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Impacts of Clay Mining Activities on Aquatic Ecosystems: A Critical Review

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Abstract: ***The unconsolidated earth surface is a rich source of minerals, of which clay is one of the richest natural minerals, having various natural and anthropogenic properties. Natural clay is widely available as a cheaper resource, which is non toxic to ecosystems and has the property of preserving ground water and aquifers. At the same time, the ubiquitous and widespread occurrence of clay will have the property to control toxic materials. The uncontrolled exploitation or mining of clay minerals will affect the aquatic ecosystem's sustainability in many ways. Water quality is very essential for the healthy environment and human life, whereas unpredictable conditions like flooding, drought, groundwater loss, loss of biodiversity, and health impacts on the surrounding inhabitants are some of the signs of ecosystem loss. The unwanted mined clay is deposited into the surrounding area of the mining environment, resulting in top soil, ground water, and surface water pollution. The review paper describes the pollution aspects of the aquatic ecosystem with special emphasis on ground water, aquifers, fresh water (lotic and lentic), sediment, and marine ecology and hydrology.***

Index Terms: Clay Mining, Aquatic Ecosystem, Fresh Water, Groundwater, Marine, Sediment, Pollution

I. INTRODUCTION

Soil is one of the cheapest resources in nature, made up of gravel, sand, clay, and loam, which constitute different types [1]. Some reports [2] explain that it is clear that the soil is a non-renewable natural resource with slow regeneration processes but a rapid degradation rate. In any environmental resource exploiting process, there should be merit and demerit, even if it is more prevalent in clay mining [3]. The beneficial activities of mining include habitat construction and economic and societal improvement, but it may be true that our agricultural well being is being depleted. Miners are economically exploiting the resource, and companies are involved in mining, legally or illegally, and it is important to realise that they have no regard for the environment. Soil quality is one of the three components of environmental quality [4], besides water and air quality. Clay is an important soil constituent, naturally occurring, fine grained material with particle properties, mostly composed of a class of crystalline hydrous silicate minerals called as clay minerals [5].

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It is formed by the chemical or mechanical weathering of aluminium silicate minerals like feldspar through a complex sequence of events. Clay particles have a sheet-like layer structure and are very small, smaller than two micrometres (7.9 105 inch) in size [6].There is a sufficient supply of minerals such as iron, alkali metals, or alkaline earth metals [7, 8]. Hence, it is one of the oldest known ceramic materials known to have a lot of properties from prehistoric periods, which has been dated to around 14,000 BC [9]. Clay minerals are categorised into six groups by the US Bureau [10] of Mines as kaolin, ball clay, fire clay, bentonite, fuller's earth, common clay, and shale. Ultimately, clay minerals have wide industrial uses, such as for paper making, cement production, chemical filtering, etc. Mining is the process of extracting precious minerals or other earthy materials from the earth's surface [11] through six consecutive stages, such as exploration, development, extraction, beneficiation, further processing, and a final decommissioning stage [12]. In the long run, mining results in environmental degradation and erosion processes [13]. Meanwhile, the miners deposited waste in open areas, causing land, air, and water pollution [14]. Continuous clay mining in an area will result in air, noise, water, and soil pollution, soil erosion, flooding, land sliding, geological and environmental disasters, loss of biodiversity, and degradation of land. Studies show that clay extraction has serious consequences for the air, soil, and water related environment in an ecosystem [15, 16]. Water purity is indispensable for the existence of biotic ecosystems. Food security will depend upon the accessibility and purity of water [17, 18, 19]. Here there is a dramatic increase in the population, which causes urbanisation, industrial growth, overexploitation of resources, production of more food products, etc., to have a substantial increase in the demand for water [20]. The natural clay mineral plays an important role as a protector of pure water in aquifers, which act as a storehouse of pure ground water. During mining, the hidden clay mineral was exposed and exploited, which will result in the loss of extra pure ground water contained within it. This water comes out of the aquifers and dissolves with the mined clay minerals at the surface, which leads to colloidal dispersion. Hence, it is one of the serious risk factors of sediment deposition in wet land (aquatic) ecosystems [21] and will cause the loss of stored ground water inside our crust. The main environmental issue arose as the clay minerals that were dispersed on the surface (top soil) were flocculated with water, resulting in soil erosion. It is essential to understand the clay dispersion, transport, and biological impact of these pollutants in the environment, and also the knowledge about their speciation and distribution [22].

Mining has some direct impacts on aquatic ecosystems, which include land filling, grading, distruction of vegetation, and construction activities that result in the change of water levels and drainage patterns. Some studies have been conducted in India on the effects of clay mining and its acid drainage problems on the nearby vegetation, aquatic ecosystem, biodiversity, ecorestoration, and revegetation strategies [23, 24, 25, 26, 27, 28, 29]. This review paper aims to find out the impacts of clay mining activity on our aquatic ecosystem, with special emphasis on ground water, aquifers, fresh water, sediment, and marine ecosystems.

II. METHODS

Protecting our water is of high urgency. Mining is one of the most important revenue generating activities of developing countries. Environmental encounters at mining and mineral processing sites are common. The manuscript review process was done using Google scholar and searched with key words such as clay mining and its impacts, ground water pollution, aquifer pollution, fresh water, sediment and marine pollution aspects, and all the remaining relevant references were included in the review process. The writing of the review article was started in February 2020 and completed in May 2021. On that account, this paper clearly states the problems faced by the clay mining activity on our treasurable water resources, and the scientific evidence is also mentioned here.

III. CLAY MINING AND ITS IMPACTS ON AQUATIC ECOSYSTEMS

This review paper focuses on the impacts of clay mining activity on our aquatic ecosystems, which are delineated as ground water and aquifers, freshwater ecosystems, sediment, and marine ecosystems, with special emphasis on the socio-economic health of human individuals in mining sites.

A. Impacts on Ground water and Aquifers

The rock pores, soil pores, and rock foldings or fractures under the earth's surface contain the groundwater. Of the world's fresh water supply, about 30 % is from ground water, which is about 0.76% of the entire world's water, including oceans and permanent ice [30], and it consists of 99% of the world's liquid fresh water supply [31]. Ground water is our planet's most exploited natural resource [32]. It is beyond doubt that, for a healthy and sustainable environment, groundwater is absolutely essential.

The underground layer of rock, rock fractures, and earthy material that contains water is called an aquifer where the soil composition is gravel, sand, or silt [33]. It was a blanket of clay of about 10 to 60 m in thickness that was present at the top of the sedimentary sequence that followed the partially confined nature of ground water or aquifer confined below the clay blanket [34]. The thickness of this clay blanket and the aquifer would vary from region to region depending on topography. Overall, the clay lens has a prominent role as a protector of the ground water. During mining, the top soil was excavated to below horizons, removing the aquifers that were protected by the clay minerals. Clay mining depletes underground clay reserves as well as ground water [35, 36].It depends on the depth of the mining activity. The exploration depth increased and widened, causing the hydraulic gradient to reverse. There is a heavy flow of ground water from the aquifers that has burst out to the earth's surface, resulting in the mixing of water with clay particles and surface soil, causing flocculation. The burst water from the aquifer pollutes and washes out nearby surface top soil, acting as a source of water borne diseases. At most mine sites, the groundwater acts as a water mass and blocks the movement of water into and below nearby wetland environments. Sometimes it acts as a favourite spot for suicidal attempts [37]. The polluted, dumped groundwater successively changes to dark green coloured water with no use and is a site of water borne disease transmission. The loss of ground water will lead to a deepening of water levels, the drying up of shallow wells, and a reduction in the sustainability of the surrounding ecosystem. Clay dispersion and flocculation increase erosion risk, which is considered one of the most serious environmental threats. Hence, the nearby top soils were recognised as highly erodible (Fig. 1.) when used in agriculture [38].

Fig 1. Impacts of Clay mining and its dispersion [Source: http://www.keralaceramics.com]

Environmental impacts are commonly due to the destruction of water tables surrounding the mining site, which leads to social, cultural, economic, and industrial disarray [39]. Honestly, the mining industry has a heavy need for water resources for extraction of minerals, processing plants, and settling of dust particles that are released from the mining site. Meanwhile, the demand is increasing, the overall stress for ground water slows down the aquifer, resulting in low recharge into wells, streams, rivers, ponds, lakes, etc., and the nearby aquatic ecosystem. Hence, the shortage of ground water is negatively affecting crop productivity and the agrarian ecosystem. The uncontrolled clay mining activities in Madayipanchayath Kerala, resulted in the formation of unproductive areas due to the reduction of ground water, which made the site unfit for living and cultivation [40].

The USDOI [41] defined different problems that come up in an open pit mine when the mine is working above or below the water table. If it is above the water table/aquifer, it has less impact on the ground water table, whereas if it is present below the water table, it causes some crucial problems for the above ground water. Meanwhile, active or abandoned/decommissioned mines cause the same problem by causing the leaching of minerals or metals into the ground water and terrestrial aquatic ecosystems, especially in the rainy season, causing soil contamination. Site-specific hydrology provides the accessibility of groundwater in open pit mines and underground mines, which are working under differing dimensions (42). Therefore, it requires basic knowledge of water flow and water movement (Darcy's law). The permeability of clay particles is in the range of 10^{-4} to 10^{-6} cm s^{-1}, whereas the movement of water is very slow inside clay. That's why the water was stagnant above the ground and water samples were alkaline along with high dissolved solids in mining areas [42]. The assessment of the quality of water in different sources around the China Clay Mine in MadayiPanchayath of Kannur District in Kerala was suspected to be polluted due to the mining operation and associated waste disposal near to the site [43]. The people residing near the China Clay Mine have an opinion that the water in their wells is not safe for consumption and that adequate remedial measures need to be taken before consumption, pointing out the significant number of health disorders in this region. There is clear cut evidence of the lowering of ground water in and around the open cast clay mining deposits in Thonnakkal, South India. In this region, the depth of the water level was increased, which hastened the impacts on the topography and general biodiversity of that region [44]. The groundwater of the area comes under the Na^+-HCO_3- type and shallow meteoric percolation type, and there were low pH, high sulfate, and trace metal concentrations in the ground water in and around the clay belt, whereas the quality is degrading very fast.

B. Impacts on the Fresh water ecosystem

Freshwater ecosystems makes of lentic and lotic systems. The term lentic ecosystems is given to standing water bodies or still water bodies, and the flow is the lotic ecosystem, which includes rivers, springs, and creeks [45]. Mining made the surrounding lotic and lentic ecosystems unfit and unhealthy due to the mobility of mining waste and leachable minerals from mines. The nearby rivers of clay harvesting sites were polluted by the leacheate waste [46] from the reclaimed land areas, waste by the trappings of domestic animals, and functioned as breeding sites for mosquitoes, etc. Stream morphology was modified by the activities of distorting channels from the clay mines, and this flocculated leacheate diverted the stream flow. In order to do this, heavy accumulation of clay particles changes the slope or bank stability, sediments are increased and deposited there, and flocculated water affects the normal aquatic ecosystem [47]. Hence, the eroded or leached out material that cements the underwater body results in a reduction in water quality and degradation of the aquatic ecosystem. This will block the incoming solar radiation, and dissolved clay particles will change the colour of the water depending upon the clay. This is one of the important issues raised by clay harvesting near water bodies. The mining impacts on water are five-fold, which are related to quality and quantity, such as acidity, heavy metal contamination, pollution due to processing chemicals and sedimentation, and reduced quantity, including scarcity of pure water [48]. The impacts of clay mining on the surrounding aquatic environment are created in all of the four phases of mining, namely, exploration, operation, closure, and post closure. There is an alteration of chemistry in surface water that ultimately creates health impacts on humans, animals, and plants, changes the reproduction, growth, and distribution of biotic flora and fauna, and may cause the proliferation of waterborne diseases [49]. Various mining activities polluted the surface environment by generating large amounts of acidic drainage containing heavy metals [50, 51, 52]. Studies have shown that the clay minerals are characterised by their high chemical reactivity [53, 54, 55] and as a major component in the suspended sediment of rivers. Trace elements such as cadmium (Cd), cupper (Cu), zinc (Zn), cobalt (Co) and others are adsorbed into riverine clay minerals, and it is speculated that their deposition in the estuaries and marine ecosystems will badly affect the ecotone community and biotic productivity [56]. The continental shelf is highly productive and the clay leads to the destruction of species rich environments. Every mining site has thepresence of polluted water of dark green coloured or reddish brown coloured nutrient rich with very low pH value of 2.5 [57]. This acidic water dissolves salt and mobilises metals from mine workings and residue deposits into the nearby aquatic environment. This water is drained out, causing surface and ground water pollution, which is responsible for the degradation and removal of soil quality, aquatic habitats, and allowing heavy metals to leach into the underground[58]. Around 10 km from the surface the effect of contaminated water from the mines can persist, and evidence of radionuclide pollution was found in the catchment area [59, 60]. The contaminated surface water resulted in the contamination of sedimentand resulted in metal contamination and could modify their bioavailability and toxicity. Finally, the result of bioaccumulation in aquatic organisms in the [61, 62] nearby ponds or lakes. Surface mines near aquatic communities cause the decline of abundant planktonic species [63]. Chemical changes modify diatom communities, water insects, and crustacean communities, resulting in low trophic competition and the community being dominated by predators [64].

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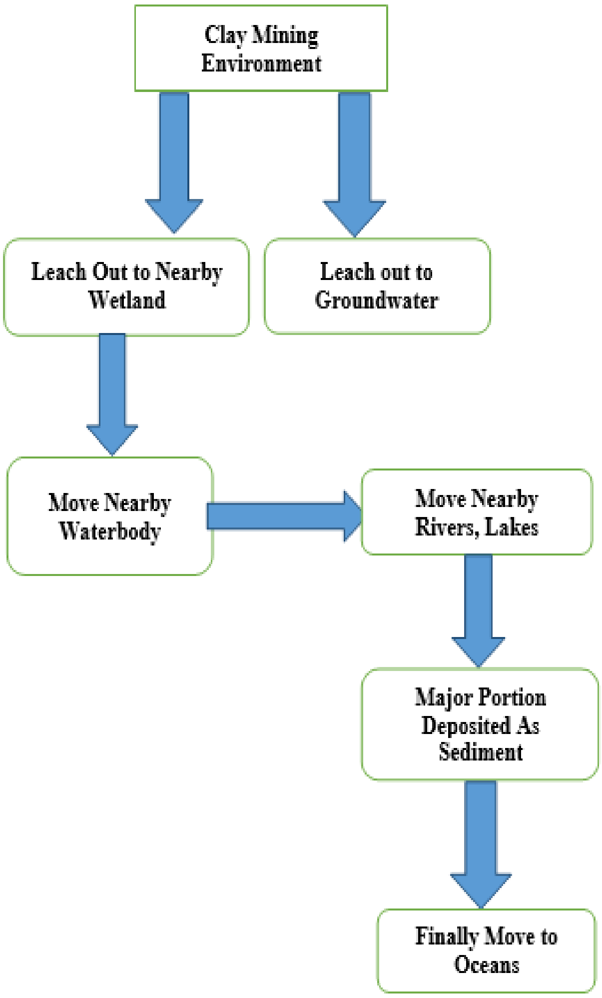
The aquatic organisms are also affected by pH, temperature variations, and chemical concentrations [65]. The species present in the aquatic environment, especially endemic species, are very sensitive. Destruction or slight modification of their habitat puts them at risk of extinction [66]. The leakage of chemicals from contaminated watersheds also has an effect on the health of the local population. In the south-west of India, indiscriminate mining and soil quarrying result in the damage of hill ecosystems, and soil fixation and function of soil leading to root system collapse [67]. They gave a set of recommendations for protecting the soil from quarrying and mining in Kerala. There was a crucial situation present in Kerala due to mining and quarrying [68]. The Muvattupuzha river is one of the major river ecosystems in urban Kerala (Kochi), where developmental activities have made the river unfit for existence due to heavy mining activities. It was stated that there is an imminent need to control the mining and quarrying occurring in nearby areas to protect the river ecosystem and river basin environment.

C. Impacts on Sediments

Sediment is a naturally occurring material that is broken down by processes of weathering and erosion, which is transported by the action of various physical factors such as wind, water, or ice or by the force of gravity acting on the particles [69]. According to the United States Environmental Protection Agency, one of the major ecological threats in the world is the contamination of water with toxic substances that leach out of mining areas. During surface mining, huge quantities of waste from the mines in the form of clay powders, removed top soil, sand, rock, gravel, etc. are overburden or spoil on the surface of the mining sites in hectares of area and are formed as arable land [70]. Toxic metals such as copper and lead are bioaccumulated in plant parts, detritus feeders, the smallest organisms, and other organisms that enter the food chain and food web [71]. Sediments act as larger resorvouirs of clay [72, 73], and the overall impact of silicate dissolution is potentially dominant. Typically, most mines discharge acids into the surrounding environment and the overburden from the mines is acidic pH, such as 2.0-3.0. Weathering and oxidation released sulfate, Fe^{2+}, and other metallic ions from the percolated sediment. In areas of heavy rain, the influx of acidic contaminants that are mixed together with the rain water is greater.

It would be transmitted to nearby aquatic and wetland ecosystems, especially the paddy fields, which are unfit for cultivation and other ecological activities. A case study reported in the paddy fields of Jaintia Hills, Meghalaya, India showed a massive decline in the yield of rice from 1.80 t/ha to 1.50 t/ha within the 5 years from 2007 to 2012 [74]. The overburden from the coal mines in the Jaintia Hills was dumped on to paddy land, and the acid drainage from it has acidified the soil, contaminated it with heavy metals, and left the soil depleted of potassium and zinc [75]. Leachate heavy metals accumulate in the biotic system, especially in the aerial organs, possibly leading to human intake through fruits and vegetables. Regular consumption of metals leads to health problems for those living near the mines [76]. Microorganisms are ecological indicators and sensitive to environmental conditions and their modifications, like pH, temperature, changes in chemical concentrations, etc. [77]. Furthermore, small changes in environmental conditions may stimulate the remobilization of contaminants to have a direct impact on sensitive organisms [78]. There were prominent changes in the pH of the area where the clay/waste were deposited. The fact that, the microbial biomass of an undisturbed area was high when compared to a disturbed area [79].

Clay has some natural properties to remove composite metals such as arsenic, iron, manganese, lead, cadmium, uranium, chromium, selenium, tungsten, and zinc [80]. Clays and their modifications have received wide attention recently for their use as adsorbents of metal ions from aqueous media. It is due to their easy availability and comparatively lower cost [81].



Flow chart on the Movement of Clay Particles In Aquatic Ecosyste

D. Impacts on Marine ecosystem

Aquatic and sediment clay deposits ultimately result in marine pollution. Most miners discharge waste into the marine ecosystem. The transportation of clay minerals to the marine environment was done by rivers in flocculated or sedimented states, where the clay minerals have high chemical reactivity and reach the sea as suspended sediments [82, 83, 84].

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Clay minerals have been shown to play a significant role in the deposition of trace elements from land to oceans, and the clay acts as an active carrier of various substances [85, 86]. There is a difference between the chemistry of riverine and marine ecosystems in which the pH of river water ranges from 2 to 8 and the ionic strength is 0.01 M. In the case of the oceans, the average pH is 8.1 and the ionic strength ranges from 0.56 M to 0.7 M because of the difference in aqueous speciation and surface particles of clay molecules. Hence, this affects the capacity and transportation load of metals bound with clay particles. Previous studies have shown that trace element adsorption (cupper, zinc, cobalt, cadmium) in the aquatic environment is proportional to solution pH, whereas high ionic strength inhibits adsorption [87, 88]. The fact that increased pH enhances the deprotonation of surface functional groups [89]. Since high ionic strength diminishes the negative electrostatic field, leading to reduced cation adsorption at the clay surface. There are drastic changes that occur when metals are transferred from riverine to marine systems, including estuaries. The major role of clay particles in acting as sinks of metals due to the ability of metal sorption behaviour of clay surfaces is critical to determining the degree to which they act as sinks of pollutants or metals into the bottom sediments or water column. Studies have clearly shown that the interactions between cadmium and clay minerals are different than those between cadmium and freshwater minerals because of elevated pH versus seawater conditions [90]. Clay deposited in aquatic ecosystem sediments will transmit to the marine ecosystem, especially if it is deposited on continental shelfs, and it is usually removed by excavation for the purpose of enlarging rivers, controlling floods, and accessing harbours and port channels.The excavated, degraded marine clay is disposed of in the environment, which ends up as a waste [91].

IV. CONCLUSION

The main economic activity of developing countries is mining. It has both negative and positive impacts, in which the pressure/strain between mining and conservation are expected to intensify as the human population grows with technological advance. All mining activities result in habitat destruction during mine construction and exploitation. This systematic review paper illustrates the problems faced by the ecosystem correlated with biodiversity in clay mining. The integration and co-operation of industrial activity with that of environmental sustainability improves controlled mining, especially in ecologically sensitive areas in developing countries. Clay mining ultimately results in different types of health hazards for biological life and humanity. The findings of this review show that clay mining causes serious health impacts on the surrounding inhabitants and leads to ecosystem disintegration. People in developing countries use well water for their day-to-day needs, and the accumulation of toxic metals results in health impacts. The leaching out of minerals from the mined environment has polluted the groundwater sustainability also. The surface leachates also disrupt the wetland sustainability and chemicals are bio-accumulated and enter the food chain. Hence, protecting water quality is a very real and urgent need, as an environmental challenge at mining and mineral processing sites.

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REFERENCES

1. Tariro M (2013) Case studies of environmental impacts of sand mining and gravel extraction for urban development in Gaborone, Thesis, University of South Africa.
2. Mwangi S (2007) Management of River Systems in East Africa. Nairobi, Macmillan.
3. Haddaway NR, Steven JC, Pamela L, Biljana M, Annika EN, Jessica JT, Kaisa R (2019) Evidence of the impacts of metal mining and the effectiveness of mining mitigation measures on social–ecological systems in Arctic and boreal regions: A systematic map protocol, 8:9. https://doi.org/10.1186/s13750-019-0152-
4. Andrews BD, Paul AG, Jeffrey DC (2002) Techniques for GIS modelling of coastal dunes. Geomorphology, 48:289–308.
5. Huggett JM (2005) Clay minerals. Richard CS, Robin MC, Ian RP (Eds), Encyclopaedia of Geology, Elsevier, pp. 358-365. ISBN 9780123693969. https://doi.org/10.1016/B0-12-369396-9/00273-2.
6. Grim RE, Kodama H (2021) Clay mineral. Encyclopaedia Britannica, Invalid Date, https://www.britannica.com/science/clay-mineral. Accessed 20 July 2021.
7. Eisenhour DD, Brown RK (2009)Bentonite and Its Impact on Modern Life. Elements 5(2):83-88. doi:10.2113/gselements.5.2.83.
8. Stephen AN (2014) Weathering and clay minerals, Mineralogy, Tulane University.
9. Scarre C (2005) The Human Past. London: Thames and Hudson. ISBN 0500290636.
10. Patterson SH, Murray HH (1983) "Clays", Industrial Minerals and Rocks, Volume 1, Society of Mining Engineers, New York.
11. Adjei E (2017) Impacts of Mining on Livelihoods of Rural Households: A case study of farmers in the Wassa mining region, Ghana. M.Phil These in the Development Studies submitted to Department of Geography, Norwegian University of Science and Technology.
12. Arzoo A, Satapathy BK (2016) Socio-economic and environmental impacts of mining in Odisha. Scholars Academic Journal of Biosciences 4(7):560-564. DOI: 10.21276/sajb.2016.4.7.2.
13. Laura J, Sonter (2018) Mining and biodiversity: Key issues and research needs in conservation science. Proceedings of the Royal Society B: Biological Sciences 285(1892):20181926. doi:10.1098/rspb.2018.1926.PMC 6283941. PMID 30518573.
14. Ugya AY, Ajibade FO, Ajibade TF (2018) Water pollution resulting from mining activity: An Overview. Proceedings of the 2018 Annual conference of the School of Engineering & Engineering Technology (SEET), The Federal University of Technology, Akure, Nigeria, 17-19 July.
15. Williamson JC, Johnson DB (1991) Microbiology of soils at opencast sites II. Population transformation occurring following land restoration and the influence rye grass/fertilizer amendments. Journal Soil Science 42:9-16.
16. Fedra K, Winkelbauer L, Pantulu VR (2005) Systems for Environmental Screening. An Application in the Lower Mekong Basin. International Institute for Applied Systems Analysis. A-2361 Laxenburg, Austria, pp169.
17. Mancosu N, Snyder RL, Kyriakakis G, Spano D (2015) Water scarcity and future challenges for food production". Water 7:975–992.
18. Ajibade FO, Adewumi JR, Ojo OM, Babatola JO, Oguntuase AM (2015) Issues, Challenges and Management of Water Supply and Sanitation in Nigeria: An Overview. Conference Proceedings on National Development Strategies towards Sustainable Civil Infrastructure, International Civil Engineering Conference held at Kwara Hotel, Ilorin, Nigeria,28th– 30th October, Nigerian Institution of Civil Engineers (www.nice-nigeria.org) 19–34.

19. Bekchanov M, Karimov A, Lamers JPA (2010) Impact of water availability on land and water productivity: A temporal and spatial analysis of the case study region Khorezm, Uzbekistan. Water 2:668–684.
20. Mhlongo S, Mativenga, PT, Marnewick A (2018) Water quality in a mining and water-stressed region. Journal of Cleaner Production 171:446–456.
21. Nguyen NM, Dultz S, Kasbohm J, Le D (2009) Clay dispersion and its relation to surface charge in a paddy soil of the red River Delta. Vietnam. Journal of Plant Nutrition and Soil Science 172:477-486.
22. Reza R, Singh G (2009a) Physico-chemical analysis of ground water in Angul-Talcher region of Orissa, India. Journal of American Science 5:53-58.
23. Swer S, Singh OP (2003) Coal mining impacting water quality and aquatic biodiversity in Jaintia Hills District of Meghalaya. ENVIS Bulletin Himalayan Ecology 11:25-33.
24. Sarma K (2005) Impact of Coal Mining on Vegetation: A Case Study in Jaintia Hills District of Meghalaya, India. Dissertation. International Institute for Geo-Information Science and Earth Observation, Enschede, The Netherlands.
25. Dowarah J, Boruah HDP, Gogoi J, Pathak N, Saikia N (2009a) Eco-restoration of a high-sulfur coal mine overburden dumping site in northeast India: A case study. Journal of Earth System Science 118:597–608.
26. Nayak B (2013) Mineral matter and the nature of pyrite in some high-sulfur tertiary coals of Meghalaya, Northeast India. Journal of Geologic Society of India, 81:203–214.
27. Sahoo PK, Tripathy S, Panigrahi MK, Equeenuddin SM (2012) Mineralogy of Fe-precipitates and their role in metal retention from an acid mine drainage site in India. Mine Water and the Environment 31:344–352.
28. Sahoo PK, Kim K, Equeenuddin SM, Powell MA (2013) Current approaches for mitigating acid mine drainage. Reviews of Environmental Contamination and Toxicology 226:1–32.
29. Masto RE, Sheik S, Nehru G, Selvi VA, George J (2015) Assessment of environmental soil quality around SonepurBazari mine of Raniganj coalfield, India. Solid Earth 6:433–811. http://dx.doi.org/10.5194/se-6-811-2015.
30. Gleick PH (1993) Water in crisis. Pacific Institute for Studies in Dev Environment & Security. Stockholm Env Institute, Oxford Univ Press, 473: 9.
31. Lall U, Josset L, Russo T (2020) A Snapshot of the World's Groundwater Challenges. Annual Review of Environment and Resources 45(1):171–194. doi:10.1146/annurev-environ-102017-025800. ISSN 1543-5938.
32. Gleeson T, Befus KM, Jasechko S, Luijendijk E, Cardenas MB (2016) The global volume and distribution of modern ground water. Nature Geoscience 9(2):161–167. Bibcode:2016NatGe...9..161G. doi:10.1038/ngeo2590. ISSN 1752-0894.
33. Post VEA, Groen J, Kooi H, Person M, Ge S, Edmunds WM (2013) Offshore fresh groundwater reserves as a global phenomenon. Nature 504(7478):71–78. Bibcode:2013Natur.504...71P. doi:10.1038/nature12858.
34. Bose S, Mazumdar A, Basu S (2020) Review on Present Situation of Groundwater Scenario on Kolkata, Municipal Area. 6th International Conference on Environment and Renewable Energy IOP Conf. Ser.: Earth and Environmental Science, pp 505. IOP Conf. Series: Earth and Environmental Science. doi:10.1088/1755-1315/505/1/012022. 2020.
35. Taylor C, Greene E (2008) Hydro geologic characterization and methods used in the investigation of karst hydrology. Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water. Techniques and Methods 4–D2. U.S. Geological Survey 107.
36. Brown A (2010) Reliable mine water technology. Journal of Mine Water and the Environment 29(2):85-91.
37. The Hindu (September 2nd 2020) Kerala's depressing suicide statistics for 2019. Anil Radhakrishnan.
38. http://www.keralaceramics.com
39. Soni AK (2019) Mining of Minerals and Groundwater in India, Groundwater-Resource Characterisation and Management Aspects, Modreck GomoIntech.DOI:10.5772/intechopen.85309. Available from:https://www.intechopen.com/chapters/66470.
40. Pillai GK, Vineetha PR (2012) Suitability of drinking water in and around clay mines in Northern Kerala, India. International Journal of Science and Research 6:1638-1646.
41. USDOI (1985) Groundwater Manual-A Water Resources Technical Publication, US Department of the Interior (USDOI), Indian Reprint. Jodhpur: Scientific Publisher, pp 480.
42. Reza R, Singh G (2009b) Physico-chemical analysis of ground water in Angul-Talcher region of Orissa, India. Journal of American Science 5:53-58.
43. Manoj B, Vineethkumar V, Prakash V (2021) Drinking water quality assessment in the water around a clay mine in Kannur district, Kerala. Radiation Protection and Environment 43:88-93.
44. Joji V (2017) Characterization, Classification and Evaluation of Groundwater in and around the Open Cast Mining of Clay Deposits of Thonnakkal, South India. International Journal of Environmental Sciences and Natural Resources 4(1):555-630. DOI: 10.19080/IJESNR.2017.04.555630.
45. Balasubramanian A (2011) Aquatic ecosystems freshwater types.10.13140/RG.2.2.22783.20642.
46. Kofi A, Alexander A (2016) The Economic and Environmental Impacts on Clay Harvesting at Abonko in the Mfantsiman West District of Central Region, Ghana. American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)18(1):120-132.
47. Johnson SW (1997) Effects of Submarine Mine Tailings Disposal on Juvenile Yellowfin Sole (*Pleuronectes asper*): A Laboratory Study". Marine Pollution Bulletin Vol. 36 (4).
48. Kearney AT (2014) Mining Takes on the Sustainability Challenge. The soil management assessment framework: A quantitative soil quality evaluation method. Soil Science Society of America Journal 68:1945-1962.
49. Mosley C (2016) Phosphate Mining brings a Mosaic of Destruction to Florida Including Sinkholes and Radioactive Wastes, Industry Tap into News, September.
50. Cheng H, HuY, Luo J, Xu B, Zhao J (2009) Geochemical processes controlling fate and transport of arsenic in acid mine drainage (AMD) and natural systems. Journal of Hazardous Materials 165:13-26. https://doi.org/10.1016/j.jhazmat.2008.10.070.
51. Zhuang P, McBride, MB, Xia H, Li NY, Li ZA (2009a) Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. Science of the Total Environment 407:1551-1561. https://doi.org/10.1016/j.scitotenv.2008.10.061.
52. Zhuang P, Zou B, Li NY, Li ZA (2009b) Heavy metal contamination in soils and food crops around Dabaoshan mine in Guangdong, China: Implication for human health. Environ Geochem Health 31:707 -715.
53. Bradbury MH, Baeyens B (2002) Sorption of Euon Na- and Ca-montmorillonites: Experimental investigations and modelling with cation exchange and surface complexation. Geochim et Cosmochim Acta 66:2325–2334.
54. Bradbury MH, Baeyens B (2009) Sorption modelling on illite Part I: Titration measurements and the sorption of Ni, Co, Eu and Sn. Geochim et Cosmochim Acta 73:990–1003.
55. Lackovic K, Angove MJ, Wells JD, Johnson BB (2003) Modeling the adsorption of Cd(II) onto Muloorina illite and related clay minerals. Journal of Colloid and Interface Science 257:31–40.
56. Weiduo H, Kashiwabara T, RongJin, Yoshio T, Murray G, Daniel SA, Kurt OK (2020) Clay minerals as a source of cadmium to estuaries. Nature research, 10:10417. https://doi.org/10.1038/s41598-020-67279-w
57. Akcil A, Koldas S (2006) Acid Mine Drainage: causes, treatment and case studies. Journal of Cleaner Production 14:1139-1145.
58. Adler R, Rascher JA (2007) Strategy for the Management of Acid Mine Drainage from Gold Mines in Gauteng. Report. No. CSIR/NRE/PW/ER/2007/0053/C. CSIR, Pretoria.
59. Naiker K, Cukrowska E, Mc Carthy TS (2003) Acid mine drainage from gold mining activities in Johannesburg, South Africa. Environmental Pollution 122:29-40.
60. Wade PW, Woodbourne S, Morris WM, Vos P, Jarvis NW (2002) Risk Assessment of Selected Radionuclides in Sediments of the Mooi River catchment. WRC Project No. K5/1095. Water Research Commission, Pretoria.
61. Tarras-Wahlberga NH, Flachier A, Lanec SN, Sangforsd O (2001) Environmental impacts and metal exposure of aquatic ecosystems in rivers contaminated by small scale gold mining: The Puyango River basin, Southern Ecuador. The Science of the Total Environment 278:239–261.
62. Niyogi DK, William M, Lewis Jr, McKnight, Diane M (2002) Effects of Stress from Mine Drainage on Diversity, Biomass, and Function of Primary Producers in Mountain Streams. Ecosystems 5:554–567.

63. Salonen VS, Tuovinen N, Valpola S (2006) History of mine drainage impact on Lake Orija¨ rvi algal communities, SW Finland. Journal of Paleo limnology 35:289–303.
64. Gerhardt A, Janssens de Bisthoven L, Soares (2004) Macroinvertebrate response to acid mine drainage: Community metrics and on-line behavioural toxicity bioassay. Environmental pollution 130:263–274.
65. Wong HKT, Gauthier A, Nriagu JO (1999) Dispersion and toxicity of metals from abandoned gold mine tailings at Goldenville, Nova Scotia, Canada". Science of the Total Environment 228(1):35–47.
66. Diehl E, Sanhudo (2004) Ground-dwelling ant fauna of sites with high levels of copper. Brazilian Journal of Biology 61(1):33–39.
67. Shiekha EJ, Maya K, Padmalal D (2016) Environmental Impact Assessment of Soil Quarrying from the Hills of Central Kerala, Southwest Coast of India. International Journal of Scientific and Research Publications 6(8):514-520. ISSN 2250- 3153.
68. Maya K, Santhosh V, Padmalal D, Aneesh Kumar, SR (2012) Impact of Mining and Quarrying in Muvattupuzha River Basin, Kerala–An Overview on Its Environmental Effects. Bonfring International Journal of Industrial Engineering and Management Science 2(1):36-40.
69. Murthy VN, Jha MK (2009) Land and Water Management Engineering, Fifth Edition: Kalyani Publishers, NOIDA, pp 556-563.
70. Dowarah J, Boruah HDP, Gogoi J, Pathak N, Saikia N (2009a) Eco-restoration of a high-sulfur coal mine overburden dumping site in northeast India: A case study. Journal of Earth System Science 118:597–608.
71. Pyatt FB, Gilmore G, Grattan JP, Hunt CO, McLaren S (2000) An Imperial Legacy, An Exploration of the Environmental Impact of Ancient Metal Mining and Smelting in Southern Jordan. Journal of Archaeological Science 27:771–778.
72. Cullers RL, Chaudhuri S, Arnold B, Lee M, Wolf CW (1975) Rare earth distributions in clay minerals and in the clay-sized fraction of the Lower Permian Havensville and Eskridge shales of Kansas and Oklahoma. Geochim et Cosmochim. Acta 39:1691–1703. doi: 10.1016/0016-7037(75)90090-3.
73. Jeandel C, Oelkers EH (2015) The influence of terrigenous particulate material dissolution on ocean chemistry and global element cycles. Chemical Geology 395:50–66. doi: 10.1016/j.chemgeo.2014.12.001.
74. Anonymous (2013) Department of Agriculture, Government of Meghalaya. http://www.megagriculture.nic.in/public/download/CropStatistics.aspx.
75. Choudhury UB, Akbar M, Richard W, Kamal PM, Bibhash CV, Manoj Kumar, Anup D, Islam M, Samarendra H (2017) Acid drainage from coal mining: Effect on paddy soil and productivity of rice. Science of the Total Environment 583:344–351.
76. Jung MC, Thornton I (1996) Heavy metals contamination of soils and plants in the vicinity of a lead-zinc mine, Korea, Applied Geochemistry 11:53–59.
77. Rosner T, Schalkwyk AV (2000) The environmental impact of gold mine tailings footprints in the Johannesburg region, South Africa. Bulletin of Engineering Geology and the Environment 59:137-148.
78. Georg S, Adlassnig W, Lendl T, Peroutka M, Weidinger M (2009)Metalloid Contaminated Microhabitats and their Biodiversity at a Former Antimony Mining Site in Schlaining, Austria, Open Environmental Sciences 3:26–41.
79. Mummey DL, Stahl PD, Buyer JS (2002) Soil microbiological properties 20 years after surface mine reclamation: Spatial analysis of reclaimed and undisturbed sites. Soil biology and chemistry 34:1717–1725.
80. Rajani Srinivasan (2011) Advances in Application of Natural Clay and Its Composites in Removal of Biological, Organic, and Inorganic Contaminants from Drinking Water. Advances in Materials Science and Engineering, vol. 2011, Article ID 872531, 17 pages,2011. https://doi.org/10.1155/2011/872531.
81. Bhattacharyya KG, Sen Gupta S (2008) “Adsorption of a few heavy metals on natural and modified kaolinite and montmorillonite: a review,” Advances in Colloid and Interface Science 140(2):114–131.
82. Sposito G (2013) Surface geochemistry of the clay minerals. PNAS96:3358.
83. Brack A (2013) In Developments in Clay Science Vol. 5 (eds. Faïza Bergaya and Gerhard Lagaly) (Elsevier) 507-521 .
84. Viers J, Dupré B, Gaillardet J (2009) Chemical composition of suspended sediments in World Rivers: New insights from a new database. Science of Total Environment 407:853–868.
85. Uncles RJ, Stephens JA, Harris C (2006) Properties of suspended sediment in the estuarine turbidity maximum of the highly turbid Humber Estuary system, UK. Ocean Dynamics 56,235–247.
86. Zhao Y (2018) Clay mineralogy and source-to-sink transport processes of Changjiang River sediments in the estuarine and inner shelf areas of the East China Sea. Journal of Asian Earth Sciences 152:91–102.
87. Gu X, Evans LJ (2008) Surface complexation modelling of Cd(II), Cu(II), Ni(II), Pb(II) and Zn(II) adsorption onto kaolinite. Geochim et Cosmochim Acta 72:267–276.
88. Gu X, Evans LJ, Barabash SJ (2010) Modeling the adsorption of Cd (II), Cu (II), Ni (II), Pb (II) and Zn (II) onto montmorillonite. Geochim et Cosmochim Acta 74:5718–5728.
89. Hao W, Flynn SL, Alessi DS, Konhauser KO (2018) Change of the point of zero net proton charge (pHPZNPC) of clay minerals with ionic strength. Chemical Geology 493:458–467.
90. Hao W (2019) The impact of ionic strength on the proton reactivity of clay minerals. Chemical Geology, 119294.
91. Weiduo H, Kashiwabara T, RongJin, Yoshio T, Murray G, Daniel SA, Kurt OK (2020) Clay minerals as a source of cadmium to estuaries. Nature research, 10:10417. https://doi.org/10.1038/s41598-020-67279-w

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