# Biological and Physiochemical Techniques for the Removal of Zinc from Drinking Water: A Review

Naseem Zahra*[1], Yasha Nazir Butt[2] and Alim-Un-Nisa[1]

[1]*Pakistan Council of Scientific and Industrial Research Laboratories Complex, Ferozpur Road, Lahore, 54600, Pakistan.*
[2]*Institute of Biochemistry and Biotechnology, University of the Punjab, 54590, Lahore, Pakistan.*

--------------------------------------------------------------------------------

**Abstract**

Presence of zinc (II) in drinking water beyond permissible limits is considered unsafe for human health. Many different anthropogenic activities including mining, burning of petroleum, industrialization, and urbanization cause a release of considerably higher amounts of zinc into the water bodies. A permissible limit of 5 mg/L is set by various environmental and pollution control authorities beyond which water may cause respiratory, liver, gonads, and brain disorders. Due to these health hazards, it is important to remove exceeding amounts of zinc from drinking water. Zinc enters drinking water from various sources such as corrosive pipelines, release of industrial effluents, and metal leaching. Different biological and physiochemical techniques are used to remove zinc involving chemical precipitation, ion exchange, adsorption, biosorbents, distillation, ozonation, and membrane filtration technology. Among these technologies, physical process of adsorption using low cost adsorbents is not only economical but abundant, efficient, and easily available. In present review different physiochemical and biological techniques are discussed for the removal of zinc from drinking water.

*Keyword:* Adsorption; Zinc; Health Hazard; Toxicity; Techniques.

--------------------------------------------------------------------------------

## Introduction

Today, increased accumulation of heavy metals in water bodies is of considerable concern due to rapid upsurge of industrialization, urbanization, and exploitation of various natural resources. Despite many health benefits for humans which are provided by various metal ions present in the body, the amount beyond permissible limits becomes hazardous for health. Like many metal cations which exist in drinking water, zinc heavy metal is found to have adverse effects on human health when its amount exceeds certain limits as set by the respective authorities. The permissible limits set by EPA as for the industrial wastewater and effluents is fixed to 2 mg/L [1]. Zinc (II) on entering the body becomes the cause of diseases such as respiration deficits leading to breathlessness, increased coughing, frequent ventilation and volume, and decreased efficiency of oxygen intake [2]. One of the major sources of zinc involves Industrial discharges contaminated with high amounts of zinc (II). Many of such industries include electroplating zones, pigment producing, battery developing, and ammunition producing industries [3]. Other sources of zinc present in wastewater disposal comprises of industrial setups involving pharmaceutical, paint

--------------------------------------------------------------------------------

*Corresponding Author Email: naseem.zahra1981@gmail.com

and galvanizers, dyes and pigments, cosmetics, and insecticide industries [4]. The departments of fishing, photography and painting, minerals excavation and extraction, pigment producing, and metal dealing are also found discharging large amounts of metals including zinc [5]. The exceeding amount of zinc enters the food chain through drinking water and cause toxicity. Many methods have been used in the past to remove toxic heavy metals from water including precipitation, efficient adsorption methods, membrane filtration technique, and ion exchange technology. Of all these conventional methods, the most easy, inexpensive, and simple method is the adsorption method [6]. A variety of efficient natural adsorbents are currently being used in adsorption such as bagasse, rice husk, dry leaves of tea, saw-dust, and bottom-ash; which are not only effective in adsorbing away zinc from aqueous solutions but are also quite inexpensive in the market. Studies have also shown that bagasse gives the best adsorption results for the removal of zinc from aqueous solution [7].

According to a comparative research, Zn (II) removal was carried out by rice husk, clarified sludge obtained through the steel mill industry, activated alumina, and bark of neem tree. Observations highlighted increase in adsorption with the increase in concentrations of adsorbents used. The maximum uptake was recorded as 10g/L with pH 5 to 7 and only 1 hour retention time for the clarified sludge [8]. Another essential process which is being applied these days is the biosorption of metals such as Zn (II) in aqueous form for the purpose of bioremediation especially through bacterial biomasses, fungal biomasses, algal biomasses, and by leaf powders such as that of Eucalyptus. The adsorption capacity is found to be dependent on contact time, rate of agitation, size of particulate matter, temperature, and pH. As for the Eucalyptus leaf powder, the rate of metal uptake was recorded around 94% at pH 5, and the temperature of 20 °C with the least particulate size of 0.5 mm [9]. This review paper mainly discusses a variety of useful physical, biological, and chemical techniques and kinetics for the removal of zinc from the drinking water which otherwise causes health hazards on entering the bodies in excess amounts. It also focuses on the

efficiency of different adsorbents required for the adsorption of zinc as one of the effective physical methods.

### Toxic and significant effects of zinc

Zinc is an essential trace element with a density of 7.14 at about 20 °C and is required in minute amounts for the proper functioning of human body in order to maintain good health. It helps in biochemical and metabolic reactions to be carried out in body. It is also used in many different industries for insecticides, dyeing and pigmentation, antibiotics, moulds and adhesives, rubber and concrete, plastics, curing processes, and for protective coatings on steel in order to reduce any corrosion [10]. Since excess of zinc has negative effects on human health; so, the safety margins are quite narrow between environment and the range of toxicity. Even some sensitive organisms such as juvenile larvae have been found to be affected due to the hazardous effects of zinc. High amount of zinc found in the estuaries seemed to have a detrimental effect on the larvae causing increased incidence of abnormalities with greater rate of mortality. The productivity of larvae gets affected too, as recorded during hatchery. The breeding of oyster gets reduced along with. Although zinc is essential for proper functioning of body, large amounts may cause toxicity and hence its intake must not exceed the permissible limits [11].

### Sources of zinc contamination

Sources of zinc are widespread in nature with different localized areas of large deposits. The main source of zinc involves industrial discharge into the water bodies and leaching of metals due to geologically deposited material. It is abundantly produced at the galvanizing pipe producing industrial setups [12]. Zinc is an important raw-material for industries for its useful properties but random re-distribution caused by anthropogenic activities is causing health problems in many people. It also becomes available especially due to the burning of hydrocarbons, coal, petroleum products, and waste which later becomes part of water bodies. Incineration waste is another important source. Zinc enters the agricultural cycle

through the water bodies with dissolved industrial and municipal waste which further gets accumulated in different soil layers. Ever since the usage of phosphatic-fertilzers has increased, the presence of exceeding amounts of heavy metals such as zinc has also increased [13]. The abundance of zinc content due to mining processes may also be the reason of water bodies' contamination [14].

### Inadequate water quality and risks

Many heavy metals are required to be removed from drinking water so that the supplies meet the standards set by State, Federal, and International Authorities. Maximum level of zinc as set by the State agency in the United States is 5 mg/L [15]. Naturally, zinc is present in the soil with a concentration of around 1 to 300 mg/kg. The excess of zinc in water imparts it as inadequate characteristics such as undesirable taste which is easily distinguishable by people when 4 mg/L of zinc sulphate is present in water. Water containing zinc brings about a layer of greasiness on boiling which further makes it go opaque [16, 17]. Various authorities have set the permissible limits for zinc including Food and Drug Administration (FDA), World Health Organization (WHO), Federal Environmental Pollution Agency (FEPA), Pakistan Standards and Quality Control Authority (PSQCA), United States Environmental Protection Agency (USEPA) and Indian Standard Institution (ISI) is 5 mg/L, whereas, Indian Council of Medical Research (ICMR) has set 0.1 mg/L and according to Central Pollution Control Board (CPCB) it is 15 mg/L beyond these limits water becomes unsafe for drinking purpose [18, 19].

### Prevalence of zinc contamination in drinking water

Zinc normally exists in chemically combined form. It either forms alloys or combines with oxygen, carbon, and other elements. In natural surfaces of water bodies there is about 10 μg/L concentration of zinc whereas in the ground waters it is estimated to be 10 μg/L to 40 μg/L [20]. The concentration seems particularly raised in the pipeline and taps along with the fittings [21]. It has been reported that the amount of zinc in wells is higher than many other water bodies. Estimated six thousand wells were observed and tested for the presence of zinc with a range of about 24 mg/L in Finland [22]. Despite the fact that zinc remains negligible in usual conditions unless sources of zinc become part of drinking water supplies, under some circumstances when the level of corrosion increases, tap water causes an immense production of zinc which increases the daily intake of zinc by 10 %. This may bring about harmful effects on health [23, 24].

### Effect of excess zinc on human health

Slight and permissible amounts of zinc have no adverse effect on human health however, high amounts of zinc found in water bodies causes toxicity. The daily estimated intake of zinc by a grown-up is around 10 to 50 mg whereas the dosage above 150 mg to 600 mg becomes hazardous. Higher dosage of zinc also causes bio-accumulation of zinc in different body organs such as liver, kidneys, and gonads. Although kidney helps to remove excess zinc through homeostasis but large amounts are difficult to remove from the body. Consuming large amounts of zinc causes nausea, vomiting, abdominal cramps, and anaemia in humans. It is important to meet not more than 50 mg/L of zinc in the river water since it can prove to be dangerous for swimmers, and water consumers with increased skin contact. An exceeded amount of zinc is not only sensitive for human beings but also flora and fauna. Marine and fresh water bodies get adversely affected due to increased levels of zinc [25]. Among many health disorders caused due to the excessive amount of zinc inhaled an effect on brain with focal neuron deficits and lethargy is also included. It affects respiratory tract causing metal fume fever and inhalation problems. It also has a negative impact on the prostate with increased chances of prostate cancer [26]. Moreover, the taste effects of zinc are found to be particularly odd. The somatosensory effects caused by the salts of zinc including its chlorides, iodides, sulphates, bromides and acetates was tested and it was concluded that bitterness and sweetness both were greatly inhibited due to the presence of zinc salts [27].

*Environmental consequences of zinc*

In the environment, zinc is ubiquitous. It is present in hydrosphere, lithosphere, atmosphere, and the biosphere through the continuous transfer due to various natural processes including precipitation, evaporation, soil erosion, surface runoff, sedimentation, and through metal transferring ways. According to studies on the presence of heavy metals like zinc in the wetlands highlighted a higher concentration of zinc in the soil especially the top layer. Zinc from the top layer seeps through the soil and become part of the water table [28]. Some elevated levels of heavy metal zinc have been found existing in the rainwater which usually carries low dissolved minerals with it. It was though that the reason could be the leaching of metal built roofs and major water storing tanks as well as the increased atmospheric pollution. Many people depend on rainwater for agriculture and domestic usage and therefore, greater amounts of heavy metals like zinc become part of their water systems through storage and other means. It is essential to keep in check the levels of zinc found in rainwater especially when water is in contact with the corroding storage tanks and pipelines [29, 30]. The transfer of metal zinc between aqueous and solid matter bodies involves soil, sedimentation, and physiochemical characteristics of zinc compound present in the water. Zinc enters the food chain through marine organisms, drinking water, skin contact, and many other ways.

**Different techniques for zinc treatment**

There are many useful techniques for the removal of zinc such as physiochemical methods and biological sorption methods.

*Chemical precipitation*

In order to remove heavy metal zinc from the inorganic effluents the most widely used method is that of chemical precipitation [31, 32]. In this process the metal easily gets precipitated or insolubilized in an aqueous solution in hydroxide form. This method is now frequently conducted in many different countries around the world [33]. Compounds including calcium carbonate and calcium hydroxide are usually used for the precipitation as for the precipitating sources. This method has tendency to remove metals from drinking water having heavy metal concentration from 500 mg/L to 1000 mg/L. Studies have shown that zinc (II) of about 450 mg/L present in aqueous form was effectively removed through chemical precipitation in batch as well as the continuous processing systems [34]. Although this method is quite feasible, it requires huge amounts of different useful chemicals to insolubilize and separate zinc [35]. Moreover it becomes difficult to remove low quantities of heavy elements present in the drinking water. This range limit is below 100 mg/L [36]. More often it produces the sludge which further needs to be processed whereby which cost effectiveness decreases [37, 38].

*Ion exchange*

The US Environmental Protection Agency has useful data where zinc removal from drinking water is carried out through Ion exchange softening method. Many softening agents are used in order to reduce the hardening caused by the presence of magnesium and calcium. The replacement of ions is done with sodium in a particular resin. Saline is used to wash away or remove the ions and resin is then regenerated to check its affectivity [39]. In order to remove toxic heavy metal discharges, NASA has also developed a novel ion exchange polymer material with high efficiency of removing zinc [40].

*Membrane filtration technology*

There are various membrane separation techniques including nano-filtration, ultra-filtration, electro-dialysis, and reverse osmosis [41]. In nano-filtration there is the usage of special filters of about $0.01\mu m$ pore size which helps to reduce the amounts of ions present in water. This also helps in softening the water [42]. Reverse osmosis involves the passage of water through special kind of reverse osmosis filters having pore size of about $0.0001\mu m$. Water is usually pressurized to overcome natural flow of the direction and it fully depends on the amount of minerals and heavy metals like zinc present in it.

This method is quite costly and has large cost of construction for a plant [43]. Ultra filtration involves the membrane with pore size $0.1\mu m$. This only helps in removing the larger particulate matter so ions are first subjected to coagulation process and then treated [44]. Electro-dialysis involves zinc removal through the selective membranes. However, it requires pre-treatment of aqueous solutions including the coagulation, carbon filtration, oxidation, and acidification steps [45]. The cost for this technique depends on the presence of contamination. Inorganic contaminants like heavy metals can easily be filtered out from the water making it pure. Many inorganic effluents can be treated in a way to remove high amounts of heavy metals which can be of potential risk when they exceed the permissible limits [46-48].

### Ozonation technique

Catalytic ozonation is one of the promising techniques for the removal of heavy metals from drinking water. It involves the treatment of water through the exposure of ozone during pre-oxidation, final oxidation and intermediate oxidation. Sand or active carbon filters may be used to remove any leftover heavy metals from drinking water [49].

Ozone does the oxidation of heavy metals or transition metals to a greater oxidation state so that to form lesser soluble oxides for the ease of removal through filter membranes. During the process of ozonation the use of oxidants is also done to make process easier. The pre-ozonation requires a few steps to be taken prior to starting the separation technique. This involves the coagulation, flocculation, and simply decanting [50, 51].

### Distillation process

Distillation is another useful technique for the removal of inorganic ions from drinking water. This process involves separation by isolating and volatilizing water from the non-volatilized materials [52]. The thermal efficiency of water is enhanced through pressurizing for the good recovery of heat. This method helps to produce only a meager amount of dissolved solids [53, 54]. This process is not only expensive to conduct but also leads towards some extent of impracticality since a large amount of water is required in order to remove very minute amount of unwanted heavy metals. A lot of energy may be required to make this process work for zinc removal which leads to a decrease in the feasibility of this process [55].

### Bacterial biosorbents

Of many new biological methods to remove heavy metals is the usage of bacterial biomasses. Since bacteria is ubiquitous, it is easily available, and is easily divided forming huge biomasses for quick recovery of water. Bacteria are resilient to a variety of niches [56]. There are selective non-toxic species of microbes which are selected accordingly. The main principle behind its efficiency is the linkage of heavy metals to the cell walls of bacterial species which reduces the amount of metals however there are several factors associated such as pH, concentration of metals, biomass amount, retention time, and the type of bacterial microbes [57]. Figure 1 highlights various bacterial biosorbents which may be used for the sorption of zinc.

### Algal biosorbents

Algae are novel biosorbents which are found to have great sorption. They are abundantly available and are very easy to grow at any suitable environment of wide range. They are found near the water bodies especially ponds, seas, and oceans [58, 59]. Of all the algal species, microalgae are the best. They can remove heavy metals quite efficiently at very low costs. Algal biomass is available at cheap costs and in greater quantities. Divalent metallic ions such as zinc are absorbed from 1 to 1.5 mmol/g [60]. There are many different types of algae such as green algae, red algae, and brown algae; from which, brown algae is reported to have greater capacity to hold up metal ions [61]. Algal biosorbents are not only economically accessible but also renewable sources which can help reducing zinc levels [62].
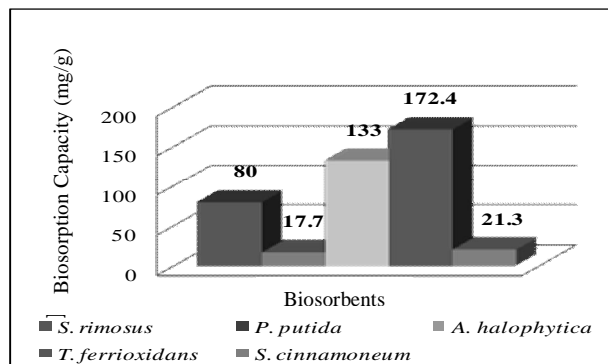
*Figure 1.* **Graph showing Biosorption Capacity of different bacterial microbes [63-67]**

## Fungal biosorbents

Most of the fungal species are found to be dependent on the metal ions for their proper functioning and the performance of their metabolic activities. In the process of fermentation, the additions of metallic ions become quite essential depending on the type of products. Through the removal of zinc from aqueous solutions not only we purify water but also recover zinc [68]. Fungal species have a cell wall made up of chitin. Due to the presence of various biomolecules in cell membrane, inorganic ions are able to bind to the metallic ions [69]. Biomasses of various fungal species can be used depending on the type of metal ions. These may include Aspergillus and Saccharomyces. Both filamentous and non-filamentous fungal species can be used for biosorption [70]. (Fig. 2) highlights the adsorption capacity of various fungal species which can be used for the sorption of zinc from water.
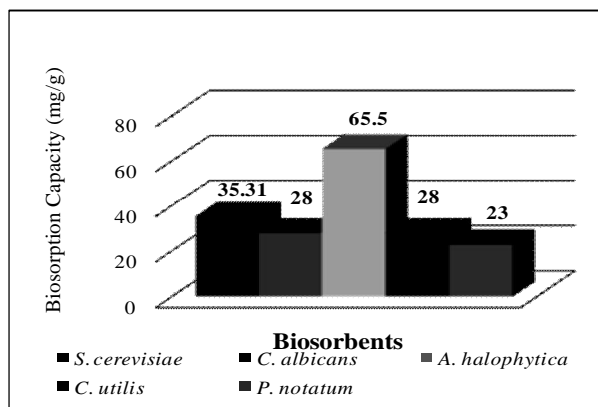


*Figure 2.* **Graph showing biosorption capacity of different fungal microbes [71-75]**

### Organic and inorganic adsorbents

Of all the techniques to remove large quantities of zinc from waterbodies, adsorption using economical organic and inorganic adsorbents is an efficient way which is not only cost effective but also very simple to work with. Many different adsorbents have been previously used to remove zinc heavy metal from drinking water such as rice husk, bagasse, eucalyptus, tea leaves, bentonite, clays, horseradish tree and many others [76]. Adsorption using horseradish tree requires pre-treatment of adsorbent using various chemicals. It is one of the factors which affect the adsorption capacity. The greatest adsorption was when NaOH was used to pre-treat horseradish tree at 30 °C, 50 minute of retention time, and the particle size of around 0.255 mm [77]. Another Adsorbent Rise husk used to adsorb zinc showed sorption depends on parameters like contact time, concentration, and pH. The best results were recorded at the concentration 30 mg/L to 300 mg/L with the pH of 8 and contact time of about 2.5 hours [78, 79]. In case of tea factory waste, zinc was adsorbed within the contact time of 4 hours at pH 4.2 and with a metal concentration of 50 mg/L [80]. A peanut hull is another adsorbent which has sorption tendency for zinc. This adsorbent contains large amounts of lignin (36.1 %) and cellulose (44.8 %) for effective adsorption with pH around 6 [81]. Eucalyptus had contact time of 6 hours; this adsorbent had the adsorbent capacity around 23.5 mg/L with the particle size 0.5 mm, 5 pH, and 20 °C temperature [82]. Many other adsorbents used for adsorption include neem bark, bottom ash, activated alumina, oxidized jute, cork powder, Phosphatic clay, jute, charcoal ash, and oil palm fiber [83-85].

The agricultural wastes including orange and banana peel, groundnut shell, coconut husk and saw dust can be used as potential and cost-effective adsorbents for zinc removal from wastewater [93].

The leaves of Ananas comosus and extract of Glycine max can also be used as bioadsorbent for the removal of lead, zinc and chromium metal ions from wastewater [94]. The adsorbents of natural origin like clays, zeolites, moss, chitin and

peat are found to be effective materials for removal of toxic heavy metals like zinc, lead, copper etc. Other useful adsorbents for zinc removal also include neem bark, black gram, waste tea; Turkish coffee, walnut shell [95]. Various adsorbents have been used for removal of zinc from waste water. Some adsorbents have the highest adsorption capacities for Zn(II) which are 168 mg/g powdered waste sludge; 128.8 mg/g dried marine green macroalgae, 73.2mg/g lignin, 55.82mg/g cassava waste, and 52.91mg/g Bentonite [96]. (Fig. 3) represents the overview of sources, health impacts, and various techniques for the removal of zinc.

*Table 1.* Adsorption capacities of various adsorbents.

| Sr. No. | Type of Adsorbents | Sorption % | References |
|---|---|---|---|
| 1. | Bagasse | 90 | [86] |
| 2. | Bottom Ash | 60 | [86] |
| 3. | Rice Husk Ash | 60 | [86] |
| 4. | Tea Leaves | 45 | [86] |
| 5. | Saw Dust | 60 | [86] |
| 6. | Neem Bark | 80 | [87] |
| 7. | Activated Alumina | 85 | [87] |
| 8. | Clarified Sludge | 90 | [87] |
| 9. | Phosphatic Clay | 73.9 | [88] |
| 10. | Sunflower | 70 | [89] |
| 11. | Unmodified Jute | 35 | [90] |
| 12. | Dye Loaded Jute | 66 | [91] |
| 13. | Oxidized Jute | 46 | [90] |
| 14. | Oil Palm Fiber | 75.6 | [91] |
| 15. | Charcoal Ash | 90 | [92] |
| 16. | Cork Powder | 90 | [92] |

.
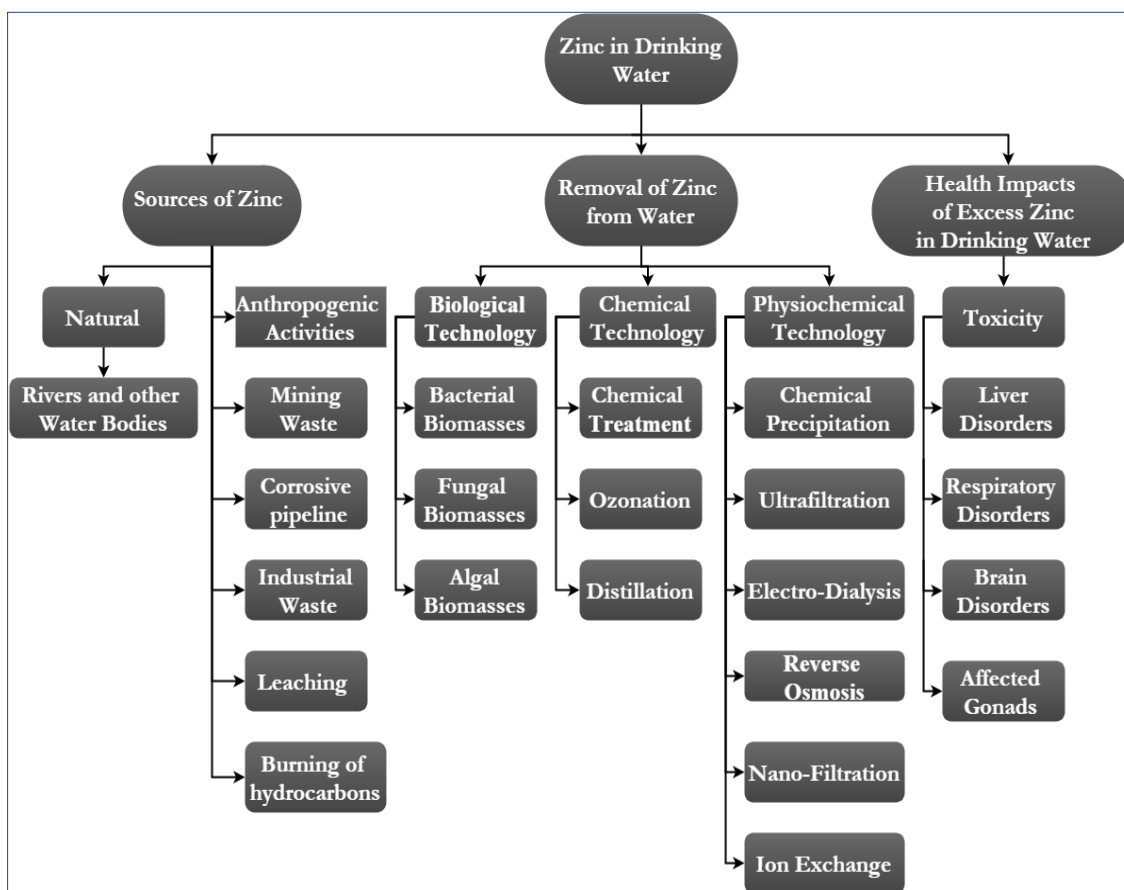


*Figure 3.* Overview of zinc removal from drinking water through various techniques [97-102]

**Conclusion**

Certain useful techniques must be applied to remove excessive amount of zinc in drinking water. These techniques involve chemical, physical, and biological methods for the removal of zinc from the drinking water. The conventional processes to do so include ion exchange method, electro-dialysis, and reverse osmosis whereas the new emerging techniques such as the use of biosorbents based biomasses of algae, fungi, and bacteria is found to be very effective as for the removal of zinc. The utility of conventional methods are limited since they are much expensive as some newly introduced methods involving biosorption. Adsorption technique involving various economical adsorbents is also very economical to use for effectively removing zinc from drinking water. Among all the techniques mentioned, the utilization of low cost adsorbents is the most applicable tool in removing heavy metals from drinking water. Many emerging technologies have created a need for increased implementation due to their increased feasibility, greater level insight, ease and simplicity of technology, and enhanced applicability. This paper would be very helpful for the researchers, chemists, and scientists who wish to conduct experimentation for better methods for the removal of zinc from the drinking water.

**Acknowledgement**

**References**

1. U. N. O., Environment Protection (Standards for effluent discharge) Regulations (2003).
2. D. R. Petrell, A. Ansari, B. Anstey, P. Doig, J. Lam, H. Wong and L. Xu, *CHBE*, 465 (2002) 1.
3. P. Puranik and K. Paknikar, *J. Biotech*, 55, (1997) 113.
4. A. Bhattacharya, S. Mandal and S. Das, *Chem. Eng. J.*, 123 (2006) 43.
5. D. Sud, G. Mahajan and M. Kaur, *Bioresource. Technol.* 99 (2008) 6017.
6. F. Gode and E. Pehlivan, *J. Hazard. Mater,* 136 (2006) 330.
7. S. Kaur, T. Walia and R. Mahajan, *J. Environ. Engg. Sci.,* 7 (2008) 83.
8. D. Sud, G. Mahajan and N. P. Kaur, *Bioresource. Technol.*, 99 (2008) 6017.
9. V. Mishra, C. Balomajumder and V. K. Agarwal, *Clean–Soil, Air, Water,* 38 (2010) 1062.
10. W. H. Organization, Guidelines for Drinking-Water Quality Electronic Resource: Incorporating 1st and 2nd Addenda, Vol. 1, Recommendations, Third Editions (2008).
11. A. Brereton, H. Lord, I. Thornton and J. Webb, *Marine Bio.*, 19 (1973) 96.
12. A. Zahra, M. Z. Hashmi, R. N. Malik and Z. Ahmed, *Sci. Total. Envir.,* 470, 925 (2014).
13. A. Daabrowski, Z. Hubicki, P. Podkoscielny and E. Robens, *Chemosphere*, 56 (2004) 91.
14. Metaleurop, Statistical Yearbook, France (1989).
15. A. William, Technical Letter, Removal of Water Supply Contaminants - Copper and Zinc, Department of Registration and Education, 22 April (1977).
16. J. M. Cohen, L. Kamphake, E. Harris and R. L. Woodward, Taste threshold concentrations of metals in drinking water. Journal American Water Works Association, (1960) 660.
17. M. Corn, Handbook of hazardous materials, Academic Press (2012).
18. M. Kumar and A. Puri, *Indian J. Occuptnl. Environt. Med.*, 16 (2012) 40.
19. R. Ullah, R. N. Malik and A. Qadir, *African J. Environ., Sci. Technol.,* 3 (2009) 12.
20. J. O. Nriagu, Zinc in the Environment Part I., Ecological Cycling, John Wiley and Sons, (1980).
21. M. Buragohain, B. Bhabajit and H. P. Sarma, *Int. J. Chem. Tech. Res.,* 4 (2009) 1014.
22. P. Lahermo, M. Ilmasti, R. Juntunen and M. Taka, The geochemical atlas of Finland, part 1: the hydrogeochemical mapping of Finnish groundwater, Geological Survey of Finland, Espoo, (1990).
23. M. E. Gillies and H. V. Paulin, *Appl. Nutr.*, 36 (1982) 287.

24. H. Aydin, Y. Bulut and C. Yerlikaya, *J. Environ. Manage.*, 87 (2008) 37.

25. Water UK, Zinc briefing paper, UK September (2001).

26. L. M. Plum, L. Rink and H. Haase, *Int. J. of Environ. Res. Public Health,* 7 (2010) 1342.

27. R. Keast, *J. Food Sci.*, 68 (2003) 1871.

28. S. Cheng, W. Grosse, F. Karrenbrock and M. Thoennessen, *Ecol. Eng.,* 18 (2002) 317.

29. W. H. Organization, Guidelines for drinking-water quality: recommendations, vol. 1, World Health Organization, (2004).

30. I. Delpla, A. V. Jung, E. Baures, M. Clement and O. Thomas, *Environ. Int.l,* 35 (2009) 1225.

31. R. D. Letterman and A. W. W. Association, Water quality and treatment, McGraw-Hill Professional, (1999).

32. J. Blais, Z. Djedidi, R. B. Cheikh, R. Tyagi and G. Mercier, Metals precipitation from effluents: Review, Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, (2008).

33. O. Tnay, *Water Sci. Tech.*, 48 (2004) 43.

34. L. Charerntanyarak, *Water Sci. Tech.*, 39 (1999) 135.

35. A. S. Dharnaik and P. K. Ghosh, *Environ. Tech.,* 35 (2014) 2272.

36. J. Wang and C. Chen, *Biotechnol. Adv.*, 27 (2009) 195.

37. X. Yang, A. Fane and S. MacNaughton, *Water Sci. Tech.*, 43 (2001) 341.

38. P. Bose, M. A. Bose and S. Kumar, *Advances Environ. Res.*, 7 (2002) 179.

39. H. Kurama and T. Catalsarik, *Desalination*, 129 (2000) 1.

40. O. M. Uy, M. J. Ginther, J. T. Folkerts and K. W. Street Jr, Use of a NASA-developed ion exchange material for removal of zinc from electroplating baths, Johns Hopkins APL Technical Digest, 17 (1996) 371-375.

41. T. A. Kurniawan, G. Y. Chan, W.-H. Lo and S. Babel, *Chem. Eng. J.,* 118 (2006) 83.

42. B. Van der Bruggen, K. Everaert, D. Wilms and C. Vandecasteele, *J. Membr. Sci.,* 193 (2001) 239.

43. A. Chianese, R. Ranauro and N. Verdone, *Water Res.,* 33 (1999) 647.

44. K. Trivunac and S. Stevanovic, *Chemosphere,* 64 (2006) 486.

45. H. K. Hansen, L. M. Ottosen, B. K. Kliem and A. Villumsen, *J. Chem. Tech. Biotech.*, 70 (1997) 67.

46. K. H. Ahn, K. G. Song, H. Y. Cha and I. T. Yeom, *Desalination,* 122 (1999) 77.

47. R. S. Juang and R. C. Shiau, *J. Membr. Sci.,* 165 (2000) 159.

48. Z. Ujang and G. Anderson, *Water Sci. Tech.,* 34 (1996) 247.

49. B. Legube and N. K. V. Leitner, *Catal. Today,* 53 (1999) 61.

50. V. Camel and A. Bermond, *Water Res.,* 32 (1998) 3208.

51. M. Perrin, Y. Bourbigot and G. Madelaine, in Aerosol Science and Technology, vol. 2, Elsevier science Inc. 655 avenue of the Americas, New York, NY, 10010 (1983) 165.

52. M. H. Nasir, R. Nadeem, K. Akhtar, M. A. Hanif and A. M. Khalid, *J. Hazard Mater.,* 147 (2007) 1006.

53. L. Solorzano, *Limno. & Oceano.,* 14 (1969) 799.

54. J. Peric, M. Trgo and N. V. Medvidovic, *Water Res.*, 38 (2004) 1893.

55. G. Annadurai, R. Juang and D. Lee, *Water Sci. Tech.,* 47 (2003) 185.

56. B. Volesky, Removal and recovery of heavy metals by biosorption CRC Press, Boca Raton, FL, 7 (1990).

57. M. Urrutia, General bacterial sorption processes, Biosorbents for metal ions, 39 (1997).

58. B. Volesky and Z. Holan, *Biotech. Prog.*, 11 (1995) 235.

59. J. Rincon, F. Gonzalez, A. Ballester, M. Blazquez and J. Munoz, *J. Chem. Tech. Biotech.,* 80 (2005) 1403.

60. Q. Yu, J. T. Matheickal, P. Yin and P. Kaewsarn, *Water Res.,* 33 (1999) 1534.

61. L. Brinza, M. J. Dring and M. Gavrilescu, *Environ. Engg. Manag. J.*, 6 (2007) 237.

62. Y. P. Kumar, P. King and V. Prasad, *Chem. Engg. J.*, 129 (2007) 161.

63. X. C. Chen, P. W. Yuan, L. Qi, Y. S. Ji, X. W. Wei and X. C. Ying, *Colloid. Surface. B:,* 46 (2005) 101.

64. A. Incharoensakdi and P. Kitjaharn, *Current Micro.,* 45 (2002) 261.

65. H. L. Liu, B. Y. Chen, Y. W. Lan and Y. C. Cheng, *Chem. Engg. J.,* 97 (2004) 195.

66. N. Mameri, N. Boudries, L. Addour, D. Belhocine, H. Lounici, H. Grib and A. Pauss, *Water Res.*, 33 (1999) 1347.

67. P. Puranik and K. Paknikar, *J. Biotech.,* 55 (1997) 113.

68. J. Wang and C. Chen, *Biotech. Adv.*, 24 (2006) 427.

69. A. Kapoor and T. Viraraghavan, *Bioresource Tech.*, 53 (1995) 195.

70. A. Ozer and D. Ozer, *J. Hazaed. Mater,* 100 (2003) 219.

71. M. Al Saraj, M. Abdel-Latif, I. El-Nahal and R. Baraka, *J. Non-Cryst. Solid.,* 248 (1999) 137.

72. T. Fan, L. Yunguo, F. Baoying, Z. Guangming, Y. Chunping, Z. Ming, Z. Haizhou, T. Zhenfeng and W. Xin, *J. Hazard Mater.,* 160 (2008) 655.

73. A. Kapoor and T. Viraraghavan, *Bioresource Technol.*, 53 (1995) 195.

74. M. Mapolelo and N. Torto, *Talanta,* 64 (2004) 39.

75. O. Muter, L. Iveta, M. Donats, G. Larisa, V. Elga and R. Alexander, *Process Biochem.,* 38 (2002) 123.

76. N. Zahra, *J. Chem. Soc. Pak*, 32 (2010) 259.

77. H. N. Bhatti, B. Mumtaz, M. A. Hanif and R. Nadeem, *Process Biochem.,* 42 (2007) 547.

78. N. Sharma, J. Singh and A. Sharma, *Int. J. of Environ. Techn. Manag.*, 12 (2010) 333.

79. A. Elham, T. Hossein and H. Mahnoosh, *J. Appl. Sci. Environ. Manag.*, 14 (2010).

80. K. L. Wasewar, *Int. J. Res. Rev. Appl. Sci.,* 3 (2010) 303.

81. F. Oliveira, A. Soares, O. M. Freitas and S. A. Figueiredo, *Global NEST Journal,* 12 (2010) 206.

82. V. Mishra, C. Balomajumder and V. K. Agarwal, *Clean–Soil, Air, Water,* 38 (2010) 1062.

83. N. Zahra, *Asian J. Adv. Basic Sci.,* 2 (2014) 70.

84. S. Naeem, N. Zahra and U. Zafar, *B. J. Sci. Ind. Res.*, 45 (2010) 367.

85. N. Zahra, *Pak J. Anal. Environ. Chem.*, 13 (2012) 01.

86. S. Kaur, T. Walia and R. Mahajan, *J. Environ. Engg. Sci.,* 7 (2008) 83.

87. A. Bhattacharya, S. Mandal and S. Das, *Chem. Engg. J.,* 123 (2006) 43.

88. S. P. Singh, L. Q. Ma and W. G. Harris, *J. Environl. Quality,* 30 (2001) 1961.

89. G. Sun and W. Shi, *Ind. Engg. Chem. Res.,* 37 (1998) 1324.

90. S. Shukla and R. S. Pai, *Sep. Pur. Technol.,* 43 (2005) 1.

91. J. Akaninwor, M. Wegwu and I. Iba, *Afri. J. Biochem. Res.,* 1 (2007) 011.

92. A. J. Alahmad, *World App. Sci. J.*, 13 (2011) 331.

93. S. Janyasuthiwong, S. M. Phiri, P. Kijjanapanich, E. R. Rene, G. Esposito and P. N. Lens, *Environ. Techn.*, 36 (2015) 3071.

94. T. Parashar and A.C. Pandey, *Euro. J. Acad. Res.*, 3 (2015) 1.

95. A. Tripathi and M. R. Ranjan, *Bioremed. Biodeg.,* 6 (2015) 1.

96. M. Z. Haider, V. Mohammadtaghi and D. Irvan, *Int. J. Chem. Engg.,* 2014 (2014) 1.

97. A. Gadgil, *Ann. Rev. Ener. Environ,* 23 (1998) 253.

98. F. Fu and Q. Wang, *J. Environ. Manag.*, 92 (2011) 407.

99. P. Puranik and K. Paknikar, *J. Biotech.,* 55 (1997) 113.

100. J. Q. Jiang and S. Ashekuzzaman, *Current Opin. Chem. Engg.,* 1 (2012) 191.

101. A. Zahra, M. Z. Hashmi, R. N. Malik and Z. Ahmed, *Sci. Total Environ.,* 470 (2014) 925.

102. I. Ali, V. Gupta, *Nat. Prot.,* 1 (2006) 2661.