12. Moher D, Liberati A, Tetzlaff J, Altman DG (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg,* 8:336-341.
13. Roberts DA, Paul NA, Dworjanyn SA, et al (2015). Gracilaria waste biomass (sampah rumput laut) as a bioresource for selenium biosorption. *J Appl Phycol,* 27:611-620.
14. Nettem K, Almusallam AS (2013). Equilibrium, kinetic, and thermodynamic studies on the biosorption of selenium (IV) ions onto Ganoderma lucidum biomass. *Sep Sci Technol,* 48:2293-2301.
15. Kalaitzidou K, Nikoletopoulos A-A, Tsiftsakis N, Pinakidou F, Mitrakas M (2019). Adsorption of Se (IV) and Se (VI) species by iron oxy-hydroxides: Effect of positive surface charge density. *Sci Total Environ,* 687:1197-1206.
16. Johansson CL, Paul NA, de Nys R, Roberts DA (2015). The complexity of biosorption treatments for oxyanions in a multi-element mine effluent. *J Environ Manag,* 151:386-392.
17. Ma Z, Shan C, Liang J, Tong M (2018). Efficient adsorption of Selenium (IV) from water by hematite modified magnetic nanoparticles. *Chemosphere,* 193:134-141.
18. Evans SF, Ivancevic MR, Yan J, et al (2019). Magnetic adsorbents for selective removal of selenite from contaminated water. *Sep Sci Technol,* 54:2138-2146.
19. Thakkar M, Mitra S (2017). Bimetallic Oxide Nanohybrid Synthesized from Diatom Frustules for the Removal of Selenium from Water. *J Nanomater,* 13:1-9.
20. Okonji SO, Yu L, Dominic JA, Pernitsky D, Achari G (2021). Adsorption by Granular Activated Carbon and Nano Zerovalent Iron from Wastewater: A Study on Removal of Selenomethionine and Selenocysteine. *Water,* 13:23.
21. Meher AK, Jadhav A, Labhsetwar N, Bansiwal A (2020). Simultaneous removal of selenite and selenate from drinking water using mesoporous activated alumina. *Appl Water Sci,* 10:1-12.
22. Albukhari SM, Salam MA, Abukhadra MR (2021). Effective retention of inorganic Selenium ions (Se (VI) and Se (IV)) using novel sodalite structures from muscovite; characterization and mechanism. *J Taiwan Inst Chem Eng,* 120:116-126.
23. Zhao X, Zhang A, Zhang J, Wang Q, Huang X, Wu Y, Tang C (2020). Enhanced selenate removal in aqueous phase by copper-coated activated carbon. *Materials,* 13:468.
24. Zhang X, Li X, Zhang F, Peng S, Tumrani SH, Ji X (2019). Adsorption of Se (IV) in aqueous solution by zeolites synthesized from fly ashes with different compositions. *J Water Reuse Desalin,* 9:506-519.
25. Bandara PC, Perez JVD, Nadres ET, Nannapaneni RG, Krakowiak KJ, Rodrigues DF (2019). Graphene oxide nanocomposite hydrogel beads for removal of selenium in contaminated water. *ACS Appl Polym Mater,* 1:2668-2679.
26. Yamani JS, Lounsbury AW, Zimmerman JB (2014). Adsorption of selenite and selenate by nanocrystalline aluminum oxide, neat and impregnated in chitosan beads. *Water Res,* 50:373-381.
27. Tang C, Huang YH, Zeng H, Zhang Z (2014). Reductive removal of selenate by zero-valent iron: the roles of aqueous Fe2+ and corrosion products, and selenate removal mechanisms. *Water Res,* 67:166-174.
28. Adio SO, Omar MH, Asif M, Saleh TA (2017). Arsenic and selenium removal from water using biosynthesized nanoscale zero-valent iron: a factorial design analysis. *Process Saf Environ Prot,* 107:518-527.
29. Okonji SO, Dominic JA, Pernitsky D, Achari G (2020). Removal and recovery of selenium species from wastewater: Adsorption kinetics

and co-precipitation mechanisms. *J Water Process Eng,* 38:101666.
30. Zhang N, Lin L-S, Gang D (2008). Adsorptive selenite removal from water using iron-coated GAC adsorbents. *Water Res,* 42:3809-3816.
31. Zelmanov G, Semiat R (2013). Selenium removal from water and its recovery using iron (Fe3+) oxide/hydroxide-based nanoparticles sol (NanoFe) as an adsorbent. *Sep Purif Technol,* 103:167-172.
32. Chan Y, Liu Y, Tzou Y, et al (2018). Kinetics and equilibrium adsorption study of selenium oxyanions onto Al/Si and Fe/Si coprecipitates. *Chemosphere,* 198:59-67.
33. Bakather OY, Kayvani Fard A, Khraisheh M, Nasser MS, Atieh MA (2017). Enhanced adsorption of selenium ions from aqueous solution using iron oxide impregnated carbon nanotubes. *Bioinorg Chem Appl,* 2017.
34. Jacobson AT, Fan M (2019). Evaluation of natural goethite on the removal of arsenate and selenite from water. *J Environ Sci,* 76:133-141.
35. Tan LC, Nancharaiah YV, van Hullebusch ED, Lens PN (2016). Selenium: environmental significance, pollution, and biological treatment technologies. *Biotechnol Adv,* 34:886-907.
36. Hageman S, Van Der Weijden R, Stams A, Van Cappellen P, Buisman C (2017). Microbial selenium sulfide reduction for selenium recovery from wastewater. *J Hazard Mater,* 329:110-119.
37. Xia X, Wu S, Li N, Wang D, Zheng S, Wang G (2018). Novel bacterial selenite reductase CsrF responsible for Se (IV) and Cr (VI) reduction that produces nanoparticles in *Alishewanella* sp. WH16-1. *J Hazard Mmater,* 342:499-509.
38. Xue G, Wang Q, Qian Y, et al (2019). Simultaneous removal of aniline, antimony and chromium by ZVI coupled with H2O2: implication for textile wastewater treatment. *J Hazard Mater,* 368:840-848.
39. Huang JC, Suarez MC, Yang SI, Lin ZQ, Terry N (2013). Development of a constructed wetland water treatment system for selenium removal: incorporation of an algal treatment component. *Environ Sci Technol,* 47:10518-10525.
40. Ohlbaum M, Wadgaonkar SL, van Bruggen JJ, Nancharaiah YV, Lens PN (2018). Phytoremediation of seleniferous soil leachate using the aquatic plants Lemna minor and Egeria densa. *Ecol Eng,* 120:321-328.
41. Rosenfeld CE, Kenyon JA, James BR, Santelli CM (2017). Selenium (IV, VI) reduction and tolerance by fungi in an oxic environment. *Geobiology,* 15:441-452.
42. Zhou C, Huang JC, Liu F, He S, Zhou W (2019). Selenium removal and biotransformation in a floating-leaved macrophyte system. *Environ Pollut,* 245:941-949.
43. Tyburska A, Jankowski K (2011). Preconcentration of selenium by living bacteria immobilized on silica for microwave induced plasma optical emission spectrometry with continuous powder introduction. *Anal Methods,* 3:659-663.
44. Tuzen M, Sarı A (2010). Biosorption of selenium from aqueous solution by green algae (Cladophora hutchinsiae) biomass: equilibrium, thermodynamic and kinetic studies. *Chem Eng J,* 158:200-206.
45. Li Z, Li H, Yang X, Zhang H, Liu C, Cao B (2013). Characterization of Se (IV) removal from aqueous solution by Aspergillus sp. J2. *Chem Eng J,* 220:67-71.
46. Soda S, Takahashi H, Kagami T, et al (2012). Biotreatment of selenium refinery wastewater using pilot-scale granular sludge and swim-bed bioreactors augmented with a selenium-reducing bacterium Pseudomonas stutzeri NT-I. *Jpn J Water Treat Biol,* 48:63-71.
47. Lai CY, Wen LL, Shi LD, et al (2016). Selenate and nitrate bioreductions using methane as the electron donor in a membrane biofilm reactor. *Environ Sci Technol,* 50:10179-10186.
48. Kieliszek M, Błażejak S, Gientka I, Bzducha-Wróbel A (2015). Accumulation and metabolism of selenium by yeast cells. *Appl Microbiol Biotechnol,* 99:5373-5382.
49. Yan S, Cheng KY, Ginige MP, Zheng G, Zhou L, Kaksonen AH (2021). Optimization of nitrate and selenate reduction in an ethanol-fed fluidized bed reactor via redox potential feedback control. *J Hazard Mater,* 402:123770.
50. Nguyen TH, Ha M-G, Kang HY (2019). Kinetics of microbial selenite reduction by novel bacteria isolated from activated sludge. *J Environ Manag,* 236:746-754.

51. Kidgell JT, de Nys R, Hu Y, Paul NA, Roberts DA (2014). Bioremediation of a complex industrial effluent by biosorbents derived from freshwater macroalgae. *PloS One,* 9:e94706.
52. Kagami T, Narita T, Kuroda M, et al (2013). Effective selenium volatilization under aerobic conditions and recovery from the aqueous phase by Pseudomonas stutzeri NT-I. *Water Res,* 47:1361-1368.
53. Nattrass M, McGrew NR, Morrison JI, Baldwin BS (2019). Phytoremediation of selenium-impacted water by aquatic macrophytes. *JASMR,* 8.
54. Khoei NS, Lampis S, Zonaro E, Yrjälä K, Bernardi P, Vallini G (2017). Insights into selenite reduction and biogenesis of elemental selenium nanoparticles by two environmental isolates of Burkholderia fungorum. *New Biotechnol,* 34:1-11.
55. Zhang Z, Xiong Y, Chen H, Tang Y (2020). Understanding the composition and spatial distribution of biological selenate reduction products for potential selenium recovery. *Environ Sci: Water Res Technol,* 6:2153-2163.
56. Espinosa-Ortiz EJ, Rene ER, van Hullebusch ED, Lens PN (2015). Removal of selenite from wastewater in a Phanerochaete chrysosporium pellet based fungal bioreactor. *Int Biodeterior Biodegradation,* 102:361-369.
57. Sinharoy A, Saikia S, Pakshirajan K (2019). Biological removal of selenite from wastewater and recovery as selenium nanoparticles using inverse fluidized bed bioreactor. *J Water Process Engin,* 32:100988.
58. Yan S, Cheng KY, Ginige MP, Zheng G, Zhou L, Kaksonen AH (2020). High-rate microbial selenate reduction in an up-flow anaerobic fluidized bed reactor (FBR). *Sci Total Environ,* 749:142359.
59. Dessì P, Jain R, Singh S, et al (2016). Effect of temperature on selenium removal from wastewater by UASB reactors. *Water Res,* 94:146-154.
60. Park Y, Yu J, Lee T (2016). Microbial selenite reduction with organic carbon and electrode as sole electron donor by a bacterium isolated from domestic wastewater. *Bioresour Technol,* 212:182-189.
61. Vohra MS, Labaran BA (2020). Photocatalytic treatment of mixed selenocyanate and phenol streams: Process modeling, optimization, and kinetics. *EnvironProg Sustain,* 39:e13401.
62. Holmes AB, Khan D, de Oliveira Livera D, Gu F (2020). Enhanced photocatalytic selectivity of noble metallized TiO 2 nanoparticles for the reduction of selenate in water: tunable Se reduction product H 2 Se (g) vs. Se (s). *Environ Sci: Nano,* 7:1841-1852.
63. Holmes AB, Ngan A, Ye J, Gu F (2022). Selective photocatalytic reduction of selenate over TiO2 in the presence of nitrate and sulfate in mine-impacted water. *Chemosphere,* 287:131951.
64. Nguyen VNH, Beydoun D, Amal R (2005). Photocatalytic reduction of selenite and selenate using TiO2 photocatalyst. *J Photochem Photobiol A: Chem,* 171:113-120.
65. Tan T, Beydoun D, Amal R (2003). Effects of organic hole scavengers on the photocatalytic reduction of selenium anions. *J Photochem Photobiol A: Chem,* 159:273-280.
66. Ahmed SA, Vohra MS (2021). Treatment of aqueous selenocyanate (SeCN–) using combined TiO. *Desalination and Water Treatment,* 211: 267–279.
67. Labaran BA, Vohra MS (2017). Solar photocatalytic removal of selenite, selenate, and selenocyanate species. *CLEAN–Soil, Air, Water,* 45:1600268.
68. Labaran B, Vohra M (2014). Photocatalytic removal of selenite and selenate species: effect of EDTA and other process variables. *Environ Technol,* 35:1091-1100.
69. Nakajima T, Yamada K, Idehara H, Takanashi H, Ohki A (2011). Removal of selenium (VI) from simulated wet flue gas desulfurization wastewater using photocatalytic reduction. *J Water Environ Technol,* 9:13-19.
70. Bajaj M, Eiche E, Neumann T, Winter J, Gallert C (2011). Hazardous concentrations of selenium in soil and groundwater in North-West India. *J Hazard Mater,* 189:640-646.
71. Gebreeyessus GD, Zewge F (2019). A review on environmental selenium issues. *SN Appl Sci,* 1:1-19.
72. Mistry HD, Kurlak LO, Young SD, et al (2014). Maternal selenium, copper and zinc concentrations in pregnancy associated with small forgestationalage infants. *Matern Child Nutr* 10:327-334.

73. Kebede S (2012). *Groundwater in Ethiopia: features, numbers and opportunities*. ed. Springer Science & Business Media.
74. Bailey RT (2017). Selenium contamination, fate, and reactive transport in groundwater in relation to human health. *Hydrogeol J,* 25:1191-1217.
75. Donner MW, Cuss CW, Poesch M, Sinnatamby RN, Shotyk W, Siddique T (2018). Selenium in surface waters of the lower Athabasca River watershed: chemical speciation and implications for aquatic life. *Environ Pollut,* 243:1343-1351.
76. Zhang H, Feng X, Larssen T (2014). Selenium speciation, distribution, and transport in a river catchment affected by mercury mining and smelting in Wanshan, China. *Appl Geochem,* 40:1-10.
77. Union E (2020). Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the Quality of Water Intended for Human Consumption. *Off J Eur Union,* 435:1-62.
78. Organization WH (2017). Guidelines for drinking-water quality: first addendum to the fourth edition.
79. Kucharzyk KH, Crawford RL, Cosens B, Hess TF (2009). Development of drinking water standards for perchlorate in the United States. *J Environ Manag,* 91:303-310.
80. Sheehan D (2014). The evolution of the Australian drinking water guidelines: The role of the Cooperative Research Centre for Water Quality and Treatment and Water Quality Research Australia in the ongoing development of the Australian Drinking Water Guidelines. *Water: J Aust Water Asso,* 41:53-58.
81. Pendersen D (2011). Oregon Department of Environmental Quality Memorandum to the Environmental Quality Commission. *Oregon Department of Environmental Quality, Salem, OR,* 28.
82. Standards SABo (2011). South African National Standard [SANS] 241. Drinking Water Standard. Standards South Africa Pretoria,
83. Khamkhash A, Srivastava V, Ghosh T, Akdogan G, Ganguli R, Aggarwal S (2017). Mining-related selenium contamination in Alaska, and the state of current knowledge. *Minerals,* 7:46.
84. Wilkin RT, Lee TR, Beak DG, Anderson R, Burns B (2018). Groundwater co-contaminant behavior of arsenic and selenium at a lead and zinc smelting facility. *Appl Geochem,* 89:255-264.
85. Morrison SJ, Goodknight CS, Tigar AD, Bush RP, Gil A (2012). Naturally occurring contamination in the Mancos Shale. *Environ Sci Technol,* 46:1379-1387.