Chapter 1

Introduction to the state of the art and relevant aspects of the applications of adsorption for environmental safety and sustainability

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We are in the midst of a rising crisis ensuing from environmental contamination, which is mainly caused by industrial and domestic activities, as well as the significant amount of these contaminants released into the environment by both natural and anthropogenic activities, which disrupts atmospheric, aquatic, and terrestrial systems. Thus, there is an urgent necessity for innovative approaches based on biosorbents for the removal of these contaminants, owing to the unique features of biosorbents, such as biocompatibility, biodegradability, and renewability. Hence, this chapter aims to present the development, utilization, and applications of the adsorption of heavy metals and dyes for reasons of environmental sustainability and safety.

List of unusual acronyms used

Acronym	Definition
AC	Activated carbon
ASB	Adsorbates
AST	Adsorption
ESS	Environmental safety and sustainability
HMI	Heavy metal ions
HMs	Heavy metals
MT	Magnetic
MO	Metal oxide
TDS	Total dissolved solids

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1.1 Introduction

As a result of the world population's rapidly increasing numbers, natural events such as volcanic explosions/eruptions, forest fires, and particle suspension in the atmosphere as well as industrialization and urbanization processes such as mining, transportation, wastewater from agriculture, and emissions into the atmosphere have all made significant contributions to environmental pollution [1–5]. Toxic gases, heavy metals (HMs)/heavy metal ions (HMIs), dyes, residential and industrial effluents, and organophosphates are all released by these anthropogenic and natural processes, which pose a serious threat to the wellbeing of humans and the environment [6–13]. The main pollutants in the environment and their origins are shown in figure 1.1.

Consequently, one of the biggest problems facing society in the twenty-first century is sustainable wastewater treatment due to these pollutants in the environment [14–21]. It will continue to be of utmost importance to create ecologically benign and economically viable treatment alternatives, especially for emerging nations, as the dumping of hazardous industrial sludge into water bodies increases [5, 22–24]. One of the most studied and applied techniques for the removal of HMs, dyes, and other industrial effluents from wastewater is adsorption (AST) or biosorption [1, 2, 25–31].

AST or biosorption, which refers to the use of both living (biotic) and non-living (abiotic) biomass, has attained significant popularity during the last few decades as a result of certain encouraging findings [1, 2, 31]. Waste products from agriculture, such as fruit, crop, and other plant wastes (collectively referred to in this chapter as 'agricultural wastes'), have frequently been utilized to remove HMs, dyes, and other

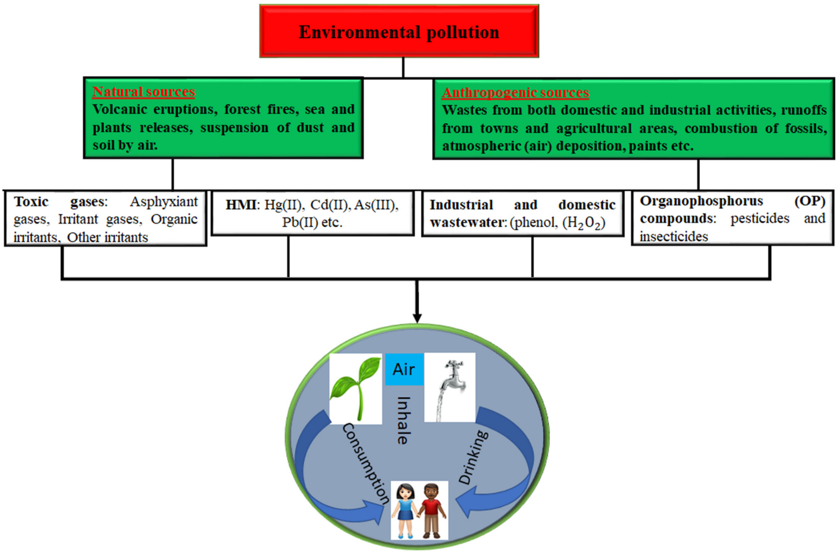

Figure 1.1. The main pollutants in the environment and their origins.

industrial effluents from wastewater via biosorption (or AST) processes [1, 2, 31]. Several of these potential uses of agricultural wastes as biosorbents for wastewater treatment have been investigated by a number of researchers, with encouraging findings [1, 2, 31]. These agricultural wastes predominantly absorb HMs, dyes, and other industrial effluents through the sorption of functional groups such as carboxyls and hydroxyls. The pH value and the co-solute content have been determined to be the key factors influencing the biosorption (or AST) of pollutants by agricultural wastes [1, 2, 31].

The quantity of solute that is adsorbed on the surface of the adsorbent per unit weight as a function of the equilibrium concentration at a fixed temperature is estimated using a representation known as an isotherm for AST [32, 33]. The Langmuir and Freundlich isotherms, which describe the AST (or biosorption) process, are the most frequently utilized [1, 34, 35]. The Temkin isotherm [34, 35], the Redlich–Peterson isotherm [36], the Koble–Corrigan isotherm [37], the Sips isotherm [38], the Toth isotherm [39], the Dubinin–Radushkevich isotherm [40, 41], Fritz–Schlunder isotherm [42], and the Radke and Prausnitz isotherm [43] models have also been utilized. The Langmuir isotherm model and pseudo second-order kinetic models are among the best models for explaining the agricultural waste-based biosorption of HMs, dyes, and other industrial effluents, according to a number of kinetic and isotherm investigations undertaken by various researchers and authors [1, 2, 31, 44, 45]. The outcomes of desorption investigations carried out by many researchers have further demonstrated the viability of agricultural wastes as reusable biosorbents [1, 2, 31]. The use of some agricultural wastes as biosorbents to remove HMs, dyes, and other industrial effluents from contaminated water, along with other significant features of this practice, has been extensively discussed in several publications [1, 2, 31]. Several reports have described the effects of a number of variables, including pH, initial solute concentration, biosorbent dose, co-solute concentration, activation, etc [1, 2, 31]. Hence, there is a substantial rationale for, and unique benefits to be obtained from investigating the variety of adsorbents and their effectiveness in removing HMs, dyes, and other industrial effluents from wastewater so as to sustain and preserve the environment (in support of environmental safety and sustainability). Nevertheless, a recent review study by Ukhurebor *et al* [31] placed a substantial emphasis on the numerous aspects of AST (or biosorption) for water treatment and some of the main issues, in addition to the potential of AST for purifying water. Figure 1.2, which was adapted from Ukhurebor *et al* [31], illustrates some of the processes involved in AST for water treatment and some of the treatment approaches for pollutants.

The underlying causes of pollutants and the idea of AST for removing emerging (newly identified) contaminants are addressed in this chapter. This chapter's major emphasis is to present an overview of what drives AST as an efficient technique for treating newly identified pollutants and the most recent developments in the technique of AST. Hence, this chapter introduces the theme of this book (which is

Figure 1.2. A schematic illustration of a variety of pollutant mitigation methods and their relationships to water purification AST (or biosorption) mechanisms. Reprinted by permission from Springer Nature [31], Copyright (2023).

centered on AST applications for environmental sustainability) and provides an introduction to the state of the art and relevant aspects of the applications of AST for environmental safety and sustainability (ESS). Furthermore, this book attempts to highlight the types, characteristics, and management options (reusability, recyclability, and final disposal) of adsorbents commonly used for environmental sustainability reasons in chapter 2. Chapter 3 addresses activated biosorbents for the removal of metals from aqueous solutions, while chapter 4 describes functionalized biosorbents for the sequestration of dyes from aqueous solutions, and chapter 5 discusses the sequestration of HMs from soil using functionalized biosorbents. The photocatalytic degradation of dyes and metal ions using functionalized biosorbents is discussed in chapter 6, and the effective sensing and sequestration of metal ions and dyes using functionalized biosorbents is discussed in chapter 7. Chapter 8 covers the use of microorganism-derived biosorbents in the removal of metal and dye ions, and chapter 9 describes biosorbents derived from invasive plants for environmental remediation. Chapter 10 deals with the use of microorganism-derived biosorbents in the sequestration of contaminants from the soil, followed by chapter 11, which deals with the modeling of AST processes that employ biosorbents for the removal of contaminants from water-soluble solutions using the kinetic and isotherm models. Green-derived biosorbents for the degradation of petroleum contaminants are discussed in chapter 12. A response surface methodology for the AST of HMs and dyes using biosorbents is discussed in chapter 13, and the cost, environmental evaluations, and comparisons of commonly used sorbents are discussed in chapter 14. The last chapter (chapter 15) deals with the challenges and perspectives of AST applications for environmental sustainability.

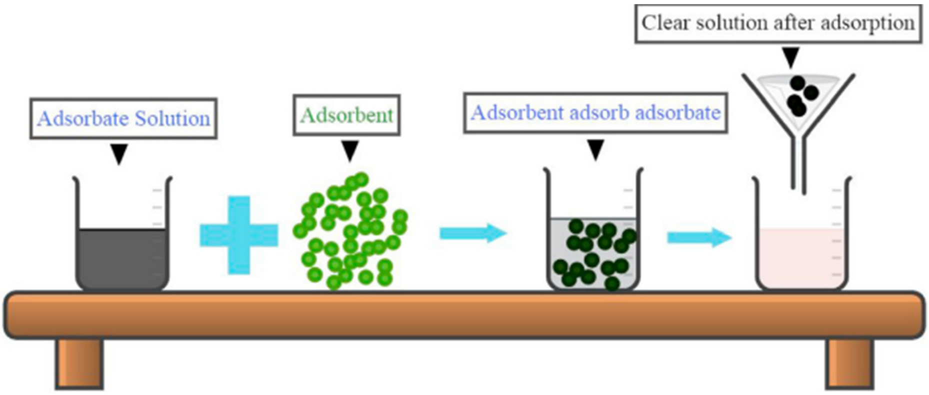

Figure 1.3. The procedure for AST. Reprinted from [1], Copyright (2023), with permission from Elsevier.

1.2 The development of AST

The process that occurs when ions or molecules from a gaseous or liquid bulk phase adhere to a solid surface is known as AST. Adsorbents are solids utilized for AST, whereas adsorbates (ASB) are molecules or ions [3]. Liquids are occasionally employed as adsorbents. ASBs should not penetrate the adsorbent's structure, since AST is a surface phenomenon that only affects the adsorbent's surface. The AST process is shown in figure 1.3 (adopted from Rathi and Kumar [1]). Desorption is the opposite process, in which a molecule is detached from an adsorbent surface [46].

1.2.1 The principle, concept, and mechanism of AST

The exchange of mass and the AST of carbon molecules from a liquid or gas (fluid) phase onto an adsorbent (solid surface) are the fundamental ideas behind carbon AST. This method of making activated carbon (AC) is used solely to produce very porous molecules of carbon with a sizable interior surface. The aforementioned porous structure captures and holds metals and organic and inorganic substances. According to Sagar *et al* [47], AST ensues when a contaminant has a restricted ability to dissolve in waste products, when it has a greater carbon affinity than its affinity for the waste materials, or both. AST is a result of the fact that the constituent parts (particles) on the surface of the adsorbent have unequal or residual attraction forces that are not in equilibrium with the larger adsorbent's molecules, in which all the forces are harmonized. The energy of the constituent parts at the surface of the adsorbent is considerably greater than that of the constituent parts within. According to Hessou *et al* [48], this extra energy per unit surface area is known as 'surface energy,' and it is necessary for the binding of the ASB to its adsorbent surface. The degree of AST tends to rise as the adsorbent's surface area per unit mass increases in a given setting. AST enthalpy and entropy are other significant factors that should be taken into account [49].

1.2.2 AST classification

Depending on how the ASB adheres to the surface of the adsorbent, AST may be categorized into two groups: physical AST and chemical AST [50]. Chemical AST is also referred to as 'chemisorption' because, in this case, the ASB is attached to the surface of the adsorbent through potent covalent bonds. Physical AST is also referred to as physisorption, in which the ASB attaches to the surface of the adsorbent owing to weaker forces such as electrostatic attraction and the van der Waals forces. Chemisorption is slower than physisorption and characteristically results in the development of a monolayer on the adsorbent's surface, while physisorption characteristically results in the development of multiple layers [35, 51]. At temperatures less than or close to the critical temperature of ASB, where it is very effective, physisorption is a process that can be reversed. Chemisorption, in contrast with physisorption, typically takes place at temperatures considerably greater than the critical temperature. Both types of AST might occur simultaneously or one may occur after the other under ideal conditions. Because physisorption is exothermic, i.e. it is defined by a decrease in free energy and entropy, it occurs relatively quickly at low temperatures and dramatically lessens with an increase in temperature. However, beyond a certain point, chemisorption increases with temperature and then starts to decline [52, 53].

1.3 Categories and sources of pollutants and emerging (newly identified) contaminants in water

The threat of emerging pollutants is rising. The environment contains an enormous variety of pollutants, each with unique physical, chemical, and toxicological properties. The pollutants come from industrial waste, household wastes, wastes from farm animals, agricultural waste, and radioactive waste. They include both organic and inorganic chemicals. A recent review by Rathi and Kumar [1] highlighted the various emerging (newly identified) pollutants and their sources.

1.3.1 Wastes from industry

Many companies produce industrial wastes which contain HMs and other pollutants [1, 2, 31]. Some of the main emerging (newly identified) pollutants from pharmaceuticals include sulfamethazine, diclofenac, carbamazepine, caffeine, ibuprofen, clofibric acid, ciprofloxacin, bisphenol A, atenolol, metronidazole, dimetridazole, datrizoate, metalaxyl, tricyclazole, fludioxonil, bentazon, carbofuran, iopamidol, etc [54–56], while the main emerging (newly identified) pollutants from the personal care industry include estrone, estradiol, progesterone, testosterone, estriol, methyl paraben, ethyl paraben, propyl paraben perflouro octane sulfonate, etc [57, 58]. The main emerging (newly identified) pollutants emitted from power plants are oxides of sulfur, nitrogen, and carbon, particulate matter (PM), formaldehyde, furans, dioxins, and HMs (such as mercury, cadmium, copper, chromium, lead, etc.) [1, 2, 31].

The next-largest industry that produces hazardous wastewater discharges is the manufacturing industry. Even though this sector includes a wide variety of production techniques, its distinctive pollutants are apparent in every manufacturing system. In addition, it is possible to identify the petrochemical and chemical industries, paper and pulp manufacturers, and electroplating businesses as sources of effluent contamination. Chemicals such as benzene, phenol, acetone, petroleum products, and nitrogen as well as other dangerous chemicals can be found in the wastes of petroleum refineries. HM ions from the paper and pulp industries, as well as zinc, calcium, magnesium, sodium, and potassium, can be found in the wastewater produced by electroplating facilities [59].

The manufacture of printed circuit boards is a significant source of HM pollution. Soldering plates made of zinc, lead, and nickel are the most frequently utilized prone overlays. The apparel, tannery, chemical, and textile-related sectors have all employed various colored pigments. Nickel is the main contaminant in the effluents from mining and smelting activities, while lead is the main contaminant in the effluent from the painting industry [1].

1.3.2 Wastes from domestic activities

Among the most common household wastes are significant sewage discharges. These are contaminants that might endanger people's health by harming wastewater treatment facilities, drainage systems, and the environment as well as by preventing the recycling of biosolids and wastewater. Caffeine, paraxanthine, and acetaminophen are a few of the emerging (newly identified) pollutants that are readily discovered in sewage systems [60]. The major pollutants in the drainage include total dissolved solids (TDS), colorants, cadmium, nickel, zinc, mercury, copper, lead, and arsenic, according to Metro Melbourne water utilities. Municipal wastewater is a mixture of the two main wastes produced: (a) gray water refers to the water from the kitchen sink, the washer, and the shower, and (b) black water is the water that bathrooms or restrooms discharge. The harmful substances found include boron, which is naturally present in glass, the majority of metals, steel, ceramic soap, and washing powder. Additionally, meals, cosmetics, and the flocculants used in water filtration frequently include iron. The natural deposition and movement of salt water involves sodium, which is also a component of water softening, cleaning, and soap-making chemicals. Ammonia is a by-product of the decomposition of biological (organic) materials, including urea from living organisms. It is frequently utilized in the manufacture of textiles, plastics, cleaning agents, and food items. These are some of the pollutants that can be found in household trash, according to some reports [1, 2, 31].

1.3.3 Wastes from animal farming

The residues from animal product contamination have an impact on the health of the population. Organic pollutants, elemental pollutants, and mycotoxins are three types of contaminants. Pesticides, animal pharmaceuticals, synthetic chemicals such as polybrominated fire retardants, and other pollutants such as dioxins are examples of natural substances that are a cause for concern. Dioxins and their related compounds, such as polychlorinated dibenzodioxins, polychlorinated dibenzofurans, and a small number of polychlorinated dioxin-like biphenyls, make up a significant compositional community. Animal health necessitates some chemical substances, among which feed is the foremost. Lead, zinc, and cadmium are others. Other pollutants include chemicals such as insecticides, pesticides, and disinfectants as well as inorganic and organic debris comprising endotoxins, bacteria, allergens, and fungi [61].

1.3.4 Wastes from agricultural activities

New agriculturally harmful compounds such as antibiotics, vaccines, growth boosters, and hormones have emerged during the last twenty years. These can enter water through runoff from the surface and leaching from fisheries and livestock farms, as well as through the fertilization of fields with sludge. Through the discharge of wastewater into aquatic environments, farming not only contributes to the presence of significant pollutants but also causes their resurgence [1]. Some of the emerging (newly identified) toxins from pesticides are caffeine, diclofenac, estriol, estrone, progesterone, testosterone, triclosan, bisphenol A, ametryn, atrazine, carbendazim, clomazone, difenoconazole, chlorpyrifos, etc [62]. Pesticides and fertilizers are used in large quantities in modern agricultural practice [1].

The greatest potential yields of food and fiber are the primary goals of such chemical alterations [1]. Nitrate poisoning of underground water typically occurs due to the overuse of nitrogen-bearing fertilizers, which cause leaching beneath the root region [1]. Fertilizers, which are typically mineral/inorganic compounds, are applied on a regular basis each year and include nitrogen, phosphorus, potassium (NPK), and metals to reduce the quantity of iron, zinc, copper, boron, and molybdenum, which are examples of micronutrients [1]. NH_4NO_3, $(NH_4)_2SO_4$, KNO_3, NO_3-, $NH_4PO_4^{3-}$, and other contaminants may behave as both pollutants and nutrients in waste from agriculture [63].

1.4 Various adsorbent types

Various chemical compositions and geometrical structural components can be present in solid adsorbent substances [1, 2, 31]. Better knowledge is required to support their use in commercial applications or laboratory procedures. Adsorbents are often divided into two categories: natural organic adsorbents and synthetic adsorbents, depending on what they are made from. Minerals, charcoal, ores, clays, and zeolites are examples of natural organic adsorbents [1, 2, 31], while synthetic adsorbents are made from waste materials such as waste sludge, agricultural waste, industrial waste, etc [1, 2, 31]. However, as rightly reported by Hoang *et al* [64], there is a third essential type of adsorbent, namely natural inorganic adsorbents (also known as commercial adsorbents).

1.4.1 Natural biological/organic adsorbents

Natural organic adsorbents are inexpensive, widely accessible, easy to use, and effective at absorbing or removing contaminants. According to Sharma *et al* [65], natural organic adsorbents are divided into four primary groups based on the material's source: (a) agricultural waste; (b) fruit waste; (c) plant waste; and (d) bio-adsorbents.

1.4.2 Synthetic adsorbents

The pharmaceutical industry and the food industry, as well as other industries, frequently employ synthetic adsorbents which are typically composed of polymers for the purification and separation of pollutants [66]. According to Weber and van Vliet [67], synthetic adsorbents are sphere-binding polymers with a substantial porosity and a particular surface area in the range of $5.00 \times 10^2 - 1.20 \times 10^3$ m^2 g^{-1} (dry).

1.4.3 Natural inorganic/mineral adsorbents (or commercial/industrial adsorbents)

Natural inorganic/mineral adsorbents (or commercial/industrial adsorbents) are commercialized adsorbents that are always readily accessible on the market. The commonest of these are activated carbon (AC), silica gel, activated alumina, zeolites, polymers, resins, and clay [1, 2, 31].

1.5 The application of the AST procedure

AST can occur in fluids (that is, in both the gaseous and liquid states). Recently, there has been a considerable increase in the number of AST technologies available in a variety of fields due to the increasing availability of different types of adsorbents. AST is used in a variety of processes, including enhanced wastewater treatment, the repossession and concentration of proteins, the removal of other emerging (newly identified) pollutants, the removal of dyes, the removal of HMs, the removal of phenolic compounds, the removal of odor and taste, etc [1, 68].

AST (or biosorption) methods are widely utilized for the removal of HMs, dye, and other industrial effluents from wastewater [1, 2, 31]. Activated carbon (AC) is the most popular adsorbent and provides the best removal of HMs, dye, and other industrial effluents [1, 2, 31]. AC is the most frequently utilized adsorbent. Although it produces the best outcomes, its expensive cost restricts its application. Its production and regeneration costs are significant. Freshwater resources are in short supply in the world today; therefore, it is necessary to find alternatives that reduce the strain on the available resources [1, 2, 31]. In addition, because HMs, dyes, and other industrial effluents are harmful even in tiny amounts, inexpensive adsorbents are necessary in order to develop environmentally acceptable techniques for their removal [1, 2, 31]. AST (or biosorption) is a technology that saves money and has become prevalent because it allows for the slightest amount of waste to be disposed of [1, 2, 31]. However, this brief study focuses on the different kinds of adsorbents that are now on the market as well as the AST process. It also includes inexpensive adsorbents, ranging from industrial waste to agricultural waste, and this helps to explain the performance of AST [1, 2, 31]. The criteria used to choose an adsorbent are cost-effectiveness, technological applicability, and ease of access to raw materials with little detrimental influence to the system [1, 2, 31]. However, this chapter only highlights the applications of AST in the removal of emerging (newly identified) pollutants, since other chapters describe further applications of AST in the removal of other pollutants such as dyes, HMs, etc.

1.5.1 The application of AST in the removal of emerging (newly identified) pollutants

The threat caused by emerging (newly identified) pollutants is rising [1]. Organic pollutants, such as those found in chemical fertilizers, pharmaceuticals, personal care products, hormonal substances, polymer compounds, food components, wood preservatives, products for cleaning, surfactants, antiseptics, and fire retardants, as well as other mineral/organic compounds, are the main emerging contaminants [1, 2, 31]. These substances are frequently found in the natural wastewater streams generated by human activities as well as in the industrial sector. The primary sources of emerging (newly identified) pollutants are illustrated in figure 1.4 (reprinted from Rathi and Kumar [1]). Even at modest concentrations, the majority of new pollutants can have harmful impacts on both people and aquatic species. Traditional basic and secondary treatment facilities can hardly remove or eliminate such dangerous poisons efficiently, necessitating cost-effective tertiary procedures.

The major roots of the emerging (newly identified) pollutants are shown in figure 1.5 (reprinted from Rathi and Kumar [1]). Some of the methods utilized to remove emerging (newly identified) pollutants are advanced oxidation procedures, membrane filtration, ion exchange, AST, coagulation, and sedimentation [1, 2, 31, 69]. AST is a successful strategy for eradicating new pollutants because it is highly efficient, has an affordable initial cost, and is simple to utilize. In research settings, activated carbons, modified biochars, nanoadsorbents, composite adsorbents, and other adsorbents have all been utilized to remove emerging (newly identified) pollutants from water and wastewater [1, 2, 31, 57, 69].

Figure 1.4. The primary sources of emerging (newly identified) pollutants. Reprinted from [1], Copyright (2021), with permission from Elsevier.

Figure 1.5. The major roots of emerging (newly identified) pollutants. Reprinted from [1], Copyright (2021), with permission from Elsevier.

Some of the emerging (newly identified) pollutants as reported by Rathi and Kumar [1] are bisphenol A, triclosan, ibuprofen, naproxen, ketoprofen, salicylic acid, diclofenac, acetaminophen, androstenedione, atrazine, caffeine, carbamazepine, Dilantin, estriol, estrone, ethynylestradiol, fluoxetine, hydrocodone, etc. The various adsorbents that have been utilized to remove the various emerging (newly identified) pollutants, along with their removal percentages, are described in a recent review work by Rathi and Kumar [1].

1.6 The state of the art and relevant advances in the applications of AST

Considering its accessibility, affordability, simplicity, and ecological friendliness, AST is a leading approach for the removal of emerging (newly identified) pollutants from wastewater [70, 71]. AST technology will continue to progress, overcoming its drawbacks and improving its ability to remove all pollutants, including emerging (newly identified) pollutants [72]. Only emerging (newly identified) pollutants from pharmaceuticals, insecticides, personal care items, and others are the main focus here. Since the AST process heavily depends on the surface area, and nanoparticle-based materials provide high surface areas, in turn boosting the AST performance, nanotechnology has recently become widespread in this industry. Nanomaterials can be developed into powerful adsorbents owing to their variable particle diameters [73, 74].

For the removal of mineral/organic pollutants or toxic chemicals, there are four distinct categories of nanoadsorbents: carbon nanotubes, silica-based nanoparticles, metal oxide (MO)-based nanomaterials, and chitosan-based nanoparticles [75, 76]. With the exception of chitosan-based nanoparticles, which are made from the shells of aquatic species and are biodegradable (also known as ‘green adsorbents,’ which are not harmful to the ecosystem), each form of nanoparticle has a shortcoming. It is also possible to use biomass-based nanoparticles for AST [77, 78].

Metal–organic framework adsorbents are thought to be among the latest developments in water treatment techniques [79]. In order to increase efficiency, hybrid technologies concentrate on techniques that may be combined with AST and chemical or biological treatments. The most recent methods of wastewater treatment may also be combined with physical techniques, such as the combination of ultrasound and gamma rays with AST using activated carbon [80]. The treatment and removal of contamination in wastewater may be done efficiently and precisely using magnetic (MT) carbon material. MT separation is an emerging form of water treatment because of its low cost and simplicity of application. In order to ease segregation, cleaning, and re-dispersion of the materials, separation is performed by introducing an external MT field. In actuality, the capability to recycle or reuse MT carbon substances or materials increases the chance that these products will be used in operations for the large-scale treatment and management of wastewater [81].

1.7 Conclusions and future insights

Contaminants are related to the emergence of dangerous substances emanating from humans and the industrial sector, which is alarmingly expanding daily. Pharmacological substances are a top target among emerging (newly identified) pollutants because of their ability to cause serious and extensive effects to the environment and human health. Numerous emerging (newly identified) contaminants present a serious risk to living things, even at extremely low concentrations.

In order to effectively remove pollutants, however, effective adsorbents such as nanoadsorbents, MT adsorbents, and MO adsorbents must be used together with hybrid AST techniques. The use of AST, its basic concepts and mechanisms, the sources and varieties of contaminants, the various adsorbents that may be utilized for treating ASB, and AST's role in removing emerging (newly identified) pollutants were all covered in this chapter.

AST-based methods for the treatment of hazardous and damaging wastewater are unquestionably a viable choice due to their affordability and accessibility. Finding the right adsorbent to take up the ASB of concern is a crucial step in the AST process.

A suitable, low-cost adsorbent must be chosen, and the best conditions must be established. This scenario must take into account variables including the starting ASB concentration, contact duration, pH, adsorbent, and operational conditions. The threat of emerging (newly identified) pollutants is rising.

The significance of AST methods for the elimination of emerging (newly identified) pollutants has been meticulously highlighted. AST has the ability to eliminate very close to 100% (about 95%) of emerging (newly identified) pollutants. For the removal of emerging (newly identified) pollutants, hybrid AST techniques, MO adsorbents, MT adsorbents, as well as nanoadsorbents can all be used to increase the effectiveness of AST. The AST procedure may successfully remove these pollutants from wastewater. By using a hybrid system consisting of AST, an

MO-based adsorbent, and a nanoscale green adsorbent, the effectiveness of the AST may be enhanced. A powerful alternative is offered by the development of contemporary adsorbents for waste and by-products that rely on organic materials, which offer the benefits of utilizing inexpensive adsorbents.

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