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Review article

Water pollution control and revitalization using advanced technologies: Uncovering artificial intelligence options towards environmental health protection, sustainability and water security

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A R T I C L E I N F O

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A B S T R A C T

In Ghana, illegal mining (galamsey) activities have polluted most of the river bodies. For example, water bodies in Ghana that are polluted amounts to 60% with most of them in deteriorating condition. However, to live a sustainable life, there is the need to follow rules of environmental management, where pollution control and advanced treatment technologies are imperative. The adoption of control strategies and advanced technologies in galamsey-affected-water basins in Ghana will help provide real-time revitalization for supply of quality water. The control strategies for water pollution management and advanced technologies would particularly help utility companies in ensuring that all Ghanaians continue to get potable, reliable, and sustainable water supplies for the current and future generations. The paper covers three key control strategies for water pollution management, vis-à-vis six major aspects of advanced technologies and the use of artificial intelligence (AI). AI based decision-making tools help optimize the use of various treatment technologies, such as adsorption, ion exchanges, electrokinetic processes, chemical precipitation, phytobial remediation, and membrane technology to effectively remove pollutants from affected water bodies. The paper also focuses on advantages and disadvantages of several advanced technologies, challenges on leveraging the technologies while identifying gaps, and possible technology roadmap. The review contributes to water quality issues in Ghana's Pra river basin by embracing AI and other cutting-edge technologies to address the current water pollution crisis and also ensure sustainable and secure water supply for future generations. This

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contribution is in line with the United Nations' Agenda 2030 Sustainable Development Goals' (SDGs) goal 6 (clean water and sanitation) and goal 3 (good health and well-being).

1. Introduction

"It is easy to throw anything into the river, but difficult to take it out again", is amongst the proverbs of Kashmiri that signifies the importance of water and the need to prevent the occurrence of pollution [1]. The continuous advancement in different forms of civilization, industrialization and urbanization have brought about the need to promote sustainability to ensure humans live longer, healthier and happier. Many human activities lead to the release of hazardous substances or materials referred to as pollutants into our ecosystem, which in turn threatens long, healthy and happy lives. Living a better and sustainable life is linked to following rules of environmental management where pollution control and advanced treatment technologies are imperative [2] to address environmental sustainability challenges, hence the focus of this paper which aims at using effective control measures and advanced technologies in addressing pollution incidents in Ghana's Pra river basin.

Beginning in the 1990s, many rivers in Africa, Asia and Latin America began to see a reduction in water quality as a result of increasing levels of water pollution [3]. Such pollution as asserted by economists Gene Grossman and Alan Krueger follows an inverted U-pattern with development. It is argued that pollution will increase as countries grow and industrialize. This is due to the fact that economic growth increases the amount of pollutants [4]. As a result of lack of specific data, the challenges of pollution and its associated effects on water quality management are likely to also increase as noted by UN-Water [5]. It is more noteworthy and not an exaggeration to say that due to the extent of pollution vis-à-vis the continuous degradation of water quality, water quality in the coming decades is likely to further deteriorate and increase dangers posed to human health, the environment and sustainable development [3] if nothing is done particularly on water pollution control and revitalization.

According to Damania et *al.* [6], as cited by the United Nations [7], certain activities undertaken by citizens for material comfort or wealth deteriorate the environment. Hence, there is a need to adopt policies and cleaner technologies to reverse the trend and possibly produce a cleaner environment. This is known as the environmental Kuznets curve, which explains how growth is the best means to environmental improvement. Importantly, water quality is a growing concern in rural communities in both high and low-income countries [8]. Therefore, it is problematic to neglect the opportunities that occur from water pollution control strategies, revitalization and the use of advanced technologies [9], especially with the situation in Ghana where the biggest source of water pollution has occurred. This is as a result of mining in water bodies and watercourses in major river basins, particularly, the Pra river basin.

According to Ibrahim et al. [10], the Environmental Protection Agency (EPA) of the United States classifies water pollutants into the following six categories: plant nutrients, biodegradable waste, heat, sediment, hazardous and toxic chemicals, and radioactive pollutants. However, the direct valuation of environmental degradation caused by water pollution is typically based on cost of damage. The cost of damage is estimated through costs of prevention, for example, the infrastructure costs to reduce damage, which also include maintenance cost approach. On the other hand, there are benefits to preventing the damage, such as productivity loss due to changes in water quality [7,11]. In Ghana, it is important to strike a balance between the benefits derived from gold mining through revenue generation to boost the economy and the cost of polluting water bodies.

The Ghana Water Company Limited asked the Public Utilities Regulatory Commission (PURC) in May 2022 for a 334% adjustment in tariffs for the upcoming tariff adjustment window. The proposed 334% upward adjustment was attributed to a high cost of treatment due to the high incidence of pollution, among many other reasons. Estimating the costs of pollution is critical and can be done using a variety of methods but one method commonly used is the cost-based approach, which has three options. These are the abatement costs, structural adjustment costs and restoration costs. The costs of introducing technologies to prevent water pollution is measured by the abatement costs, which is the most common. However, tackling water pollution problems in Ghana by using advanced technologies, revitalization processes and implementation of strict policies and laws is critical since in the opinion of Braimah [12], cost and tariffs will reduce if water pollution is checked. Also, to reorganize the economy in terms of production and/or consumption patterns, the costs incurred is termed structural adjustment costs. More importantly, structural adjustment costs often require complex economy-wide modelling and is done particularly to reduce water pollution or other environmental degradation forms to a recommended standard. The third, restoration cost, measures the cost of restoring a degraded ecosystem or water body back to a useable condition [7,11].

Several studies including Chen et al. [13], Zhang and Jiang [14], Meng et al. [15], Zhang et al. [16], Zhang et al. [17] and Zhu et al. [18] have demonstrated water purification performances using different advanced technologies. For example, Chen et al. [13] fabricated a high efficiency method for advanced treatment of dye wastewater and noted that using biomimetic dynamic membrane (BDM) is the best. Zhu et al. [18] also explored gravity-driven biomimetic membrane (GDBM) as a water purification treatment technology in an open natural water system in contrast with closed membrane reactor system. The GDBM proved to be effective to treat real micro polluted water (natural water body polluted by soy sauce pollutants) and was the most cost-effective ecological water treatment technology with high efficiency [18]. Even though artificial intelligence (AI) can help tackle most of the environmental sustainability problems especially in water management, with machine learning models, water resources conservation can be optimized [19]. The knowledge gap in the application of AI in water pollution particularly on pollution control is significant and needs to be addressed. Generally, the long-term performance under optimized conditions for water resources conservation depends on the ability to implement sustainable and adaptive water management practices and technologies that ensure efficient use and conservation of water resources for the unforeseeable future. Nevertheless, water pollution seeks to be the focus of this review because all other forms of pollution eventually make their way into water resulting in high cost of treatment and possible high tariffs for the populace. In this review, strategic progresses made in pollution control of water bodies are highlighted and technologies in various treatment methods are given much importance [10]. The exact cost of illegal mining (galamsey) to water pollution is unknown for most basins in many countries, particularly in the developing world. Such knowledge is crucial and critical for national governments to develop cost-effective policies [1] in terms of control strategies and technologies.

Furthermore, the number of studies published in pollution related literature, specifically advanced pollution control, have increased strikingly over the years and is still counting. The richness of literature in pollution control and advanced technologies make it very complex such that knowledge from various research is often required to inform a particular water pollution control decision. However, available studies are often heterogeneous in terms of the design vis-à-vis the subject under study, which technically adds to the complexity of evidence and conclusion synthesis. This is a critical research gap and there is therefore the need to study a particular case with a high incidence of pollution and homogeneously, then, apply the necessary pollution control and advanced technologies in context specificity. This review therefore fills the gap by providing an overview of water pollution control and revitalization strategies. This can be employed in addressing the pollution incidents in the Pra basin in Ghana and other countries with similar incidents. The review covers three key control strategies in relation to six key aspects of advanced technologies in water pollution management (adsorption, ion exchanges, electrokinetic processes, chemical precipitation, phytobial remediation, and membrane technology) and the use of artificial intelligence in water pollution management for environmental health protection, sustainability and water security.

1.1. Objective

Following the negative impact caused by illegal mining (galamsey) activities in the Pra basin area, this review provides a response by answering this question: what effective control measures and advanced technologies exist in addressing water pollution incidents with a focus on the Pra basin area in Ghana? This is important because pollution control protects the environment by conserving and protecting natural resources, promoting innovation and reducing danger to the population and the environment.

1.2. Pollution incident in the Pra River Basin

Water pollution, considering Ghana's geographical region, comes from chemical or material waste dumping, oil spills, pollutants

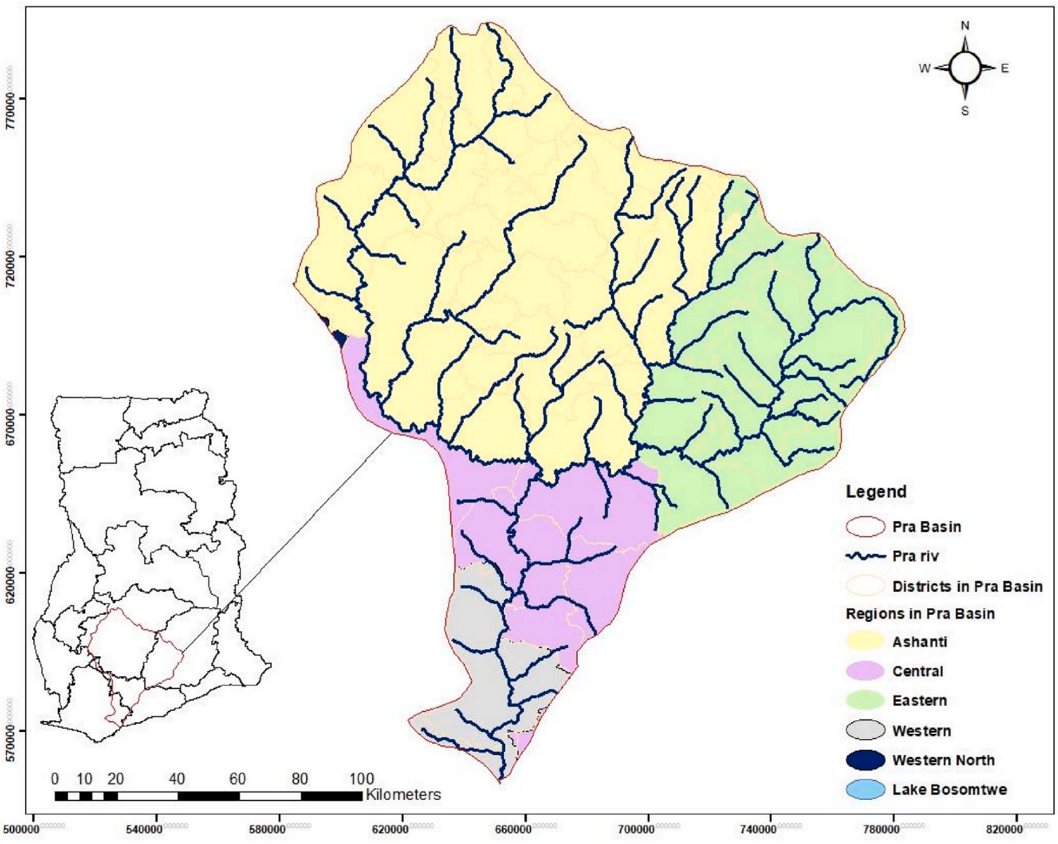

Fig. 1. Map of Ghana showing the Pra river basin.

from livestock operations, illegal fishing activities and illegal mining (galamsey) in and around water bodies, with the latter accounting for 60% of critically polluted water bodies [20]. The main water pollution problem caused by illegal mining (galamsey) activities in the Pra basin is heavy metal pollution due to high levels of illegal mining activities [21,22]. The pollutants – heavy metals as reported by Duncan et al. [21], six metals namely lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), iron (Fe), zinc (Zn) were the principal metal pollutants in at least a sample in both the dry and wet seasons. These parameters fell outside the World Health Organization (WHO) acceptable guideline and were generally not safe for domestic activities like drinking and cooking. The turbidity was relatively higher for the dry and wet seasons in the downstream communities. Thus, the release of trace metals, particularly arsenic, and the turbidity have increased due to illegal mining (galamsey) activities [21]. Fig. 1 presents the map of the Pra River Basin.

As noted by the UN-Water [5], the difficulty of pollution in relation to water quality management is exacerbated by the lack of specific data and its impact on water quality degradation. As a result, a comprehensive pollution control and water security system or policy is required, with the goal to not only capture the dimensions of water, but also resolve water-related concerns and provide a holistic approach to managing water-related challenges. With reference to the Pra basin, which houses nine (9) artificial reservoirs and shared by five (5) out of the sixteen (16) regions in Ghana (Fig. 1), this review provides an overview of pollution control and revitalization strategies by highlighting ways of controlling pollution using advanced technologies including the challenges of leveraging the technologies whiles identifying gaps, and technology roadmap for water utility companies.

1.3. Revitalization incident in the Golden Horn of Istanbul, Turkey

A clear example of revitalization can be found in the Golden Horn of Istanbul, Turkey. The economic, social and environmental benefits that can be derived from the revitalization of urban waterways and waterfronts have been evident in most case studies [23]. In restoring waterways in urban waterfronts, there is a need for an agreement between governments, upstream and downstream residents, as well as businesses to devise ways to prevent pollution, reduce erosion and siltation along the riverbanks to help maintain water quality. Such projects may require commitments and economic resources from both ends; however, the dividends pay into the near future. The Golden Horn project in Istanbul can therefore be used as a case study.

UNESCO and UNESCO i-WSSM [23] report shows that the polluted waterway in the city of Istanbul in Turkey has now become a vibrant economic venture after it was revitalized. The sole aim of the project was to improve water quality and navigation in the estuary. According to the report, the estuary finds itself surrounded by operational dockyards and industrial zones, and the devastating activities in such areas affected the nature of the estuary, rendering it incapable for boat sailing and aquatic-life in 1985. It also developed a fetid smell that could be scented kilometers away due to anaerobic degradation.

The Golden Horn Restoration Project implemented by the Istanbul Metropolitan Municipality in conjunction with the Istanbul Water and Sewage administration (ISKI) cost huge amounts of money to both government and the private sector. The project was carried out in five phases: investigation, dredging, construction of wastewater facilities, landscaping and repurposing the estuary for tourist and cultural purposes. Much of the work centered on dredging and collection of sewage to treatment facilities. As such, the quality of the water gradually improved and aquatic-life returned to the estuary. Nonetheless, the landscaping and repurposing strategies brought economic growth due to the increase in tourist activities. Currently, the revitalized waterfront is used for all activities varying from fishing, boating, walking, hoteling, sporting events, small enterprises, cultural destinations, amongst others. Thus, the historical waterfront now serves an economic, social, cultural and environmental purpose to the society of Istanbul, and the world at large [23].

2. Methods

This study consists of a review of literature developed based on studies on pollution control and revitalization, more specifically, on water pollution using advanced technologies. The methodology framework of pollution control and revitalization using advanced technologies trails a high level of evidence that follows the systematic review framework. Systematic review is based on literature as pointed out by Linde and Willich [24] and Heberle et al. [25] as the primary data source and considered as the most reliable tool to summarize existing evidence. In that regard, steps that began with questions and then proceeded to the identification of relevant works on the subject matter were done. The nature of the review objective followed an effective strategy of identifying journals that are Scopus-indexed, and using keywords that are appropriate for the search criteria while accepting a paper for inclusion in the review.

The descriptors "water pollution," "pollution control," "Pra basin," "revitalization," and "advanced technologies" were used in scientific databases in order to obtain the articles analyzed. Also, based on the article titles, abstracts and full texts, a screening process was implemented to identify the suitable studies for analysis. Inclusion criterion of articles was based on papers that focused on water pollution control using various technologies and adopting an exclusion criterion, papers that do not analyze the association between pollution control and advanced technologies were excluded. This was followed by summarizing and finally presenting the results and discussion on the main objective of the study.

3. Water pollution control strategies and revitalization

Water is an essential substance needed by living organisms for growth and is vital for all forms of life [26], yet one major problem is how to provide the necessary and suitable conditions required to supply clean, affordable and safe water to meet the demands of the world at large [10]. The world is known to share 96.5% of global water found in the seas that are domestically not appropriate for any purpose unless treated. While only 0.07% can be used as potable water for human consumption and other purposes (freshwater), others found in the glaciers, as well as surface and groundwater, make up about 3.5% [26]. Water is said to be potable if it is tasteless, odorless, colorless and suitable for all domestic and other purposes. However, if such characteristics are absent in water, then it is polluted [27]. Developed and developing countries experience some level of water pollution, although the extent varies depending on the types of pollutants due to human activities [27]. This results in water pollution classification, which lowers the amount of potable water that is available on Earth [26]. These pollutants are classified into different types and include discharges from point sources and non-point sources; from industries are dangerous for water quality and affect its characteristics [10].

3.1. Cultural asset mapping

The Pra River Basin, together with its tributaries, serve over forty-three administrative districts within the south-western part of Ghana. Thus, it is harnessed for varied uses ranging from domestic usage to irrigation, fishing and agriculture. However, the clearance of forest for mining activities and other infrastructural developments and settlements have increased pressure on the basin's water resource. Since the cultural purpose of the river varies from one community to the other, it is necessary to devise a technique that will curb pollution and provide water management value and security which will handle all cultural functions of this water body in all communities. UNESCO, upon scrutiny, recognized a research technique or tool like cultural mapping as a crucial way of preserving the world's intangible and tangible cultural assets [4,28].

Cultural mapping is simply trying to identify a community's strength and its resources, with the aid of helping the community to plan and implement processes with regards to their ecosystem. This helps to articulate the locals' holistic values and educate the indigenous people to become decision and policy-makers who value the health and wellbeing of waterscapes. Cultural mapping can also be used to support environmental flow assessment, for example, to record the values associated with various water bodies according to their cultural significance and social function [4,29]. It is important to juxtapose the cultural functions of the Pra River Basin to the social importance of the cultural activities (example galamsey). In the case of the Pra River Basin, the cultural functions of the water body and the social importance of the activities of gold mining are realized. This calls for the need to devise a policy/plan that will safeguard all these cultural assets without pollution.

3.2. Relational values of water usage

Water usage allocation depicts a process in which water would be distributed and allocated within the Pra-river confluence, as well as laws governing land ownership for mining, in and around this water body [4] is as critical as a control strategy for revitalization. Water usage allocation, however, whether in the form of concessions (which happens to be the most used mechanism in the region) or water rights (which is a legal right given to property owners on ways to use water bodies close to their lands), as in the case of Chile, has not been very effective in reducing conflicts or regulating pollution of these bodies throughout the region. Again, each community (indigenous or not) has its own diverse knowledge and value systems. Moreover, different stakeholders relate differently to water bodies, nature, the environment, as well as to groups in the society [4], hence usage, maintenance, and measures of security may vary from one community to the other in this case. Therefore, 'relational values' which will foster pluralistic approach and help tackle diverse values in relation to the water bodies must be introduced [4,30]. This is because since the Pra River, together with its tributaries constitutes a major source of water supply to many of the communities in the basin, it is evident that the values will vary from place to place, due to the different cultures in these communities. Hence, there is a need for an approach that will keep in check all these diverse values to protect and safeguard the water body.

3.3. Overlay analysis in geographic information system (GIS)

Furthermore, the priority of mining activities and the hot-spot nature of water pollution caused by illegal mining (galamsey) with its associated consequences must be well verified using overlay analysis in GIS in the study area [31,32], by utilizing remote sensing technologies, that will offer very effective ways to observe the distribution, quality and seasonal dynamics of earth surface water bodies. Optical remote sensing can identify water bodies based on their characteristics and as such, their potential lower reflectivity of water compared to other land objects [33,34]. Based on the characteristics of water bodies, three types of extraction methods for water bodies from optical remote sensing imagery have been developed. They include first, using indices to extract water bodies, second, the extraction of water bodies without the use of indices and third, to differently use a combination of indices to delineate water [33]. Using satellites in the Pra basin, the optical remote sensor will produce data on the water quality by detecting harmful substances or blooms (pollutants) as well as the impacts of land use land cover changes on the water quality as a result of illegal mining. This will help the government and water managers to formulate a plan or policy to purify the water body based on the data produced by the optical remote sensor.

4. Advanced water pollution control technologies

In literature, water pollution control technologies involve various technologies which include physical separation, chemical breakdown mechanisms as well as biological degradation [26]. Some of the most current control technologies used are adsorption, phytobial remediation, ion exchanges, electrocoagulation, electrokinetic processes, phytoremediation, nano phytoremediation, chemical precipitation and membrane technology [35]. Also, the recent advancements in nanotechnology is seen as a cost-effective treatment that is deemed to have control over the various problems that have come up as a result of current treatment methods

[10]. Fig. 2 summarizes the advanced water pollution control technologies discussed.

4.1. Adsorption

One of the most known technologies of water treatment is Adsorption and, in this method, activated carbon is used as a universal adsorbent to absorb hazardous metal ions from ground, surface, and wastewater to remove different pollutants [36]. Adsorption is mostly used for the treatment of water or wastewater with dissolved impurities (which tends to make the water colored), and thus eliminates or lowers the various impurity concentrations [35]. Activated carbon is a typical adsorbent used in adsorption technology to remove numerous pollutants [37,38]. As noted by Alka et al. [35], adsorbents have been studied and used as a treatment and/or control technology to obtain an environmentally friendly alternative intended to remove the efficiency of pollutants which stems from the fact that the technology is not self-monitoring [35]. As an example, Nath et al. [39] and Lakshima et al. [40] demonstrated how biochar made from rice husks was penetrated with iron oxide to remove arsenic from effluents. Modeling of the biochar was done to determine how pH, adsorbent dosage, adsorbate dosage, and contact time affected the adsorption process. The development prospect of using biochar made from rice husks for arsenic removal through iron oxide penetration is promising and can lead to the creation of new water treatment systems. This can contribute to achieving the United Nations Sustainable Development Goal 6, which aims to ensure the availability and sustainable management of water and sanitation for all.

4.1.1. Artificial intelligence (AI) applications in adsorption

AI can optimize and analyze interactions amongst various features, and this makes it play an important role in constructing frameworks for remediation of polluted water bodies due to illegal mining activities. As a result of the widespread distribution of the illegal mining business ranging from lands, undergrounds and waterbodies, the use of mercury to extract the ores tend to pollute the environment [41]. Miners prefer mercury for operations because it is easy to use, highly effective, and cheaper as compared to other methods of extraction. The residue of the mercury gets into soils, surface waters and the environment at large. The safest process to remove metalloids and heavy metal pollutants from surface water, and/or separate the two is through adsorption.

In the adsorption process, the aim is to adopt an absorbent substance that can remove many of the dissolved impurities in the water body. The process's operational parameters, such as temperature, heating rate, adsorbent surface area, dosage, initial concentration, particle size, contact time, and pH value, have an impact on how well adsorption works [40]. As a result, there is a need to consider a development model that requires a higher amount of experimental investigation. AI models like artificial neural networks (ANNs), adaptive neuro-fuzzy inference system (ANFIS) and multiple linear regression (MLR) as robust models can be adopted to evaluate the adsorption processes of polluted water bodies.

Lakshimi et al. [40] and Wong et al. [42] employed rambutan peel biochar to remove Cu(II) from water bodies, and investigated how operational parameters including contact time, operating temperature, dosage, and initial biochar concentration affected the adsorption process. Investigations were carried out on the previously mentioned operational parameters using AI models such as ANN, ANFIS and MLR. Also, Nath et al. [39] employed iron oxide permeated mesoporous rice-husk nano-biochar to remove arsenic, where they achieved over 96% removal efficiency by arriving at optimal conditions using ANN and response surface methodology (RSM) analysis. In addition, Li et al. [43] similarly developed an AI model using the support vector machine (SVM) algorithm for adsorption of Pb (II) on EDTA modified biochar. They all achieved a high percentage removal efficiency rate since the AI model helped them

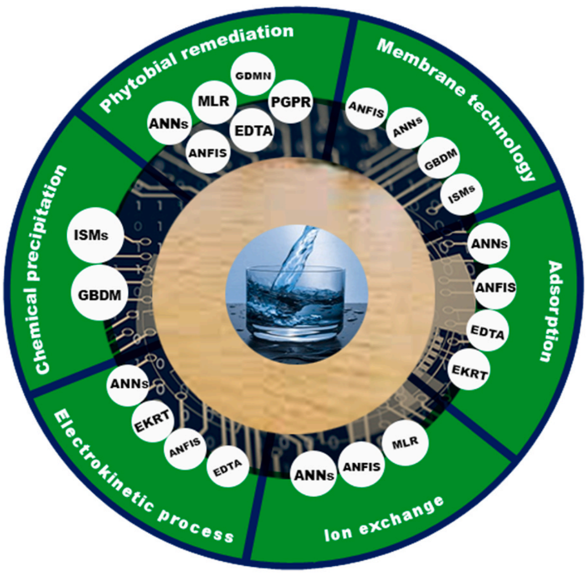

Fig. 2. Water pollution control technologies, materials and AI examples.

establish suitable adsorption mechanisms.

4.1.2. Challenges on leveraging adsorption technology and gaps

The limitation associated with adsorption is the low capacity for high concentrations of pollutants, low specific surface area that is not self-monitored [35], loss of adsorbent and high cost of adsorbent regeneration [44].

4.1.3. Technology roadmap

Adsorption technology can be adopted in addition to other removal technologies to promote its efficiency.

4.2. Ion exchange

In ion exchange, most arsenic pollutants are removed using a technique known as physicochemical, which uses solid phase ions with the same ion numbers that come from polluted water as part of its mechanism. That is, unwanted ions in the water will simply be replaced with another ion. In ion exchange, electrostatically retained ions are used to remove contaminants from waste or contaminated water as well as to reduce water hardness. The disadvantage of this technology is that it is very expensive, and often goes through rejuvenation processes to completely remove pollutants. However, as it results in the removal and recovery of metal items, and for example, with a removal efficiency rate of 97.9% in the pH range of 3.5 to 7, its advantages are significantly greater [35,45]. The development prospect of ion exchange for the removal and recovery of metal items has the potential to contribute to achieving both SDG 3 and SDG 6 by improving human health and well-being and ensuring access to clean water and sanitation. Exposure to heavy metals can cause a range of health problems, including neurological disorders, cancer, and reproductive issues. However, removing heavy metals from water sources through the process of ion exchange can help improve access to clean water and improve human health.

4.2.1. Artificial intelligence (AI) applications in ion exchange

In the process of exchanges between a solution and an insoluble solid, one of the best approaches to remove arsenic pollutants is through ion exchange. This mechanism can be adopted for both removal and recovery of ions. However, in water treatment caused by illegal mining (galamsey), ion exchange is employed to simply replace unwanted ions from the water and replace them with relevant ions. This can be done using top AI technologies. This method offers a convenient option for purification, isolation and removal of contaminants containing ionic substances [46]. The activities of illegal miners tend to contaminate water and hence through water purification, ion exchange resins are used to remove toxic heavy metals such as lead (Pb) and mercury. For instance, AI models such as ANNs and ANFIS can be used to adjust the ionic content of the water. In doing so, an ion-exchange resin would allow water to flow through it; while it does, it exchanges ions of similar charges. This would help in removing magnesium and calcium ions with a higher efficiency rate as well.

4.2.2. Challenges on leveraging ion exchange technology and gaps

One major setback of the ion exchange technology is the high costs involved in its operation. It also requires continual renewal and therefore not self-renewing. In developing countries like Ghana, this technology may not be sustainable for large and polluted water bodies like the Pra river [47] due to the high costs of operation.

4.2.3. Technology roadmap

The resins used in this technology are expensive, therefore, pre-treatments like filtration can be used to eliminate organic molecules before passing the filtrate through the resins [35].

4.3. Electrokinetic processes or methods

The transfer of water and other fluids, as well as the movement of ions and other particles that are comparative to one another under an electric field, are all explained by electrokinetic technology [48]. Specifically, this process helps extract and separate pollutants and charged particles through electrical adsorptions from the soil [35], and water substances [49] which helps in controlling pollution in water. However, the electrokinetic process is inadequate pertaining to the elimination of arsenic pollutants because of its difficult dissolved phases that must be addressed and the risk of heavy metals [35].

4.3.1. Artificial intelligence (AI) applications in electrokinetic processes or methods

The activities of illegal mining cause pollution in most of the water bodies in the southwestern part of Ghana. These pollutants range from heavy metals like mercury, lead and other ionic substances due to these illegal mining (galamsey) activities. Electrokinetic process is crucial for remediation of polluted water bodies. According to Vocciante et al. [50], electrokinetic processes have proven particularly efficient and environmentally friendly as compared to other processes. He argued that the process's main advantage is that it theoretically uses electrons as the sole reagent to function. To obtain a measurable effect, though, in a fair amount of time and with sustainable energy use, these electrolytes are necessary. For instance, the method can be applied in both original state and temporal state and allows for higher efficiency, where the applied electric fields would easily reach pollutants in the surface water or beneath. Similarly, as an example, electrokinetic remediation technology (EKRT) approach was adopted to apply an electric potential gradient to induce low electric current across a portion of contaminated soil [50], even though the latter would not be easily permeated. The intensity of the resulting electric current and the characteristics of the system were very necessary for different physical, chemical and electrochemical processes during induction. These would enable significant species to migrate through the water and into the wells (electrode housing and electrolyte solution), where they could eventually be eliminated by adsorption, electrodeposition, removal of polluted electrolyte solution, and/or precipitation.

4.3.2. Challenges on leveraging electrokinetic processes and gaps

During operation, the potential of a high pH can reduce the ability to remove heavy metals. The technology reduces the heavy metals into their mobile phase, thereby making it difficult to be treated, an example being arsenic. Movement of heavy metals also increases during the process [35].

4.3.3. Technology roadmap

Since electrokinetic technology is emerging, coupling it with other technologies such as permeable-reactive barriers will improve upon its efficiency.

4.4. Chemical precipitation

This can be said to be a solidification process where dissolved materials in water are altered into solid particles [51]. The most common technique for dealing with pollutants, such as arsenic or wastewater, is chemical precipitation [35]. Thus, this process aids in removing anions such as fluoride, cyanide, phosphate, and phenols precipitate as well as converting dissolved arsenic to low solubility compounds [51]. For example, as noted by Alka et al. [35] chemical precipitation has equally been employed to treat gold-mining waste using two-stage nanofiltration for both arsenic and calcium.

4.4.1. Artificial intelligence (AI) applications in chemical precipitation

AI technology can be adopted and applied in chemical precipitation to aid in the removal of arsenic pollutants such as heavy metals like mercury and lead in water bodies due to illegal mining (galamsey) activities. Chemical precipitation processes are adopted for the conversion of soluble pollutants in water bodies into insoluble form as a water treatment measure. AI based techniques can be used to indicate the contaminations in the precipitated particles for future precipitation estimations based on their observations. This is done by merging precipitation datasets from multiple satellites and atmospheric reanalysis. For example, AI techniques were used to generate enhanced precipitation estimates over the Upper Blue Nile Basin [52]. Thus, AI will help predict the heavy metal variables in the precipitated solid particles for future adsorption or ion exchange processes.

4.4.2. Challenges on leveraging chemical precipitation and gaps

The use of hydroxide as precipitants can lead to the production of huge volumes of sludge, which is less dense. This hinders dewatering and ultimately disposal processes. Another challenge is that if complex compounds are in a solution, they can obstruct the precipitation of metal hydroxides. In the case of metal sulfides, colloidal precipitates are formed which causes filtration problems after precipitation. The cost involved in the use of the chemicals is also a challenge [53] especially for developing countries like Ghana.

4.4.3. Technology roadmap

Chemical precipitation in combination with nanofiltration and ion exchange techniques can improve the process. The use of chelating agents can also help in eradicating the challenge of meeting environmental discharge limits of the process [53].

4.5. Phytobial remediation

Phytobial remediation is a pollution control technology that employs the use of microorganisms (bioremediation) to assist phytoremediation [35,54,55]. Thus, as explained by Kaur et al. [56] phytobial remediation helps plant by promoting and improving detoxification as well as stress tolerance while enhancing nutrient availability through the provision of phytohormones. The mechanism uses plants and microorganisms interactions meant to help advance plant sequestration. Phytobial remediation aside its presence, is not expensive and at the same time very sustainable because it supports the environment while achieving successful processes for a long period [35].

4.5.1. Artificial intelligence (AI) applications in phytobial remediation

Due to the hazardous nature of arsenics to water bodies, utilization of bioremediation potentials is essential to overcome environmental related issues. According to Roy et al. [57], phytoremediation and bioremediation potentials are regarded as two innovative tools with cutting edge applications for sustainable mitigation of Arsenic epidemic. This is because they both help in the removal of arsenics from the soil and groundwater. AI techniques can be employed to monitor the growth of the plants in different contaminated soils and groundwater, as advanced measures to harness the removal of arsenic from water bodies using the phytobial remediation process. For example, previously, heavy metals hyperaccumulator plants were extensively utilized to extract higher concentrations of heavy metals. Now, plant growth promoting rhizobacteria (PGPR) helped reduce heavy metals challenges and remediate contaminated sites as well [58]. Various novel remote sensing devices like sensors, cameras, and associated modern technologies can be employed as AI devices to monitor plant growth. In addition, Singh et al. [59] noted that AI techniques were further used to detect, monitor the mobility, bioavailability, seasonal variation and plant response to heavy metals, amongst others. This technique can also enhance and aid in the removal of heavy metals like mercury from the water bodies polluted by these illegal miners.

4.5.2. Challenges on leveraging phytobial remediation and gaps

Phytobial remediation is time consuming, as it has to allow the plants develop well to begin the uptake of heavy metals from polluted sources. The root system of the plants is also very sensitive to metal concentration, hence can cause slow or stunted growth and in turn become ineffective in metal uptake [35].

4.5.3. Technology roadmap

The use of genetic modification of microbes and nanotechnology can improve the plant/root system to overcome the challenges stated above. In the case of the polluted Pra basin of Ghana, the enforcement and implementation of policies that prevent unlawful mining in the catchment area combined with phytobial remediation can be employed to reclaim the polluted water body.

4.6. Membrane technology

Membrane technology operates by the use of selective barrier pores, which allows and rejects materials from the influent water [60]. There are several types of membrane technology but the most common ones are microfiltration, ultrafiltration, nanofiltration and reverse osmosis [61]. The application of a potential gradient separates undesirable materials from the feed solution. Among the different types of membrane technology, nanofiltration has been found to have the ability to remove very minute undesirable solutes compared to the other forms [61]. For example, membrane technology as an environmental water purification treatment technology is known to be prevalent in the closed membrane reactor system. Zhu et al. [18] applied the technology in the open natural water system with gravity-driven biomimetic membrane (GDBM). This is a demonstrated niche application to transform membrane technology from environmental water treatment technology to a highly efficient and cost-effective ecological water treatment technology in the open natural water system. Another practical example was given by Petrinic et al. [62] where ultrafiltration in combination with reverse osmosis were found to be effective in the metal finishing industry. Here, components such as Nickel were completely removed and other metal ions and organic components had removal efficiencies of above 90% [62]. Although membrane technology in itself is not a low cost technology, the development prospect is such that there is a need to develop membrane materials from cheap and locally available alternative sources. Also, a look at how the membranes can be reused over time to cut down cost of operations is also critical.

4.6.1. Artificial intelligence (AI) applications in membrane technology

Membrane technology has been found to be one of the most effective procedures for water treatment or to curb water pollution. The process separates unwanted materials from feed solutions, and with the application of AI technology like ANN, complicated problems from this membrane process can be resolved. As noted by Asghari et al. [63], the membrane separation field requires an alternative model that can work alone and effectively with theoretical or numerical types, and ANN modeling is best fit for such task since, neural networks are notably used for the estimation of membrane performance characteristics. The ANN models help in the development, training and modeling programs irrespective of the type of application (whether nanofiltration, ultrafiltration, microfiltration and/or reverse osmosis) being adopted. Thus, the AI technique will render an accurate translation of the processes.

According to Damania et al. [6], AI can be used to discover materials for ion-selective membranes (ISMs) as well. The ISMs are used solely to recover raw materials from wastewater and other natural resources. They further noted that the limitation of research and development methods, such as time consuming computer simulations and costs of experiments have impeded the growth and development of ISMs. When AI techniques are employed, they can eliminate the limitations of existing 'research and development' methods and rather play a vital role in ISMs material recovery. AI output models like ANN, SVM etc., will use both atomic properties and experimental data for their material recoveries and ISM engineering through data collection. Their algorithms can be used to create predictive models with good accuracy based on experimental data.

4.6.2. Challenges on leveraging membrane technology and gaps

Fouling of membranes during operation is a major limitation. Secondly, different membranes are selective for different materials during operation and this can affect the permeability of other essential materials as well [61].

4.6.3. Technology roadmap

The fusion of nanocomposite materials into the membranes can improve their physicochemical characteristics in their operation.

4.7. Technological options for handling water pollution incidents of heavymetal pollution in the Pra River Basin

The negative effects of water pollution on water quality including the rising demand for water as well as climate change and its associated weather events amongst others are forcing infrastructure to seek innovative solutions out of necessity for water treatment technologies [64]. As further noted by Bhunia et al. [64], even achieving a single water treatment technology to make water fit-for-purpose in regards to quality incorporates various treatment technologies. Thus, inventive business models have been created that integrate various treatment technologies. For the treatment of river bodies, one technology is not adequate to produce safe water for consumption but a combination of technologies [65], taking into cognizance the nature of metal pollutants in context specific to the Pra River Basin. This is due to the myriad of impurities in rivers, especially as a result of heavy metal pollution. Therefore, in such instances, practitioners combine two or three technologies to give expected results. In this paper, all the technologies can be combined to treat the polluted water from the Pra River as presented in Table 1.

5. Conclusion

The review sought to put together the effective control strategies and advanced technologies that exist in addressing water pollution incidents with a particular focus on the Pra basin area in Ghana. The water pollution control strategies that could be employed were discussed and these include cultural asset mapping, relational values of water usage and overlay analysis in geographic information system (GIS). The review also discussed some of the most current advanced water pollution control technologies which include adsorption, ion exchanges, electrokinetic processes, chemical precipitation, phytobial remediation, and membrane technology. There is currently no one technology that can effectively or thoroughly address all pollution incidents, hence in order to meet water quality standards, multi objective and multi-benefit technologies are required. Contemporarily, in dealing with pollutants be it in water, air or soil, there are some advanced technologies that can be employed. However, several factors need to be considered in doing so. More importantly, since remedial actions to clean up polluted sites and water bodies are generally more expensive, it is imperative to apply measures to prevent pollution from occurring. The study recommends the need to emphasize on the importance of intensive sensitization and education of the public to reverse the practice of illegal mining (galamsey) activities in and around waterbodies and water courses. There is the need to promote University of Mines and Technology (UMaT) ASM projects like Sustainable Mining Awareness day in collaboration with the Ministry of Lands and Natural Resources and the Small Scale Miners Association to create awareness on best environmental practices in the sector to bring sanity into the artisanal small-scale mining industry and to adopt remedial measures such as phytoremediation technology project involving the planting of specific tree species that can absorb pollutants like mercury from the environment, and subsequently be harvested, thereby removing the pollutants from the ecosystem. Also, the deployment of AI has proven critical because of its ability to increase adaptation, mitigation capacity and decision making. We recommend that further research should be conducted to explore the specific tree species that are most effective in phytoremediation that have high affinity for absorbing and accumulating hazardous materials, such as mercury, as well as evaluating their growth and adaptability in different polluted environments with AI support. The research could lead to the development of innovative approaches to tackle pollution challenges in the mining industry and other industries leading to a cleaner, safer, and more sustainable environment for future generations through the help of AI. Further, the government in collaboration with environmental agencies, and industry stakeholders should bolster Ghana's capacity to respond and urgently address the debilitating effects of illegal mining (galamsey) on water resources. Finally, embracing advanced technologies including AI, enforcing laws on illegal mining as well as formalizing and implementing effective regulations devoid of hindrances in terms of costs and bureaucracies would help address mining activities that pollutes waterbodies.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

No data was used for the research described in the article.

Table 1
Advanced technologies, materials and artificial intelligence options for water pollution of metal pollutants.

Pollutants	Advanced Technologies	Materials	Example of AI technologies
Lead (Pb)	Adsorption, Ion exchange, Membrane technology, chemical precipitation, Electrokinetic process	Activated carbon, carbon nanotubes (CNTs), graphene (GN), 2- acrylamido-2-methyl propane sulfonic acid-based hydrogel and PVC, Metal-Organic Framework (AMOF-1), sodium carbonate or calcium carbonate, Fenton reaction [66–70]	artificial neural networks (ANNs), adaptive neuro-fuzzy inference system (ANFIS), multiple linear regression (MLR), electrokinetic remediation technology (EKRT), response surface methodology (RSM), support vector machine (SVM) [39,40,42,43,50]
Cadmium (Cd)	Adsorption, Membrane technology, Chemical precipitation, Ion exchange	Polyvinyl alcohol/zeolite nanofibrous, Iridium oxide-coated titanium anode, steel (iron) or aluminum electrodes, AMOF-1, CNTs, GN [67,69–72]	
Chromium (Cr)	Adsorption, Membrane technology, Ion exchange	Molecularly capped silver nanoparticles (N-MCNPs), Zeolite, CNTs, GN [70,73–75]	
Nickel (Ni)	Adsorption, Ion exchange, Membrane technology, Phytobial remediation	Coconut husk, 2- acrylamido-2-methyl propane sulfonic acid-based hydrogel and PVC, Activated carbon, Zeolite [67,68,70,76]	
Iron (Fe)	Chemical precipitation, Membrane technology	Metabolic Network Reactor, calcium hydroxide, sodium carbonate, calcium carbonate [66,77]	
Zinc (Zn)	Membrane technology, adsorption, Ion exchange	Poly (amidoamine)/carbon nanotube, Amberlite, Diaion CR11, Zeolite, AMOF-1 [67,69,70,78,79]	

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] WWAP, in: (United Nations World Water Assessment Programme). The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. Paris, UNESCO, 53, 2017, pp. 1–189.
[2] M. Rani, U. Shanker, Advanced treatment technologies, in: Handbook of Environmental Materials Management [Internet], Springer International Publishing, Cham, 2019, pp. 1289–1339. Available from: http://link.springer.com/10.1007/978-3-319-73645-7_33.
[3] WWAP, The united Nations world water development report 2018: nature-based solutions for water [Internet], UNESCO (2018) 1–139. Available from: www.unwater.org/publications/%0Aworld-water-development-report-2018/.
[4] United Nations, The United Nations World Water Development Report 2021:Valuing Water, UNESCO, Paris, 2021.
[5] UN-Water, Towards a Worldwide Assessment of Freshwater Quality: a UN-water Analytical Brief, 2016.
[6] R. Damania, S. Desbureaux, A.-S. Rodella, J. Russ, Quality Unknown: the Invisible Water Crisis, World Bank Publications, 2019.
[7] United Nations, The United Nations World Water Development Report 2021:Valuing Water, UNESCO, 2021.
[8] UNESCO WWAP, The United Nations World Water Development Report 2019, Leaving No One Behind, Paris, 2019.
[9] UNESCO, The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. Paris, UNESCO, 2017, pp. 1–189.
[10] R.K. Ibrahim, M. Hayyan, M.A. AlSaadi, A. Hayyan, S. Ibrahim, Environmental application of nanotechnology: air, soil, and water [Internet], Environ. Sci. Pollut. Res. Int. 23 (14) (2016) 13754–13788, https://doi.org/10.1007/s11356-016-6457-z.
[11] UNDESA, System of Environmental-Economic Accounting, 2012.
[12] C. Braimah, Joy News NewsFile. Ghana, 2022.
[13] W. Chen, J. Mo, X. Du, Z. Zhang, W. Zhang, Biomimetic dynamic membrane for aquatic dye removal [Internet], Water Res. (2019 Mar;151) 243, 51. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0043135418310078.
[14] W. Zhang, F. Jiang, Membrane fouling in aerobic granular sludge (AGS)-membrane bioreactor (MBR): effect of AGS size [Internet], Water Res. 157 (2019 Jun) 445–453. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0043135418306122.
[15] S. Meng, X. Meng, W. Fan, D. Liang, L. Wang, W. Zhang, et al., The Role of Transparent Exopolymer Particles (TEP) in Membrane Fouling: A Critical Review [Internet], Water Res, 2020 Aug, 181:115930, https://linkinghub.elsevier.com/retrieve/pii/S004313542030467X.
[16] W. Zhang, W. Liang, Z. Zhang, T. Hao, Aerobic granular sludge (AGS) scouring to mitigate membrane fouling: performance, hydrodynamic mechanism and contribution quantification model [Internet], Water Res. 188 (2021 Jan), 116518, https://linkinghub.elsevier.com/retrieve/pii/S0043135420310538.
[17] W. Zhang, W. Liang, Z. Zhang, Dynamic scouring of multifunctional granular material enhances filtration performance in membrane bioreactor: mechanism and modeling [Internet], J. Memb. Sci. (2022 Dec), 663:120979. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0376738822007244.
[18] Z. Zhu, Z. Chen, X. Luo, W. Zhang, S. Meng, Gravity-driven biomimetic membrane (GDBM): an ecological water treatment technology for water purification in the open natural water system [Internet], Chem. Eng. J. 399 (2020 Nov), 125650. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1385894720317782.
[19] E.K. Nti, S.J. Cobbina, E.E. Attafuah, E. Opoku, M.A. Gyan, Environmental sustainability technologies in biodiversity, energy, transportation and water management using artificial intelligence: a systematic review, Sustain Fut. 4 (2022), 100068.
[20] B. Ampomah, 60% of Ghana's water bodies polluted—water Resources Commission. Executive Secretary of the Commission at a workshop in Ho,. Source: GNA, May 13, 2017, 2017.
[21] A.E. Duncan, N. de Vries, K.B. Nyarko, Assessment of heavy metal pollution in the main Pra River and its tributaries in the Pra Basin of Ghana [Internet], Environ. Nanotechnol. Monit. Manag. 10 (2018 Dec) 264–271. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2215153218300291.
[22] E. Bessah, A.O. Raji, O.J. Taiwo, S.K. Agodzo, O.O. Ololade, A. Strapasson, et al., Assessment of surface waters and pollution impacts in Southern Ghana [Internet], Nord. Hydrol 52 (6) (2021 Dec 1) 1423–1435. Available from: https://iwaponline.com/hr/article/52/6/1423/85022/Assessment-of-surface-waters-and-pollution-impacts.
[23] UNESCO, UNESCO i-WSSM, Water Security And The Sustainable Development Goals (Series L). Global Water Security Issues (GWSI) Series. Paris: UNESCO Publishing, 2019, pp. 1–212.
[24] K. Linde, S.N. Willich, How objective are systematic reviews? Differences between reviews on complementary medicine [Internet], J. R Soc. Med. 96 (1) (2003) 17–22. Available from: http://journals.sagepub.com/doi/10.1177/014107680309600105.
[25] Heberle SM, Marques G, Barros N, Rosa MSG. The Effects of Atmospheric Pollution in Respiratory Health.
[26] S. Khamparia, D. Jaspal, Technologies for treatment of colored wastewater from different industries, in: Handbook of Environmental Materials Management, 2019, pp. 417–430, https://doi.org/10.1007/978-3-319-73645-7_8.
[27] G. Kaushik, A. Chel, S. Patil, S. Chaturvedi, Status of particulate matter pollution in India: a review, in: Handb Environ Mater Manag, 2019, pp. 167–193.
[28] U.B. Office, Cultural Mapping, UNESCO Bangkok, 2017.
[29] G. Tipa, K. Nelson, Environmental flow assessments: a participatory process enabling maori cultural values to inform flow regime setting, in: Water, Cultural Diversity, and Global Environmental Change [Internet], Springer Netherlands, Dordrecht, 2011, pp. 467–491. Available from: http://link.springer.com/10.1007/978-94-007-1774-9_32.
[30] M. Parsons, J. Nalau, K. Fisher, C. Brown, Disrupting path dependency: making room for Indigenous knowledge in river management [Internet], Global Environ. Change 56 (2019) 95–113. . Available from: https://linkinghub.elsevier.com/retrieve/pii/S0959378018310380.
[31] R.A. McDonnell, Challenges for integrated water resources management: how do we provide the knowledge to support truly integrated thinking? Int. J. Water Resour. Dev. 24 (1) (2008) 131–143.
[32] R. Srinivas, A.P. Singh, K. Dhadse, C. Garg, A. Deshmukh, Sustainable management of a river basin by integrating an improved fuzzy based hybridized SWOT model and geo-statistical weighted thematic overlay analysis, J. Hydrol. 563 (2018) 92–105.
[33] W. Bie, T. Fei, X. Liu, H. Liu, G. Wu, Small water bodies mapped from Sentinel-2 MSI (MultiSpectral Imager) imagery with higher accuracy [Internet], Int. J. Rem. Sens. 41 (20) (2020) 7912. –30. Available from: https://www.tandfonline.com/doi/full/10.1080/01431161.2020.1766150.
[34] C. Huang, Y. Chen, S. Zhang, J. Wu, Detecting, extracting, and monitoring surface water from space using optical sensors: a review, Rev. Geophys. 56 (2) (2018) 333–360.
[35] S. Alka, S. Shahir, N. Ibrahim, M.J. Ndejiko, D.-V.N. Vo, F.A. Manan, Arsenic removal technologies and future trends: a mini review [Internet], J. Clean. Prod. 278 (2021), 123805. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0959652620338506.
[36] V.K. Gupta, I. Ali, Water treatment for inorganic pollutants by adsorption technology, in: Environmental Water [Internet], Elsevier, 2013, pp. 29–91. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780444593993000027.
[37] N.R.J. Hynes, J.S. Kumar, H. Kamyab, J.A.J. Sujana, O.A. Al-Khashman, Y. Kuslu, et al., Modern enabling techniques and adsorbents based dye removal with sustainability concerns in textile industrial sector -A comprehensive review, J. Clean. Prod. 272 (2020), 122636.
[38] G.M. Walker, L.R. Weatherley, Adsorption of acid dyes on to granular activated carbon in fixed beds, Water Res. 31 (8) (1997) 2093–2101.

[39] B.K. Nath, C. Chaliha, E. Kalita, Iron oxide Permeated Mesoporous rice-husk nanobiochar (IPMN) mediated removal of dissolved arsenic (As): chemometric modelling and adsorption dynamics [Internet], J. Environ. Manag. 246 (2019) 397–409. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301479719307935.
[40] D. Lakshmi, D. Akhil, A. Kartik, K.P. Gopinath, J. Arun, A. Bhatnagar, et al., Artificial intelligence (AI) applications in adsorption of heavy metals using modified biochar [Internet], Sci. Total Environ. 801 (2021), 149623. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0048969721046982.
[41] J. Mantey, K.B. Nyarko, F. Owusu-Nimo, K.A. Awua, C.K. Bempah, R.K. Amankwah, et al., Mercury contamination of soil and water media from different illegal artisanal small-scale gold mining operations (galamsey) [Internet], Heliyon 6 (6) (2020), e04312. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2405844020311567.
[42] Y.J. Wong, S.K. Arumugasamy, C.H. Chung, A. Selvarajoo, V. Sethu, Comparative study of artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS) and multiple linear regression (MLR) for modeling of Cu (II) adsorption from aqueous solution using biochar derived from rambutan (Nephelium lappaceum) pee [Internet], Environ. Monit. Assess. 192 (7) (2020) 439. Available from: https://link.springer.com/10.1007/s10661-020-08268-4.
[43] M. Li, D. Wei, T. Liu, Y. Liu, L. Yan, Q. Wei, et al., EDTA functionalized magnetic biochar for Pb(II) removal: adsorption performance, mechanism and SVM model prediction [Internet], Sep. Purif. Technol. 227 (2019), 115696. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1383586619311438.
[44] S. Khamparia, D. Jaspal, Technologies for treatment of colored wastewater from different industries [Internet], in: Handbook of Environmental Materials Management, Springer International Publishing, Cham, 2019, pp. 417–430. Available from: http://link.springer.com/10.1007/978-3-319-73645-7_8.
[45] S. Karakurt, Removal of carcinogenic arsenic from drinking water by the application of ion exchange resins, Oncogenesis J 2 (1) (2019) 5.
[46] M. Laad, B. Ghule, Removal of toxic contaminants from drinking water using biosensors: a systematic review [Internet], Groundwater Sustain. Dev. 20 (2023), 100888. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2352801X22001655.
[47] M.I. Litter, A.M. Ingallinella, V. Olmos, M. Savio, G. Difeo, L. Botto, et al., Arsenic in Argentina: technologies for arsenic removal from groundwater sources, investment costs and waste management practices, Sci. Total Environ. 690 (2019) 778–789.
[48] J.K. Wittle, S. Pamukcu, Electrokinetic Treatment of Contaminated Soils, Sludges, and Lagoons. Final Report, Electro-Petroleum, Inc., Wayne, PA (United States); Lehigh Univ., Bethlehem, 1993.
[49] Z. Yang, M. Du, J. Jiang, Reducing capacities and redox potentials of humic substances extracted from sewage sludge, Chemosphere 144 (2016) 902–908.
[50] M. Vocciante, V.G. Dov, S. Ferro, Sustainability in ElectroKinetic remediation processes, Crit. Analy. 1–15 (2021).
[51] L.K. Wang, D.A. Vaccari, Y. Li, N.K. Shammas, Chemical precipitation, in: Physicochemical Treatment Processes, Springer, 2005, pp. 141–197.
[52] R.S. Khan, M.A.E. Bhuiyan, Artificial intelligence-based techniques for rainfall estimation integrating multisource precipitation datasets, Atmosphere 12 (10) (2021).
[53] F. Fu, Q. Wang, Removal of heavy metal ions from wastewaters: a review [Internet], J. Environ. Manag. 92 (3) (2011) 407–418. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301479710004147.
[54] S.R. Manoj, C. Karthik, K. Kadirvelu, P.I. Arulselvi, T. Shanmugasundaram, B. Bruno, et al., Understanding the molecular mechanisms for the enhanced phytoremediation of heavy metals through plant growth promoting rhizobacteria: a review [Internet], J. Environ. Manag. (2020), 254:109779. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301479719314975.
[55] N.K. Niazi, I. Bibi, A. Fatimah, M. Shahid, M.T. Javed, H. Wang, et al., Phosphate-assisted phytoremediation of arsenic by Brassica napus and Brassica juncea: morphological and physiological response [Internet], Int. J. Phytoremediation 19 (7) (2017) 670–678. Available from: https://www.tandfonline.com/doi/abs/10.1080/15226514.2016.1278427.
[56] P. Kaur, S. Singh, V. Kumar, N. Singh, J. Singh, Effect of rhizobacteria on arsenic uptake by macrophyte Eichhornia crassipes (Mart.) Solms, Int. J. Phytoremediation 20 (2) (2018) 114–120.
[57] M. Roy, A.K. Giri, S. Dutta, P. Mukherjee, Integrated phytobial remediation for sustainable management of arsenic in soil and water [Internet], Environ. Int. 75 (2015) 180–198. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0160412014003432.
[58] S.A. Asad, M. Farooq, A. Afzal, H. West, Integrated phytobial heavy metal remediation strategies for a sustainable clean environment - a review [Internet], Chemosphere 217 (2019) 925–941. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0045653518321180.
[59] P. Singh, A. Pani, A.S. Mujumdar, S.S. Shirkole, New strategies on the application of artificial intelligence in the field of phytoremediation [Internet], Int. J. Phytoremediation (2022) 1–19. Available from: https://www.tandfonline.com/doi/full/10.1080/15226514.2022.2090500.
[60] R. Singh, S. Singh, P. Parihar, V.P. Singh, S.M. Prasad, Arsenic contamination, consequences and remediation techniques: a review [Internet], Ecotoxicol. Environ. Saf. 112 (2015) 247–270. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0147651314004746.
[61] A. Asad, D. Sameoto, M. Sadrzadeh, Overview of membrane technology [Internet], in: Nanocomposite Membranes for Water and Gas Separation, Elsevier, 2020, pp. 1–28. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780128167106000018.
[62] I. Petrinic, J. Korenak, D. Povodnik, C. Hélix-Nielsen, A feasibility study of ultrafiltration/reverse osmosis (UF/RO)-based wastewater treatment and reuse in the metal finishing industry [Internet], J. Clean. Prod. 101 (2015 Aug) 292–300. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0959652615003753.
[63] M. Asghari, A. Dashti, M. Rezakazemi, E. Jokar, H. Halakoei, Application of neural networks in membrane separation [Internet], Rev. Chem. Eng. 36 (2) (2020) 265–310. Available from: https://www.degruyter.com/document/doi/10.1515/revce-2018-0011/html.
[64] G.S. Bhunia, Shit Pk, S. Brahma, Groundwater conservation and management: recent trends and future prospects [Internet], in: Case Studies in Geospatial Applications to Groundwater Resources, Elsevier, 2023, pp. 371–385. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780323999632000018.
[65] M. Puri, K. Gandhi, M.S. Kumar, Emerging environmental contaminants: a global perspective on policies and regulations [Internet], J. Environ. Manag. (2023 Apr), 332:117344. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301479723001329.
[66] N.A.A. Qasem, R.H. Mohammed, D.U. Lawal, Removal of heavy metal ions from wastewater: a comprehensive and critical review [Internet], npj Clean Water 4 (1) (2021 Jul 8) 36. Available from: https://www.nature.com/articles/s41545-021-00127-0.
[67] M. Karnib, A. Kabbani, H. Holail, Z. Olama, Heavy metals removal using activated carbon, silica and silica activated carbon composite [Internet], Energy Proc. 50 (2014) 113–120. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1876610214007504.
[68] M. Nemati, S.M. Hosseini, M. Shabanian, Novel electrodialysis cation exchange membrane prepared by 2-acrylamido-2-methylpropane sulfonic acid; heavy metal ions removal [Internet], J. Hazard Mater. 337 (2017 Sep) 90–104. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0304389417303357.
[69] Q.-R. Fang, D.-Q. Yuan, J. Sculley, J.-R. Li, Z.-B. Han, H.-C. Zhou, Functional mesoporous Metal−Organic frameworks for the capture of heavy metal ions and size-selective catalysis [Internet], Inorg. Chem. 49 (24) (2010 Dec 20) 11637–11642. Available from: https://pubs.acs.org/doi/10.1021/ic101935f.
[70] X. Li, X. Gao, L. Ai, J. Jiang, Mechanistic insight into the interaction and adsorption of Cr(VI) with zeolitic imidazolate framework-67 microcrystals from aqueous solution [Internet], Chem. Eng. J. 274 (2015 Aug) 238–246. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1385894715004647.
[71] T. Zhang, W. Wang, Y. Zhao, H. Bai, T. Wen, S. Kang, et al., Removal of heavy metals and dyes by clay-based adsorbents: from natural clays to 1D and 2D nano-composites [Internet], Chem. Eng. J. 420 (2021 Sep), 127574. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1385894720336962.
[72] E. Baghban, A. Mehrabani-Zeinabad, A. Moheb, The effects of operational parameters on the electrochemical removal of cadmium ion from dilute aqueous solutions [Internet], Hydrometallurgy 149 (2014 Oct) 97–105. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0304386X14001704.
[73] A. Dror-Ehre, A. Adin, G. Markovich, H. Mamane, Control of biofilm formation in water using molecularly capped silver nanoparticles [Internet], Water Res. 44 (8) (2010 Apr) 2601–2609. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0043135410000369.
[74] L. Wang, W. Kinzelbach, H. Yao, J. Steiner, H. Wang, How to meter agricultural pumping at numerous small-scale wells?—an indirect monitoring method using electric energy as proxy [Internet], Water 12 (9) (2020 Sep 4) 2477. Available from: https://www.mdpi.com/2073-4441/12/9/2477.
[75] Y. Zhang, H. Chi, W. Zhang, Y. Sun, Q. Liang, Y. Gu, et al., Highly efficient adsorption of copper ions by a PVP-reduced graphene oxide based on a new adsorptions mechanism [Internet], Nano-Micro Lett. 6 (1) (2014 Jan 13) 80–87. Available from: https://link.springer.com/10.1007/BF03353772.
[76] A. Bhatnagar, V.J.P. Vilar, C.M.S. Botelho, R.A.R. Boaventura, Coconut-based biosorbents for water treatment — a review of the recent literature [Internet], Adv. Coll. Inter. Sci. 160 (1–2) (2010 Oct) 1–15. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0001868610001338.

[77] S.S. Moersidik, R. Nugroho, M. Handayani, Kamilawati, M.A. Pratama, Optimization and reaction kinetics on the removal of Nickel and COD from wastewater from electroplating industry using Electrocoagulation and Advanced Oxidation Processes [Internet], Heliyon 6 (2) (2020 Feb), e03319. Available from: https://linkinghub.elsevier.com/retrieve/pii/S240584402030164X.
[78] S.-Y. Kang, J.-U. Lee, S.-H. Moon, K.-W. Kim, Competitive adsorption characteristics of Co2+, Ni2+, and Cr3+ by IRN-77 cation exchange resin in synthesized wastewater [Internet], Chemosphere 56 (2) (2004 Jul) 141–147. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0045653504000931.
[79] S.A. Cavaco, S. Fernandes, M.M. Quina, L.M. Ferreira, Removal of chromium from electroplating industry effluents by ion exchange resins [Internet], J. Hazard Mater. 144 (3) (2007 Jun) 634–638. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0304389407001549.