Review

Heavy Metals Removals from Wastewater and Reuse of the Metal Loaded Adsorbents in Various Applications: A Review

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Highlights:

- Heavy metals are a threat to water bodies
- Adsorption process has been frequently used for heavy metals uptake
- Heavy metals laden adsorbents may lead to secondary pollution
- Reuse of heavy metals loaded adsorbents in various in environmental application
- Gender based violence is a global challenge which needs addressing
- Reuse of heavy metal laden adsorbents as biosensor component to tackle GBV

Abstract: Water contamination has intensified over the year as the world's population and industrial activities have grown. Heavy metals (HMs) are amongst the environmental contaminants commonly found in water and wastewater. These include Lead, Manganese, Chromium, Mercury, etc. Various techniques have been used to remediate this environmental challenge and adsorption has proven to be more effective because it is simple to use, excellent efficiency, low cost, possibility to operate in several experimental conditions. Regrettably, this method yields waste materials, which represents a scaling restriction. Furthermore, after the HM has been removed and loaded onto the adsorbent, there is still a question of the fate of the metal-loaded adsorbent. Most of the time these metal loaded adsorbents are discarded in the environment and constitute a secondary pollution. New applications for heavy metals laden have been investigated. This review article presents the various applications that had been investigated to reuse the loaded metal adsorbent. A case study on developing tools for combatting gender-based violence (GBV) has also been discussed.

Keywords: adsorption; GBV; heavy metals; secondary pollution; spent adsorbent reuse

1. Introduction

The value of our ecology is degrading daily, with the world's biggest metropolitan areas attaining capacity and unable to deal with the mounting pressure on their infrastructure. The contaminants polluting the environment are industrial effluents, sewage, and farm wastes. The majority of industries release untreated wastewater and effluents comprising toxic materials into rivers. The most significant problem in the world is environmental pollution, notably from heavy metals and minerals in wastewater. Environmental pollutants (EPs) from mining, metal refining, and tanneries, medical products, agrochemicals, organic chemicals, rubber and plastics, jumble and wood products are the major pollutants sources. HMs are carried by streamflow water and pollute waterbodies

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down - stream from the manufacturing area. To prevent well-being risks, these pernicious HMs must be removed from effluents prior disposal.

The majority of HMs released into effluents have been identified to be harmful and cancer causing, posing a significant threat to human well-being. The discharge of significant amounts of precarious materials into the ecology has resulted in numerous environmental problems. Furthermore, these hazardous materials can build up in the environment because of their imperishable and tenacity properties [1]. This review paper aims at reviewing some heavy metals; their toxicity, conventional and non-conventional approaches used to remediate these HMs from wastewater and then explore the diverse applications used to reuse the metal loaded adsorbent to avoid secondary pollution.

2. Heavy metal toxicity

At small doses, heavy metals can be toxic or harmful. Although a few HMs such as zinc, copper, and chromium, are nutritionally vital for our bodies in small amounts, they can also be toxic if ingested in large quantities. Lead, mercury, arsenic, and cadmium are the heavy metals most frequently linked to human poisoning. Figure 1 illustrates some heavy metals that are harmful when present in water and Figure 2 presents the allowed concentration of these heavy metals that can be ingested when present in water according to WHO (World health organization) and USEPA (United States Environmental Protection Agency) [2,3].

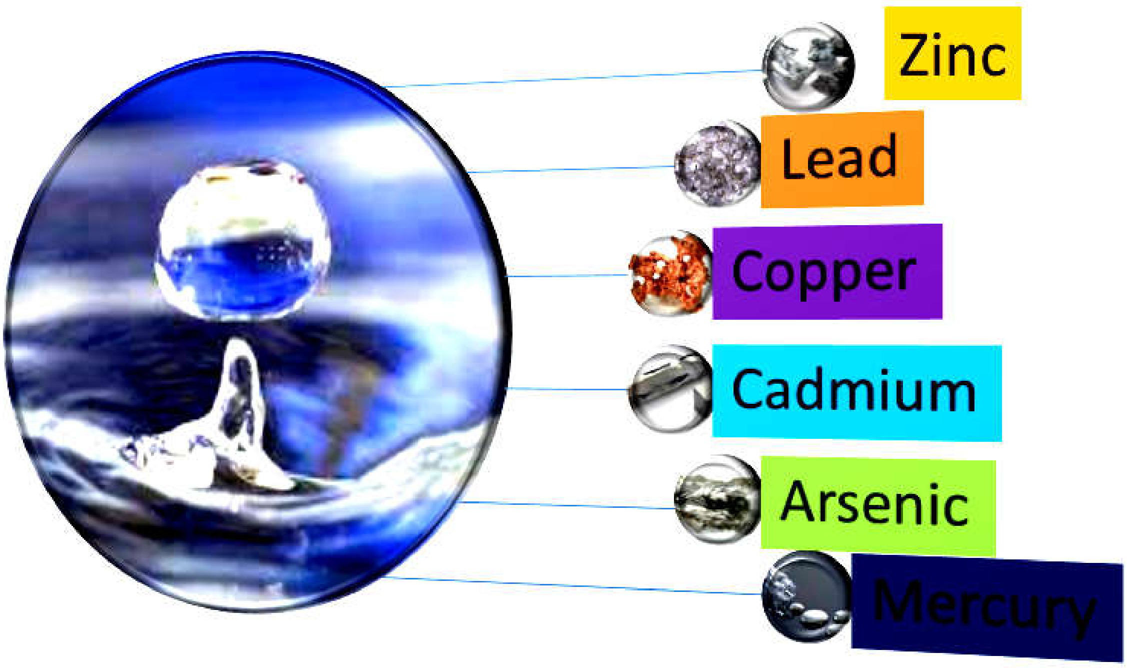

Figure 1. Toxic heavy metal in water.

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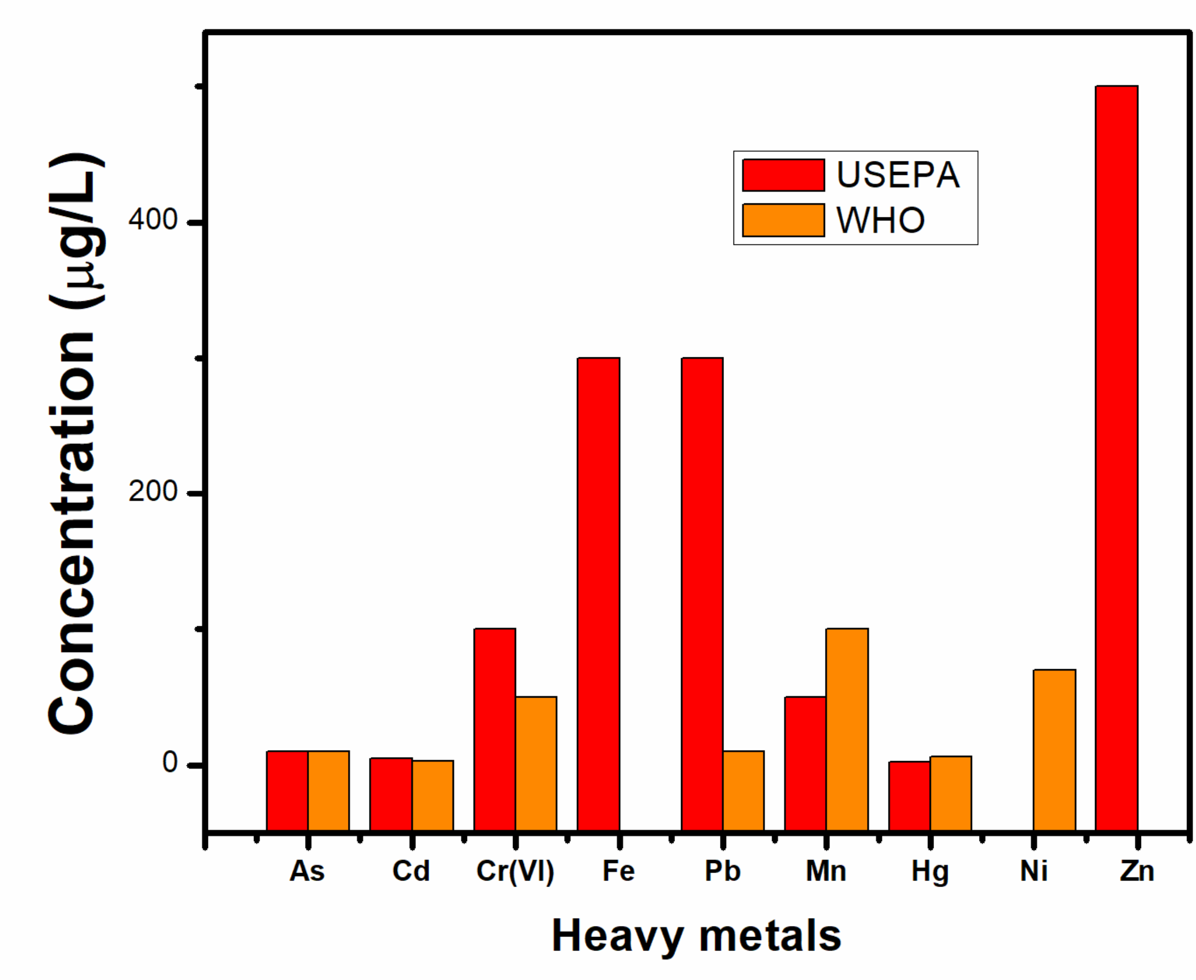

Figure 2. Acceptable amount of selected heavy metal in water.

2.1. Lead (Pb)

Lead is a hazardous environmental pollutant that is highly poisonous to a variety of body organs. Pb could be ingested, although it is primarily absorbed through gasping and gastrointestinal tracts. Immunomodulatory, oxidative, and erythrogenic pathways in Pb subjection may create neurological, respiratory, urinary, and cardiovascular diseases. Additionally, Pb has the potential to disrupt the oxidant–antioxidant system's steadiness and gives rise to erythrogenic reactions in a variety of organs. Pb poisoning can cause changes in the body's physiological systems and is linked to a variety of disorders [3]. Pb is significantly poisonous substance with negative effects on the body's neurological, biochemical, and cognitive capabilities. Pb contamination has an established concern level of 10 grams per deciliter in the blood [4].

2.2. Chromium (Cr)

Cr is a heavy metal is used in various industrial applications [5]. Intake of food and drink having Cr, as well as skin exposure with goods having Cr, is the main source of transmission for non-occupational human populations. In addition, different industrial sectors such as in metallurgy, refractory, and chemical discharge a significant quantity of Cr in to soil, ground water, and air, causing health problems in humans, animals, and marine life. Through eutrophication in the body, Cr may induce a range of sicknesses. This involves anything from skin problems to renal, neurological, and digestive tract disorders, along with the growth of tumors of the lungs, throat, bladder, kidneys, testicles, bone, and thyroid [6].

2.3. Cadmium (Cd)

Cadmium is widely distributed in the environment due to anthropogenic activities namely the burning of hydrocarbon deposit, metal ore, and garbage. Releasing sewerage sludge into agricultural soil can lead to the shifting of cadmium compounds absorbed by plants, which can then develop in numerous human organs and play a vital role in the food webs. Smoking cigarettes is as well a significant contributor of cadmium poisoning. Smokers had 4-5 times greater cadmium levels in their blood than non-smokers when cadmium levels were evaluated in blood samples [7]. This exposure to cadmium on human health may cause renal damage, affect the reproductive system of mankind and various animal species, it could impact on the cardiovascular system [8].

2.4. Zinc

Zinc is a metal that is used in a variety of industrial applications, including paints, cleansers, solvents, and other building materials. Rubber, varnish, dyes, and rust-proofing chemicals all contain zinc. Substantial zinc contamination can occur if you are exposed to large levels of the metal. Zinc poisoning can also be caused by taking too many zinc pills. Zinc is required for proper copper metabolism. Toxicity to zinc obstructs healthy copper absorption. Convulsions and seizures, fever, aches and pains, shock, fainting, a prolonged metallic taste, difficulty to pee, rash, low blood pressure, and vomiting are all signs of zinc poisoning.

2.5. Mercury (Hg)

Hg is detected in the earth's crust at a concentration of about 0.5 mg/L as inorganic mercury or as a sulfide. Outgassing from rocks or volcanic activities cause atmospheric exposures. Coal combustion and mining are two human-made sources of mercury in the atmosphere (mercury and gold in particular). Humans are exposed to mercury largely by inhaling mercury vapor from industrial or dental amalgam exposure, or intake of mercury bound to organic groups from seafood. Health complication related to mercury toxicity include impaired function of any organ, weakness, fatigue, anorexia, weight loss, gastrointestinal disturbance, memory loss, depression [9].

2.6. Arsenic

Arsenic is a naturally existing metalloid element that is present in low concentrations in the atmosphere and food products, notably crustaceans and shellfish. Weathering and mining activities, as well as other natural occurrences like volcanic activity, all contribute to the discharge of arsenic into the surroundings. Many ores, such as gold, lead, cobalt, nickel, and zinc, produce arsenic as a byproduct of the smelting process. Pesticides, wood protectant items, several traditional treatments, and defoliants utilized in the distilling procedure in beer, wine, whiskey, and other having alcohol all included arsenic. Polluted potable water, which comes from erosion of land sources and polluted wells and aquifers, is one of the most common causes of chronic arsenic toxicity [10, 11].

Perdurable pollutants are continuously causing human kind and other living beings health problem. To remedy this issue, adequate approaches need to be put into place. Advanced techniques such as precipitation, reverse osmosis, ion exchange, membrane separation, electrodialysis, filtration and adsorption had been used previously to remove heavy metals or pollutants from wastewater.

3. Conventional techniques for heavy metals remediation

3.1. Chemical Precipitation (CP)

CP is one of the most extensively used method in industrial sector, owing to the ease with which the procedure may be controlled. It is the most cost-effective since it is efficient over a broad range of temperatures and operates at a low cost. HMs ions are converted to less soluble compounds like hydroxide, sulfide, and carbonate that could subsequently be eliminated by physical approaches among which we have sedimentation, flotation, or filtration. The size, density, and surface charge of the particles to be removed influence these processes [12 - 14]. pH is one of the most essential factors in chemical precipitation. pH is an important factor in the coagulation process. At a pH of 6.5, polymeric coagulant emerges with a highly positive charge. The kind and concentration of metal ions in solution, the reagents chosen, the reaction parameters, and other inhibitory substances all have an effect on CP. The amount of chemicals required in the method is hard to ascertain. It is determined, among other things, by the pH and alkalinity of the wastewater, the amount of phosphate, the input location, and the blending procedures [15]. Table 1 demonstrates the advantages and disadvantages of some selected conventional methods used in heavy metals remediation

Table 1. Advantages and disadvantages of some selected conventional methods for heavy metals remediation [16, 17].

Methods	Advantages	Disadvantages
Chemical precipitation	-Low capital cost -Simple operation	-Operational additional cost to disposal the huge sludge
Ion exchange	-Convenient operations -Treating wastewaters with low concentrations of HMs	-Too expensive -Highly sensitive to pH value of solution -Difficult in elution of toxic metals from the chelating type
Adsorption	-Easy operation conditions -Applicable for wide range of pH -High metal binding capabilities	-Low selectivity -Generation of waste products
Membrane filtration	-High selectivity -Small space requirement	-High operational cost due to membrane fouling
Electrochemical /phochemical	-Rapid process and effective for some ions -No sludge production	-High energy cost and formation of large particles -Formation of byproduct
Filtration	Good removal of heavy metals	-Concentration sludge production and expensive
Reverse osmosis	-Environmentally friendly	-Huge amount of waste water is produced
Electrocoagulation	Economically feasible	-High sludge formation and formation of large particles

3.2. Reverse osmosis

The membrane in this case is semipermeable, which means it permits the solvent but not the solute to pass through. The reverse osmosis membranes possess a robust barrier layer in the polymer matrix in which most separation takes place. In most circumstances, the membrane is developed to facilitate only water to go through while keeping solutes from passing through. This technique necessitates applying a lot of pressure to the greater concentration side of the membrane. RO is a separation process that utilizes pressure for the solution to be driven through a membrane that maintains the solvent on one side and allows the pure solvent on the other side. More exactly, it drives a solvent from a high solute location over a membrane to a low solute region by supplying more pressure than the osmotic pressure. For a solution of low solution concentration.RO has a number of disadvantages, including high running costs, carbon dioxide emissions, brine handling, irrevocable membrane fouling, and the need for substantial pretreatment. Additionally, because of the use of high hydraulic pressures, RO cannot directly treat extremely saline streams and is energy intensive. RO is also an unaffordable technique owing to significant capital and operational costs. Furthermore, because of the excessive energy utilization, RO has the potential to transform the water crisis into an energy crisis [18].

3.3. Ultrafiltration (UF)

UF is a separation technique that employs membranes having pore dimensions ranging from 0.1 to 0.001 micron. It is a pressure-driven purification method that allows water and low molecular weight compounds to pass through a membrane while retaining colloidal particles, and

biomolecules. It is commonly used to extract large molecular compounds, colloidal materials, and organic and inorganic polymeric molecules. Even though the electrical charge and surface chemistry of the particles or membrane might influence the water treatment effectiveness, size exclusion is the predominant elimination method [19].

3.4. Ion exchange (IE)

IE process is a continuous chemical process which is applied to substitute harmful metal ions with effective and eco favorable ones. A HM ion is extracted from a wastewater solution by binding it to an immobile solid particle and replacing the solid particle cation with it. The substance of solid ion-exchange particles might be natural, such as inorganic zeolites, or synthetic, such as organic resins. HM ions like Pb^{2+}, Hg^{2+}, Cd^{2+}, Ni^{2+}, V^{4+}, V^{5+}, Cr^{3+}, Cr^{4+}, Cu^{2+}, and Zn^{2+} can be removed from wastewater using the ion-exchange process [19].

3.5. Electrodialysis (ED)

Electrodialysis is a technique for separating ions based on electric potential differences. ED has a high water recovery rate, no phase shift, no reaction, and no chemical involvement. It can function across a wide pH range and has no chemical or physical involvement [20]. ED was employed to remove Ni^{2+}, Pb^{2+}, and K^{+} from typical synthesis using a unique ED heterogeneous CEM (composed of 2-acrylamido-2-methyl propane sulfonic acid-based hydrogel and PVC) with extraction efficiencies of 96.9%, 99.9%, and 99.9% for Ni^{2+}, Pb^{2+}, and K^{+}, accordingly. To recover Pb^{2+}, a batch ED method was used, with an optimum separation efficiency of 100 percent. A pilot-scale ED system was also used to remove Cu^{2+}, Ni^{2+}, and traces of Cd^{2+}, Fe^{3+}, Cr^{6+}, and Zn^{2+}, and the removal rate approached 90%. ED eliminated As^{3+} and As^{5+} from metallurgical effluent with a removal efficiency of 91.38% [21] .

3.6. Electrocoagulation

Electrocoagulation (EC) is a method of producing metallic hydroxide flocs inside a solution by electrodissolving soluble anodes, often formed on Fe or Al. electrochemical oxidation of the electrode produces metallic cations at the anode, whilst H_2 gas is mostly produced at the cathode. Many chemical and physical processes occur during the EC process. In contrast to chemical metal precipitation, the liquid in an EC method is not supplemented with anions. This promotes the creation of more close-packed metallic sludges in EC than CP. Other benefits include a small footprint, a faster reaction time, inexpensive equipment and operation costs, and simple operation [22, 23]. EC has the potential to overcome the drawbacks of traditional treatment methods and create a sustainable and cost-effective treatment of dirty wastewater. This procedure does not need any additional chemical additions and lowers the volume of produced sludge. Coagulating ions are created in situ, and the treatment procedure includes a variety of chemical and physical processes like discharge, oxidation at the anode, reduction at the cathode, coagulation, electrophoretic migration, and adsorption. EC has been utilized with success to remediate wastewaters including electroplating wastewater and chemical mechanical polishing wastewater [24].

3.7. Adsorption

Numerous technologies have been established and implemented over the past years to handle HMs contaminated wastewater, with adsorption being acknowledged as a viable way to treat industrial waste effluents with the advantage of ease of operation [25, 26].

When dealing with high metal concentrated wastewater, traditional treatment procedures including chemical precipitation and electrochemical treatment are successful [26]. They do, however, fail in some circumstances when the metal concentration is low. Adsorption can be used in the treatment of low-concentration metal-contaminated wastewater. Nonetheless, even if the levels of HMs are fairly low, an adsorption process can fully utilize specific varieties of adsorbent materials. HMs can be eliminated simultaneously or separately by using several kinds of adsorbent materials. Activated carbons (ACs), zeolites, and synthetic polymeric adsorbents are the three types of adsorbent materials that are commercially accessible in water treatment. Most ACs have a broad range of pore sizes that may accept big organic molecules; zeolite, which refers to aluminosilicate minerals with varied Al to Si ratios, has very small pores; and synthetic polymeric adsorbents usually only have micropores [25].

3.7.1. Common adsorbents for metals uptake

ACs, zeolites, and synthetic polymeric resins have been effectively applied in a variety of water handling applications, with ACs being the most often applied adsorbent material. ACs can be made from natural or carbonaceous materials like coal, peat, coconuts, and others through high-temperature steam activation or other techniques. However, the temperature required in the carbonization or activation method is substantially elevated, ranging from 600–1200 °C, yielding in high energy usage, whilst the yield of ACs from biomass is very low, typically less than 20%, yielding in a relatively high cost to control large quantities. To substitute traditional ACs, cost-effective adsorbent materials are required [27].

The capacity to adsorb differs greatly based on the source material and the remodeling method. Aside from uptake capabilities, pricing is a significant factor to consider when evaluating and selecting different adsorbent materials. The cost of a single adsorbent material differs based on numerous factors, including local availability and the degree of activation or modification needed. Generally inexpensive adsorbents should satisfy the conditions of being available in nature and requiring as little processing as feasible. Crop residues are typically accessible in high volumes at a low cost, meeting the need for inexpensive commodities. These materials' primary components are lignin and cellulose, that might as well contain additional lignin functional groups including alcohols, ketones, aldehydes, phenolic, carboxylic, and ether groups [28]. These groups can provide a single pair of electrons to bond with HMs and form coordination complexes, making these waste products ideal adsorbents for HMs uptake. Rice husks, peanut hulls, sawdust, Pinus bark and various bark samples, tea leaves, banana and orange peels, palm kernel husk, coconut husk, modified cotton, modified cellulose, modified corncob, wool fibers, and other agricultural by-products are examples of commonly used agricultural wastes [29, 30].

In addition to agricultural waste by-products, industrial waste by-products have been examined and researched for HMs adsorption applications. By-products and waste materials are produced in massive quantities as a result of industrial activity. Some will be reused, while others will be disposed away in landfills. The most appealing part of these materials is that they are frequently supplied for free or at a cheap cost. Several industrial wastes, including fly ash from the energy generation industry and bark and sawdust from the forestry industry, have been researched with or without treatment techniques and used to metal adsorption systems throughout the previous decades [27].

Chitin is another substance that has been found to be capable of adsorbing HMs. It is abundant in nature and can also be obtained from the canning of shrimp, prawns, and crab meat. Furthermore, chitosan, a deacetylated derivative of chitin, has a greater capacity to adsorb than chitin. Chitosan can be synthesized chemically from chitin or typically found in certain fungal cell walls [29].

Adsorption is critical in the removal of HMs from wastewater. ACs are the utmost frequently utilized adsorbent material and have been applied in waste management for the past years. Nevertheless, commercial ACs have shortcomings with regard to HMs

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removal efficiency and market-price issues. Hence So the main goal is to identify appropriate expense substitutes to standard ACs. In such conditions, new adsorbent materials, particularly cost-effective adsorbent materials, must be created. The capacity to adsorb is frequently a difficulty with low-cost adsorbent materials; hence, inexpensive and effective modification strategies should be devised to improve adsorption capacity . Furthermore, another key challenge issue with adsorption is the fate of the adsorbent. If the metal loaded adsorbent is not reused or recycled, this metal loaded adsorbent will be discarded into environment which now will be contributing to secondary pollution.

3.8. Possible applications of spent adsorbents

One of the key issues defining the potential industrial application of organic and inorganic adsorbents is their ultimate fate. Few studies have looked into the long-term disposal or reuse of spent adsorbent organic or inorganic compounds like carbon monoxide and nitrogen dioxide [31, 32].

3.8.1. Environmental remediation

Contents of exhausted sorbents and catalysts applied in textile sewages could be used to develop current materials for environmental remedy. Moreover, these may be employed without adjustment and provide numerous advantages. Among them are the reduction of environmental pollution and the low-cost recycling of adsorbent and catalyst materials. Table 2 summarizes the main and secondary applications of exhausted sorbents as published in latest publications.

Table 2. Principal and secondary applications of exhausted sorbents as published in publications.

Adsorbent	Primary adsorption	Spent adsorbent	Secondary use	Operative conditions	Efficiency (mg/g)	Ref
Wheat straw	Neutral red (50 mg/L)	Neutral red-wheat straw	Congo Red		56	[33]
Poly(AAc/AM/SH)	Cu^{2+} (1g/L, pH=5, 24h	Poly(AAc/AM/SH)-Cu	Phosphate ions	Spent adsorbent: 50 mg, 180 mg/L, 24 h at 30°C	87.62 mg/g and 83.14 mg/g(after 5 cycles)	[34]
Mag-LDH	Humic acid(0.05g), 20mg/L, 20 mL	Mag-LDH/HA calcined to yield Mag-LDO/C	-Cu(II) -Cd(II) -Pb(II)	298 K, pH 6	-192.7 -386.1 -359.7	[35]
Carboxymethyl cellulose(CMC)	Methylene blue(MB)	MBs-CMC	Methyl orange (MO)	-298 K, pH 10	-300 mg/g for the first adsorption. 100 mg/g for the secondary adsorption	[36]

Spent adsorbents in pollution removal have been shown helpful in specific applications with up to ninety-five percent efficiency. This reusability is precisely indicative of a circular bio-economy. It is critical to consider an analysis of the current literature and findings when designing an adsorbent's life cycle. The exhausted sorbents and biocatalysts applied in effluent treatment plants (ETPs) mainly in advance oxidation processes (AOPs), may possess extensive reutilization prospectives. For example, Kaur et al. (2021) created a bio-adsorbent from biofuel waste. Finding a secondary use for exhausted sorbents or catalysts in the same ETPs where they are originated would improve wastewater treatment efficiency. This would also reduce procedure costs and improve environmental remediation. Although interesting, each case must be thoroughly investigated to ensure that contaminants adsorbed on the spent solids are not discarded into the streams to be managed [37].

3.8.2. Sorbent usage in the manufacture of cement-containing materials

Cement manufacturing consumes a lot of essential supplies and strength, and it emits a lot of carbon dioxide [38]. The innovation of sustainable building materials using sustainable natural unprocessed materials can help to reduce environmental effect. The applications of calcareous, siliceous, and aluminous industrial end-of-life products were reported [39]. Phillip et al. (2021), for example, investigated Pal Oil Fuel Ash as an additional material for the cement-containing materials barrier in an unused sealable radioactive source borehole disposal facility [40].

Ashes generated from agricultural waste have pozzolanic properties and may be utilized as additional cementitious material. According to Chandra Paul et al. (2019), heavy metals in activated sludge had no effect on cement resistance, starting time set, or hydration of cements [41]. Biomass ash can be used as a heavy metal adsorbent and as a construction material additive. According to the authors, research should give attention to the true benefits of utilizing biogas ash because its making needs a lot of energy and supplies with carbon dioxide emissions. The leaching potential of some chemical components that may be harmful should be investigated.

Ceramics made from industrial waste have a history. This concept has been expanded to include the reuse of used adsorbents. The findings revealed that Mo is sustained in the matrix and that runoff concentrations are well below the regulatory limit values for organic solvents.

Depending on the foregoing, exhausted adsorbents may be useful as constituents in cement or ceramic materials. It is critical to focus endeavours on the expansion of these materials together with research into their scientific capacity, continuing properties, and general life cycle costs. If these sorbents could be used as building materials, they could be used as decorative elements on building exteriors.

3.8.3. Usage of the spent adsorbent as a catalyst

The recovery of exhausted sorbents as stimulants has been investigated to lessen waste discharge in landfills and raw material intake in catalytic mechanisms. To adsorb mercury, a method was reported in which polypyrrole model adjusted with L-cysteine (PPy@L-Cyst) was formed. At pH = 5.5, the sorbent had an uptake capacity for Hg^{2+} of 2.0427x 10^3 mg/g [42]. The exhausted sorbent was used as a stimulant in the changing of ethynylbenzene to phenylethanone in aqueous medium, yielding 52%. He et al. (2019) described hybrid inorganic-organic silicon materials mainly Mobil Composition of Matter number 41 (MCM-41) as Cr sorbents. The Cr-loaded spent adsorbents were used to remove methanethiol (CH_3SH) and dehydrogenation of propane [43].

Cations degradation in exhausted sorbents had limited influence on catalytic activity, whereas anions degradation causes the production of inert Cr^{6+} species, lowering reactivity. Nevertheless, keeping away from inserting some anions might enable this exhausted sorbent to be reused for this application. Fu et al. (2019a) created sorbent by polymerizing 3-aminobenzenethiol onto an MCM-41 surface that had been adjusted with 3-aminopropyltriethoxysilane. The acquired product was applied to detach Hg in 15 minutes with a maximum uptake capacity of 96.56% and 242.42 mg/g. The exhausted sorbent was used as a stimulant in the 97.01% yield reaction of ethynylbenzene to phenylethanone [44]. By incorporating poly(3-aminobenzenethiol) and poliglusam onto mesoporous silica (MS)-NH_2 with tannic acid as a cross linker, a magnetic network polymer composite (MCTP) was created [45]. An amine-mesoporous silica/poly(m-aminothiophenol) nanocomposite (MAP) was created [44]. This adsorbent was applied to remove Hg^{2+}, and the exhausted sorbent was reapplied as a stimulant for the 89% yield phenylethanone synthesis.

Xu et al. (2019) investigated phosphoric acid-adjusted Santa Barbara Amorphous-15 as an adsorbent for the removal of Cr^{3+}. The catalyst Cr^{3+}/phosphoric acid- Santa Barbara Amorphous -15 was then used to convert wood sugar and xylan into furan-2-carbaldehyde. Cr^{3+}/phosphoric acid- Santa Barbara Amorphous -15 composite not only yielded ninety one percent and fifty eight percent furan-2-carbaldehyde from wood sugar and xylan, respectively, moreover maintained nearly a continuous catalytic capacity after five runs. They were used to extract Cu^{2+}, with uptake efficiencies of 11. 04 and 80. 19 mg/g at pH = 6, subsequently, for activated carbon adjusted with sulfuric acid and oxidized activated carbon adjusted applying Hummer's approach [46]. In another study, biochar made from waste rick husk acquired from a rice manufacturing facility utilized to adsorb heavy metal ions [47]. Furthermore, the exhausted sorbent biochar/heavy metals was functionalized in a heterostructured electrocatalyst for oxygen evolution reaction by boriding process.

Further research is required to verify the economic viability of large-scale reutilization of spent adsorbents based on the experimental work demonstrated above. The reuse of spent adsorbents will empower the proper process configuration, techno-economic survey, and life cycle examination. Notwithstanding, it is transparent that there is a significant potential in the reapplication of these materials. Besides the fact that could heavy and harmful metal contamination be lessened, but reusing harmful exhausted sorbents for catalytic applications seems to to be an ensuring replacement for traditional high-cost materials.

3.8.4. Other applications

Besides the applications discussed in the preceding sections, other options for recycling spent adsorbents have been explored. The objective is to lower the lethality of HMs and dye loaded sorbents discharged into the surroundings while minimizing secondary pollution. Fouda-Mbanga et al. (2021) investigated the use of nanocomposites of chitosan, carboxymethyl cellulose, alginate, and lignin as sorbents to extract extremely harmful HMs (Cd^{2+}, Pb^{2+}, and Zn^{2+}) [48]. Additionally, the authors talked about 4 heavy metal spent adsorbent reuse applications such as stimulus, cement additives or ceramic manufacturing factories, fertilizers and soil conditioners, and latent fingermark identification. Ma and Liu (2021) synthesized Fe_3O_4/C composites from orange peel as a carbon source, which were then used to extract Cr^{6+} from water. Cr^{6+}-loaded adsorbent was then probed as an anode in K^+-batteries, revealing that its K-depot extent was greater than 300 mAh g^{-1} at an ongoing density of 0.1 A g^{-1}. Cr^{6+} chemisorption increases as Fe_3O_4 content increases, as does K-storage capacity [49]. In addition, both modified and unmodified orange peels were used to remove Mn^{2+} from aqueous solutions. Mn^{2+}-laden sorbent was then reapplied in the detection of organic compounds that are inflammable [50].

It is clear that the applications of exhausted sorbents has enormous potential. They could differ based on the unprocessed material utilized in its synthesis and the contaminant eliminated from the effluent, both of which will evaluate its properties.

There is a rapid growth of the population worldwide, which results in increase of crime rate in many countries. This issue has led to governments and safety bodies to find ways to combat the crime rate. Among the main issue of crime there is gender based violence which is really a concern for governments in general and individuals in particular.

4. Gender based violence (GBV)

GBV is a problem that is firmly founded in gender disparity and is the utmost visible civil rights abuses in many communities. GBV is when someone is harmed due to their identity. GBV affects both men and women, although women and girls are disproportionately affected. GBV and women violence are expressions frequently employed simultaneously because it is commonly known that men perpetrate the majority of GBV against women and girls. Nonetheless, adopting the term gender-based is significant because it emphasizes the idea that several types of violence against women are founded in power disparities between men and women [51, 52].

4.1. Types of GBV

GBV may happen in diverse forms such as physically, sexually, emotionally, financially, or structurally in nature, and it could be committed by lovers, friends/colleagues, strangers, or organizations. Men perpetrate the majority GBV acts against females, and the one doing the assault is frequently familiar to the woman, like a spouse or friend or relative [53].

Domestic violence is defined as violence perpetrated by partners or family members. It includes violence towards children or other relatives.

Intimate partner violence is by far the frequent type of GBV, and it encompasses, sexual, and emotional abuse as well as manipulating behaviors by the present or former lover or spouse, and it could arise in straight or same-sex partnerships [54].

Any coition, effort to acquire intimacy, unsolicited intimidation or advances, or attempt to traffic, or else conducted, against a person's coition making use of coercion, by anyone, irrespective of their connection to the victim, in any circumstance, together with but not confined indoors and workplace, is considered sexual violence.

GBV primarily affects women and girls. As a result, some definitions utilize GBV and violence against women and girls (VAWG) simultaneously [55].

Structural violence (SV) is defined as violence embedded into institutions, manifesting as unequal power relations and, as a result, unequal opportunity. When specific category, classes, identity, or nations have preferential access to commodities, materials, and chances over others, and when this uneven privilege is integrated into the socio-political, and economic structures that control their lives, SV occurs. Due to the obvious methods wherein systemic violence is established in systems, long-term political and societal reform is required to detect and eliminate SV.

4.2. Causes of GBV

In general, violence has been found to escalate during pandemics. Rose, for example, reported a breakdown in social norms and a rise of turbulence in Bologna, Italy, in the aftermath of an infestation and catastrophe [56]. As per United nations populated funds (UNPFA), outbreaks frequently result in the destabilization of social infrastructures, exacerbating already shortcomings and conflicts [57]. Consequently, the pandemic situations exacerbate the present gender disparity. It escalates as well the vunerability of young ones and females to harrying and turbulence coition when they attempt to obtain essentials including water, food, and firewood. Numerous investigations reveals that GBV is highlyy common in HIV hyper-endemic countries[58].

Previously, crises were associated with an increase in instances of GBV [59]. Because of joblessness, relatives, and other sources of stress, there was an increase in IPV during other crises like the Haiti earthquake in 2007, Hurricane Katrina in 2005, and Mount Saint Helens eruption in the 1980s [60]. Even during the 2004 South Asian Tsunami, there was an increase in GBV. Fisher reiterated that many other cases of abuse against women and nonconsensual were disclosed in Sri Lanka in the Tsunami repercussions [60].

Throughout the Ebola virus upsurge women and girls were mainly exposed to violence due to the incapacity to get away from their offender. Furthermore, the abused were not accepted and often neglected [61]. Based on Yasmin, instances of rape, assault against women, and sexual abuse also surged amid the Ebola pandemic in West Africa [62].

GBV is ultimately driven by gendered power disparities entrenched in patriarchy. GBV and IPV are further common in communities with a violent culture and where male supremacy is accepted as normal. Men who believe they have a right to have sex with women, tight enforcement of gender rules and ranking women with little social status and authority, and connecting manhood with control of women are all examples of male supremacy. These characteristics combine with a variety of other factors, including cultural and religious standards, female empowerment is moderate, insufficient social aid, socioeconomic disparity, and substance misuse [63].

4.3. The impact of GBV

GBV causes emotional damage and could have emotional, behavioral, and physical implications in the lives of those who survived. Numerous survivors are incapable of getting the care they require because of a lack of access to professional psychological or even medical assistance in several areas of the country. Relatives and dear ones of subsisters may as well endure secondary anguish, and some may not comprehend how to supply meaningful aid. Violence has major financial implications. The increasing occurrence of GBV put a significant strain on the medical and judicial networks, together with leaving countless subsisters unable to perform or freely socialize in public. According to a 2014 report by Muller and Gahan in South Africa for example, GBV, particularly violence against women, cost the economy between R 28.4 x 10^9 to R 42.4 x 10^9, or between 0.9 to 1.3 percent of gross domestic product (GDP) in 2012/2013[64].

4.4. Handling of GBV

To stop GBV from occurring in the first place, is a primary goal in many countries.GBV avoidance initiatives are inextricably related to attempts to enhance gender equality in general, since it is based on gender norms and power disparities. As a result, rather than treating GBV as a separate and independent issue, it must be contextualized within the framework of gender disparities. Several organisations have been tirelessly working to create awareness of the crisis and help victims of GBV using diverse approaches such as a focus change which consist on changing the way women are viewed from victims to survivors, actors of change [65].

Furthermore, some of these organisations work on boosting women's political engagement and power. Women are entitled to engage in political entities on an equal footing with men in all aspects of society, even in peace negotiations. Women are poorly represented politically in several countries, and they are frequently sidelined from official diplomatic talks. This has far-reaching implications for the prospect of achieving long-term prosperity, peace, and human security. Other efforts are to promote female empowerment, which increases negotiating power and the capacity of women to exit violent marriages. This comprises increasing entrepreneurial and job prospects, boosting women's procuring lands and property rights, supporting gender equality in unsettled care work, and fostering entry to high-quality education [66].

At the state level, countries have come up with methods to combat this scourge of GBV and consequently decrease the number of victims each year. Kenya saw its first application called “Report it! Stop!’’see the light to combat this scourge [67]. France installed detection systems in supermarkets and health centers to allow victims of gender and family abuse to notify authorities. They might as well use newly developed passwords to notify personnel of the need for assistance [68]. Domestic violence resource Center (DVRC) in Australia published special recommendations for family and friends on how to assist those who are victims of domestic violence (DV) [69]. In addition to what has been said above, many nations have opted to use electronic devices such as watches, bracelets, jewelry, tags to be able to track down GBV offenders. France has set up electronic bracelets to put the victims of their offenders out of reach. Global positioning system (GPS) detecting devices, that are comparable to labels applied to follow sexual criminals, identify when an offender goes nearer and send a warning to a private security service, that instructs him to surrender. If the person refuses, protecting services are alerted. Similar mechanisms have been in operation in Spain and the USA, and have been tested in the United Kingdom and Australia.

Some studies have also been reported on GBV control. Rituerto-Gonzalez and colleagues proposed BINDI that is a portable solution for detecting people being assaulted. This device is capable of identifying and alerting when a person is in an acute emotional situation such as panic, anxiety, or tension as their mild relative that may be induced by a gender violence incident, so that appropriate assistance can be provided [70]. The principal challenge faced by this device is the lack of available data. Shu and co-workers

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presented physiological signal-based emotion detection, encompassing emotion models, emotion elicitation methods, released emotional physiological datasets, features, classifiers, and the entire system for emotion detection based on physiological signals [71]. A multi-modal technique to measuring the Gender-Based Violent Index that detects the coverage of green canopies using satellite photography as well as sensing the degree of atmospheric pollution to quantify violence incidents before they occur in a certain neighborhood. To aid in the detection phase, a computer vision technique was used to satellite imagery to monitor and map the Vegetation Index (VI) on a scale of 0-100 in a neighborhood, in addition to applying air pollution sensors and the Internet of Things to monitor the level of stimulants that amplify the origin of sexual violence [72].

Although these technologies put together to curb this plague of GBV have been proven to be effective and slows down the plague, they have also been criticized because of the shortcomings that they have presented. For example, if the offender is determined to commit the crime, these giveaways will not stop the person from continuing their act. Additionally, the intervention time when the person is attacked is often not prompt.

5. Biosensors

Biosensors are devices that convert biological signals or responses into an electrical wave or signal that can then be established or adapted to showcase some constructive form of eventual result. These sensors are typically outfitted with some type of modification and sensing structure. These are well known for their magnificent sensitivity and selectivity conditions. A biosensor should be highly precise, independent of somatic parameters, eco sustainable, reproducible, inexpensive, and reusable [73]. Biosensors may be classified into three classes based on their generation as illustrated in Figure 3[74].

Applications of biosensors have been investigated in numerous applications such as tackling health related issues. Bahl et al.(2020) elaborated on the use of biosensors to tackle the covid-19 pandemics by detecting early manifestations such as respiration and heart rate of the virus infections [75]. Integrated printed microfluidic biosensors for healthcare was presented by Loo et al (2019). In developing countries, these biosensors could supply prompt healthcare administration, such as pathogen antigen screening for arising disease outbreak management and protective immunoglobulin G (IgG) antibodies for global serological surveillance to evaluate population-level immunity and the effectiveness of an immunization program [76].

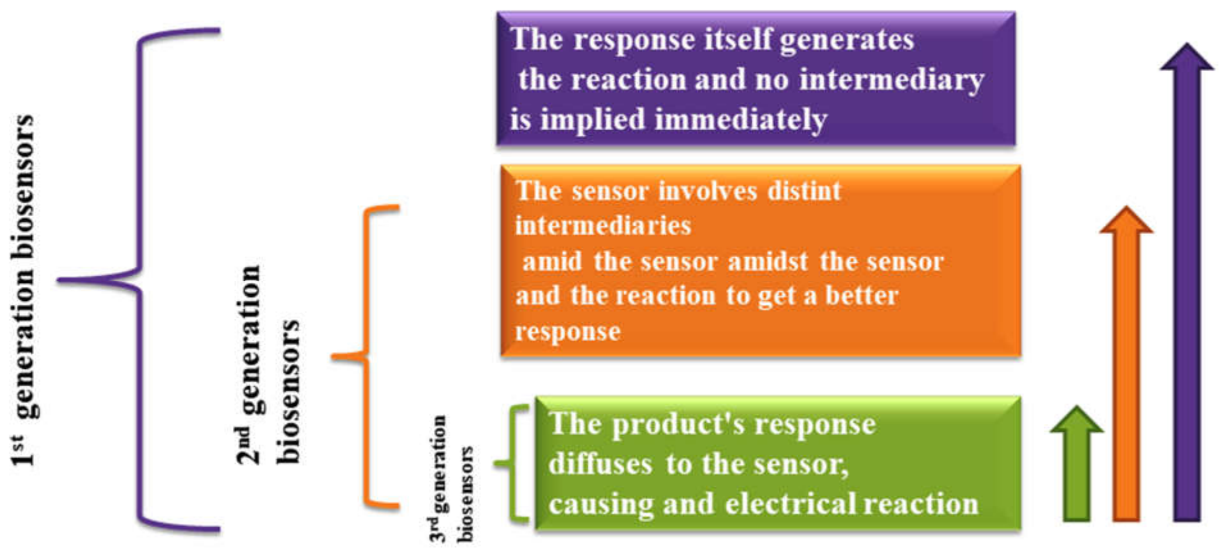

Figure 3. Forms of biosensors based on their generation.

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Printed microfluidic biosensors are currently used in healthcare for molecular diagnostics, in vitro and in vivo applications. Table 3 shows some of these implementations using different printed microfluidic biosensors.

Table 3. Instances of Integrated Printed Microfluidic Biosensors Used in Healthcare and Food Safety Implementations [77].

Application	Microfluidic	Target	Recognition element	Signal detection	Detection limit	Ref
Vaccination antibody screening	2D-printed polymer	Antibody igG	Elisa	Optical	0.14 mU/mL	[78]
Toxin contamination	2D-printed paper	Alfatoxin-B1 in corn	Anti-alfatoxin B1 antibody	Optical (luminescence)	< 5 ppb (in spiked corn sample)	[79]
Determination of HIV antiretroviral therapy initiation	3D-printed FDM	$CD4^+$ cell counting	APC-αCD3 (stains all T lymphocytes); PerCP-αCD4 (stains $CD4^+$ subpopulation),	Optical (microscopic imaging)	< 200/µL (in whole blood)	[80]
Metabolic profile analysis	3D-printed FDM	Pyruvate, lactate; overall conversion rate (metabolic flux)	Radioactive ^{13}C	Magnetic resonance [hyperpolarized micromagnetic resonance spectrometer (HMRS)]	10^4 cells (K562 and Jurkat cells)	[81]
Cancer diagnosis	2D-printed paper	Cancer overexpressed biomarkers [e.g., carcinoembryonic antigen (CEA), alphafetoprotein (AFP), cancer antigen 125 (CA125), carbohydrate antigen 153 (CA153)]	Nano-liposomal amplification	Electrochemical (impedance spectroscopy)	0.01 ng/ml (CEA); 0.01 ng/ml (AFP); 0.05 ng/ml (CA125); 0.05 ng/ml (CA153) (in 2 µl buffer)	[82]

Other applications of biosensors include cancer detection, diabetes detection. Kaur et al.(2022) in their work reviewed some latest advancement of biosensors in cancer detection. In this study, it was demonstrated that numerous biosensors were fabricated for cancer detection. Nevertheless, these biosensors presented some drawback mainly, control of the binding site of a fluorescent molecule that can occupy the antigen binding site is difficult. There is a chance that the fluorescent tag will interact with the target molecule, producing false results. further limitations such as limited multiplexing, long assay times, photobleaching and phototoxicity, and false positive and false negative results caused by intensity changes in a single emitter, high background noise, low sensitivity and output signal intensity, high detection limit, and specificity are often noticed [83].

6. Conclusion

Extensive research has been conducted for the removal of pollutants from wastewater. However, few of these studies have gone far to explore the fate of these adsorbents once it has successfully removed the pollutants which most of the time is discarded into the environment constituting a secondary application. In aqueous solutions, adsorbents or catalysts that are used to remove dyes from wastewater gain charge on their surface. Furthermore, when these exhausted negatively charged solids come into contact with aqueous solutions, they may decrease the hardness of other wastewaters. As a result, the reuse of exhausted sorbents or exhausted catalysts appears to possess a strong potential, particularly if the factory is situated in a geographical area with access to hard water. However, there is little to no literature on the inclusion of exhausted sorbents laden with dyes and poisonous metals in the unprocessed material for its production. It is therefore critical that significant investigations be conducted in numerous applications to monitor the fate of the adsorbent. One of this reuse application could be trapping the spent adsorbent in a solid phase for fingerprint detection or in sensors. The metal loaded adsorbent could be reused in jewelries, bracelets, watches, tags, necklaces as tracking devices. This incorporated onto the gadgets that will be made as sensors could be intensively applied and used in the GBV fight to reduce this scourge.

Biosensors can have a significant impact on transforming current analytical methods into diagnostic approaches by reorganizing their sensing strategies, upgrading conventional biosensors with nanotechnology and biotechnology, and sensing various viruses. There are general applications in health-care monitoring, metabolite measurement, disease screening, insulin treatment, clinical psychotherapy, medical diagnostics, drug development, and so on.

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