

Review Article

The Ecogeographical Impact of Air Pollution in the Azerbaijan Cities: Possible Plant/Synthetic-Based Nanomaterial Solutions

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The current paper deals with the major causes of air pollution in the big cities of Azerbaijan. In this context, industrial gas wastes and transport systems are the most important sources of air pollution. Also, relevant factors following the intensity of air pollution have recently been recognized. The motor transport system and its detrimental effects on human health are tightly connected with air pollution. Therefore, the use of ecological and geographical data could be an efficient approach to preventing air pollution in urban regions. Also, the advantage of nanotechnology in removing air contaminants has been introduced as a promising solution. Nanomaterials can serve as nano adsorbents, nanocatalysts, nano filters/membranes, and nanosensors in air pollution remediation. Moreover, the green synthesis of nanomaterials from plant-based origins is promising in this context. Also, nanotechnology is a robust candidate for the production of green and sustainable energy resources. In a nutshell, recommendations on the prevention and alleviation of air pollution, as well as the methods of refining the urban environment and controlling polluting agents are represented.

1. Introduction

Expansion of petroleum-based industries and developments in urban areas in Azerbaijan, as well as other regions of the world, has been following ecological challenges in crowded cities due to the increment in population, vehicles, and industries [1]. The emitted pollutants to the atmosphere have mostly (at least 2/3) been attributed to Baku city [2]. Also, the low quality of air-cleaning apparatuses has significantly increased the emit of deleterious substances from chemical, petrochemical, and aluminum generating industries [3]. Furthermore, the rapid growth of the population has induced a negative impact on the atmosphere [4]. It should be noticed that the emission of toxic pollutants is increasingly continued despite the occurrence of modern filtration equipment [5]. The main sources of air pollution are industrial facilities and motor vehicles. The increase in polluting sources is not in correlation with the territorial capac-

ities of the urban area in Azerbaijan [3]. Therefore, this ecological situation influences the human health of the living urban negatively, it has been reported that several gastrointestinal, neurologic, respiratory, and nephrology health problems are connected with air pollution [6]. Thus, the investigation of air pollution, its causes, and its consequences are of great importance. The current review focuses on the main causes of air pollution in the urban areas of Azerbaijan and offers possible ecological solutions as concluding remarks. Also, the potential role of nanotechnology in the remediation of air pollution is discussed.

1.1. Transport System and Air Pollution. Surely, the transport system plays a chief role in inducing air, water, and soil pollution. Particularly, its role in the contamination of the air is an international problem. With the growth of population and enlargement of the cities, the transport vehicles are also increasing, which triggers the current problems of

human health as well as environmental destruction [7]. Vehicles produce up to 80% of gaseous substances responsible for air pollution in Azerbaijan [3]. Therefore, the assessment of vehicle-induced air pollution is an emerging issue. Currently, over 860 thousand vehicles are used in Azerbaijan [8]. Motor vehicles produce non-combustible carbohydrogenic agents such as lead, mercury, sulfur, nitrogen, carbon oxides, benzopyrene, and carcinogenic substances [9]. These toxic wastes enter the active zone of the biosphere with a harmful effect [10]. Notably, emitted lead with gaseous contaminants exhibits highly toxic effects. Windy weather, high building, and areas with lower relief spread the waste and form pollution in the atmosphere which can influence human health as well [5]. Currently, transport is a chief portion of the economic infrastructure in Azerbaijan [11]. It shows a fundamental role in organizing socio-economic issues. On the other hand, social and economic matters are based on meeting the requirement of the transport sector [11]. In this context, the function of the transport system should be in agreement with demand and supply. The transport system highly affects the economic issues via enhancing labor efficiency and diminishing the good delivery time. Moreover, the transport system plays a crucial role in the operative use of natural reservoirs of a country and its global integration. The development of market mechanisms in Azerbaijan in economy elevates the plausibility of utilizing transport services by different individual and legal entities. Azerbaijan's economy is highly connected to sea transport [12]. In this regard, it is important to expand the seaport network of this country concerning the perspective plans of the developments of the international trade and increment of transport capacity for effective transmission of liquid, containers, and goods. Regarding the air transport system, optimizing the number of international airports, transitioning to unified types, and technical refinements should be considered [13]. Collectively, the establishment of extra effective and internationally practiced mechanisms of utilizing private capital is required for the improvement of the transport sector of Azerbaijan.

From the environmental point of view, it should be noticed that the use of new vehicles is proposed to avoid the production of larger levels of waste [3]. Also, the technical situation of automobiles, prevention of utilizing obsolete cars, and enlargement of greening urban areas can prohibit air pollution. Atmosphere air pollution is directly linked with the growth of motor transport systems. Over 86000 thousand motor vehicles are found in Azerbaijan (70 thousand lorries and 20 thousand buses) [3]. The majority of the vehicles (90%) have been used for more than five years which increases air pollution. Approximately, 500 thousand tons of waste are released from motor transport into the air [14]. Also, technical problems are found in about 60% of automobiles and 25% of lorries and most of the cars are not qualified with ecological standards [3]. The use of these cars is linked with the elevated consumption of fuel and thus the production of deleterious substances which are emitted into the air. Furthermore, the ineffective privatization of a fleet of motor vehicles with a poor technical base is another important problem. Cars, which work with an internal com-

bustion engine are key sources of air pollution. These automobiles with the combustion of benzene result in the emergence of carbon oxides (20 kg/100 L of fuel). Moreover, incomplete combustion of fuel is another reason for pollution. It should be noted that 85% of the fuel is emitted into the air as burning material. The number and intensity of automobiles have raised in Baku-Sumgait agglomeration in the last years, and this is responsible for arising which is connected with the higher waste formation in Baku as well as Sumgait city [3]. The average level of pollutants in the air of Baku and Sumgait cities has changed in recent years, while concentration is constant in the cities except for Ganja city [3].

1.2. Industrial Waste and Air Pollution. Previous research has shown the regularities of the level of air pollution in connection with different factors [15]. The regularities monitor air pollution in the regions of intensive man-made effect (cities, industrial and agrarian-industrial centers, etc.) and control the circumstance of air pollution in the areas, located far from the sources of pollution. The investigations also have dealt with the study of the impact of the conduction of centralized monitoring over the air of cities and industrial centers [16] through automatized gas analyzers to find out the level of detrimental substances and their major meteorological elements [17]. This novel technique of determination of air pollution is typically applied in association with the location of points of monitoring. The point source of air pollution consists of factories and electric power plants. Volatile organic compounds (VOCs) and nitrogen oxide is elevated due to petroleum, and chemical industries' combustion in power stations. Also, O_3 is more concentrated, and more smog is formed in industrial areas [18]. Coal and sulfur originated fuel oils oxidize into Sulphur dioxide. These types of fuels are implemented to move, heat, and produce the required energy for industrial processes. Furthermore, the industry generates distinct pollutants as waste, such as fluorine derivatives or aluminum.

The main industrial sources of air pollution in Baku include the plant of Garadagh-cement, Baku Steel, refineries, the Baku Plant of construction materials, oil and gas producing plants, heating power stations, and different manufacturing plants [3]. Currently, there are 300 stationary industrial entities significantly polluting the air [3]. Normally, about 50% of their waste is neutralized by gas and dust extraction apparatuses. Approximately 80% of the neutralized pollutants are solid materials. However, the necessary tools that neutralize gas and carcinogenic substances are not used. We have previously analyzed the levels of substances emitted into the air by industrial enterprises in Baku, and Sumgait. As the result, the amounts of pollutants were 30,3% and 28,4% for all wastes; 23,7% and 13,5% for dust; 37,2% and 23,6% for carbon oxide, 58% and 75% for nitrogen oxide (NO_2) and 26% and 25,8% for SO_2 agents [19]. the emission of hydrogen wastes of chlorine and fluoride were prominent in Sumgait city, while the major pollutants in Baku city were hydrocarbons and SO_2 from oil refineries [3, 20]. The majority of the hydrocarbon waste in the city of Sumgait is donated to the Organic Synthesis and Synthetic Rubber,

whereas the sources of sulfur dioxide emissions mostly belong to the heating power stations and superphosphate plants. NO₂ wastes of Baku city are in relation to the heating power stations followed by the Garadagh cement plant [3]. Generally, air pollution in these cities occurs predominantly due to the emission of industrial dust. Figure 1 depicts the distribution of air pollution by industries sources in Azerbaijan.

1.3. Ecogeographical Effects of Air Pollution. Simultaneous assessment of ecology and geography can help us solve several environmental challenges. Firstly, this integration leads to the formation of political geography. Also, an appropriate assessment of this connection results in the production of geography-related sciences and clarification of misinterpreted concepts such as geographical ecology.

The natural climate conditions such as the speed and direction of the wind, temperature, synoptic processes, and humidity exert a pivotal role in air pollution. The investigation of the air pollution in multi-functional large cities and protecting their atmosphere is an important concept of the ecogeographical studies [22]. It is highly critical to not only study the spreading of the air pollutants throughout the anthropogenic aspects but also meteorological parameters as well as the annual seasonal changes should be evaluated. Mesoscale and macroscale climatic processes influence atmospheric air pollution due to the extensive boundaries of big cities. The shape and height of air pollutants emitting chimney sources affect the movement of pollutants in the atmosphere, particularly in windless conditions. It has been shown that traffic is the major cause of higher anthropogenic air pollutants including carbon monoxide and nitrogen during the warmer periods of the year in Azerbaijan. The traffic emissions share accounts for 65–70% of air pollution in Azerbaijan [22, 23]. It has been reported that the quantities of traffic emission were 229,9 and 410,7 thousand tons, respectively, in 2000 and 2007 years, while these were 20,8 and 37,2 thousand tons in Ganja city and 14,3 and 8,2 thousand tons in Sumgait city [24]. Unfavorable weather circumstances such as high temperature, breeze, and humidity significantly increase the concentration of pollutants [25]. As a result, the density of dust, nitrogen 4-oxide, and Co₂ were escalated by 1.2-2, 1.5-2.5, and 2-3 times higher in Sumgait city. Also, the concentration of nitrogen 4-oxide and dust reached higher than the maximum threshold in Ganja city. However, the level of air pollutants in the atmosphere was within the tolerance in the other cities of Azerbaijan. Collectively, it has been found that the concentration of pollutants in Baku is high, whereas it is moderate in Ganja and Sumgait and low in the rest. However, Nakhjavan is mainly considered a safe city.

Large industrial centers with several sources of pollution are found in the Absheron megapolis [3]. It has been shown that when the wind speed is lower than 2 m/sec and the humidity is over 90% and a strong inversion exists the smoke cloud is formed over the Absheron peninsula. Therefore, the steady temperature stratification and high air humidity at nighttime are not associated with the scattering of harmful impurities, and their accumulation occurs on the

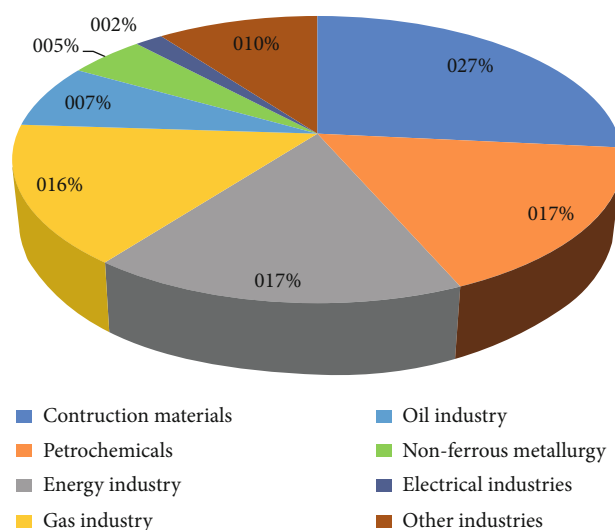


FIGURE 1: Distribution of air pollution by industries sources in Azerbaijan. (Adapted from the Effects of Petrochemicals on Climate Change and the Case of Azerbaijan) [21].

surface but in the more intensive inversion at nightfall more detrimental agents are observed. The surface inversion collapses and height inversion is generated in the morning due to the Sun's surface heating and wind speeds in the morning. The lower boundary of such inversion is gradually elevating, and in this context, the air volume is enhanced, which also encompasses deleterious impurities from pollution sources. As a result, a cloud of smoke is generated in the inversion layer at high air humidity [26–28]. Industrial fumes mainly show strip monograde in space images, whereas the texture is matte or fibrous. Also, fogs are formed over industrial cities which are depicted with a clearer tone and higher albedo value in space images of Sumgait city [3].

1.4. The Effects of Air Pollution on Human Health. One of the most important ecogeographical challenges is the air pollution of the urban environment is preserving human health. Annual analysis has shown an increment in the mortality of the working-age community after 2000, in particular after 2005 [29]. Also, infant mortality which is a chief indicator of environmental quality and human health has shown an increasing trend in distinct years in the last decade [29]. It is well documented that air pollution is amongst the most pivotal causes of serious human health problems such as respiratory, cardiovascular, and metabolic diseases. Tremendous evidence has confirmed the harmful influences of air pollution on the behavior, productivity, and well-being of exposed communities [30]. Figure 2 represents the effects of air pollution on human health.

Recently, numerous investigations have shown a tight connection between air pollution and respiratory diseases, such as asthma, chronic obstructive pulmonary disease (COPD), and lung cancer. Zhu et al. has assessed the link between both respiratory disease and lung cancer mortality and the main air pollutants in this context [32]. It was found that the elevation of the levels of SO₂, NO₂, and PM₁₀ significantly augmented the percentage of respiratory disease

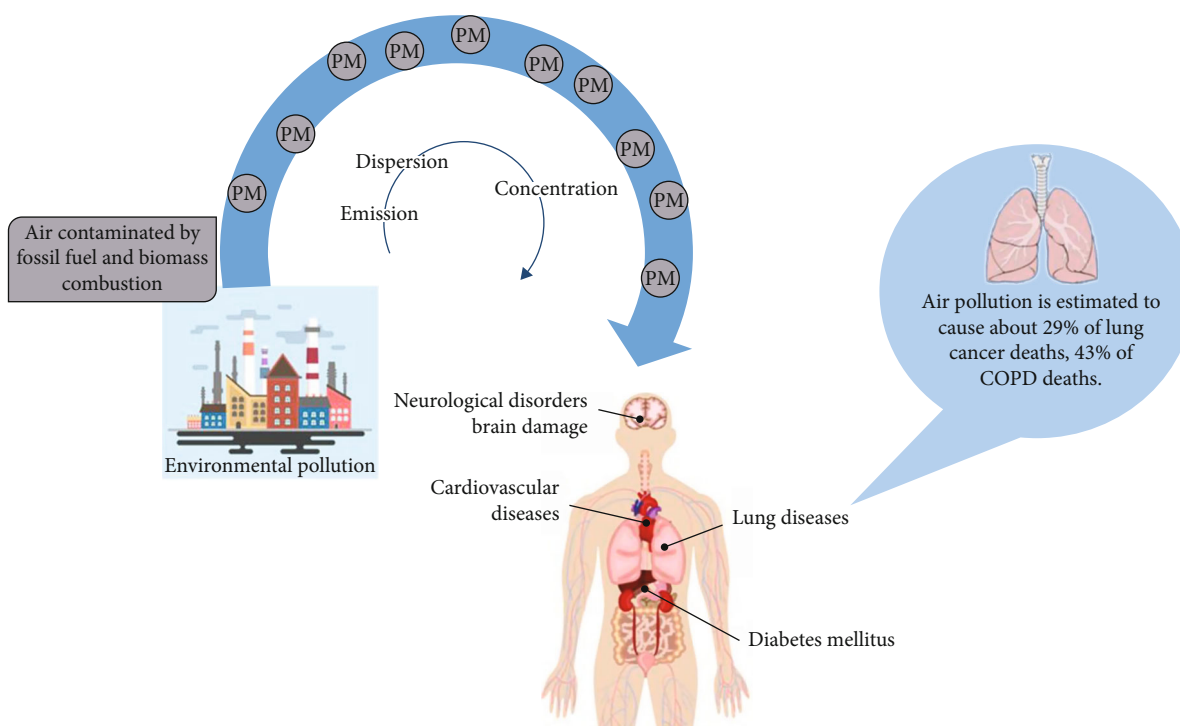


FIGURE 2: The effects of air pollution on human health. Particulate matter (PM) in the atmosphere contains a combination of elements, such as arsenic, cadmium, and lead. Air pollution shows a harmful effect on human health leading to the elevated risk of disease onset. (adopted from [31]).

mortality. Also, SO_2 was the only air contaminant considerably connected with lung cancer mortality [32]. In another study, it was reported that short-term exposure to ambient air pollutants such as NO_2 , SO_2 , CO, ozone, and $\text{PM}_{2.5}$ significantly escalated the number of asthma patients, which produces staggering costs [33]. Greenberg and co-investigators examined the long-term exposure to air pollutants particularly NO_2 and SO_2 and the worsening of asthma in adult patients. It was found that high levels of SO_2 and NO_2 substantially elevate the risk of asthma occurrence and induction of disease severity [34]. However, the results indicated that NO_2 is the most influential pollutant in the incidence of asthma. Epidemiological studies have revealed a strong connection between lung cancers and air pollutants [35]. Also, traffic-related air pollution is closely related to COPD development [36]. Sulfur dioxide has been reported to be the major air pollutant responsible for COPD has reported [37].

The noxious effects of air pollutants on the cardiovascular system have been documented [38]. In this context, SO_2 and CO are the most influencing air contaminants. In addition to cardiovascular diseases, metabolic disorders such as diabetes are strongly connected with air pollution. It has been shown that air pollutants such as NO_2 , and O_3 adversely affect glucose metabolism and insulin sensitivity [39]. In addition, it was also found that air pollution can surge the risk of type 2 diabetes [40].

Recent studies have shown the serious and negative impact of air pollution on human behavior, productivity, and well-being. It has been reported that air pollution nega-

tively affects the labor productivity of agriculture workers [41]. Chang et al. showed that air pollutants particularly $\text{PM}_{2.5}$ lead to lower productivity during work hours [42]. In children of school age, CO and $\text{PM}_{2.5}$ have been reported to diminish cognitive performance and result in lower standardized test scores [43].

1.5. Nanomaterial-Based Solutions. Similar to many other fields, nanotechnology has offered an appealing opportunity in ecosystems [44], agriculture [45], medicine [46] and air pollution remediation [47, 48]. Nanotechnology have vital role to encompass the imperative demand to sensing and treatment of the emerging hazardous bioaerosols, volatile organic compounds, and greenhouse gases with lower cost and time [48, 49] (Table 1).

In this context, green nanotechnology-based solutions are promising. In addition, several types of nanomaterials have been proposed including nano adsorbents, nanocatalysts, nano filters, and the application of nanosensors.

1.6. Green Nanotechnology-Based Solution. Green synthesis of nanomaterials based on plant origins is a novel platform to develop new nanomaterials that are non-toxic to environmental and human health and exhibits a broad potential to revolutionize large-scale nanotechnology-based processes [50, 51]. Green NPs have extensive possibilities in the realm of energy, nanomedicine, and engineering [52, 53]. Greener fabrication of nanomaterials provides the platform to design cleaner, safer, and sustainable nano-sized products [54, 55]. The elementary bases of green chemistry are the use of

TABLE 1: Various Nanomaterial based solutions are based on the target and mechanism against air pollution.

Type of nanomaterial	Plant-based or synthetic	Target pollutant	Mechanism	Reference
APTES-functionalized MWCNTs	synthetic	CO ₂	Treatment (adsorption)	[73]
APTES and pristine-modified CNTs	synthetic	CO ₂	Treatment (adsorption)	[75]
SWNTs and MWNTs)	synthetic	H ₂ S and SO ₂	Treatment (adsorption)	[108]
Si-doped and Boron-doped SWCNTs	synthetic	CO ₂ and CH ₃ OH	Treatment (adsorption)	[76]
Graphene oxide (GO)/nanocomposites	synthetic	CO ₂ , NH ₃ , SO ₂ , H ₂ S, and N ₂	Treatment (adsorption)	[77, 78]
ZnO NPs	synthetic	H ₂ S	Treatment (adsorption)	[79]
ZnO NPs	synthetic	CO ₂	Treatment (adsorption)	[80]
ZnO NPs	plant	methylene blue	Treatment (photocatalytic Degradation)	[109]
Nano iron Oxide	synthetic	SO ₂	Treatment (adsorption)	[83]
TiO ₂ /reduced graphene	synthetic	HCHO	Treatment (Degradation by Nanocatalysis)	[88]
Silicate- TiO ₂	synthetic	HCHO	Treatment (Degradation by Nanocatalysis)	[89]
cerium oxide NPs using the extract of <i>Jatropha curcas</i> plant	Plant-based	acetaldehyde	Treatment (Degradation by Nanocatalysis)	[93]
CNTs	synthetic	HC, NO _x , CO ₂ , and CO	Protection (filtering)	[99]
Polyacrylonitrile-based carbon nanofiber membrane	synthetic	formaldehyde	Protection (filtering)	[97]
Multifunctional metal-organic framework and CNT-modified filter	synthetic	ultrafine dust, SO ₂ , NO _x , and H ₂ S	Protection (filtering)	[100]
Gelatin based nanofibers	Green synthesis	HCHO, CO, PM	Protection (filtering)	[101]
Graphene-SnO ₂ Nanocomposites	synthetic	NO ₂	Protection (sensor)	[104]
Cu nanoparticle SWCNTs	synthetic	H ₂ S	Protection (sensor)	[106]
Palladium-Doped Tin Oxide	synthetic	CO	Protection (sensor)	[107]

nonhazardous, available, and biodegradable, resources and energy-efficient reactions. These nanomaterials are mainly produced using plant sources but other natural resources such as microorganisms may be applied [52]. Mounting evidence reports similar efficacy of green nanomaterials with their chemical counterparts. It should be mentioned that green chemistry-based strategies are simpler, more efficient, environmentally friendly, and cost-effective. In comparison, in chemical construction techniques toxic solvents, and high energy, temperature, and pressure conversion are utilized [56]. The chief implementation of green NPs is in the development of nanosensors, nano-drugs, and energy production and storage. Of note, green chemistry has opened the avenue in the development of safe and sustainable nanotechnology [57]. Although several, problems are connected with the green synthesis of nanomaterials, its potential as a green and sustainable method is not plunged. Figure 3 illustrates the production of green nanomaterials from plant-based origins.

Numerous multifunctional green NPs with a distinct structure, size, shape, and crystallinity have been produced by several approaches, and their potential uses have been examined. Green chemistry mainly uses plants to produce nanomaterials in a bottom-up technique in which oxidation

and reduction reactions occur [58]. Plant extracts encompass different primary and secondary metabolites such as phenols, flavonoids, alkaloids, and terpenoids which are necessary for the reduction or conversion of the substance into nanomaterials [59]. The aforementioned metabolites pave the way for the eco-friendly green synthesis of nanomaterials. The production phase of the nanomaterials is the key contributor to the environmental effects of NPs since toxic waste is mainly generated in this step [60].

Increasing demand for nano-sized products is reported, and their annual synthesis rate is 100,000 metric tons. Therefore, the development of sustainable substitutes for novel design and fabrication strategies with lower risks is an emerging field [61]. Also, regulatory authorities are required to control toxic synthesis techniques and unsafe products. The nanomaterial producing processes linked with harmful human and environmental effects should be comprehensively retrieved while assessing NPs for their greenness and sustainable fabrication [62].

1.7. Nanotechnology for the Generation of Renewable Energy.

The main research focus in this realm is the development of nano-enabled solar cells using green chemistry. Titanium dioxide, cadmium telluride, silver, and quantum dots in

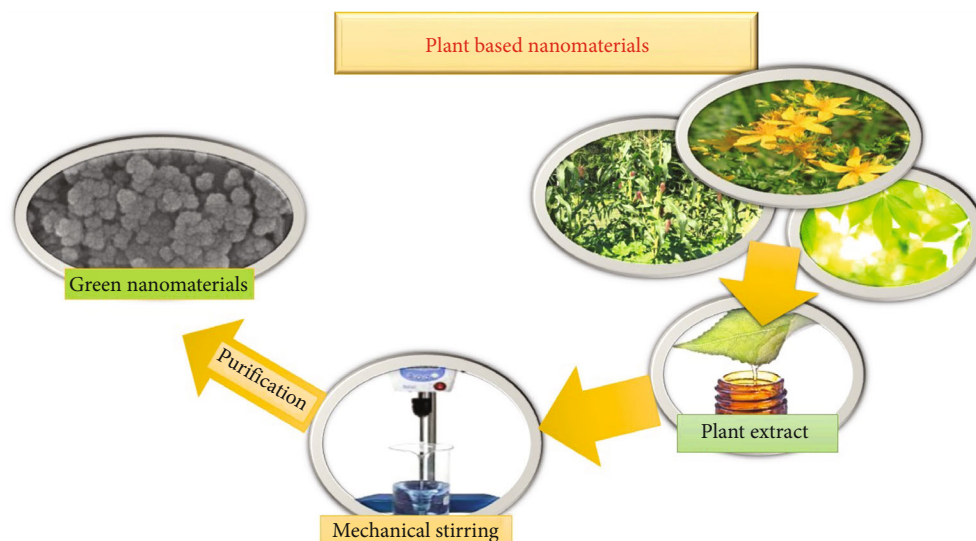


FIGURE 3: The general methodology of green synthesis.

combination with polymers that absorb solar energy to a great extent are novel nanomaterials used in this context [63]. The solar cell containing nanomaterials are much cheaper than commercially available cells [64]. Currently, researchers are working on a new method to enhance the efficiency of solar cells. Moreover, the fabrication of a sustainable product is possible by the deposition of nanocrystals, and the use of quantum dots and nanowires [65]. In addition, high-capacity energy storage is possible with the aid of nanotechnology in the field of renewable energy. Photovoltaic apparatuses incorporated with nanomaterials are promising in the production of cost-effective and efficient energy resources [66]. In the setting of the versatility of plant synthesis, this is connected with its different biochemical composition since plant segments contain several chemical components such as lipids, peptides, proteins, polysaccharides, vitamins, and nucleic acids. Also, plants contain several active constituents including, aglycones, polyols, pigments, steroids, flavonoids, terpenoids, alkaloids, saponins, polyphenols, resins, and phytohormones (Figure 4) [54, 67–72]. These agents comprise functional groups such as aldehyde, ketone, alcohol, unsaturated segments, and/or thiols which provides chemical reactions platforms for reduction-oxidation and/or stabilization of NPs during synthesis reactions [54, 67, 68].

2. Nanoadsorbents

The commonly used nano adsorbents in air pollution remediation are carbon nanotubes (CNTs) and zinc oxide nanoparticles (NPs). The enhanced properties of CNTs such as high affinity for selective adsorption of contaminants have turned them into promising tools for eliminating different types of pollutants. Moreover, CNTs exert specific properties such as high surface area, and elevated pore diameter and volume, which subsequently increase their reactive site with the particulars found in the air [73]. Also, functional groups can be added to their structure and in turn, increase the

active sites [74]. Single-walled (SWCNTs) and multi-walled (MWCNTs) CNTs are two important kinds of these NPs. It has been shown that 3-aminopropyl triethoxysilane (APTES)-functionalized MWCNTs can adsorb CO₂ through the formation of carbamate as the result of a reaction between the amino groups of APTES and CO₂ [75]. Accordingly, an enhanced reflux duration was recorded based on the thermogravimetric analysis, which leads to the attachment of more amino groups on the surface of MWCNTs that will in turn work as the reactive sites of CO₂. The increasing mass load of APTES has been used to functionalize MWCNTs, which are also commercially available [76]. In another study, Lu et al. implemented APTES and pristine-modified CNTs in the adsorption of CO₂ with increased adsorption capability from air streams [77]. Density functional theory (DFT) has been used to assess the structural, electronic, and optical features of un-doped and doped CNTs. Pristine, Si-doped and B-doped SWCNTs have been used in the adsorption of O₂, CO₂, and CH₃OH gases, which have shown either physical or chemical adsorption [78].

The hexagonal assembly of carbon atoms results in the formation of graphite and graphene. Graphite oxide has been used as an adsorbent of different contaminants. Petit et al. Have developed a graphite oxide with the addition of a polymer and then impregnation with Keggin polyanions, H₃PW₁₂O₄₀ or H₃PMo₁₂O₄₀ to remove ammonia [79]. The produced nanocomposite showed a high adsorption efficiency due to the interactions between polyanions and ammonium. In another study, manganese oxide and manganese oxide/graphite oxide composites were constructed to remove ammonia [80]. The results showed that this nanocomposite has a strong adsorptive efficiency. The NPs differ in their surface properties based on the amount of graphite oxide oxidation.

Zinc oxide (ZnO) NPs are the other common nano adsorbents in the remediation of air pollution. ZnO NPs show resistance against heat and have been extensively used

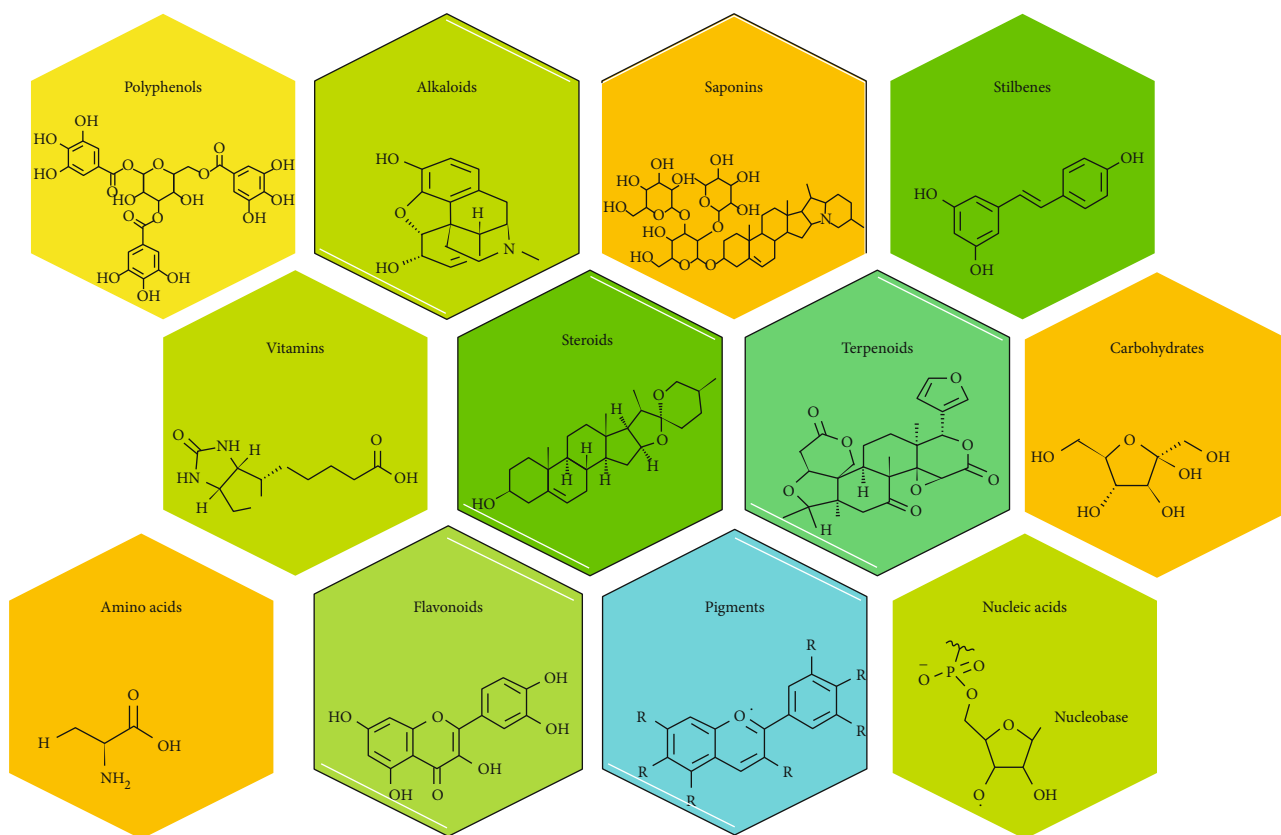


FIGURE 4: Bioactive compounds of Plants related to green nanotechnology.

for removing hydrogen sulfide (H_2S), especially in high-temperature situations [81]. Huy and coworkers have developed ZnO NPs via a simple one-step method through an ultrasonic-bases precipitation approach [82]. The produced NP was utilized to remove H_2S from the air in a rapid, convenient, efficient, and eco-friendly manner. ZnO NPs produced via a wire explosion method have been used for CO_2 adsorption [83]. The adsorption ability of this NP was reported to be 0.4 mmol/g at 283 K and 1 bar equilibrium pressure. The authors also reported that by reducing the temperature and enhancing the pressure, the adsorption ability elicited an upward trend. Also, the adsorbed CO_2 on ZnO NPs was regenerated according to the thermodynamic analysis. In another study, ZnO NPs were prepared by the wire explosion method for CO_2 adsorption [84]. In this investigation, the effect of charging voltage and chamber pressure on the morphology of NP was assessed, and the adsorption test was done for equilibrium pressure up to 1 bar and temperature of 10–25°C [84]. According to the results, ZnO NPs exhibited an adsorption ability of approximately 0.4 mmol/g at the aforementioned condition. Also, it was shown that by reducing the temperature and increasing the pressure, CO_2 adsorption escalated [84]. Natural clinoptilolite and clinoptilolite containing iron oxide NPs, have been also developed for SO_2 adsorption [85]. This NP was able to adsorb SO_2 in synthetic and actual samples with an efficiency of 80% and 66%, respectively [85]. Also, the SO_2 removal percentage was calculated at 43.8 for the synthetic sample and 31.3 for the actual specimen at room temperature [85].

3. Nanocatalysts

Another technique for controlling air pollution is using nanocatalysts as semiconducting materials for photocatalytic remediation [86]. The active surface of NPs turns them into pivotal catalysts. It should be mentioned that by reducing the size of the catalyst, the active surface is enlarged and thus the reaction efficiency is increased [87]. Titanium dioxide (TiO_2) as a non-toxic, stable, economic, and available agent has widely been used to generate photocatalysts in the purification of contaminated air [88]. Nanosheets produced from surface-fluorinated TiO_2 using the hydrothermal method have been developed as catalytic agents [89]. This fabricated catalyst exhibited better activity in separating gaseous ammonia. However, they show lower adsorption affinity towards air pollutants. Therefore, the combination of TiO_2 with compounds that improve their adsorption capability is suggested. In this context, distinct carbon-based materials such as graphene, CNTs, and carbon fibers have been implemented. For instance, TiO_2 /reduced graphene has been developed via hydrothermal reaction to remove formaldehyde (HCHO) as a pivotal volatile organic compound [90]. HCHO can result in different health problems such as nasal tumors and skin irritation. The use of graphene oxide extends the lifespan of charge carriers that in turn increases the possibility of photochemical reaction and formation of reactive radicals. In another study, the hybrids of silicate with TiO_2 have been used for photocatalytic degradation of HCHO. This nanocatalyst showed enhanced

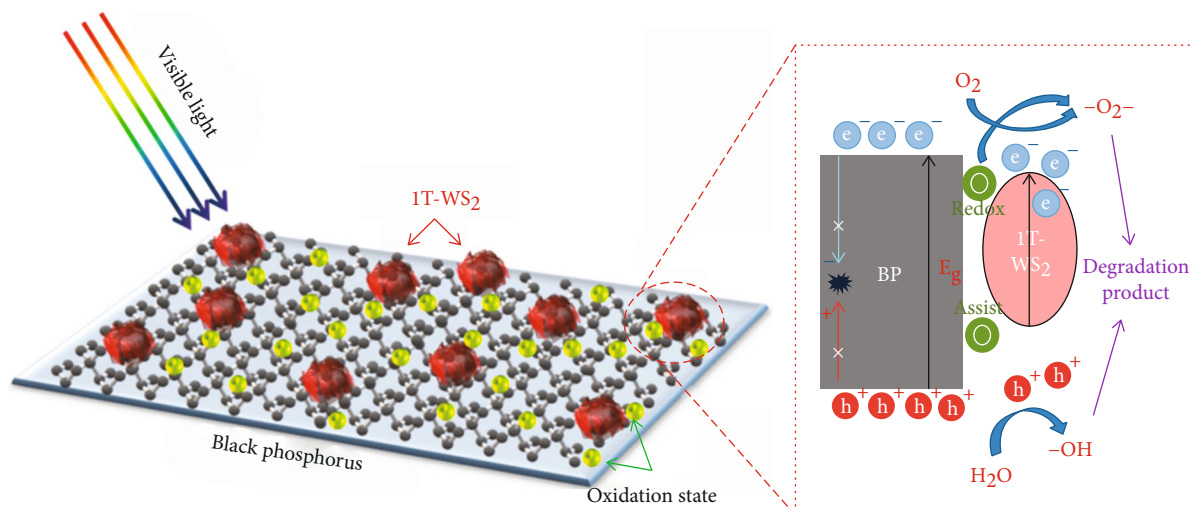


FIGURE 5: A possible representation of Air/Water Pollutant Degradation through Functionalized Black Phosphorus/1T-WS2 Nanocomposite (Adopted from [94]).

adsorption capability and enhanced photocatalytic activity [91]. Novel synthesis strategies for effective metal oxide nanocatalysts will assist in attenuation and might resolve the problems of air pollution. Nanofiber of gold, iron, silver, and manganese oxide are examples of the recently utilized nanosized metals and metal oxides with the capability to remove different volatile organic compounds released from industrial sources. Gold-based nanocatalysts have shown an extremely pivotal treating impact on several contamination control experiments to convert the toxic air pollutants into safer agents [92]. For instance, it can remove carbon monoxide from indoor air. In another research, the use of eliminated trichloroethylene is 100 times stronger than the traditional removing materials. Currently, ZnO photocatalysts are being developed and can simultaneously detect and reduce air pollutants [93].

Coal combustion is associated with the discharge of several toxic pollutants such as mercury (Hg). The accumulation of mercury in the atmosphere leads to detrimental environmental effects that negatively influence human health. TiO₂ nanorods-supported CrOx, FeOx, MnOx, and MnOx-FeOx-CrOx nanocatalysts have been synthesized to remove mercury. The developed nanocatalyst showed a high mercury separation efficiency at lower temperatures in the presence of O₂. Also, a higher separation efficiency was achieved in the presence of NO in similar reaction status. Of note, both large surface area and high crystallization properties of TiO₂ nanorods led to the uniform dispersion of the Cr-Fe-Mn mixed metal oxide NPs and enhanced its activity Figure 5. illustrates the plausible schematic representation of photocatalytic degradation using OBP/1T-WS₂ nanocomposites [94].

Plant-based NPs have successfully been applied in the photocatalytic degradation of pollutants. Magudieswaran et al. have developed cerium oxide NPs using the extract of the *Jatropha curcas* plant that could sufficiently degrade acetaldehyde. Also, the authors revealed that the green synthesized NPs has a lower size and a more homogenous structure compared to the synthetic particle and thus pro-

vided a better photocatalytic activity [95]. Also, previous study showed the good photocatalytic proprieties of silver nanoparticles using *Chlorella pyrenoidosa* which proposed for eco-friendly wastewater treatment [96].

3.1. Nanofilters/Nanostructured Membranes. The use of nanofillers and/or nanosized membranes that encompass pores that remove contaminants from the exhaust is another nanotechnology-based approach. Numerous studies have focused on the construction and optimization of nano filters for trapping gas contaminants [97]. Currently, nanofiber-coated filter media are used for filtering air, in particular for volatile organic carbon vapors [98]. For example, HCHO removal via electrospun polyacrylonitrile-based carbon nanofiber membrane that possesses high microporosity with nitrogen-containing functional groups that enhances the adsorption sites [99]. Polyacrylonitrile activated carbon nanofiber has efficiently adsorbed HCHO even at low concentrations. Also, nanosilver and nano copper-based filters have been used to remove bioaerosols as interior air pollutants [100]. Romero-Guzmán et al. have developed CNTs-based filters that collect CO, CO₂, NO_x, and HC with an efficiency of up to 60% [101]. Also, ultrafine dust and acid polar gas species such as SO₂, NO_x, and H₂S were filtered with a multifunctional, metal-organic framework (MOF: UiO-66-NH₂) and CNT-modified filter. In this nano filter, a thin layer of amine-functionalized CNT was utilized to develop network skeletons on a polytetrafluoroethylene (PTFE) substrate. CNTs acted as an intermediate between the letters. The resulted filter exhibited an extremely high capture efficiency (99.997%) for ultrafine dust and SO₂ [102].

In the synthesis of efficient filters, the use of environmentally friendly agents is of high importance. Souzadeh et al. have used gelatin as a natural protein to construct a high-performance air filter [103]. In this filter green synthesis of nanofibers was achieved using the electrospinning technique, which shows a high removal efficiency for HCHO, CO, and PMs with a lower areal density [103].

4. Nanosensors

Ecological pollutants at sub-picomolar or nanomolar levels have been detected with nanosensors [104]. Nanosensors encompass 3 main constituents including nanomaterials, detection elements, and signal transduction apparatus. The detection element determines the specificity of the nanosensor while the signal transduction method provides a means of relaying the analyte's existence. Recent research has focused on the development of different nanosensors for the detection of H₂S, nitrogen oxide, and sulfur oxide gases [105]. Graphene and metal-oxide-based nanostructures have been used to detect these contaminants [106]. For instance, graphene-SnO₂ nanocomposites have been constructed via a microwave oven, which detects NO₂ gas with high sensitivity and selectivity [107]. In another study, Bai et al. developed hybrids of ethylenediamine-modified reduced graphene oxide (RGO) and polythiophene (PTH) loaded on a flexible polyethylene terephthalate (PET) film to yield a sensor for BO₂ detection. The produced sensor showed a high sensitivity (10 ppm) [108]. Also, it was portable, cost-effective, and flexible. The sensing activity of the sensor was improved by incorporating graphene into PTH resulting in a large specific surface of the hybrid and providing synergistic effects between the hybrid constituents [108].

Cu NPs-decorated with SWCNTs has been utilized for H₂S detection. In this nanosensor, SWCNTs are used to decorate the metallic clusters of Cu NPs via a chemical reduction process which are then spin-coated on a PET. The fabricated sensor showed high sensitivity, selectivity, and reproducibility in H₂S gas detection [109]. Jebakumar et al. have developed tin oxide (SnO₂) NPs via a chemical precipitation method to detect CO [110]. In this sensor, different concentrations of palladium were also utilized. The diameter of the constructed NPs was approximately 7-20 nm. The results indicated that the tin oxide sensor, doped with palladium (0.2%), shows the optimal CO sensitivity [110].

4.1. The Effects of Nanomaterials on the Environment. Air pollution is considered one of the major global challenges, and thus mounting research is focused on producing novel nano adsorbents, nanocatalysts, nanofilters, and nanosensors with high efficacy. The previous research has implemented several NPs to treat and/or prevent air pollution. In this context, outstanding developments are achieved concerning increased efficiency and low toxicity.

However, it can be observed that the NPs could result in several threats to the environment from fabrication to disposal. Thus, the toxicity of nanomaterials should be strictly evaluated in ecological studies in the context of detailed procedures, experimental protocols, and study designs. It has been shown that NPs can affect the environment through several ways: 1) development of pollution level of air, water, and soil, 2) acceleration in the ecological network, 3) intervention with the life cycle of living organisms. Also, NPs can reveal both short-term and long-term effects in ecosystems. However, the majority of the research is devoted to the short-term effects of nanomaterials. The prolonged research in the future will clarify the exact toxicological pro-

file of these NPs. Since NPs are extremely reactive constructions, they can easily interact with other contaminants to form more/less detrimental agents. Therefore, upcoming studies should consider the combinational effect of contaminants and provide disposal guidelines. Moreover, the negating consequences of NPs on animals and humans are inadequately explored. On the other hand, the toxicity profile of the NPs on lower organisms and human cell lines exhibited that nanomaterials might hurt human health. Therefore, it is recommended to warrant standard measures to allow for environmentally friendly use of the NPs and consent to a practicable future growth, from industrial consumption to environmental tactics.

5. Conclusion

Currently, research on the main resources and deleterious effects of air pollution is growing. Air pollution unfavorably influences human health and disturbs the planet's environment, and also spoils society physiologically, psychologically, and economically. The current review information regarding the different sources of air pollutants in Azerbaijan and their detrimental effects on human health and other ecogeographical aspects. Also, the role of nanotechnology in air pollution remediation was discussed. Keynotes, main challenges, and suitable suggestions, regarding the topic of this manuscript can be presented as follows: one-sided and incomplete liquidation of contaminants will not be effective in preventing air pollution. Meteorological and ecological parameters such as air temperature, speed of winds, and their direction monitoring of atmospheric air are highly necessary. Reconstruction of Azerbaijan-related highways and traffic management is required. The use of modern transport infrastructures in Baku and other large cities should be taken into account. Conduction of studies to remove detrimental substances from the composition of liquid fuel is advisable. In this context, the use of nanotechnology has offered promising solutions to detect, remove and degrade contaminants. However, the safety of NPs and their possible toxic effects on the environment and human health should be evaluated. Furthermore, the implementation of green chemistry techniques for the synthesis of nanomaterials should be developed substantially for providing advanced stable, cost-effective, and eco-friendly materials. In general, there is a huge number of favorable air-remediation applications for nanomaterials. And finally, it is important to create strict standards and rules for ecological certification.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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