International Journal of Ecology and Environmental Sciences 51: 37-43, 2025
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2025.0488

Review article

Impact of Coal Fly Ash on Freshwater Fishes and the Ecosystem

SHEETAL M. JAUNJAL AND TEKCHAND C. GAUPALE*
Department of Zoology, Vivekanand College, Kolhapur (Empowered Autonomous), C.S. 2130, E ward, Tarabai Park, Kolhapur, 416003, Maharashtra, India
Email ID: bakaresheetal@gmail.com, tcg@vivekanandcollege.ac.in
***Corresponding author**

ABSTRACT
Coal fly ash (CFA) is a powdery solid waste byproduct of thermal coal power industries. CFA is hazardous to the environment, ecosystem and human health because of its contents such as various oxides and metals. The improper dumping of CFA is a leading environmental concern. It can disperse into the environment and water bodies. The management of fly ash is a major environmental challenge worldwide. The leaching of metals in aquatic systems is leads to bioaccumulation, induction of oxidative stress, tissue damage, and alteration in blood biochemistry has been emphasized in the fishes. Excess accumulation of fly ash in the water ecosystem significantly affects organisms by altering the physical properties of ecosystem, physiological biomechanisms, toxicity stress, and health issues. Consumption of contaminated foods results in the bioaccumulation and biotransformation of hazardous elements in the food chain that threaten to aquatic biodiversity. Therefore, the present review aims to overview and highlight the toxicological impact of fly ash pollution on aquatic ecosystems and fish health. In addition, it is helpful to understand the level of toxicity and assess its effect on the environment.

Key words: Coal fly ash, Adverse impact, Tissue damage, Oxidative stress.

INTRODUCTION

Coal Fly ash (CFA) is a fine-gray color powder consisting of spherical glossy particles produced as a byproduct in coal-fired power stations. CFA is usually produced during the combustion of coal. Fly ash also called bottom ash or Firefox, falls from a boiler combustion chamber. The particles of ash are about 0.5 to 300 µm. In recent years, anthropological approaches and developmental activities have been amplified with the increase in human population, which are essential to fulfilling human demands. Therefore, energy needs are partially fulfilled by various sources such as biofuel, thermal power plants, and coal. The thermal power station is the major consumer of coal and produces a billion tons of huge amounts of fly ash annually (Sultan et al. 2021, Zierold et al. 2020). Fly ash is usually dumped in the surrounding areas and enters the ecosystem through air, water, and food chains (Yi et al. 2024) affecting the flora and fauna. Fly ash particles generally travel by wind over long distances and disperse (Sabir et al. 2014). Recently, managing and handling this waste has been a hazardous and challenging issue worldwide. The fly ash is toxic and chemically comprised of Cd (Cadmium), Cr (Chromium), Hg (Mercury), As (Arsenic), Pb (Lead), Se (Selenium), Ni (Nickel), and radioactive elements such as U (Uranium) and Th (Thorium). It also contains some oxides silicon oxide (SiO_2), Calcium oxide (CaO), Sodium oxide (Na_2O), Aluminum oxide (Al_2O_3), Iron oxide (Fe_2O_3), Magnesium oxide (MgO), Potassium oxide (K_2O), Phosphorous oxide (P_2O_5), Sulphate oxide (SO_4) and unburned carbon (Mukharjee et al. 2006, Huggins et al. 2007, Pandey et al. 2011, Blissett and Rowson 2012, Ram and Masto 2014). Fly ash also contains several organic compounds, polyaromatic hydrocarbons, polychlorinated biphenyls, polychlorinated dibenzofurans, polychlorinated dibenzo-p-dioxins, monomethyl, and dimethyl sulfate (Sahu et al. 2004, Jambhulkar et al. 2018). In the past decade, more than 70% of countries demand electricity from coal-based thermal power plants. It increases the generation of fly ash, in the present scenario, 160 million tons of fly ash were produced which is nearly twice over the last decade (Ahmed et al. 2014). According to the World Bank, by 2015 India will require 1,000 km^2 of land to dispose of coal fly ash (Pandey and Singh 2010).

The excessive production of CFA may harm terrestrial and aquatic ecosystems due to its contents. During the rainy season fly ash contents (heavy metals) leach out and contaminate the ecosystem (Choi et al. 2002, Ugurlu 2004, Izquierdo and Quorel 2012). CFA is a noxious environmental pollutant; it causes several ailments in humans. Its release in water adversely affects the aquatic ecosystem's chemical composition and physical and biological components (Borm 1997, Manz et al. 1999, Adriano et al. 1980, Ghio et al. 2002). Fly ash deposition into ponds, lagoons, rivers, etc, adversely affects the environment of soil, microflora, aquatic animals as well as human health (Pandey et al. 2010). In the ecosystem, metal and metal components are natural constituents in the atmosphere, hydrosphere, lithosphere, and biosphere (Bargagli 2000). Metals are required in trace amounts and play a crucial role in living organisms. The metals are used in industries, households, cosmetics, etc. which released into the environment and induce adverse effects on living organisms.

CFA contamination in aquatic ecosystems results in the accumulation of heavy metals in different tissues like the gills, liver, kidney and muscle and induces oxidative stress in fishes (Besser et al. 1996, Lohner et al. 2001a,b, Reash et al. 2006). Accumulation of contamination causes alternation of tissue structure and quality (Ali et al. 2004). It produces poor fish-quality protein for human consumption. Bioaccumulation and biotransformation of these metals adversely affect human health and cause metal toxicity to aquatic organisms. Therefore, it is necessary to study the effect of fly ash and its contents on ecosystems and fish. The impact of fly ash on the aquatic system is not well studied. Furthermore, the effect of fly ash on fish is poorly understood. Therefore, the present review aims to highlight the impact of fly ash on fish.

CHARACTERISTICS OF FLY ASH

The CFA is classified a) Class F and b) Class C. These two types of fly ash are commonly used in concrete. Class C is often high-calcium fly ashes with less than 2% carbon content. It is produced from burning sub-bituminous or lignite coals, having both pozzolanic and varying degrees of self-cementitious properties. Class F are generally low-calcium fly ashes with less than 5% carbon contents but sometimes as high as 10%. This type of ash generally produced from burning anthracite or bituminous coal, exhibits pozzolanic properties. The total calcium ranges from 1 to 12% in the form of calcium hydroxide, calcium sulfate, and glassy components in combination with silica and alumina.

IMPACT ON FISH

Tissue damage and histopathology

Fly ash comprises several components that adversely impact aquatic and terrestrial organisms. The effect of fly ash on different organs of fish is described in Figure 1. Fly ash and its leachates induce histological changes in the different organs of the fishes. The gill is the first target organ in fishes exposed to pollutants and fly ash induces hyperplasia, hypertrophy epithelium lifting, necrotic, shrank, curved, and fusion lamellae in gills (Lease et al. 2003). The degradation of gills epithelium results in the loss of osmoregulation and hypoxic conditions (Xu et al. 2021). The gill lamellae are primarily exposed to water contamination from fly ash, which allows the entry of contaminants and reaches the bloodstream. Therefore, it affects the respiration and osmoregulation function (Javed et al. 2017). Furthermore, fly ash also induces vacuolation, nucleus enlargement, cytoplasm condensation, disarray of hepatic cords, hypertrophied necrosis and damaged liver (Ali et al. 2004, 2007). The degeneration of pancreatic blood capillaries was noticed in fish (Ali et al. 2004), and more profound damage was induced in acute exposure than in chronic exposure. The glomerulus, bowman's capsule, tubular structure degeneration and necrosis were reported in the kidneys of fishes (Ali et al. 2004, 2007, Elbeshti et al. 2018). Fly ash leachate can induce DNA fragmentation and apoptosis in exposed cells of fish hepatocytes (Ali et al. 2007), structure degeneration, necrosis, vascular degeneration, and atrophy of muscle bundles in fishes (Elbeshti et al. 2018, Ghio et al. 2002). Metals toxicity can damage the central nervous system, lungs, and blood composition (Zeitoun and Mehana 2014). Long-term exposure results in physical, muscular, and neurological degenerative processes that mimic

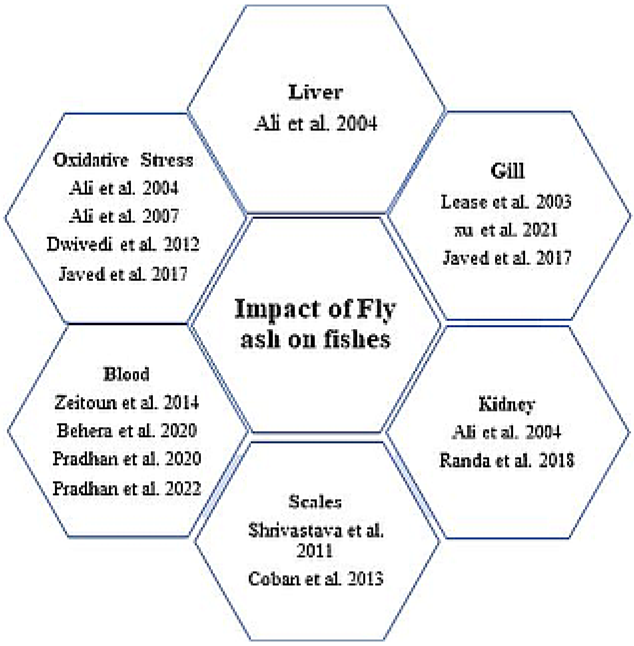

Figure 1. Effect of fly ash exposure on different organs of fishes

Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis (Zeitoun and Mehana 2014).

Induction of oxidative stress

Fly ash contamination in aquatic systems induces the production of reactive oxygen species (ROS) in aquatic organisms including fishes and leads to toxicity (Javed et al. 2017). Fly ash leachate (FLA) treatment increases the activities of catalase, glutathione s-transferase and glutathione in the liver, kidney, and gills of fish C*hanna punctata* (Ali et al. 2004). The CFA nanoparticles may act as mutagen and genotoxicants which induce oxidative stress and DNA damage (Dwivedi et al. 2012). FLA exposure enhances the production of H_2O_2, superoxide ions and lipid peroxidation in hepatocytes of fishes (Ali et al. 2007). In addition, FLA contamination induces a profound antioxidant enzyme system in the liver and gill suggesting that it is the most vulnerable organ (Ali et al. 2004). The heavy metal concentrations in the water increase excretion of ammonia in fish resulting in increased CO_2 levels in the water. The bioavailability of transition metal content of fly ash induced inflammatory response and generation of ROS species in lung epithelium cells has been reported (Diabate et al. 2011).

Blood biochemical parameter

The fly ash induces hematological changes in hemoglobin (Hb), total RBC count, packed cell volume (PCV), and differential count of leucocytes (Pradhan et al. 2020, Behera et al. 2020), blood urea, nitrogen, and creatinine in the blood of *Hetropneustens fossilis* (Bloch) (Pradhan et al. 2020).

Effect on scales

Fly ash induces damage in growing or undeveloped scales and causes erosion, reduces the growth of scales and growth rate and reduces the function of scales (Shrivastava 2011, Dwivedi 2011). Deformation of scales mainly occurs in an anterior region, radius, circulars, and lepidonts on scales (Coban et al. 2013). The anterior margin of the scales was irregular, and the central part of the focus was destroyed. The developing focus was disturbed, chromatophores were reduced and small sizes of scale and annuli of scales disappeared (Coban et al. 2013).

IMPACT ON AQUATIC ECOSYSTEM

Fly ash from thermal power plants has an adverse impact on aquatic habitats, diversity, ecology and the environment (Javed et al. 2014). The properties of fly ash are responsible for its deposition and sedimentation in the water body. The CFA causes a negative effect on the physiochemical properties of water and planktonic pollution. The disposed fly ash, metal contents, and toxic waste are also deposited into natural water bodies like ponds, rivers, seas, and streams (Mandal and Sengupta 2006, Pandey et al. 2011, Dragovic et al. 2013). CFA in open areas is dispersed in the water and affects the diversity of streams, rivers, lakes, etc. Fly ash discharge reduces the number and diversity of bacteria (Gutherie et al. 1978). CFA is also affecting the zooplankton diversity, aquatic community (Spencer et al. 1983, Zhang et al. 2015), and a decreased diversity of benthic macro-invertebrates (Shrivastava and Dwivedi 2011, Walia and Mehra 1998, Magnuson et al. 1980, Bamber 1984, Webster et al. 1985). It also reduces fish community (Olmsted et al. 1986), fish spermatogenesis (Cochran, 1987), and a reduction in the number of water birds (White et al. 1986, Cain and Pafford, 1981). Fly ash also affects the animal growth and development. In addition, researchers have noted that; fly ash reduced river fish diversity (Naik et al. 2013, Sukla and Singh 2013, Pitchaikani et al. 2010, Wallia and Mehra 1998). The fish diversity in the Rupnarayan River (Mrinmay et al. 2015) and carp fish in the Chandrabhaga River (Pal et al. 2016) were reduced. This results in the lesser fish production and the loss of several species.

Recently, fly ash has been utilized for construction that may enter the ecosystem and affect living organisms. At threshold concentration in the aquatic ecosystem, it acts as a pollutant and induces toxicity at various levels (Shrivastava and Dwivedi 2012). The fly ash and related metals increase in water and may seriously affect freshwater and marine water habitats (Ahmaruzzaman 2011, Yi et al. 2011, Nemr et al. 2014). The metals are essential to aquatic life, but their concentration above permissible limits adversely affects aquatic animal health. This metal contamination affects the food chain, and toxic substances accumulate in various organs and tissues of aquatic animals (Islam et al. 2004, Yi et al. 2011). Major environmental issues include leaching and accumulation of organic and inorganic toxic compounds from fly ash. Around the thermal power station, deposition of various metals like As, Zn, Pb, Cd, Co, Ni, Mn, Fe, Cr, Al, and Cu has been reported in varying quantities in water. CFA also increases the water's temperature, hardness, and salinity (Witeska et al. 2006, Diabate et al. 2011). The physicochemical properties of water from the Chandrabhaga River were raised and significantly affected above drinking and irrigation standards (turbidity, TDS, BOD, COD and DO) (Pal et al. 2016). It also increases the temperature hardness and salinity of the water (Witeska et al. 2006, Diabate et al. 2011). This suggests fly ash adversely affects terrestrial and aquatic animals and produces several adverse physiological impacts on organisms. The fishes with metal contamination have been reported in the stream receiving coal fly ash effluents (Besser et al. 1996, Lohner et al. 2001a,b, Reash et al. 2006, Reash 2012). Significant bioaccumulation of selenium, arsenic, and mercury was reported in various fish species collected from water streams receiving CFA effluent (Besser et al. 1996, Lohner et al. 2001a,b, Reash et al. 2006). It has shown that fly ash adversely affects terrestrial and aquatic animals. Its contamination has severe adverse impacts such as bioaccumulation of metal, oxidative stress, DNA damage, and reproduction on terrestrial and aquatic ecosystems (Ali et al. 2004, Chakraborty and Mukharjee 2009, Grumiaux et al. 2007, Pandey and Singh 2010).

CONCLUSIONS

Fly ash is used in our surroundings and in parallel; it enters the ecosystem through air, water, and soil and affects living organisms and different trophic levels. Therefore, properly dumping and utilizing of fly ash may reduce aquatic ecosystem pollution and defend aquatic animal life. It suggests that the toxic effects of fly ash contents on fish and other aquatic animals are multidirectional. The depletion of fly ash in water bodies may cause a reduction in pond productivity, food competition, decline in biodiversity, migration, changes in physiological and chemical processes, accumulation of metals and functional disturbance. Thus, this may suggest that fly ash contamination affects animals in several ways. Therefore, appropriate utilization of fly ash may reduce CFA pollution and protect the environment. Furthermore, CFA's utilization rate is lower than its production, which affects the environment. Therefore, thorough research on the impact of fly ash on the environment and physiology of organisms is necessary.

ACKNOWLEDGMENTS

Sheetal Jaunjal is a MAHAJYOTI fellow and grateful to the government of Maharashtra (India) for the financial support under Mahatma Jyotiba Phule Research and Training institute (MAHAJYOTI) [MAHAJYOTI/2022/Ph.D. Fellow/1002(930) dated 13/12/2022]. The authors are thankful to the Principal and Head of Department of Zoology, Vivekanand college Kolhapur, (Empowered Autonomous) for providing necessary facilities to carry out the present work.

Authors' contributions: Both the authors contributed equally.

Conflict of interest: Authors declare no conflict of interest.

REFERENCES

Adriano, D.C., Page, A.L., Elseewi, A.A., Chang, A.C. and Straughan, I. 1980. Utilization and disposal of fly ash and other coal residues in terrestrial ecosystems: A review. Journal of Environment Quality, 9, 333-334. https://doi.org/10.2134/jeq1980.00472425000900030001x

Ahmaruzzaman, M. 2010. A review on the utilization of fly ash. Progress in Energy and Combustion Science, 36, 327-363. https://doi.org/10.1016/j.pecs.2009.11.003

Ahmed, M.A., Shahnawaz, M., Siddiqui, M.F. and Khan, Z.H. 2014. A statistical review on the current scenario of generation and utilization of fly-ash in India. International Journal of Current Engineering and Technology, 4, 2434-2438. https://inpressco.com/wp-content/uploads/2014/07/Paper252434-2438.pdf

Ali, M., Parvez, S., Pandey, S., Atif, P., Kaur, M., Rehman, H. and Raisuddin, S. 2004. Fly ash leachate induces oxidative stress in freshwater fish *Channa punctata* (Bloch). Environment International, 30, 933-938. https://doi.org/10.1016/j.envint.2004.03.004

Ali, M., Rehman, S., Rehman, H., Bhatia, K., Ansari, R. and Raisuddun, S. 2007. Pro-apoptotic effect of fly ash leachate in hepatocytes of freshwater fish *Channa punctata* (Bloch). Toxicology in vitro, 21, 63-71. http://dx.doi.org/10.1016/j.tiv.2006.08.011

Alterary, S.S. and Marei, N.H. 2021. Fly ash properties characterization, and application: A review. Journal of King Saud University, 33, 1-8. https://doi.org/10.1016/j.jksus.2021.101536

Baker, F.J. and Silverton, R.E. 1982. Introduction to Medical Laboratory Technology. 5th edition. Butterworth & Co. (Publishers) Ltd, London. 746 pages.

Bamber, R.N.1984. The benthos of a marine fly ash dumping ground. Journal of the Marine Biological Association of the United Kingdom, 64, 211-226. https://doi.org/10.1017/S0025315400059737

Bargagli, R. 2000. Trace metals in Antarctic are related to climate change and increasing human impact. Reviews of Environmental Contamination Toxicology, 166, 129-173.

Bernet, D., Schmidt, H., Meier, W., Burkhardt, H. and Wahli, T. 1999. Histopathology in fish: Proposal for a protocol to assess aquatic pollution. Journal of Fish Diseases, 22, 25-34. http://dx.doi.org/10.1046/j.1365-2761.1999.00134.x

Besser, J.M., Giesy, J.P., Brown, R.W., Buell, J.M., and Dawson, G.A. 1996. Selenium bioaccumulation and hazards in a fish community affected by coal fly ash effluent. Environmental Safety, 35, 7-15. http://dx.doi.org/10.1006/eesa.1996.0076

Blaxhall, P.C. and Daisley, K.W. 1973. Routine hematological methods for use with fish blood. Journal of Fish Biology, 5, 771-778. https://doi.org/10.1111/j.1095-8649.1973.tb04510.x.

Blissett, R.S. and Rowson, N.A. 2012. A review of the multi-component utilization of coal fly ash. Fuel, 97, 1-23. https://doi.org/10.1016/j.fuel.2012.03.024.

Borm, P.J. 1997. Toxicity and occupational health of coal fly ash (CFA): A review of data and comparison to coal mine dust. The Annals of Occupational Hygiene, 41, 659-676. http://dx.doi.org/10.1016/S0003-4878(97)00026-4

Cain, B.W. and Pafford, E.A. 1981. Effect of dietary nickel on survival and growth of mallard duckling. Archives Environmental Contamination Toxicology, 10, 737-745. http://dx.doi.org/10.1007/BF01054857

Chakraborty, R. and Mukherjee, A. 2009. Mutagenicity and genotoxicity of coal fly ash water leachate. Ecotoxicology and Environmental Safety, 72, 838-842. https://doi.org/10.1016/j.ecoenv.2008.09.023

Choi, S.K., Lee, S., Song, Y.K. and Moon, H.S. 2002. Leaching characteristics of selected Korean fly ashes and its implications for the groundwater composition near the ash disposal mound. Fuel, 81, 1083-1090. http://dx.doi.org/10.1016/S0016-2361(02)00006-6

Claiborne, A. 1985. Catalase activity, pp. 283-284 In: Greenwald, R.A (Ed.). Handbook of Method for Oxygen Radical Research, CRC Press Inc., Boca Raton.

Coban, M.Z., Eroglu, M., Canpolat, O., Calta, M. and Sen, D. 2013. Effect of chromium on scale morphology in scaly carp (*Cyprinus carpio* L.). The Journal of Animal & Plant Sciences, 23, 1455-1459. https://www.thejaps.org.pk/docs/v-23-5/36.pdf

Cochran, R.C. 1987. Effect of coal leachate on fish spermatogenesis. Canadian Journal of Fisheries and Aquatic Sciences, 44, 134-139. https://doi.org/10.1139/f87-01

Deshpande, A.S. 2020. Histopathological changes in tissues of freshwater fish Rohu, (*Labeo rohita*) exposed to TPS effluent. International Research Journal of Science & Engineering, 2020(A7), 686-699. https://oaji.net/articles/2020/731-1582800242.pdf

Diabate, S., Bergfeldt, B., Plaumann, D., Ubel, C. and Weiss, C. 2011. Anti-oxidative and inflammatory responses induced by fly ash particles and carbon black in lung epithelial cells. Analytical and Bioanalytical Chemistry, 401, 3197-3212. https://doi.org/10.1007/s00216-011-5102-4

Dragovic, S., Cujic, M., Slavkovic-Beskoski, L., Gajic, B., Bajat, B., Kilibarda, M. and Onjia, A. 2013. Trace element distribution in surface soils from a coal burning power production area: A case study from the largest power plant site in Serbia. Catena, 104, 288-296. http://dx.doi.org/10.1016/j.catena.2012.12.004

Dwivedi, S., Saquib, Q., Abdulaziz, A., Al-Khedhairy, Al-Yousef S.A. and Musarrat, J. 2012. Characterization of coal fly ash nanoparticles and induced oxidative DNA damage in human peripheral blood mononuclear cells. Science of the Total Environment, 437, 331-338. http://dx.doi.org/10.1016/j.scitotenv.2012.08.004

Elbeshti, R.T.A., Elderwish, N.M., Abdelali, K.M.K. and Tastan, Y. 2018. Effects of Heavy Metals on Fish: Menba Journal of Fisheries Faculty, 4, 36-47.

Ghio, A.J., Silbajoris, R., Carson, J.L. and Samet, J.M. 2002. Biologic effects of oil fly ash. Environmental Health Perspectives, 110, 89-94. https://doi.org/10.1289%2Fehp.02110s1189

Grumiaux, F., Demuynck, S., Schikorski, D., Lemiere, S., Vandenbulcke, F. and Lepretre, A. 2007. Effect of fluidized bed combustion ashes used in metal polluted soil remediation on life history traits of the oligochaeta *Eisenia andrei*. European Journal of Soil Biology, 43, 256-260. http://dx.doi.org/10.1016/j.ejsobi.2007.08.038

Guthrie, R.K., Cherry, D.S. and Singleton, F.L. 1978. Responses of heterothrophic bacterial populations to pH changes in coal ash effluent. Journal of the American Water Resources Association, 14, 803-808. https://doi.org/10.1111/j.1752-1688.1978.tb05580.x

Habig, W.H., Pabst, M.J. and Jakoby, W.B. 1974. Glutathione s-transferases: the first enzymatic step in mercapturic acid formation. Journal of Biological Chemistry, 249, 7130-7139. https://doi.org/10.1016/S0021-9258(19)42083-8

Huggins, F.E., Senior, C.L., Chu, P., Ladwig, K. and Huffman, G.P. 2007. Selenium and arsenic speciation in fly ash from full-scale coal-burning utility plants. Environmental Science and Technology, 41, 3284-3289. http://dx.doi.org/10.1021/es062069y

Islam, M.S., Lucky, N.S., Islam, M.R., Ahad, A., Das, B.R., Rahman, M.M. and Siddiqui M.S.I. 2004. Hematological parameters of Fayoumi, Assil and local Chickens reared in Sylhet Region in Bangladesh. International Journal of Poultry Science, 3, 144-147. http://dx.doi.org/10.3923/ijps.2004.144.147

Izquierdo, M. and Querol X. 2012. Leaching behavior of element from coal combustion fly ash: An overview. International Journal of Coal Geology, 94, 54-66. https://doi.org/10.1016/j.coal.2011.10.006

Jambhulkar, H.P., Siratun, M.S., Shaikh. and Kumar, M.S. 2018. Fly ash toxicity, emerging issues and possible implications for its exploitation in agriculture; Indian scenario: A review. Chemosphere, 213, 333-344. http://dx.doi.org/10.1016/j.chemosphere.2018.09.045

Javed, M. and Nazura, U. 2017. An overview of the adverse effect of heavy metal contamination on fish. The National Academy of Science, India, 89, 389-40. http://dx.doi.org/10.1007/s40011-017-0875-7

Javed, M., Usmani, N., Ahmad, M. and Ahmad, M.I. 2017. Multiple biomarker responses serum biochemistry oxidative stress, genotoxicity, histopathology in Channa Punctatus exposed to heavy metal loaded wastewater. Science Reporter, 7, 1675. http://dx.doi.org/10.1038/s41598-017-01749-6

Lease, H.M., Hansen, J.A., Bergman, H.L. and Meyer, J.S. 2003. Structural changes in gills of lost river suckers exposed to elevated pH and ammonia concentrations. Comparative Biochemistry and Physiology part c: Toxicology Pharmacology, 134, 491-500. https://doi.org/10.1016/S1532-0456(03)00044-9

Lohner, T.W., Reash, R.J. and Williams, M. 2001b. Assessment of tolerant sun fish populations (*Lepomis* sp.) inhabiting selenium-laden coal ash effluents. Ecotoxicology and Environmental Safety, 50, 217-224. http://dx.doi.org/10.1006/eesa.2001.2099

Lohner, T.W., Reash, R.J., Willet, V.E. and Fletcher, J. 2001a. Assessment of tolerant sunfish populations (*Lepomis* sp.) inhabiting selenium-laden coal ash effluents. Ecotoxicology and Environmental Safety, 50, 225-232. https://doi.org/10.1006/eesa.2001.2097.

Mandal, A. and Sengupta, D. 2006. An assessment of soil contamination due to heavy metals around a coal-fired thermal power plant in India. Environmental Geology, 51, 409-420. https://doi.org/10.1016/j.enceco.2021.11.003

Manguson, J.J., Brandt, S.B. and Stewart, D.J. 1980. Habitat preferences and fishery oceanography. Pp. 514. In: Bardach J.E., Maguson, J.J., May, R.C. and Reinhart, J.M. (Eds.). Fish Behaviour and its Use in the Capture and Culture of Fishes. ICLARM Conference proceeding. International Centre for Living Aquatic Resources Management, Manila, Phillippines.

Manz, M., Weissflog, L., Kuhne, R. and Schurmann, G. 1999. Ecotoxicological hazard and risk assessment of heavy metal contents in agricultural soils of central Germany. Ecotoxicology Environmental Safety, 42, 191-201. http://dx.doi.org/10.1006/eesa.1998.1741

Mrinmay, G., Patra, B.C., Kumar, U., Bhattacharya, M., Jana, H. and Kar, A. 2015. The Impact of coal fly ash power station on distribution and biodiversity of freshwater fishes in Rupnarayan river, West Bengal, India. International Journal of Current Research, 7, 23954-23961.

Mukharjee, T., Schafer, U. and Zeidler, M. P. 2006. Identification of *Drosophila* genes modulating janus kinase/signal transducer and activator of transcription signal transduction. Genetics, 172, 1683-1697. http://dx.doi.org/10.1534/genetics.105.046904

Naik, A.S., Kumar, J., Mahesh, V. and Benakappa, S. 2013. Assessment of fish diversity of Tunga River, Karnataka, India. Nature and Science, 11, 82-87.

Nemr, A.El., El Sadaawy, M.M., Khaled, A. and El-Sikaily, A. 2014. Adsorption of the anionic dye direct red 23 onto new activated carbons developed from *Cynara cardunculus*: kinetics, equilibrium and thermodynamics. Blue Biotechnology Journal, 3, 121-142.

Olmsted, L.L., Degan, D.J., Carter, J.S. and Cumbie, P.M. 1986. Aquatic biodiversity and the electric utility industry. In: Hall, G.E. and van den Avyle, M.J. (Eds.), Reservoir Fisheries Management: strategies for the 80's, American Fisheries Society, Bethesda, MD.

Pal, S., Mahato, S. and Sarkar, S. 2016. Impact of fly ash on channel morphology and ambient water quality of Chandrabhaga River of Eastern India. Environmental Earth Sciences, 75, article number 1268. https://doi.org/10.1007/s12665-016-6060-0

Pandey, V.C. and Singh, N. 2010. Impact of fly ash incorporation in soil systems. Agriculture, Ecosystems and Environment, 136, 16-27. https://doi.org/10.1016/j.agee.2009.11.013

Pandey, V.C., Singh, J.S., Singh, R.P., Singh, N. and Yunus M. 2011. Arsenic hazards in coal fly ash and its fate in Indian scenario. Resources, Conservation and Recycling, 55, 819-835. http://dx.doi.org/10.1016/j.resconrec.2011. 04.005

Pitchaikani, J.S., Anabthan, G. and Sudhakar, M., 2010. Studies on the effect of coolant water effluent of Tuticorin Thermal Power Station on hydro biological characteristics of Tuticorin Coastal waters, South East Coast of India. Current Research Journal of Biological Science, 2, 118-123. https://maxwellsci.com/print/crjbs/v2-118-123.pdf

Pradhan, S., Behera, R.K. and Nanda, P. 2020. Hematological alteration in fish *Hetropneustens fossilis* (Bloch) on exposure to fly ash. International Research Journal of Biological Sciences, 9, 47-50. https://www.isca.in/IJBS/Archive/v9/i2/9.ISCA-IRJBS-2019-116.php

Ram, L.C. and Masto, R.E. 2014. Fly ash for soil amelioration: A review on the influence of ash blending with inorganic and organic amendments. Earth-Science Reviews, 128, 52-74. http://dx.doi.org/10.1016/j.earscirev.2013.10.003

Reash, R.J. 2012. Selenium arsenic and mercury in fish in habiting a fly ash exposure gradient: interspecific bioaccumulation patterns and elemental associations. Environmental Toxicology and Chemistry, 31, 739-747. http://dx.doi.org/10.1002/etc.1745

Reash, R.J., Lohner, T.W. and Wood, K.V. 2006. Selenium and other trace metals in fish inhabiting a fly ash stream; Implication for regulatory tissue thresholds. Environmental Pollution, 142, 397-408. http://dx.doi.org/10.1016/j.envpol.2005.10.025

Sabir, R.I., Akhtar, N., Bukhari, F.A.S., Nasir, J. and Ahmed, W. 2014. Impact of training on productivity of employees: A case study of electricity supply company in Pakistan. International Review of Management and Business Research, 3, 595-604. https://www.irmbrjournal.com/papers/1399180743.pdf

Sahu, S.K., Pandit, G.G. and Sadasivan, S. 2004. Precipitation scavenging of polycyclic aromatic hydrocarbons in Mumbai, India. Science of the Total Environment, 318, 245- 249. https://doi.org/10.1016/S0048-9697(03)00370-X

Shrivastava, S. and Dwivedi, S. 2011. Effect of fly ash pollution on fish scales. Research Journal of Chemical Sciences, 1, 24-28. https://www.isca.me/rjcs/Archives/v1/i9/05.ISCA-RJCS-2011-154.php

Sinha, A.K. 1972. Colorimetric assay of catalase. Analytical Biochemistry, 47, 389-394. https://doi.org/10.1016/0003-2697(72)90132-7

Spencer, D.F., Yeung, H.Y. and Greene, R.W. 1983. Alteration in zooplankton community of a fly ash treated lake. Hydrobiologia, 107, 123-130. https://doi.org/10.1007/BF00017427

Srivastava, P.K. and Chakrabarti, R. 2012. Effect of dietary supplementation of *Achyranthes aspera* seed on the immune system of *Labeo rohita* fry. Israeli Journal of Aquaculture, 24, 1-10. https://doi.org/10.46989/001c.20615

Sukla, P. and Singh, A. 2013. Distribution and diversity of freshwater fishes in Aami River, Gorakhpur, India. Advance in Biological Research, 7, 26-31. http://dx.doi.org/10.5829/idosi.abr.2013.7.2.7186

Sultan, S., Ahsan, S., Tanvir, S., Haque, Alam, F. and Yellishetty, M. 2021. Coal fly ash utilization and environmental impact. pp. 381-402. In: Jyothi, R.K. and Parhi, P.K. (Eds.). Clean Coal Technologies. Springer, Cham. http://dx.doi.org/10.1007/978-3-030-68502-7_15

Ugurlu, A. 2004. Leaching characteristics of fly ash. Environmental Geology, 46, 890-895. http://dx.doi.org/10.1007/s00254-004-1100-6

Walia, A. and Mehra N.K. 1998. A seasonal assessment of the impact of coal fly ash disposal on the River Yamuna, Delhi. II. Biology. Water, Air, Soil Pollution, 103, 315-339. http://dx.doi.org/10.1023%2FA%3A1004953715779.

Webster, K.E., Forbes, A.M. and Magnuson, J.J. 1985. An Evaluation of Environmental Stress Imposed by Coal Fly Ash Effluent. Wisconsin Power Plant Impact Study. EPA/600/3-85/045, Environment Research Laboratory, Duluth, Minnesota.

White, D.H., King, C.A., Mitchell, C.A. and Mulhern, B.M. 1986. Trace elements in sediments, water and American coots (*Fullica americana*) at coal fired power plant in Texas 1979-1982. Bulletin of Environmental Contamination and Toxicology, 36, 376-386. https://doi.org/10.1007/BF01623523

Wills, E.D. 1966. Mechanisms of lipid peroxide formation in animal tissue. Journal of Biochemistry, 99, 667-676. https://doi.org/10.1042/bj0990667

Witeska, M., Jezierska, B. and Wolnicki, J. 2006. The metal uptake and accumulation in fish living in polluted waters. Aquaculture International, 14, 141-152. http://dx.doi.org/10.1007/978-1-4020-4728-2_6

Xu, Z., Cao, J., Qin, X., Qiu, W., Mei, J. and Xie, J. 2021. Toxic effects on bioaccumulation, hematological parameters, oxidative stress, immune responses and tissue structure in fish exposed to ammonia nitrogen: A review. Animals, 11, 330-338. http://dx.doi.org/10.3390/ani11113304

Yi, Y., Yang, Z. and Zhang, S. 2011. Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metal in fishes in the middle and lower reaches of the Youngtze river basin. Environmental Pollution, 159, 2575-2585. https://doi.org/10.1016/j.envpol.2011.06.011

Yi, C., Yingjie, F., Yu, H., Xiaoling, L., Xu, W. and Zhang, T. 2024. A comprehensive review of toxicity of coal fly ash and its leachate in the ecosystem. Ecotoxicology and Environmental Safety, 269, 1-20. https://doi.org/10.1016/j.ecoenv.2023.115905

Zeitoun, M. and Mehana, E.F. 2014. Impact of water pollution with heavy metals on fish health: Overview and updates. Global Veterinaria, 12(2), 219-231. http://dx.doi.org/10.5829/idosi.gv.2014.12.02.82219 (https://www.idosi.org/gv/gv12(2)14/12.pdf)

Zhang, G., Xi,Y-L., Xue, Y-H., Xiang, X-L. and Wen, X-L. 2015. Coal fly ash effluent affects the distributions of *Brachionus calyciflorus* sibling species. Ecotoxicology and Environmental Safety, 112, 60-67. https://doi.org/10.1016/j.ecoenv.2014.09.036

Zierold, K.M., Hayemeyer, A.N. and Sears, C.G. 2020. Health symptoms among adults living near a coal burning power plant. Archives of Environmental and Occupational Health, 75, 2154-4700. http://dx.doi.org/10.1080/19338244.2019.1633992

Received: 5th September 2024
Accepted: 20th October 2024