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A Comprehensive Look at the Detection, Monitoring, and Control of Environmental Pollution with Particular Focus on New and Emerging Solutions to Address the Problem

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Abstract

With the evident increase in environmental pollution around the globe, it is becoming ever more necessary for researchers to develop new technologies and solutions to mitigate the effects of pollution. This article highlights some selected solutions and technologies proposed by several researchers who focused on the problem in recent years. For the sake of simplicity and clarity, the global pollution problem is divided into a few major categories as air, water, soil, agricultural, and general environmental pollution and emerging solutions are discussed under each individual category. Additionally, the effects of each major type of pollution on the general health and well-being of human beings and other living organisms of the planet are highlighted.

Keywords: Environmental pollution • Wireless sensor networks • Carbon monoxide • Sulphur dioxide • Drones • Internet of things • Nanotechnology • Air pollution • Water pollution • Sensors • Biosensors

Introduction

It is now very well established that the emission of many harmful pollutants into the environment by industrial manufacturing activities around the globe is the main reason behind the growing pollution problem. The pollutants usually come in the form of toxic gases such as carbon monoxide and sulfur dioxide or harmful wastes such as heavy metal discharges. Additionally, the use of human made chemicals has contributed to the degradation of environmental health. These later pollutants include substances such as pesticides, insecticides, and herbicides.

In order to mitigate the effects of the substances on living organisms and the environment, many new solutions and technologies have been introduced in recent years. Most notably, research groups around the globe are using sensor technology to monitor different types of pollutants in the air, water, and soil. These sensors come in many different forms and types such as biosensors, biological (bacterial) sensors, chemosensors, thermal sensors, etc. Also, another prevalent technology that is emerging rapidly is nanotechnology, which can target specific gases and heavy metals. While it is true that pollution is spreading rapidly in the present day by an ever expanding manufacturing industry, there are more solutions and technological innovations being proposed and developed to curb the harmful effects of the raising pollution.

The Growing Problem of Air Pollution and its Harmful Effects

Air pollution remains prominent in today's society, and it is believed to have assumed an alarming proportion within the last few decades. In his review of air pollution over the past fifty years, Jes Fenger provides an overview of the changes that occurred in air pollution [1]. According to the author, sulfur dioxide combined with soot was increasingly used after World War II, to power industrial processes and to generate heat. In later years, more sustainable organic fuels were used, but these gave raise to photochemical air pollution. With new technologies and a growing interest in mass production, more volatile compounds are being manufactured. This, in turn, is causing more air pollution, which is leading to the degradation of ecosystems and the ozone layer, thus increasing the greenhouse effect and accelerating climate change.

In their study which is described as Bojnourd Cement Factory study a group of researchers highlighted the correlation between air pollution and industrial manufacturing [2]. The emission parameters of the Bojnourd cement factory were analyzed in terms of the amount of CO, SO_2, NO_x, and PM_{10} produced during different periods of operation. During the second emission period, the cement factory was found to release a high emission load per unit area of PM_{10} and SO_2 (164% and 262% respectively compared to the first emission period). The concentrations of pollution were measured in three villages, one suburban area, and one nearby city. This study highlighted how the different forms of emission of the cement factory negatively affected local living areas due to the high amount of air pollutants released, thus showcasing the large roles that manufacturing companies play in increasing air pollution.

In another assessment, a group of scientists studied the health risks caused by prolonged exposure to air pollution in northwest China [3]. Some of these health risks include increased incidences of cardiovascular diseases, respiratory diseases, lung cancer, and reduction in life

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expectancy. In a 2014 study, the number of deaths in China due to air pollution within a certain period of time was estimated as 700 million. Shorter life expectancy associated with air pollution is believed to be caused by the presence of SO_2, NO_2, O_3, and CO in the air. Increased intake of sulfur dioxide is believed to make the respiratory tract to close and make it difficult to breathe. This in turn has been found to be associated with many respiratory tract diseases. The inhalation of NO_2 has been shown to adversely affect kidneys and other organs due to its high level of toxicity. Also, absorption of O_3 is shown to result in inflammation and destruction of pulmonary epithelial cells. Inhalation of CO reduced the oxygen carrying capacity of blood. Additionally, consuming O_3 reduced the supply of oxygen to specific organs, like the brain. Thus, it has been clearly demonstrated that air pollution leads to the absorption of pollutants by the body, which in turn negatively impacts the health and life expectancy of humans.

Recent Innovations that can help mitigate the Problems of Air Pollution

The work of a group of scientists highlights a way to monitor air pollution by utilizing Wireless Sensor Networks (WSN) [4]. Wireless Sensor Networks are small, low cost sensors that collect and spread environmental data. Sensor networks can be used for environmental monitoring, indoor climate control, surveillance, structural monitoring, medical diagnosis, disaster management, emergency response, ambient air monitoring and aslo to gather useful information from inhospitable locations. A wireless sensor network was implemented in Mauritius where wireless sensors were deployed throughout the island. The WSNs made use of measured ‘Air Quality Index (AQI)’ values and a new data validation technique known as ‘Recursive Converging Quartiles (RCQ)’ technique to successfully monitor and remedy the air pollution problem.

Hodgeson and his associates discussed different spectroscopic techniques that can monitor and detect air pollution [5]. The first technique they used is the chemiluminescence technique. Chemiluminescence is an analytical technique that occurs in exothermic chemical reactions in which material’s electrons and their vibrational states become excited. A chemiluminescence detector which consists of a reagent gas generator, photomultiplier tube, a current amplifier, and a recorder can be used in conjunction with the chemiluminescence phenomenon to detect O_3 and NO in any desired area. In the technique used by the researchers to measure O_3, O_3 and ethylene occur at atmospheric pressure inside the chemiluminescence detector. Another technique used to measure pollutants is known as ‘Molecular Gas Phase Fluorescence’ technique. Molecular fluorescence is a phenomenon that is usually observed in condensed phase. It is strongly affected by molecular interactions. The study of fluorescence spectra in the gas phase can provide a nearly ideal model for the evaluation of intrinsic properties of the fluorophores. The technique can be used to measure NO_2, SO_2, NO, and Cl2 in the atmosphere. The visible absorption bands of these pollutants are used to excite the fluorescence of a molecule. Laser induced fluorescence can measure NO_2 by using an argon ion laser that operates at 488 nm. Additionally, the ultraviolet absorption approach utilizes electronic circuitry, a stabilized mercury source, dual monitors with unique referencing systems, and signal integration. The system allows the operating device to have stability for the accurate measurement of O_3 in a region.

Through her low cost environmental experiments, Jennifer Gabrys, was able to evaluate the efficacy of different methods of air pollution monitoring, including that of oral data acquisition [6]. This was done by conducting an “Air Walk” through South London neighborhoods of New Cross Gate and Deptford in the year 2013. Many people were asked to participate in the walk and were asked as to how they would approach monitoring air quality in the exposed area. This gave researchers new ideas on how to monitor air pollution, whether it be through digital, bodily, or institutional means. The ideas generated from the walk were built from the personal experiences that people perceived while being subjected to air pollution in their neighborhood.

The work of Liu et al highlighted the development of a new mobile vehicle –‘Light Detection and Ranging (LiDAR) System’ that has been designed and produced to detect air pollution [7]. This vehicle was used to detect air pollution in the Binhai New Area of Tianjin in China. By using the directional information from a GPS, the distribution and dispersion of aerosols in the air were investigated. Additionally, the vehicle was able to detect the macro distribution of pollutants on different scales within an area. Specifically, LiDAR used echo signals from the interaction of the atmosphere and its laser to discover more information about the locations of the aerosol particles in the atmosphere. The vehicle was made up of an emitting unit, receiving unit, signal acquisition unit, and GPS unit. In Tianjin, the vehicle was deployed along the highway near Tianjin port to collect the concentration of aerosol particles in the air. Through this experiment, it was noted that this LiDAR system was more accurate than ground based LiDAR systems.

The work of another group of scientists introduced a new low cost method for detecting air pollution [8]. This system utilized multiple gas sensors, a dust device, sound sensor, temperature sensor and digital hardware for obtaining atmospheric data, and software to analyze the data. Also, this newly developed system had the ability to connect to the internet and also to any other device with Internet of Things (IoT) based electronics. The data obtained can be transferred to laptops, tablets, and smartphones. The system can be used to measure concentrations of CO_2, CO, CH_4, and dust particles in different environments. The online data storage system can share the information gathered on this device to responsible people who can use the data to improve the lives of the general population by improving the air quality. The researchers have outlined that the data from the sensors first gets transmitted to the device’s microcontroller, then to the operating server which then allows the data to get uploaded to the internet.

Another research team developed a multi pass absorption cell which can be used to reduce harmful pollutants in the environment [9]. This absorption cell can detect gases in ultraviolet and visible spectrums of light due to its hollow interior and reflective inner coating that was manufactured to absorb and release various gases. This new cell has been able to detect sulfur dioxide in the ultraviolet region, ozone in the visible region, and nitrogen dioxide in both the ultraviolet and visible regions. Furthermore, this cell could detect SO_2 concentrations as low as 10 ppm, NO_2 concentrations as low as 4 ppm, and O_3 levels as low as 500 ppm. In experimentation, the cell was seen to be working in conjunction with a spectrometer, ozone analyzer, wideband light source, quintox gas analyzer, UV LED and driver circuitry, and photoiodide and detector circuitry.

Yet another new study showed how unmanned aerial vehicles (UAVs) can be used in air pollution detection [10]. UAVs have been previously used for protection and security. However, in this research, UAVs were used to measure air pollution through the implementation of appropriate sensors, cameras, and software that will collect the data taken in by the UAV. Sensors that can be placed in a UAV include biological sensors that can detect biochemical elements such as CO present in the air. Additionally, thermometric sensors, gravimetric sensors, and magnetic sensors can be implemented onto a UAV to further increase the UAV’s ability to intake atmospheric data.

Yunus et al highlight the use of nanotechnology in their work to mitigate the effects of air pollution in the atmosphere [11]. They suggest that Nanotechnology carries the potential not only to improve the existing technologies but also to create new technologies. This technology, according to them can serve three main functions: remediation and purification, detection of contaminants, and prevention of environmental pollution. One specific application example of nanotechnology cited as being very useful is carbon nanotubes. Carbon nanotubes can be used to adsorb and remove NO_x and CO_2 (caused by fossil fuel emissions) from the atmosphere. Nanowires and nanotubes can also be applied to sensors. The study showed how the implementation of nanotechnology into sensors improves the response rate and sensitivity of probes that are used to detect NO_2 and NH_3 in the air. In nanotechnology based biosensors, nanoparticle labels were used to increase the sensitivity of biosensors. This allowed the sensors to detect and interpret biomarker signals on people who have been exposed to hazardous pollutants in the air. Another nanotechnology related sensor described is the cantilever sensor which uses a silicon cantilever array with nano coating. This coating reacts to specific pollutants, which causes its structure to bend. The amount of bending is then measured by a laser beam which can give a quantitative measurement of the amount of pollutant present in an area.

In a study that involved CO_2 laser photoacoustic monitoring of trace gases, scientists were able to utilize CO_2 lasers to monitor gases in the air [12]. This system was programmed to run through a computer and could be left unattended for long durations of time. Most of the testing for this device was done in rural air where it was able to read traces of water vapor, carbon dioxide, ammonia, ethene, and ozone. The team tested this device by having it measure signals on nine laser transitions. The tested laser showed emissions in 9 μm^{-11} μm wavelength range, which allowed it to read in the atmospheric window of 8 μm^{-14} μm. Additionally, using a CO_2-laser reduced the interference that ambient carbon dioxide has with the data.

The research work of Das et al further demonstrated the feasibility of using nanotechnology to remove contaminants from air [13]. One way of achieving this is by using nanocatalysts. Nanocatalysts have a large surface area that allows them to absorb harmful gases and convert them into harmless gases. One type of nanocatalyst is a nanofiber catalyst made of manganese oxide nanoparticles that removes volatile gases from industrial smokestacks. Additionally, gold nanoparticles can be observed to transform toxic carbon monoxide to carbon dioxide gas. Another proposed solution for purifying air is to use nanostructured membranes. Nanostructured membranes contain small pores that can separate methane or carbon dioxide from exhaust produced by cars or industrial processes. Furthermore, silica-titania nanocomposites can also purify air by removing mercury vapor from combustion sources. This is due to nanosilica's high surface area and titania's unique photocatalytic property which aids in improving mercury absorption. Another form of nanotechnology to improve air quality is metalorganic frameworks (MOFs). These nanostructures act as small cages to trap CO_2 particles. MOFS are made from organic ligand molecules that can associate with multiple metal ion bonding, forming an extended porous network.

Water Pollution Problem and its Harmful Effects

Along with air pollution, water pollution is another highly potent pollution caused by industrial manufacturing processes. According to Davaasuren and his coworkers, plastic products in the ocean have reached over 270,000 tons or 5.25 trillion pieces [14]. The group went on to prove that due to the movement created by ocean circulation patterns, the plastic products have accumulated into garbage patches. Quite frequently, these patches of plastic were observed to entangle, suffocate, or starve marine wildlife. Additionally, marine wildlife was seen to be subjected to the ingestion of plastic particles, which often leads to marine population deaths. Furthermore, due to the presence of plastic in the ocean, many corals were seen to be diseased as a result of the pathogen growth stimulated by plastic waste.

Pollutants in the ocean were analyzed in another study which ctegorized the pollution in ocean bodies as point and diffuse pollutions [15]. The study regarded point pollution as the type of pollution that entered the main body from specific points such as waterways, pipes, and drains. Diffuse pollution is regarded as the one that stemmed from local, urban, and city water run offs that are naturally polluted and sprung into the ocean. The methods of diffusion were noted as not being commonly monitored, which makes them a great risk to the ecological health of oceanic wildlife. The study stated that the data obtained from the NORMAN network suggests that 700 of these pollution substances present in the European ocean bodies have been classified into 20 classes.

Another research effort that focused on water pollution highlighted the vast water pollution problems in China [16]. While it is known that China has greatly invested resources to reduce water based environmental protection, there still remain a great number of problems and that water pollution is still not sufficiently controlled. In many water bodies and lakes in China, the study reported that there were high amounts of nitrogen and phosphorous concentrations which cause eutrophication problems and an increase in algal bloom. It was reported that the rivers in China contained large quantities of nitrogen, phosphorous, organic compounds, and heavy metals. In this study, it was also reported that 80% of urban rivers are polluted to varying degrees. Additionally, human industrial activity is believed to have caused the deterioration of ground water due to the presence of varying amounts of fluorine, metals, and other organic substances.

Emerging New Solutions for the Mitigation of Water Pollution

The feasibility of large scale water pollution monitoring and regulation was studied by Derbew and Libsie [17]. The researchers analyzed and created 'Wireless Sensor Networks (WSNs)', which satisfied two requirements for water pollution monitoring namely, early warning of compliance and long term data collection from various industrial sites for pollution trend analysis. Designing and implementing WSNs was challenging because WSNs were application specific, and each new application requirement had a different set of constraints for the sensor system to overcome. The article concluded that wireless sensors were useful due to their ability to detect plastic species and other chemicals such as organic compounds and heavy metals.

One team of researchers studied the use of an 'Automated Water Analyzer Computer Supported System (AWACSS)' to monitor water pollution [18]. This system was based on immunochemical technology that was designed to measure organic pollutants in water at the level of nanogram per liter. The performance of this system was tested on drinking, ground, and surface water. Specifically, the system was used to measure environmental organic micro pollutants, pesticides, endocrine disrupting compounds, and pharmaceuticals. An in depth look at the AWACSS shows that it used fluorescence based monitoring to detect fluorophore tagged biomolecules on the surface of an optical waveguide chip. The excitation light distributed to 32 chips allowed the system to read a sample injected to the sensor surface, enabling rapid detection of 32 pollutants.

In addition to AWACSS, another system known as the 'River Analyzer (RIANA) System' was studied and analyzed by the same group that is mentioned above [19]. This system was regarded as a cost effective system that worked autonomously to continuously monitor rivers for environmental pollution. It reported ultra-sensitive immunoassays for progesterone, testosterone, and estrone. These substances are hormones and pollutants commonly found in rivers. The substances were detected by the sensor system at levels as low as 0.2 pg mL^{-1}. Specifically, the most common limits of detection (LOD) were between 0.2 and 6.0 pg mL^{-1}. Commercially available antibodies and derivatives were incorporated into the immunoassays of the sensors in order to automate the biosensors. The assay performance was tested before hand in rivers that were purposefully spiked with different hormones.

Davaasuren and coworkers who focused on plastic pollution in oceans discussed the possibility of using surface imaging (Sentinel 1A and COSMO-SkyMed SAR Imaging) to detect plastic patches in the ocean [14]. They observed that microorganisms were present in the garbage patches that were polluting the ocean and the patches created surfactants and biofilms. The microbial colonization of plastic patches was shown to result in metabolic byproducts that released short chain and other complex carbon molecules. The byproducts were shown to affect the fluid dynamic properties of waves by changing their viscosity and surface tension. This change in turn allowed for plastics to be detected using the Sentinel 1A and COSMO-SkyMed SAR Imaging. The behavior of the colonizing microbes was also examined, notably that of the microbes found in polyethylene (PE) and polyethylene terephthalate (PET) microplastics. The SAR images detected that surface wind speed and ocean circulation pattern are the factors responsible for creating the distinct appearance of the surfactants, sea slicks and microbial biofilms. This means that SAR imaging can be used in the future to detect more plastic pollution in the ocean.

The work of Patel et al highlighted the use of bacterial strains to help mitigate water pollution [20]. Biosensing strains were developed by cloning a hydrocarbon recognizing promoter operator reporter gene. The most common reporter gene used was luxAB. The strains in bacteria were used for sensing the pollutants at low concentrations. These strains were tested in wastewater and were found to be more successful in measuring hydrocarbon samples compared to other techniques.

Bacterial sensor arrays were also developed by a group of scientists to hinder water pollution [21]. The development of an inhibition electrochemical sensor array on bacteria took into account many organic and inorganic pollutants. These included heavy metals, $HgCl_2$, $PbCl_2$, $CdCl_2$, atrazine, simazine, DDVP, and petrochemicals (hexane, octane, pentane, toluene, pyrene, and ethanol) in water. For this project, electrochemical measurements such as cyclic voltammograms and impedance spectroscopy were made on gold electrodes. These electrodes had three different types of bacteria namely, Escherichia coli, Shewanella oneidensis, and Methylococcus capsulatus. The researchers observed that many pollutants can be detected by this system. The data for this experiment was analyzed using an artificial neural network (ANN) which aided in correctly identifying the pollutants and their concentrations.

Another research article discussed the importance of using electrochemical detection in mitigating water pollution [22]. It was observed that electrochemical detection cuts down detection time and permits real time monitoring of pollutants in water bodies. A potentiometric electrochemical sensor was made from a membrane containing ion-exchangers, lipophilic salts and plasticizers. The membrane converts ion-recognition into a potential signal that provides information on pollutants. Voltammetry sensors were also reported as a type of electrochemical sensor that had high selectivity and specificity. These sensors were seen to detect at low detection limits. Separation of species was not required for these sensors. The detection tools were found to be desirable due to their compactness, easy handling, and portability, compared to other analyzing devices.

Recent research in the field of nanotechnology has also been found to be useful to address water pollution [11]. It has been observed that nanomaterials focus on remediation, which is the process of removing water pollutants from bodies of water. Remediation was demonstrated using thermal, physicochemical, and biological methods in this particular research study. The work highlighted the role of one nanomaterial called ferritin, which plays a critical role in the remediation of water pollutants. Ferritin contains iron and is able to form mineralized structures. It was reported that the 24 polypeptides present in ferritin create cage like structures that could transform iron molecules into ferrihydrite nanoparticles. This could be done for other substances as well. Polymer nanoparticles were also used in the remediation of water. Polymeric nanoparticles were reported to have amphiphilic properties with hydrophobic and hydrophilic parts in them. These nanoparticles were used for surfactants to enhance remediation of hydrophobic organic contaminants. Furthermore, nanofiltration was reported as a type of filtration that used pressure to reject multivalent ions. This was done with a nanofiltration membrane which rejected pesticides and heavy metals.

A group of scientists who reviewed new developments in automated biosensing observe that unique improvements in biosensor technology allow for the purity of water to be tested accurately [23]. Specifically, real time monitoring allowed the experimental biosensors to detect the breathing changes of local aquatic life in water in response to water quality changes. Also, with the use of microprocessor based monitors to measure fish breathing rates, the group used NASA's remote data collection satellite to collect and analyze the breathing data. Physical information was also collected on site and analyzed in a similar way by using government owned data acquisition software.

When the wall of a wastewater reservoir in Hungary was disrupted in 2010, red sludge mud (a solid waste byproduct from industrial activities in the area) polluted surface waters. A group of researchers discussed how the AVITAR (Accredited Water Quality Telemetry System) was used to combat this problem [24]. This system had instruments to measure, display and gather data, and to emit an alarm signal when ecological disaster happened. This system was reported to have been installed in the Stream Torna in order to monitor its water quality. The data obtained highlighted how the stream had returned to its previous ecological state after a certain period of the waste reservoir spill incident.

In a journal article that reviewed advancements in water quality technology, certain technologies and methods were highlighted as potentially useful tools [25]. The first technology discussed was chemosensors which operate according to physical principles and provide useful information for real time monitoring and control. Organic monitors were also discussed as monitors of organic compounds in bodies of water. Examples of these include TOC analyzers, UV absorption, and differential spectroscopy. Inorganic monitors were reportedly used to detect influent and effluent water quality. These were based on online monitoring that used complex colorimetric methods developed for laboratory applications. Additionally, indirect monitoring (also known as "fingerprinting") was defined as the use of unique chemical signatures, isotopic ratios, and mineral species which were used to detect different chemicals in water. UV, VIS, and NIR absorption spectroscopy are categorized as typical low cost methodologies that can be used for fingerprinting.

Suresh and his co-workers highlighted how the deployment of Internet of Things (IoT) sensors can aid the surveillance of water quality [26]. These sensors were reported to require communication links among them to transfer and receive data from other sensors over a large body of water. There should be suitable means available to upload the data to a central cloud so that researchers could further analyze the same. IoT sensors require batteries which means that battery levels must be constantly monitored, and replacements must be readily available. This system was also seen to determine the pH and other information about a body of water by using Surface Acoustic Wave (SAW) technology and a cellular code reuse scheme based reader infrastructure. Sensor communication was substantially enhanced and optimized through the use of Interdigital Transducer (IDT) based reflectors.

Soil and Agricultural Pollution and their Harmful Effects

As mentioned previously, point and diffuse pollution were reported to discharge large amount of pollution into bodies of water. However, this type of pollution was also known for the degradation of soil and sediments. In a previously mentioned study, emerging pollutants in the environments were observed to be present in soil, which can be caused by acid rain, pesticides, herbicides, insecticides, organic pollutants, inorganic pollutants (detergents, cosmetics, chlorinated solvents), etc [15]. Additionally, many heavy metals like lead and mercury were found in soil which are known to have adverse effects on soil condition, environmental conditions, and human life.

Soil pollution can be seen to negatively affect human and environmental health according to another previously mentioned article [11]. Many of the pollutants found in soil were reported as being carcinogenic to humans, which lead to incidence of cancer. Also, because of pollution in the soil, plants were seen to be able to readily absorb these pollutants. Once animals or other humans began to consume these polluted plants, they were reported of being in danger of falling ill from consuming the pollutants. Pollution was also seen to affect plants because when the amount of heavy metal pollution was high in soil, plant growth was often hindered. Another serious adverse effect of pollution was reported as erosion, which caused the topsoil to be swept away with vital nutrients that were necessary for soil to harbor plant growth.

According to Baruah and Dutta the rise of global population has increased the demand for food supply [27]. This demand for more food supply, in turn, is believed to have driven scientists to find new ways of improving agricultural yield and production. The article goes on to say that the improvement of agricultural production has paved the way for excessive use of fertilizers and pesticides. Although these substances can improve crop growth and increase overall agricultural output, they left the unconsumed substance in the soil and increased environmental pollution on a massive scale. Over the past six decades, the use of these substances is believed to have caused the degradation of not only soil, but also groundwater and the health of the organisms that depend on the ecological health of the environment they live in.

New Solutions to Reduce Soil and Agricultural Pollution

The work of Gavrilescu talks about the use of various biotechnologies and bioremediation for the environmental protection of soil [28]. One form of bioremediation discussed is phytostabilization in which plants reduce the mobility of polluted soil. Specifically, the polluted contents of the soil were found to be bound to the plant in the form of concentrated mass and this binding ensured that the the pollution would not spread far from the plant into the surrounding soil. Another form of bioremediation reported was phytoextraction in which the plants housed the contaminants in their roots, thus allowing the pollutants to be easily removed and disposed of or recycled. Different types of bacteria could also be applied to hinder soil pollution. For example, the Bacillius subtilis is a type of bacteria that removes crude oil and remediates chlorpyrifos contaminated soil. Another category of bacteria known as Streptococcus was shown to degrade hydrocarbons, heavy oil, and dairy industry waste present in the soil. As was observed, smart usage of remediation techniques and bacteria was seen to hinder soil pollution.

Another previously cited research work explained the benefits of using nanosensors for agricultural improvements and soil remediation [27]. Nanosensors were reported to be used in soil to detect various pesticides, toxic materials, proteins, and antibiotics. Nanosensors were shown to be capable of predicting the emergence of soil diseases through the estimation of the relative activity of microbes in the soil. The growth of microbes, in turn, is determined on the basis of differential oxygen consumption due to their respiration. For agriculture, the paper stated that nanosensors could be used to detect odors emitted from bacteria that deteriorate grown foods, thus allowing for foods to be better preserved and consumed. Additionally, electromechanical sensors were reported as being used to detect the moisture of the soil. This was important because the moisture of the soil is an indicator of the proper functioning of the irrigation systems. Majority of these sensors usually come in the form of micromachined cantilever beams that are coated with a water sensitive nanopolymer to detect water level in the soil.

The work of Dan, Sen and Debnath highlighted the use of nanotechnology to purify soil and to mitigate pollution [29]. Iron nanoparticles which possess a high surface area to volume ratio were shown to carry the ability to remove chloroform, DDT, chlorobenzene, trichloroethane, arsenic, perchlorate, nitrate, dichlorobenzene, lindane, and trichloroethane from soil. Additionally, iron nanoparticle that are covered with catalytic metals such as Pd and Pt were shown to be useful for sediment and solid waste treatment. Nanoparticles were also seen to be used to monitor soil conditions. For example, silver nanoparticles that are modified with an optical fiber tip could be used as sensing devices to detect Rhodamine 6G dye in the soil. Furthermore, certain nanoparticles were shown to serve as better alternatives to commonly used pesticides and insecticides. Nanosilica based insecticides have been reported to be effective against insects. Specifically, the nanosilica based insecticides have been seen to disrupt the cuticular water barrier of insects, which ultimately caused them to die. Toxicology studies indicated that the nanosilica based insecticides were not toxic to human beings if they are applied in correct dosage amounts. Thus, there is clear scientific evidence to prove that nanotechnology can play a beneficial role in improving the state of the soil and agricultural health.

General Environmental Pollution

The work of another group of researchers discussed how to protect the first responders from environmental hazards and volatile chemicals [30]. One idea proposed was the use of unmanned aerial vehicle (UAV). The UAV in this experiment was equipped with low cost sensors, which allowed it to gather data on what chemicals and how much of each type was present in the environment. There was also an alarm installed in the device that detected anomalies in the environment. Additionally, the device used lidar standoff systems for environmental monitoring. Lidar was described as a laser based system that used a transmitter, receiver, and a light pulse transmitted into the atmosphere in the range of optical radiation. The light beam from the lidar was scattered and was then backscattered back into the lidar system by a receiving optic. The UAV used in this experiment was also reported as being able to house photo ionization detectors (PID) which were used for identifying many hazardous substances. Furthermore, the UAVs were reported to be using ion mobility spectrometry (IMS) and miniaturized sampling systems such as an air sampling pump which aided the detection process.

Yet another research group used biosensors for the monitoring of organic and inorganic pollutants in the environment [31]. Bacteria were used as biosensors. Bacterial sensors were categorized according to the types of substances they could measure and account for. The article discussed how different bacterial sensors could be used to measure endocrine disruption, cytotoxicity, carcinogenicity, mutagenicity, or genotoxicity. For example, recombinant bioluminescent bacteria were used to detect and classify environmental toxicity. Biosensors for genotoxicity and mutagenicity were created and used. They were based on the interaction of organic compounds and nucleic acids which allow changes in toxicity to be detected. Additionally, endocrine effect biosensors have been used to measure endocrine disrupting chemicals in the environment. These biosensors were seen to have estrogen receptors which aided in measuring the endocrine disrupting effect. Furthermore, biochemical oxygen demand sensors were used to determine the amount of biodegradable organic material in the environment. Specifically, this type of sensor relied on the measurement of bacterial respiration rate in close proximity to a transducer. The article also discussed the use of DNA biosensors, which could be used to detect disease causing microorganisms in water supplies, food, plants, animal and human tissues using polymerase chain reaction (PCR) methods.

Goradel and co-workers discussed how harmful pollutants such as pesticides, heavy metals, and pharmaceuticals could be detected through the use of biosensors [32]. Biosensors were generally reported to be made of three main components. These include a biological recognition element, a transducer, and a signal processing system. Electrochemical biosensors are regarded as low cost and easy to use sensors. These types of sensors were seen to measure the electrical properties of biological systems. Three electrodes were used to make an electrochemical sensor. These include the reference electrode, auxiliary electrode, and working electrode. Optical biosensors used optical transducers to measure properties such as adsorption, fluorescence, luminescence, and refractive index. The paper discussed piezoelectric biosensors which aid in measuring physical properties such as mass, density, and viscosity. The operation of optical biosensors is linked to the resonant frequency of an oscillating piezoelectric crystal and the mass deposited or adsorbed on the crystal surface. Thermal biosensors quantify the exchange of thermal energy during a reaction in the environment. These biosensors could utilize biological molecules, living biological systems, and biomimetic materials for detection and recognition.

Another review article discussed how biosensors could be applied to detect toxic heavy metals in the environment [33]. An enzyme based biosensor could be applied to measure toxic heavy metals. In application, enzymes such as acetylcholinesterase, alkaline phosphatase, urease, invertase, peroxidase, L-lactate dehydrogenase, tyrosinase, and nitrate reductase had been applied to detect different types of heavy metals in the experiment. The inhibition of an immobilized enzyme was detected by an enzyme based biosensor through electrochemical measurements. DNA-based biosensors were used to detect heavy metals in the environment. Heavy metals have shown to be highly interactive with nucleic acids. The interaction between metal ions and DNA molecules was shown to result in healthy or adverse effects in living organisms. One of these interactions is associated with changing the structure of genetic materials through development of malignant tumors. Biosensors were used by the research group to monitor concentrations of heavy metals inside DNA. Another type of biosensor is a whole cell based biosensor which utilizes whole cells with physical transducers in order to generate a measurable signal proportional to the concentration of analytes. These were able to bind to heavy metals and express their toxicity in many forms of environmental mediums such as soil, water, and air.

The work of Ho et al highlighted the use of both government regulation and sensors to curb the environmental pollution problem [34]. One type of trace metal sensor discussed was the nanoelectrode array which was used to identify and measure the quantity of dissolved metals in an environmental medium. It is stated that one million electrodes could have been placed on a one square inch substrate. This was done by using electron beam lithography. The small electrode size coupled with a high density was observed to produce a strong signal to measure toxic metals. A miniature chemical flow probe sensor was also used to detect toxic metals in the environment. It was particularly used to measure copper. Another sensor mentioned in the article was a cadmium zinc telluride (CZT) detector. This sensor serves as a semiconductor gamma and neutron radiation detector, which emits current when it is exposed to enough radiation. Over time, these sensors were known to be degrading, but were otherwise seen as promising and sensitive sensors. Furthermore, a low energy pin diode beta spectrometer was reported as being used to measure tritium contamination. This was done by using pin photodiodes. This sensor functions by measuring the current pulses generated in the diode when beta particles strike. These signals were converted by the research group to a voltage pulse whose amplitude was proportional to the energy of the particle.

As risk of pollution grows in drinking water and agricultural soil, the need for sensors to monitor these pollutants increases. An article summarized these sensors that could be used to mitigate the effects of pollution in the environment [35]. One solution proposed in the article is the use of whole cell biosensors. Living organisms were also used in the detection of pollutants. The amperometric biosensor used the cyanobacterium Synchococcus as its biocatalyst. This allowed for the biosensor to monitor herbicides in the environment. Additionally, this biosensor could detect many herbicides with its sites of action being on the photosynthetic electron transport chain. With concentrations being from 20 μg litre−1, the working life of this sensor was reported to be up to 7 days.

IoT Based Monitoring

Wan and his coworkers [36] discussed how industrial advancement has created the degradation of ecological balance and an increase in pollution in certain areas. They found it difficult to measure and detect the level of pollution in certain areas due to their poor accessibility. Some of these locations include far sea and mountain zones where there is no linked communication system established. However, a proposed solution to this problem was a satellite terrestrial framework which was used to detect pollution by using IoT monitoring. With a massive amount of sensor arrays, data about measured pollution was delivered to a satellite using a ground base station. Also new methods based on local attribute detection were proposed in this article to detect polluted sections. Stable wavelet statistic (SWS) was mentioned, which modeled the classical wavelet as a graph based wavelet. In order to improve the ability of this system, a cluster center discovery method was used, which lessened the distance between vertices. Additionally, a smooth scan statistic was also used to simplify the problem formulation of the likelihood ratio test. This graphical method was used because it aided in evaluating real datasets for detecting industrial pollution in many areas.

Nanotechnology and Nanomaterials

A review article on remediation technologies to clean up the environmental pollutants discussed the use of different nanotechnologies to sustain a cleaner environment [37]. Nanoparticles were observed in the article to demonstrate unique characteristics such as having a high surface area to volume ratio, some anti-bacterial properties, hardness, electric, and magnetic properties. Different nanotechnologies were seen to be used to deal with different pollutants in the environment. Carbon nanotubes were described as a type of nanotechnology that targeted NO_x by having NO and O2 pass through them and having NO oxidized to nitrogen dioxide. Nitrogen dioxide was then adsorbed on the surface of nitrate species. Fullerene was described as another type of nanotechnology which targeted carbon dioxide. Fullerene was described as having a high adsorption capacity for CO_2 by using strong chemisorption. Additionally, graphene was described as a type of nanotechnology which targets CO_2, NH_3, SO_2, H_2S, and N_2. In summary, it was observed that different nanotechnologies can be utilized to target different substances in the environment to prevent further environmental degradation.

Summary and Conclusion

The information gathered in this review paper summarized the causes and effects of different types of environmental pollution caused by industrial manufacturing practices. It also highlighted many known and emerging solutions to curb the rising industrial pollution problem. The information shared in this paper will enhance awareness and facilitate a deeper understanding of the health, ecological, and societal risks that environmental pollution will cause if left unattended. The information presented on emerging solutions is intended to stimulate the inspiration of others to build upon these solutions, create their own, and increase their understanding of the subject.

The technologies and solutions proposed in this paper to hinder environmental pollution were summarized under the categories of air pollution, water pollution, soil and agricultural pollution, and general environmental pollution.

For air pollution, the solutions highlighted in this paper are based on various sensor arrays, human surveys, mobile vehicle lidar systems, UAV monitoring, absorption cell monitoring, CO_2-laser photoacoustic monitoring, nanotechnology, and IoT-based monitoring.

For water pollution, the solutions highlighted cover 'Automated Water Analyzer Computer Supported System (AWACSS), wireless sensor networks, bacterial strains, Sentinel 1A and COSMO-SkyMed SAR Imaging, electrochemical monitoring, nanotechnology, bacterial sensor arrays, biosensors, chemosensors, and IoT based monitoring.

The solutions covered for soil and agricultural pollution include bioremediation, Nano sensors, and other general nanotechnologies.

Common solutions mentioned for general environmental pollution include various types of sensors, IoT-monitoring, and nanotechnologies.

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