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STATUS OF HEAVY METAL CONTAMINATION IN MAJOR RIVERS OF KERALA, SOUTH INDIA – A REVIEW

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This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

ABSTRACT

In the past few years, rapid urbanization and industrialization have led to an enormous increase in the amount of industrial waste generated, including heavy metals. Metal contaminants are usually found in a variety of sources, including soils, sediments and water. Rivers are the major source of fresh water for drinking, domestic needs, irrigation, industries etc. Kerala is home to 44 rivers, most of which are now polluted to a great extent due to anthropogenic activities. This manuscript reviews the research work on the heavy metal status of 10 rivers in Kerala. The levels of heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), mercury (Hg), iron (Fe), manganese (Mn), nickel (Ni) etc. are increasing substantially in rivers of Kerala. Heavy metals cause irrevocable damage to the biota, when they are transferred from water bodies to the food chain via assimilation, bioaccumulation and biomethylation processes.

Keywords: Cadmium; chromium; copper; iron; lead; mercury; nickel; pollutants; sewage; water quality; zinc.

1. INTRODUCTION

Water is an inevitable part of our daily life. Most part of freshwater for human utilization are provided by inland water bodies like ponds, streams, rivers etc. With increased industrialization, expanding urbanization and aggressive use of chemical fertilizers, rivers worldwide are under the threat of ecological degradation [1]. "Accumulation of heavy metals in the bottom sediments is an important factor in the self-purification of aquatic environments. The concentration of heavy metals increases by a factor of 1.5-3 after the drawdown of the water level. The main reason for the rise in the concentrations of metals is exchange between the bottom sediments and the water column. The rate of heavy metal migration is

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connected with their form of occurrence in solid substrates and pore solutions in the bottom sediments, as well as with physicochemical conditions arising at the sediment/water boundary" [2]. An alarming problem associated with water pollution is the substantial increase of heavy metal content in natural waters. Natural processes influencing heavy metal concentration include weathering of soils and rock, erosion, forest fires and volcanic eruptions whereas anthropogenic activities include urban development and expansion, industrial effluents, mining and refining, agricultural drainage and domestic discharges . "Research has proven that long term use of sewage effluents may contains considerable amount of potentially harmful substances including soluble salts and heavy metals like Fe^{2+}, Cu^{2+}, Zn^{2+}, Mn^{2+}, $Ni^{2+}$and Pb^{2+} which are accumulated by plants in their tissues in such concentrations above the permitted levels. This represents a threat to the life of humans and animals feeding on these crops. It may lead to contamination of food chain, as it was observed that soil and plants that received irrigation water mixed with industrial effluent contained many toxic metals" [3].

"The extent of pollution by heavy metals in the river Korotoa of Bangladesh implies that the condition is much frightening to the biota and inhabitants in the vicinity of the river as well .Trends in developing countries to use sewage effluent as fertilizer has gained much importance as it is considered a source of organic matter and plant nutrients and thus serves as good fertilizer" [4]. "Prevalence of heavy metals in different environmental media and their impact depend on the physical and chemical states of the metal, which tends to persist in their localities because they cannot be biologically or chemically degraded as with organic substances. Mine fugitive dust clouds the environment; in most cases causing irrevocable damage to the biota, with harmful metals usually transferred from water bodies to the food chain via assimilation, bioaccumulation and biomethylation processes" [5].

"Heavy metal contamination has an adverse effect on the aquatic, terrestrial, and atmospheric environment as they are not easily degradable. Anthropogenic activities have unwantedly transferred these heavy metals in our food chain and food web" [6]. "Some heavy metals are able to create toxicity at low level of exposure, and metals like nickel, cadmium and chromium are able to produce carcinogenicity in humans" [7].

"The main metal sources differed across the five continents, with fertilizer and pesticide use, along with rock weathering, being dominant in Africa. Mining and manufacturing, along with rock weathering, were dominant in Asia and Europe. Mining and manufacturing, along with fertilizer and pesticide use, were dominant sources in North America, while four sources were responsible for the majority of heavy metal pollution in the river and lake water bodies of South America. Additionally, implementing rigorous standards on metal emissions and recycling metals from wastewater are effective for controlling heavy metal source pollution" [8]. "Most of the rivers in the urban areas of the developing countries are the ends of effluents discharged from the industries. African and Asian countries are experiencing rapid industrial growth which is making environmental conservation a difficult task" [9]. "A study carried out to assess the heavy metals (Cu, Fe, Cr and Zn) concentration in the subsurface water of Hindon River in Uttar Pradesh and its stretches during pre- and post-monsoon months revealed that the estimated values of all heavy metals were found above their permissible value at each sampling location in both pre- and post-monsoon months" [10]. "Surface water heavy metal pollution is recognised as one of the most significant environmental dangers. The surface water of the Gebeng rivers was polluted with six heavy metals, according to Malaysian heavy metals standards: Cd, Co, Cu, Pb, Mn, and Ni" [11]. The main objective of this review was to find the status of heavy metal pollution in the major rivers of Kerala.

2. POLLUTION EFFECTS OF MAJOR HEAVY METALS TO LAND AND WATER

"Soil is crucial to food safety, and the negative effects of contaminants such as heavy metals on crop quality have put human health at risk. As a result of the importance of food safety and agricultural soil pollution by heavy metals, soil remediation technologies such as soil amendments, phytoremediation, and foliar sprays were introduced. concentrate on food safety and heavy metal pollution of agricultural soil" [12]. Agricultural runoff and industrial discharges transport these heavy metals into the aquatic system [13]. "Mangrove ecosystems in the coastal zone have experienced rapid land-use conversion in recent decades, but the effects of land use on heavy metal pollution in mangrove sediments are still unclear" [14]. Heavy metal pollution, waste, and COVID-19 are all harmful to all living things in the environment. COVID-19 transports a massive amount of biomedical waste. The biomedical waste from COVID-19 appears to be causing a variety of health problems. Recycling, on the other hand, has been identified as a new source of pollution in south China. Furthermore, heavy metal contamination is the most serious environmental impact. Similarly, every problem has a solution in the form of new waste management and pollution monitoring policies [15]. Heavy metal pollution, waste, and COVID-19 are all harmful to all living things in the environment. COVID-19 transports a massive amount of biomedical waste. The biomedical waste from COVID-19 appears to be causing a variety of health problems. Recycling, on the other hand, has been identified as a new source of pollution in south China. Furthermore, heavy metal contamination is the most serious environmental impact. Similarly, every problem has a solution in the form of new waste management and pollution monitoring policies [16]. Heavy metal pollution in the environment continues to degrade soil quality and crop yields. Heavy metals are frequently found in soil in less bioavailable forms that plant roots can extract [17]. Rapid industrialization and urbanisation have increased heavy metal exposure, and this exposure, along with dietary and lifestyle changes, may have increased the incidence of depression [18]. Cd was ranked first in the potential ecological risk index of major heavy metals, followed by Cu, Pb, Ni, Zn, and V. Cd was rated as having a high potential ecological risk, Cu as having a medium potential ecological risk, and Zn, Pb, V, and Ni as having a low potential ecological risk [19]. "Coal thermal power plants are major sources of heavy metal pollution in groundwater, posing a serious health risk" [20].

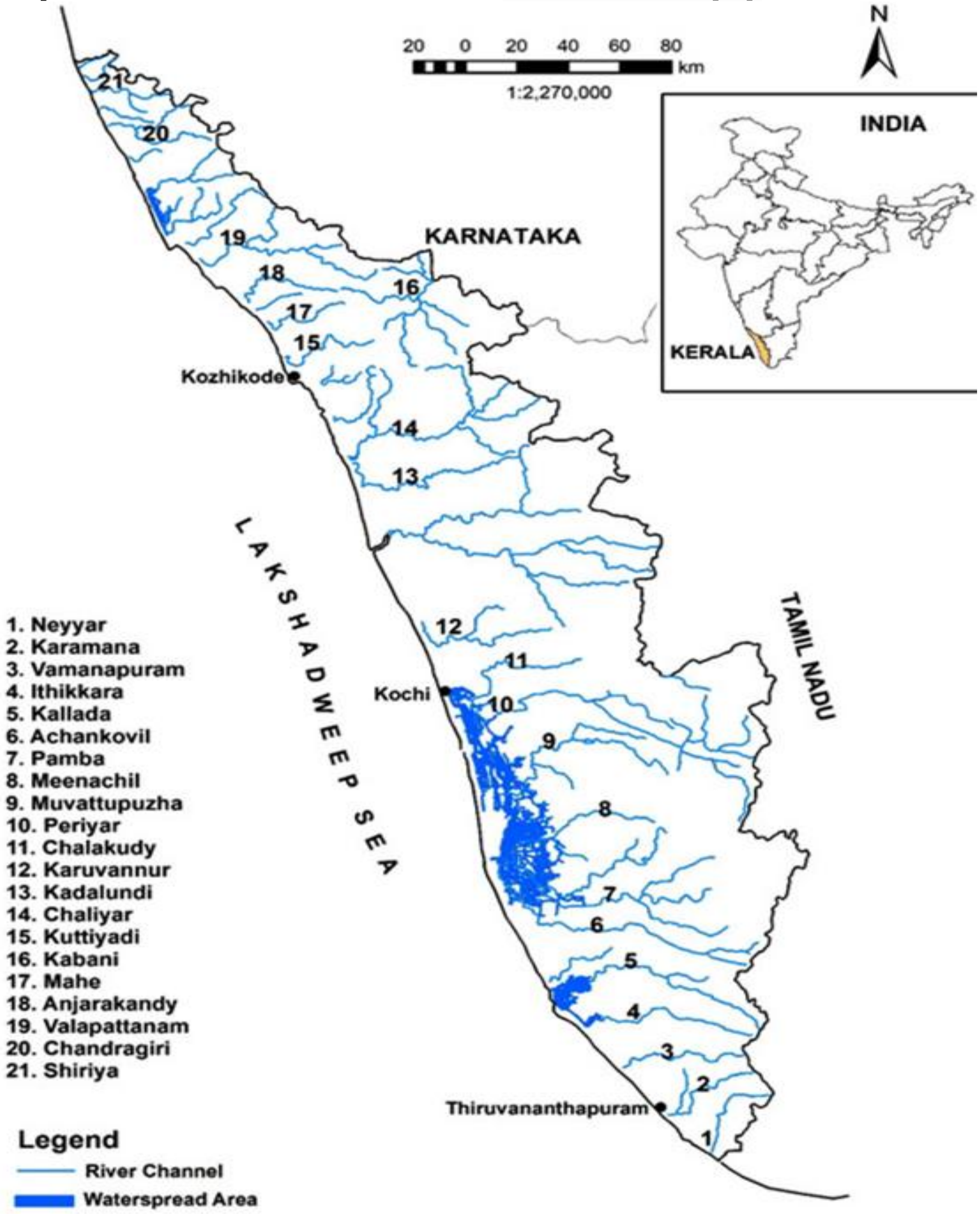

Fig. 1. Map showing major rivers of Kerala (Courtesy Shaji J , 2021)

3. RIVERS AND HEAVY METAL POLLUTION

"The freshwater that Indian rivers carry is often so severely polluted due to heavy load of domestic sewage and industrial wastes that rivers now threaten the very life they once nurtured. The rivers of Kerala are no exception and are getting polluted day by day due to anthropogenic activities and natural processes" [21]. A persistently high density of population with particular settlement pattern, whereby people are scattered over the entire land area has resulted in increased production of wastes which are eventually dumped in to water bodies. There are 44 rivers in Kerala, Periyar being the longest one followed by Bharathapuzha and Pampa, all of which originate from the Sahyadri hills and 41 of them west flowing while the other 3 are east flowing. The rivers in Kerala have been increasingly becoming polluted with heavy metals from the derived source of industrial and domestic waste and also from the extensive use of pesticides and fertilizers in the agricultural sector. A recent study has revealed the enhanced levels of trace metals including Cd, Ni, Pb, Mn, Cu, Fe, Co and Zn in the coastal zones of central Kerala. "Heavy metals reaching the water bodies are consumed by organisms such as plankton, benthos or fish and finally magnified and transferred to humans. Therefore, trace element pollution exists as Key environmental problem in Kerala" [22]. The status of heavy metal pollution in the following rivers of Kerala are discussed.

3.1 Periyar River

Periyar is Kerala's longest river (244 km), and its basin, which has an inverted 'L' shape, is the state's second biggest river basin, having a catchment area of 5398 square kilometres and drains sections of the state's Idukki and Ernakulam districts [23]. Several water quality investigations have been undertaken in the Periyar river. Elements such as Fe, Mn, Cu, and Zn were sometimes discovered and were much below the maximum permissible range. Mercury and lead were found in Kanakkankadavu samples taken in January and March 2021. During specific months of the investigation, trace quantities of As, Se, Cr, and Cd were identified in some samples. Magnesium and calcium levels were found to be significantly higher during the summer months [24]. Cadmium, copper, lead, zinc, and chromium were found in high concentrations. Except for chromium, all heavy metal concentrations were over the permitted level. Lead and zinc concentrations were greater than those of other heavy metals including cadmium, copper, and chromium. Maintaining the water quality of the Periyar river, particularly in its lower levels, requires considerable attention. The Periyar River gets a large volume of industrial and sewage pollution as a result of urbanization and growing industry. Due to industrialization, the Periyar has been severely contaminated with heavy metals such as lead, zinc, cadmium, copper, and mercury [25].

3.2 Chaliyar River

"As it approaches the sea, the Chaliyar River is also known as the Chulika River or the Beypore River. The Chaliyar River begins in the Western Ghats, and its two main branches, the Punnapuzha and Chola rivers, spring in the Kunda mountains on the Nilgiri plateau and the lower ranges of south east Wayanad, respectively. The results of water samples obtained over various seasons reveal that the amounts of some heavy metals such as Hg, Zn, and Pb were higher than the permissible limits" [26]. "The bioaccumulation of metals (Cr, Mn, Fe, Cu, Zn, and Pb) in selected tissues (Gill, Liver, Kidney, and Muscle) of the freshwater fish *Trichiurus lepturus* collected from Chaliyar River was studied between 2013 and 2014, and it was discovered that gills accumulated the most heavy metals during the monsoon period, followed by the post monsoon, summer, and pre monsoon periods. Heavy metals were also collected in the liver, kidney, and muscle tissues during the monsoon and post-monsoon seasons. The sequence of accumulation was Fe > Zn > Mn > Cu > Cr > Pb, indicating that the Chaliyar river has been heavily contaminated" [27].

3.3 Chalakudy River

Sholayar, Parambikulamar, Kuriarkuttyar, and Karappara River join to create the river. Heavy metal contamination has been discovered in the Chalakudy River sediments, according to studies. In investigations done on the Chalakudy river, substantial quantities of chromium, lead, zinc, nickel, manganese, and iron were discovered [28]. Iron, manganese, lead, zinc, copper, and cadmium were found in decreasing order of abundance. These sediments have the potential to introduce heavy metals into the Chalakudy River. The water showed the presence of heavy metals and traces of manganese, lead, nickel, zinc, copper, and cadmium [29].

3.4 Pamba River

"River Pampa is the holy river of the Hindus in southern India. In the northwest foothills of the Pampa Plateau, Sabarimala is a popular forest shrine. The shrine is being visited by millions of pilgrims in November and January, and every first month of Malayalam" [30]. "The largest Christian

Congregation in Asia, the Maramon Conference, takes place every year on the sand beds of this river. The river is also notorious for poor water quality in downstream municipalities and parts of Kuttanadu. Untreated hospitals, municipal waste, and agricultural waste disposal are the subject of river bed conventions which have caused unspeakable harm to the river and have serious effects on the quality of life of the people relying upon the river. The indiscriminate mining of river sand caused the aquatic system to deteriorate too. A broad variety of pumping plants operate on the pampas and a contaminated water supply is not accessible for proper and efficient treatment to nearby communities" [30].

"Studies on the water quality of Pampa River showed that the water quality at Ranni is fit for domestic use in terms of heavy metals. But biological oxygen demand (BOD) levels were elevated due to the pressure of organic waste that could have been entered due to the presence of chemical and sewage wastes in water bodies at Ranni. Among the five heavy metals (cadmium, chromium, lead, mercury and copper) copper and chromium were below the standard limit and the other three heavy metals lead, cadmium and mercury were below detectable level" [31]. "The regular water treatment methods adopted in the area due to recent flood may be the result of water quality in Ranni with respect to heavy metals. The total dissolved salts (TDS) levels are normal in all five sources but biological oxygen demand (BOD) levels are elevated due to the presence of organic wastes entered from chemical and sewage disposal in water bodies" [32].

3.5 Manimala River

Manimala river is an important waterway of central Travancore flows through the districts of Kottyam, Idukki and later joins with Pamba river. It is highly polluted due to the effluent discharge from nearby factories, posing serious health risks to the people living there. Recent water quality studies of Manimala river shows that the water quality is poor. Heavy metals, micropollutants, factory and toilet discharges, market wastes are the major sources of pollutants in the river [33].

3.6 Vamanapuram River

"The Vamanapuram River found in Kerala, one of the India's major west-flowing rivers, rises in the Western Ghats and flows north-westerly to the Arabian Sea. It is a 7th order basin with a drainage area of 560 km^2 and a length of 86 Km" [34]. "The pH of the post monsoon water samples varies from 4.2 to 7.6 with an average of 5.59 and in the pre monsoon samples from 4.5 to 7.8 with an average 5.72 indicating an acidic trend for the groundwater in a good number of locations. The granulometric distribution of trace metals in medium sand, fine sand, very fine sand, silt and clay fractions of the Vamanapuram river sediments has been determined for selected samples and the variation is compared with that of the respective bulk sediments.Trace elements abundantly present in sand fractions and are Fe> Mg> Zn> Mn> Pb> Cr> Ni> Cu> Co> Cd, and in mud fractions are Fe> Mg> Zn> Mn> Cr> Pb> Cu> Ni> Co> Cd" [35].

3.7 Meenachil River

Meenachil river, which originates in the Western Ghats near Vagamon, one of the major tourist attractions in Kottayam District, is a 78-kilometres-long river formed by several streams and brooks and drift amidst the numerous agricultural fields and many townships before emptying itself into the Vembanad Lake at Kumarakom, another major tourist spot. The dominance of various trace metals in the surface water of the river Meenachil followed the sequence Fe >Pb>Mn> Cu > Cd > Zn. The metals did not show any correlation with pH while Mn and Cd showed good correlation with electrical conductivity (EC) . "Among the metals analysed, iron, lead and cadmium showed higher concentrations above the permissible limit for drinking water prescribed by Bureau of Indian Standards (BIS). Over all seasonal and locational variation was significant for Cu, Mn, Pb, Zn and Cd while all other showed non-significant variation. Iron and lead showed higher concentration during post monsoon and the cadmium content was high during pre-monsoon. The increase in Fe content might be mainly attributed to the terrestrial runoff from the Charnockite groups of rocks present in the area" [36].

"The surface water quality of Meenachil river with emphasis on heavy metals reveals that mean hazard quotient of heavy metals such as Cu, Cr, Zn and Pb falls to a permissible level throughout pre-monsoon and monsoon while the level slightly exceeds the level during post-monsoon whereas As and Cd concentrations are below detectable limit in all seasons. The heavy metal pollution index (HPI) and contamination degree (CD) index level were escalated which may be due to heavy application of agrochemicals" [37].

3.8 Achankovil River

"Achankovil is one of the major rivers of Kerala with a drainage area of 1484 km2 and annual average discharge of about 1.5 km3 /year. The river receives discharge from the Pamba and Manimala tributaries.

The sediment of Achankovil has 415 ppm of Zn, 224 of Cu, 11858 of Fe, 72.42 of Pb, 6.23 of Cd and 699.26 ppm of Mn. The level of heavy metal in sediments can be a sensitive indicator of contaminants in hydrological systems" [38]. Studies showed that the average metal concentrations in Achankovil river decreases in the order Fe > Mn > Zn > Cu > Pb > Cd [39]. "Concentrations of six heavy metals (Cd, Cr, Ni, Zn, Pb and Cu) in surface sediments of Achankovil river basin which is draining into a Ramsar site in India viz. the Vembanad wetland system was determined. The concentrations of Zn, Cr and Pb in all sediment samples are lower than the proposed threshold effect concentrations which indicate that there are no harmful effects from these metals. On the other hand, the concentrations of Cd in one station, Cu in three stations and Ni in all stations exceeded the threshold levels indicated that these stations were in potential risk" [40].

3.9 Neyyar River

"The Neyyar River originates from the Western Ghats at Agasythyakoodam. The river flows through Neyyattinkara taluk and joins the Lakshadweep Sea. Water quality analysis studies of sediments showed that iron content of the sediments is much high in all the stations. This is can be attributed due to geological origin. The analysis highlights that the lead content of the sediments is high and the maximum concentration of 90.80 mg/kg was found at Koompichalkadavu. Manganese is reported to be high at all the stations. Heavy metals like nickel and cadmium were also detected in high concentration at all the stations. The maximum value of copper detected was 32 mg/kg at Neyyattinkara. The high concentration of heavy metals might have occurred due to dumping of municipal waste to the river. Heavy metals are present in a variety of industrial effluents. They are absorbed by hydrophytes" [41].

3.10 Karamana river

"Envirometrics and pollution indices are proxies for assessing wetland ecosystem water quality. As a result, the current study focuses on determining water quality and elucidating the pollution status of the Karamana River (KR) in Kerala, India's southwest coast. The Karamana River Basin - KRB (n=6th; L=68 km, A=695 km2) is the city of Thiruvananthapuram's primary source of domestic and drinking water" [42]. Karamana river, which has its origin in the Chemmunjimottai and Agasthyamalai of the Nedumangad hills at an altitude of about 1860 m, is the 17th largest out of 44 rivers of Kerala state, having a length of 68 km and is flowing through the state capital in southern direction and joins the Arabian Sea near Pachallur. The concentration of iron in the river was found to be much high in all the sediment samples. The maximum value was found in the sample collected from Pappanamcode. One of the drains is discharging at this station. The maximum value of manganese was found at the station Pappanamcode. The station also reported high values of other metals such as copper and nickel. The analysis indicated that, the sediment collected from the station Pappanamcode is highly contaminated with heavy metals. "A 2019 study revealed that the heavy metal distribution in the order of abundance is Fe>Mn>Zn>Pb>Cr>Cu>Cd in Karamana river. Concentration of the heavy metals in the sediment is higher is compare to the world average concentration shale samples" [43].

4. DISCUSSION AND CONCLUSIONS

Several studies have been conducted on the pollution levels in Kerala's rivers. The majority of the research is focused on physicochemical and biological factors. "Scientific research institutions under Kerala State Council for Science Technology and Environment (KSCSTE) – led by Centre for Water Resources Development & Management (CWRDM) – monitored the water quality and pollution levels of all 44 rivers in Kerala from 2009 to 2017 and found that they were polluted and under threat" [44].

Heavy metal pollution studies of several rivers have been conducted and most of them has reported high levels of various trace metals. This paper reviews the heavy metal pollution in water and sediments of 10 rivers in Kerala. The rivers Periyar and Meenachil were found to be having high metal pollution. This could be attributed to the industries, anthropogenic activities and dumping of untreated wastes in the rivers. The levels of toxic heavy metals such as copper, lead, cadmium, chromium zinc etc. were observed to be higher in the studies. This can have far reaching effects as the water is used for human consumption in several areas.The main causes of heavy metal contamination might be due to the discharge of domestic wastes, municipal wastes, terrestrial runoff from seepage sites, agricultural sites and also due to geological weathering process . It is suggested that better agricultural management practices need to be implemented in for maintaining ecological integrity and protecting the lotic system from further degradation [45].

"Although some heavy metals are essential trace elements, most of them can be toxic to all forms of life at high concentrations due to formation of complex compounds within the cell. Unlike organic pollutants, heavy metals once introduced into the environment cannot be biodegraded. They persist indefinitely and cause pollution of air, water, and soils. Thus, the main strategies of pollution control are to reduce the bioavailability, mobility, and toxicity of metals" [46]. "Heavy metal pollution poses a great threat to the health and well-being of organisms and human beings due to potential accumulation risk through the food chain. Remediation using chemical, physical, and biological methods can been adopted to solve the problem" [47].

The strategies recommended for reducing heavy metal pollution in the rivers of Kerala include:

1. Regulatory standards for emission of effluents containing heavy metals from industries
2. Proper survey and surveillance of river pollution by pollution control boards
3. Strict laws and penalty for defaulters should be implemented
4. Awareness campaigns to sensitize locals about the need to maintain rivers in an unpolluted state.

Heavy metal status of river water and sediments has not been conducted in many rivers of Kerala. This review paper points out this lacuna in research and further studies may be carried out in those rivers too. A comprehensive heavy metal pollution data on all the rivers of Kerala could benefit the overall health of man and the environment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol Appl. 1998;8(3):559-68.
2. Linnik PM, Zubenko IB. Role of bottom sediments in the secondary pollution of aquatic environments by heavy-metal compounds. Lakes & Reservoirs. 2000;5(1):11-21. Available: https://doi.org/10.1046/j.14.
3. Amin A, Ahmad T, Ehsanullah M, Irfanullah K, M, Ayaz Khan M. Evaluation of Industrial and city effluent quality using Physicochemical and Biological Parameters. Electron J Environ Agric Food Chem. 2010;9:931-9.
4. De Carvalho Aguiar VM, de Lima MN, Abuchacra RC, Abuchacra PFF, Neto JAB, Borges HV et al. Ecological risks of trace metals in Guanabara Bay, Rio de Janeiro, Brazil: an index analysis approach. Ecotoxicol Environ Saf. 2016;133:306-15. Available:https://doi.org/10.1016/j.ecoenv.2016.07.012.
5. Sedibe M, Achilonu MC, Tikilili P, Shale K, Ebenebe PC. South African mine effluents: heavy metal pollution and impact on the ecosystem; 2017. Available:http://ir.cut.ac.za/handle/11462/1628
6. Hembrom S, Singh B, Gupta SK, Nema AK. A comprehensive evaluation of heavy metal contamination in foodstuff and associated human health risk: A global perspective. In: Singh P, Singh RP, Srivastava V, editors, Contemporary environmental issues and challenges in era of climate change. Springer. 2020;33-63. Available:https://doi.org/10.1007/978-981-32-9595-7_2.
7. Gupta V. Vehicle-generated heavy metal pollution in an urban environment and its distribution into various environmental components. In: Shukla V, Kumar N, editors, Environmental concerns and sustainable development. Air. Water and energy Resources. Springer. 2020;1:113-27. DOI: 10.1007/978-981-13-5889-0_5.
8. Zhou Q, Yang N, Li Y, Ren B, Ding X, Bian H et al. Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017. Glob Ecol Conserv. 2020;22:e00925. DOI: 10.1016/j.gecco.2020.e00925.
9. Agarwal A, Saxena M. Assessment of pollution by Physicochemical water Parameters Using regression analysis: A Case Study of Gagan River at Moradabad-India; 2021.
10. Mishra S, Kumar A, Shukla P. Estimation of heavy metal contamination in the Hindon River, India: an Environmetric Approach. Appl Water Sci. 2021;11(1):2. DOI: 10.1007/s13201-020-01331-y.
11. Islam M, Bin Khalid Z, Gabar S, Yahaya F. Heavy metals pollution sources of the surface water of the Tunggak and Balok river in the Gebeng industrial area, Pahang, Malaysia. Int. J Energy Water Resour. 2022;22:6.
12. Qin G, Niu Z, Yu J, Li Z, Ma J, Xiang P. Soil heavy metal pollution and food safety in China:

effects, sources and removing technology. Chemosphere. 2021;267:129205.
DOI: 10.1016/j.chemosphere.2020.129205

13. Vardhan KH, Kumar PS, Panda RC. A review on heavy metal pollution, toxicity and remedial measures: current trends and future perspectives. J Mol Liq. 2019;290:111197.
DOI: 10.1016/j.molliq.2019.111197.

14. Li P, Li X, Bai J, Meng Y, Diao X, Pan K et al. Effects of land use on the heavy metal pollution in mangrove sediments: Study on a whole island scale in Hainan, China. Sci Total Environ. 2022;824:153856.
DOI: 10.1016/j.scitotenv.2022.153856

15. Adnan M, Xiao B, Xiao P, Zhao P, Bibi S. Heavy metal, waste, COVID-19, and rapid industrialization in this modern era—fit for sustainable future. Sustainability. 2022;14(8): 4746.
DOI: 10.3390/su14084746.

16. Hamad MNM, Et al. Qahtni, A. J Pharm Res Int. Understand COVID-19 through Heavy Metals Pollution. 2022;34:19-35.

17. Gavrilescu M. Enhancing phytoremediation of soils polluted with heavy metals. Curr Opin Biotechnol. 2022;74:21-31.
DOI: 10.1016/j.copbio.2021.10.024

18. Nguyen HD, Oh H, Hoang NHM, Jo WH, Kim MS. Environmental science and pollution research role of heavy metal concentrations and vitamin intake from food in depression: a national cross-sectional study (2009-2017). Environ Sci Pollut Res Int. 2022;29(3):4574-86.
DOI: 10.1007/s11356-021-15986-w

19. Tang B, Xu H, Song F, Ge H, Yue S. Effects of heavy metals on microorganisms and enzymes in soils of lead–zinc tailing ponds. Environ Res. 2022;207:112174.
DOI: 10.1016/j.envres.2021.112174

20. Matta G, Kumar A, Nayak A, Kumar P, Kumar A, Naik PK et al. Assessing heavy metal index referencing health risk in Ganga River System. Int J River Basin Manag. 2022:1-11.
DOI: 10.1080/15715124.2022.2098756.

21. Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol Appl. 1998;8(3):559-68.
DOI: 10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2.

22. Nisari AR, Sujatha CH. Assessment of trace metal contamination in the Kol wetland, a Ramsar site, Southwest coast of India. Reg Stud Mar Sci. 2021;47:101953.
DOI: 10.1016/j.rsma.2021.101953.

23. Sudheer KP, Bhallamudi SM, Narasimhan B, Thomas J, Bindhu VM, Vema V et al. Role of dams on the floods of August 2018. In: Periyar River Basin, Kerala; 2019.

24. Kumar A, Bisht BS, V. D. Joshi, Dhewa T. Review on bioremediation of polluted environment::A management tool. Int J Environ Sci. 2011;1(6):1079.

25. Lakshmi E, Madhu G. Evaluation and modelling of dissolved oxygen and re-aeration rate in river Periyar, South India. Indian J Sci Res. 2020;10(2):1-15.
DOI: 10.32606/IJSR.V10.I2.00001.

26. Kennedy AD, Jacoby CA. Biological indicators of marine environmental health: meiofauna–a neglected benthic component? Environ Monit Assess. 1999;54(1):47-68.
DOI: 10.1023/A:1005854731889.

27. Jithesh M, Radhakrishnan MV. Seasonal variation in water quality parameters of Chaliyar river, Kerala, southern India. Environ Ecol. 2020;38(1):71-7.

28. Vandana M, John SE, Maya K, Padmalal D. Environmental impact of quarrying of building stones and laterite blocks: a comparative study of two river basins in Southern Western Ghats, India. Environ Earth Sci. 2020;79(14):1-15. DOI: 10.1007/s12665-020-09104-1.

29. Kurian P. Adopt a river. Kottayam, Kerala, India: Tropical Institute of Ecological Studies; 2021.
Available:https://www.globalgiving.org/projects/adopt-a-river.

30. Narayan S. Seasonal water pollution and its health impact observed in Pampa River. 2021;9(2):5.

31. Saha A, Salim SM, Sudheesan D, Suresh VR, Nag SK, Panikkar P et al. Geochemistry, mineralogy and nutrient concentrations of sediment of River Pampa in India during a massive flood event. Arab J Geosci. 2020;13(20):1086. DOI: 10.1007/s12517-020-06053-8.

32. Devy RA, Lakshmi G. Study of heavy metal contamination of water bodies collected from flood affected area—Mammukku, Ranni, Pathanamthitta District, Kerala, India. AIP Conf Proc. 2020;2287(1):020027.
DOI: 10.1063/5.0029897.

33. Kurian P. Adopt a river. Kottayam, Kerala, India: Tropical Institute of Ecological Studies; 2021.
Available:https://www.globalgiving.org/projects/adopt-a-river.

34. Aju CD, Achu AL, Raicy MC, Reghunath R. Identification of suitable sites and structures for artificial groundwater recharge for sustainable

water resources management in Vamanapuram River Basin, South India. HydroResearch. 2021;4:24-37.
DOI: 10.1016/j.hydres.2021.04.001.

35. Nair VM, Kumar RBB. Assessment of groundwater quality for drinking and agricultural purposes in Vamanapuram River Basin, South Kerala, India. Nat Environ Pollut Technol. 2013;12(4):6.
36. Nair IV, Singh K, Arumugam M, Clarson D. Monitoring of trace metal pollution in Meenachil River at Kottayam, Kerala (India). E-Journal of Chemistry. 2011;8(1):257-63. DOI: 10.1155/2011/952040.
37. George P, Joseph S, Moses SA. Heavy metal monitoring and health risk assessment of a tropical mountainous river in Kerala, India. Int J River Basin Manag. 2017;15(4):475-84.
DOI: 10.1080/15715124.2017.1315813.
38. Prasad MBK, Ramanathan AL, Shrivastav SK, Anshumali R, Saxena R. Metal fractionation studies in surfacial and core sediments in the Achankovil river basin in India. Environ Monit Assess. 2006;121(1-3):77-102.
DOI: 10.1007/s10661-005-9108-2.
39. Srivastava N, Satheesh SK, Blond N, Moorthy KK. Anthropogenic aerosol fraction over the Indian region: model simulations versus multi-satellite data analysis. Int J Remote Sens. 2016;37(4):782-804.
DOI: 10.1080/01431161.2015.1136445.
40. Harikumar PS, Jisha TS. Distribution pattern of trace metal pollutants in the sediments of an urban wetland in the southwest coast of India; 2010.
41. Sivaruban T, Barathy S, Venkataraman K, Arunachalam M, Srinivasan P. Diversity of the EPT complex (Ephemeroptera, Plecoptera and Trichoptera) in the Western and Eastern Ghats (South India) caused by the variations of landscape elements and mesohabitats. Ege J Fish Aquat Sci. 2022;39(1):24-31.
DOI: 10.12714/egejfas.39.1.04.
42. Sukanya S, Joseph S. Water quality assessment using environmetrics and pollution indices in a tropical river, Kerala, SW Coast of India. Curr World Environ. 2020;15(1):11-23.
DOI: 10.12944/CWE.15.1.04.
43. Krishnakumar A, Jose J, Kaliraj S, Aditya SK, Krishnan KA. Assessment of the impact of flood on groundwater hydrochemistry and its suitability for drinking and irrigation in the River Periyar Lower Basin, India. Environ Sci Pollut Res Int. 2022;29(19):28267-306.
DOI: 10.1007/s11356-021-17596-y
44. Nair IV, Singh K, Arumugam M, Clarson D. Monitoring of trace metal pollution in Meenachil River at Kottayam, Kerala (India). E-Journal of Chemistry. 2011;8(1):257-63.
DOI: 10.1155/2011/952040
45. George P, Joseph S, Moses SA. Heavy metal monitoring and health risk assessment of a tropical mountainous river in Kerala, India. Int J River Basin Manag. 2017;15(4):475-84.
DOI: 10.1080/15715124.2017.1315813
46. Mohammed AS, Kapri A, Goel R. Heavy metal pollution: source, impact, and remedies. Environmental Pollution. 2011:(1-28).
DOI: 10.1007/978-94-007-1914-9_1.
47. Li C, Zhou K, Qin W, Tian C, Qi M, Yan X et al. A review on heavy metals contamination in soil: effects, sources, and remediation techniques. Soil Sediment Contam An Int J. 2019;28(4):380-94.
DOI: 10.1080/15320383.2019.1592108.