PERSPECTIVES ON GENERAL ASPECTS OF POLLUTION TOXICOLOGY

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ABSTRACT

The advances in the study of adverse effects of particular chemicals on living systems allowed the prediction of the risks associated with it. The geographical environment involving industrialization, urbanization, and globalization has created an altered ecology that severely affected organisms. Toxic chemicals are also finding their way into our food chain, and the people develop bronchial problems and breathing difficulties. An understanding of the polluted environment helps the governments to determine, regulate and enforce environmental pollution control measures, such as legislation, governing the massive use of pesticides, or large-scale discharging of highly toxic industrial effluents that are central to conservation. If the human impact continues to transform the ecosystems because of the growing population and waste disposal, nature cannot bear the damage. The knowledge about environmental toxicology informs us about the risks, to promote higher levels of human intellect and attitudinal development, which will help ensure the future survival of the planet. Environmental education, adoption of the standardized environmental management systems, production of less toxic materials, sustainable management of resources, environmental auditing, and developing an eco-friendly technological innovation goes a long way in environmental protection. Novel waste treatment methods must be devised, and non-conventional power sources such as solar, wind, and biogas plants must be developed on a large scale to control the pollution and make the earth more habitable, peaceful, and safe for all creatures to live and thrive on. *[African Journal of Chemical Education—AJCE 13(1), January 2023]*

INTRODUCTION

Many different types of harmful materials are released into the atmosphere due to different sorts of human activities on micro- and macroscales in the rapidly urbanizing planet. Farmers spray pesticides on the crops, and some enter the soil, streams, rivers, and oceans. Harmful waste chemicals from industrial processes are discharged into rivers. Smoke and gases release from factories, power stations, and vehicles continuously spread in the air, causing severe air pollution. Chemicals from soaps and detergents and other household cleaning products finally enter the water system. Mining waste and rubbish are often dumped on the ground, contaminating the soil. Industrial operations produce wastes that pollute the air and groundwater. These different pollution types pose a threat to animal and plant life on the planet [Fig.1]

Global demand for certain plantation products such as coffee beans or cocoa can impact the ecology because of illegal plantations across protected areas of some countries, affecting the local animal population. Burning large amounts of impure coal in inefficient ways contribute to excess and maximize harm. Forest fires, accidental fire in buildings, mass cremation in natural disasters like a devastating massive earthquake, adulterated diesel-burning in vehicles, use of older vehicles, agricultural crop burning, and domestic cooking stoves also contribute to the air pollution problem and unpredictable climate change [1-4]. Construction of hydroelectric powerhouses, illegal sand mining, and deforestation

contribute to declining groundwater resources and polluted water bodies, disturbing the socio-economic fabric of the society. Even adventure sports events like off-roading rallies using all-terrain vehicles lead to soil erosion, noise, and air pollution, causing damage to the environment. The introduction of seaplane services in several coastal areas to encourage sea tourism will adversely impact the local fishing communities' livelihoods and marine ecology. Such operations will displace fish populations and migratory birds, degrade the environment by spillage of fuel, and result in higher carbon emission and noise pollution.

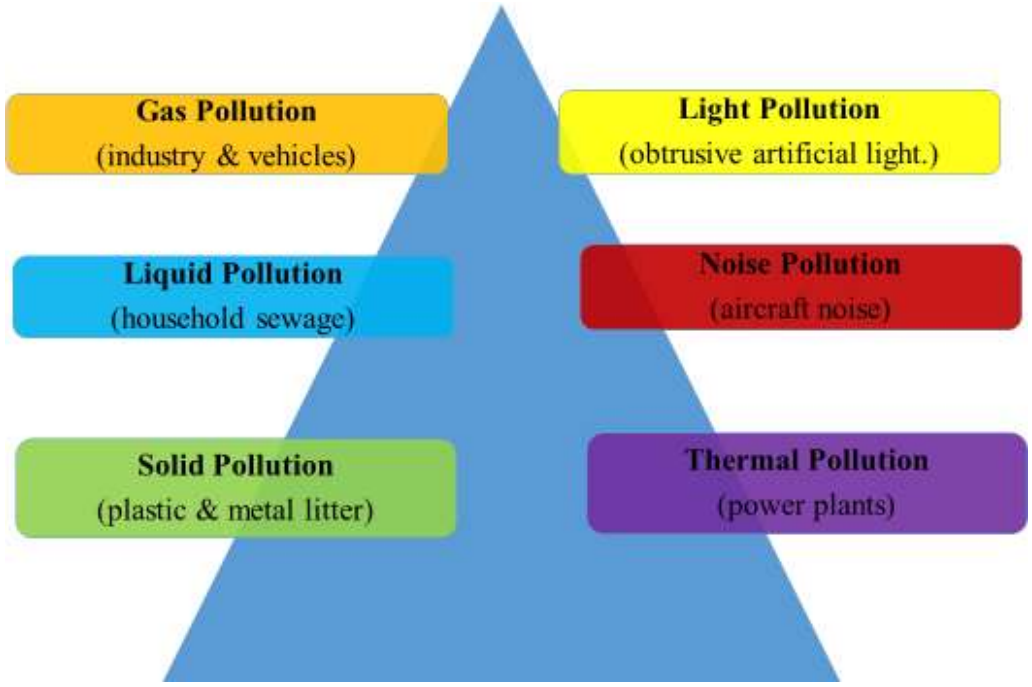

Fig. 1. Samples of selected different types of pollution in the troposphere, which poses potential health risks.

Thin-film technologies and microelectromechanical systems (MEMS) enable the integration of multifunctional sensor arrays (motion/sound/light/temperature/humidity) for home use [5]. There is an explosion in connecting devices such as personal computers, smartphones, tablets, internet of things, smart televisions, and wearables. Electronic waste (e-waste) generated worldwide from home appliances, computers, and smartphones is a growing concern over the next decade [6-7]. It contains hazardous substances such as mercury, sulfur, cadmium, lead, beryllium oxide, and hexavalent chromium, which has a severe environmental impact [8]. Biomedical waste, generated from biological and medical sources and activities, could potentially lead to the spread of infectious diseases.

When microorganisms such as virus and bacteria enter the human body produces toxins and affect the immune mechanism, leading to muscle and joint pains and fever. The noise pollution adversely affects the lives of millions of people worldwide, as there are direct links between unwanted sound and health. The sources include transportation systems, construction of buildings, industrial noise, public address systems, boilers, generators, and vacuum cleaners. The transport noise (road, air & rail traffic), occupational noise (high-tech machines, tractor, power-drill), and neighborhood noise (loudspeakers, television & radio sets, generators) are the three major categories of noise.

Radioactive waste and pollution increase the risk of damage to DNA, cells, and tissues. Climate change poses an existential threat to the species on the planet, and it is an

issue that is very important for the future of humankind. We have to maintain the global temperature within the 2o C threshold to avoid the problematic consequences of climate change. The primary human activities - deforestation, water and energy use, industrial and agricultural practices, and urban sprawl - contribute significantly to climate change [9]. These human activities have led to enhanced concentrations of greenhouse gases such as carbon dioxide, chlorofluorocarbons, methane, nitrous oxide, water vapor, and ozone in the atmosphere. These molecules absorb different wavelengths in the infrared region, causing the atmosphere to become warm (greenhouse effect), and this effective barrier prevents some heat from escaping the earth's surface. When released into the atmosphere, the CFCs are carried into the stratosphere, where they can absorb a significant amount of high energy ultraviolet light, forming chlorine radicals. These reactive radicals can catalyze the destruction of the ozone layer. The Montreal protocol called for reductions in the production and use of CFCs. The pollutants which enter the atmosphere directly from their sources are called primary pollutants [dust, soot (elemental carbon), nitric oxide, sulfur dioxide]. In contrast, those formed by the reaction of a primary pollutant in the environment under the influence of sunlight are called secondary pollutants (ozone, hydrogen peroxide, aldehydes). These two types of pollutants, along with dust, soot, and droplets of water form smog.

It is important to note that nature also pollutes the air on a large scale with volcanic ash, sulfur oxides, hydrogen chloride, pollen, methane gas, and odorous organic compounds from coniferous forests, dioxin emissions from forest fires. The excessive obstructive artificial skylight, particularly in highly industrialized and densely populated urban areas, cause light pollution. The streetlights and other human-made sources in the night have a disruptive effect on natural cycles and inhibit the observation of stars and planets. Public lighting is a significant source of greenhouse gas emissions. Another type of pollution called 'thermal pollution' causes damage to the environment from the waste heat of industrial processes. Water discharged from power stations is an example source of heat pollution.

Other sources of thermal pollution include nuclear power plants, hydroelectric power generation, and domestic sewage disposal. Particulate pollutants such as fly ash, silica, and dust released from volcanoes, fossil fuel burning, mining, and forest fires. The extent of such pollution and its effect depends on their size range, concentration, chemical nature, rate of settling, a period of exposure, and individual health. There are two sources of water pollution; point sources of constant volume and definite composition such as industrial wastewaters and diffused sources of unknown volume and composition such as agricultural and street run-off. Sludge from the sewage plants contains harmful toxic chemicals that affect the fertility of the soil. Accidental pollution, such as the recent massive

earthquake in Nepal (April 2015), has taken nearly 8,000 lives and does not provide enough time for humans and animals to escape.

Household air pollution (HAP) from fuels (charcoal, wood, kerosene) burnt at home for cooking, lighting, and heating purposes generate high concentrations of smoke particles. Even cigarette smoke causes much-localized air pollution and can lead to different kinds of health problems. Lung cancer incidence is nearly 20 times higher in smokers than in non-smokers. Many organic products may contaminate air, water, soil, and persistent organic pollutants (POPs) include dioxins generated from municipal or biomedical incinerators and polychlorinated biphenyls (PCBs) and organochlorine pesticides manufactured from chemical industries. These substances, because of their low solubility and high stability, persist in the environment and enter the food chain as pollutants to cause health risks. Freshwater pollution can occur by chemical effluents from industries, and marine pollution takes place by oil spills from tankers. When released into the environment, the vast quantities of organic solvents used in chemical manufacturing, industrial cleaning, textile dyeing, and food processing operations, lead to groundwater contamination and the buildup of GHGs. Thus, there are different categories of the introduction of harmful substances into the environment. Massive industrialization and urbanization and balancing economic development with environmental quality is a real challenge.

POLLUTION HAZARDS AND PUBLIC HEALTH ISSUES

The environment is a complex and dynamic system with interconnected life forms. The primary characteristics of the environment have been changing due to the removal of essential components like dioxygen and the addition of undesired components such as carbon, sulfur, and nitrogen dioxides. The effects of pollution can be gradual or dramatic, small-scale, or global. Pollution hazards include injury or poisoning of animals, reduction of oxygen supply in contaminated water, destruction of food sources or vegetation cover, acid rain, and climate change. The photochemical smog produced mainly by the action of sunlight on auto-exhaust gases creates an unpleasant condition of pollution in specific urban environments. The eye irritants that cause tears, lachrymators, are oxidation products (peroxyacetyl nitrates) of primary pollutants.

The earlier Los Angeles and the more recent Beijing smog in 2014 created a piece of worldwide news, and these incidents indicate an early warning to take immediate corrective measures. One of the effects of thermal pollution of lakes is the decreased solubility of oxygen in water with an increase in temperature, and warm water tends to remain on top of cold water as it is less dense. This effect further impedes the oxygen dissolution in water, and fishes may die, and respiration of other aquatic life will be affected under these conditions. Water quality will be affected by the accumulation of organic materials such as sewage disposal, industrial wastes, and effluents in water. Water pollution is also caused by different types of microorganisms, including pathogens and chemical contaminants such as fluoride, chloride, and arsenic.

Aerobic bacteria consume dissolved oxygen to oxidize organic materials, leading to the depletion of oxygen in the water, and such poor-quality water is detrimental to animal life due to less than usual amount of dissolved oxygen. The ailments associated with water consumption with high fluoride concentration include dental and skeletal fluorosis, and it is crucial to overcome the impact of fluoride on water-table in the affected areas. Household air pollution exposure can cause reduced immune function, increasing the risk of bacterial pneumonia. When hydrocarbons and nitrogen oxides, released by automobiles, react with sunlight to produce ozone. The causes of a diminished population of some varieties of sparrow include pollution, pesticides, habitat destruction, lack of food, and signals from cell towers. The decline in honeybee population threatens crops like almonds and apples that depend on insects for pollination.

Noise has been considered as one of the dimensions of pollution that causes environmental degradation and health hazards. The loudest sound ($\geq$ 130 decibels) causes pain to the human ear and listening to loud music for long can damage our hearing. The noise-induced hearing loss (NIHL) is common among the factory workers in the textile, automobile, fertilizers, and chemical industries. Other effects include headache, mental tension, blood pressure, heart diseases, and stomach trouble. Low-frequency noise at night can disturb the sleep of senior citizens and patients, causing adverse health effects. High-intensity noise is one of the major factors for chronic mental exhaustion. Beyond maximum recommended noise dose exposure levels, environmental noise causes widespread

damage to the human mind and body. Pollution in the troposphere can have adverse effects from burning eyes and cough to the destruction of vegetation and ancient monuments.

The current ozone concentrations in some urban areas are good enough to cause health hazards in children, pregnant women, people with respiratory disorders, and veterans with decreased respiratory capabilities. The road salt (sodium chloride) is used during winter in some parts of the globe, and this helps to lower the freezing point of ice and snow, facilitating their removal from roads. However, the dissolved salt runs off into adjacent streams, increasing their chloride ion concentration, and this water is not potable for humans and is toxic to some aquatic life. Some other effects of pollution are acid rain, the greenhouse effect, and the creation of an ozone hole allowing ultraviolet radiation that offers more exciting challenges.

Sulfur dioxide is produced by burning coal containing sulfur, and it is a major contributor to acid rain and industrial smog. It is released during the process of extraction of the free metals from their sulfides. This gas is corrosive and damages plants, structural materials, and causes throat and lung irritation. When it combines with moisture in the air, it forms sulfuric acid, the main cause of acid rain. The water in some lakes, streams, and ponds around the world are highly acidic and unfit for fishes, shrimp, and other aquatic organisms to live. The plant leaves suffer skeletal damage, and as a result, photosynthesis is affected. An aerosol of sulfuric acid, when inhaled, gets trapped in the lung, and cause severe damage. Aerosol particles in the atmosphere cause light scattering and haze in the atmosphere can lead to limited visibility in the area, raising the number of accidents. The

stratospheric ozone layer prevents ultraviolet radiation from reaching the earth's surface by undergoing a photodissociation reaction. This reaction is essential for the protection of people and plants on the earth's surface because the harmful UV radiation that reaches the earth's surface by ozone depletion can cause DNA-damage, skin cancer in humans, and damage to living plants.

Global warming, temperature increase due to the greenhouse effect, will cause more of the polar ice caps to melt, increasing the sea level and flooding coastal areas. Recent studies indicate a sudden dramatic change in the Antarctic Peninsula glaciers, and much of the ice streams are particularly sensitive to any changes in the ocean water temperature. Significant changes in atmospheric currents and weather patterns could affect agricultural productivity. Light pollution by misdirected or obtrusive artificial light in the outdoor environment causes energy waste, affects animals, human health, and psychology (impaired thinking and depression), and disrupts ecosystems. The light confuses and interferes with the migration of birds, and millions of birds die each year from collisions with tall towers and multistoried buildings with bright lights. Light clutter may create confusion, distract from obstacles, and potentially cause accidents. Oxygen becomes less soluble as the water temperature rises, and warm water rises to the surface of rivers as it is less dense.

This feature acts as an insulating blanket that prevents absorption and penetration of oxygen into inner layers of water, affecting the population of many marine species. Particulates scatter light and reduce visibility, causes allergic reactions, irritation and respiratory disorders, and silicosis. Polychlorinated biphenyls and the pesticide dichlorodiphenyltrichloroethane (DDT) are nonpolar.

Moreover, they are stored in the body of fish and certain animals. Suspended solid particulates aggravate bronchitis and asthma, and damages lung tissues. It is also important to note that certain diseases like cancer or byssinosis may strike 5-10 years after exposure, and some diseases occur in specific human population groups. Environmental toxins such as aluminum, lead, mercury, cadmium, and dioxins may contribute to Alzheimer's disease, respiratory ailments, skin diseases, and cancer.

Further investigation of population studies is required to establish a link between the amount of these toxins and the prevalence of particular diseases. The scale of biodiversity loss has increased as human activities, and a consequent change in the environment led to major extinction events. Air pollutants discolor historic buildings, marble structures, statues, and other monuments of cultural significance. The devastating earthquake and tsunami can cause partial damage or total collapse of buildings, contributing to environmental changes. The overall impact of pollutants and environmental chemistry depends on the pollution level, exposure to sunlight, nature of pollutants, and altitude.

CONTROL OF POLLUTION TOWARDS A SOLUTION

It is essential to regulate principal toxic pollutants like carbon monoxide, sulfur dioxide, nitrogen oxides, lead, mercury, and particulate matter (PM) to reduce local and global pollution levels and the adverse effects of atmospheric pollutants on human health and the environment [10].

It is important to note that many of the environmental issues are global as reflected in several international level conferences and meetings in the last two decades, and resources are limited and environmental challenges are huge [11]. We need to take certain immediate corrective measures such as a self-imposed code of conduct, instituting industry norms, imposing trade restrictions, and government policy and legislation to reduce harmful environmental impacts [Fig. 2]. It is essential to provide environmental education to realize the importance of environmental protection and develop the proper mindset of a progressive planet. Further focus on new domain expertise to address emerging environmental issues worldwide will pay rich dividends. It is important to stimulate and instill the passion of environment conservation amongst the local people and initiate movement towards sustainable development in harmony with nature to fulfill the greater cause of a healthy society.

Creating awareness about the harmful effects of pollution, using public transport vehicles, organic farming practices, controlling polluting activities, and adopting less-polluting lifestyles go a long way in reducing pollution, a pressing environmental issue. Organic farming methods to produce agricultural commodities help conserve soil and water quality and reduces pollution to a certain extent, in addition to personal health benefits. Agricultural model based on organic farming, irrigation projects, spraying herbal pesticides, timely water, and electricity supply can enhance farm productivity. Regular servicing and tuning of automobiles, planting bushes and trees, designing buildings with noise absorbing materials, and personal protective equipment can effectively reduce

noise pollution. Other measures to tackle the problem of noise pollution include the use of limited hour horns or no horns, increasing no vehicle entry zones, and banning use of loudspeakers in public functions, festivals, or cultural programs. Thus, noise pollution reduction measures include control of noise intensity at the source, noise absorption measures between the source and the recipient, and use of personal protective devices.

The cumulative effect of many corrective and preventive measures such as environmental education in the curriculum, political will and policy decisions, planned urbanization, land use, and mobility planning, reliable and efficient public transport systems, reducing the number of vehicles, adopting a variety of energy conservation measures, and use of lead-free and quality petrol will have an overall global impact. Other measures such as the use of natural dyes to color leather or textile, biodiversity conservation, use of CNG in vehicles, reducing the number of new vehicle registrations, and increasing green cover will enhance the local ecosystem to a large extent. To combat the problem of stratospheric ozone depletion, more than 150 countries have signed the protocol to ban ozone-depleting compounds such as chlorofluorocarbons (CFCs), halons, and methyl bromide. The recent results indicate that the levels of ozone-depleting chemicals are declining and will reach the pre-1980 levels by 2050. We have to control carbon dioxide emissions throughout the world to reduce global warming (1.5 to 4.5 oC) and ocean acidification. There is uncertainty in the temperature changes due to global warming because of complex parameters - warming due to human activities versus part of a natural cycle, the response of the earth's climate to the warming, and the extent of

GHGs in the coming decades. Trends in polluting gas emissions vary widely among different countries, and local control of such emissions, including the use of improved emissions- control technology and policy decisions, will result in significant reductions of adverse effects.

Use of alternative sources (CNG, methanol) in place of fossil fuels (natural gas, gasoline, coal, oil, and kerosene), planting more trees, improved combustion technologies, and improvements in emission control systems help achieve satisfactory levels of air pollutants. The use of catalytic converters in motorized vehicles to help convert the nitrogen oxide gases back to nitrogen and oxygen and also help in the complete oxidation of unburned hydrocarbons. Now, most of the sulfur dioxide is trapped and used in the manufacture of sulfuric acid to limit the amount of gas that escapes into the atmosphere.

The reverse osmosis (RO) method using a membrane (cellulose acetate) can be used to construct large scale plants to purify drinking water, and a portable RO unit designed for individual use provides the freshwater in our daily use. Use of energy-efficient lighting sources and motion-sensing lights, turning lights off when not required, and lighting legislation are some of the measures required to reduce severe photo pollution problems [12, 13]. A large-scale light-emitting diode (LED) bulb adoption will significantly bring down the global electricity bill as it uses less electricity. The thermal pollution problem due to industrial effluents can be tackled by installing cooling towers, which cool water before it comes out of the plant.

Cooling ponds and artificial lakes also offer other ways of fighting thermal pollution.

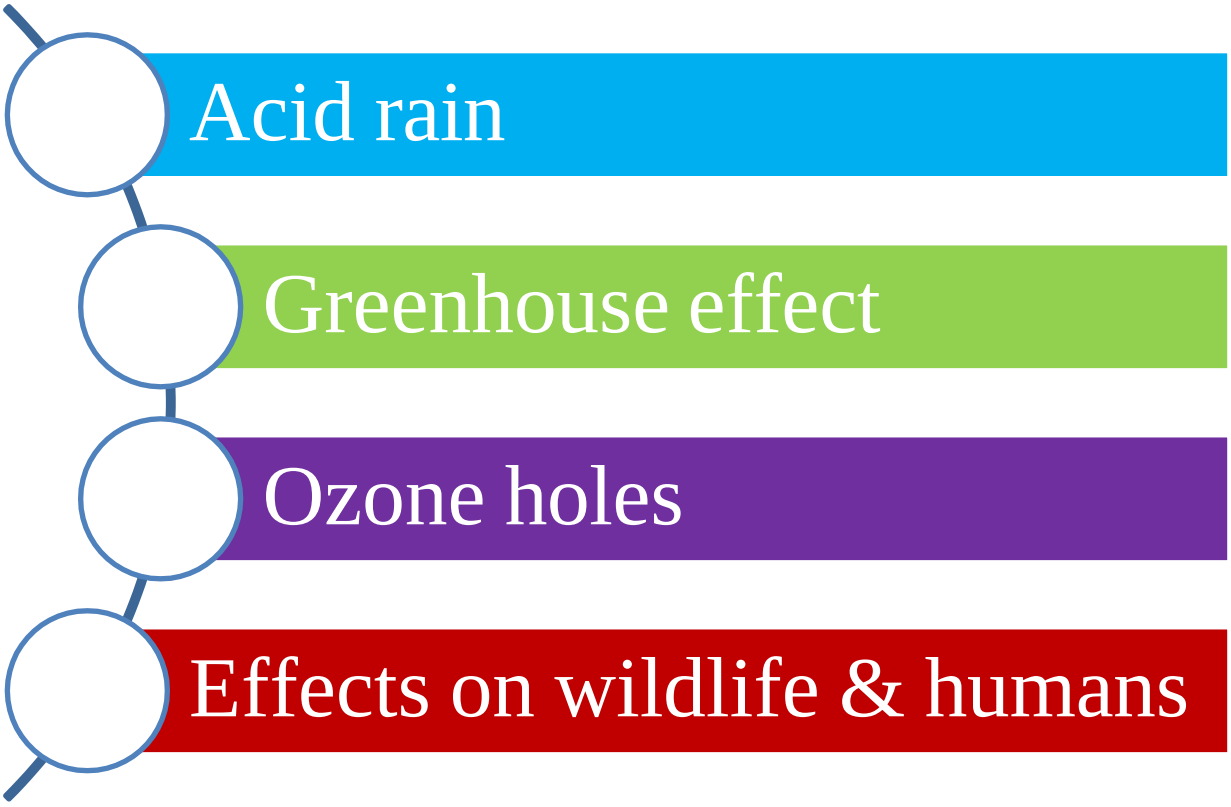

Fig. 2. Selected examples of the effects of pollution leading to climate change.

High levels of toxic waste from industry, noxious emissions from vehicles, fine dust particles from construction work, exhaust fumes from coal plants, adulterated fuel, diesel exhausts, and superfine particles from cooking and garbage fires contribute to the air pollution problem. The harmful contaminants such as carbon monoxide, nitrogen dioxide, and volatile organic compounds, caused by cooking via frying, grilling, or toasting in the indoor environment affect human health to a large extent. Inhaled poisonous fumes such as carbon monoxide produced in an indoor closed space

can cause breathing difficulties, unconsciousness, and even death. The carbon monoxide is ae excellent ligand toward the iron present in hemoglobin and can affect the normal functioning. The strong affinity of CO for the Fe(II) in hemoglobin, results in a stable complex, carboxyhemoglobin.

This complexation prevents the normal uptake of oxygen, and asphyxiation can result if CO concentration is high enough in the surrounding air. There is a need for better ventilation standards in kitchens to remove cooking contaminants from inside closed space. The outdoor suspended ultrafine particulate matter will affect the health of vulnerable veterans, children, pregnant women, construction workers, traffic police, and people with a history of respiratory and cardiovascular disorders. The ultrafine and nanoparticle toxicology indicates the link between nanoparticles of titanium dioxide, carbon black, and polystyrene, and respiratory disorders [14,15]. Nanotoxicology, though in its infancy, that studies the interactions of nanoparticles with cellular components and biological systems will help in understanding the mechanism of toxicity and predicting potential human health hazards [16].

The study of the effects of factors such as particle size, composition, solubility, surface chemistry, length of exposure, different structures (nanotubes, nanofilaments), the total number of particles in suspension, degradability and distinctive properties of various engineered nanoproducts and their kinetics within the body system are essential in assessing the toxicity profile and risk to human beings and their harmful effects on our ecosystems. Therefore, the objective of green nanotechnology is to enhance productivity with minimum possible damage to human health and the

environment. It is interesting to note that even naturally occurring nanoparticles such as pollen fragments can cause allergy in some individuals, and viral particles can cause certain diseases. Long-term academic and industrial research projects, the scientific validity of research outcome, substantial research evidence, likely scenarios in the real world, and tested real-world solutions would provide invaluable insight in understanding the interactions between nanomaterials and environment, other development interests, ethical aspects, and legal perspectives. These aspects would eventually lead to framing environmental law and regulation of nanotechnology to serve the greater human good [17].

The rapid growth in the use of fertilizers and pesticides in the last 50 years contributes to contamination of food by persistent residues and certain chemicals enter the food chain through the environmental dispersion [7]. These could cause effects from the slight physical discomfort to dangerous side effects in human beings. Therefore, it is essential to collect water samples from rivers or lakes and monitor its quality frequently by qualitative and quantitative chemical analysis and to track the source of pollutants if their concentrations exceed acceptable levels. Similarly, it is important to monitor air and soil quality at different locations to make them fit for industrial, agricultural and domestic purposes. Environmental laws are necessary to protect environmentally sensitive areas (ESAs) of ecological and landscape significance, from irreparable damage due to pollution. The objective is to prevent further damage, to protect the environment from pollutants, discourage public from activities causing similar damages, and continue to promote environmental

harmony. Particulate pollution from industries can be controlled by using techniques such as gravity settling, centrifugal separation, electrostatic precipitation and use of filtration systems and wet scrubbers.

The wet bio-waste generated in large scale in cities can be processed in the bio methanation plants to generate electricity. The dry waste plastic can be mixed with bitumen that can be used as road topping, as part of plastic waste management. Manufacturing biodegradable plastics that are compostable on a large scale could contribute to a cleaner environment and a greener world. It is important to process biodegradable waste into manure by aerobic or vermicomposting techniques, as part of clean initiatives. Hazardous waste management technologies include incineration, chemical and physical treatment, bioremediation and stabilization and solidification technologies and other treatment technologies are still in the research and development stage.

A comprehensive study involving mapping of particulate pollution in major cities and development blocks around the world, and its acute and chronic impacts on human health, including cancers of the trachea and the lung, will help us to understand the problem in the context in which it occurs. This will allow us to take serious long-term measures to tackle air pollution problem with fresh and special emphasis on improving the present particulate pollution scenario. There is an urgent need to control air pollution in the public health interest and to allow the safe and sustainable development of products, with a comprehensive action plan and effective implementation of a working solution to strive for growth-environment balance. The flow of undertreated drainage water

from urban areas to nearby tanks will result in the accumulation of toxins and it has been observed that the bird population in such ecologically sensitive areas has gradually decreased in the last decade. We need to sensitize civil society groups to issues of fresh air, pure water and productive soil and take appropriate actions using problem solving skills, monitor their progress by suitable follow-up actions. At one level the specific local solution is viable. For instance, protective regulations to preserve or rebuild the rare, threatened or endangered species of plants and animals.

Alternative practices involving integrated efforts are required in our constantly evolving world to have the universal solutions. Integrating renewable sources of power, such as solar and wind on a large scale into the mix and reducing the coal or gas burning power plants would spare millions of tons of greenhouse gases across the globe. Poor energy efficiency in coal power plants reflects the extra coal burning to obtain the same power output. It is important to implement environmental, health, and safety guidelines for phosphatic, nitrogenous and potash fertilizer factories and other chemical manufacturing plants generating toxic metal waste and volatile organic compounds [7]. Hazardous waste reduction efforts in industry results in increased efficiency and lower costs for waste disposal. The recycling efforts also reduce the discharge of pollutants into the environment. Intensive research on immediate and long-term damages to the natural resources due to major oil spills on waters and coastlines is required. Further, determination of specific chemical and biological effects of oil spill, development of oil recovery techniques, clean-up efforts and species restoration programs help recover the ecosystem.

We live in an information age based on connectivity and international early warning systems and network should communicate about the forthcoming environmental events such as earthquake, tsunami, hurricane and epidemics to take timely action to save lives. Establishing a reliable emergency response system and disaster management mechanism will help reduce consequent pollution problems. Proper functioning of trained and professionally skilled manpower could help address the real public health issues due to environmental disasters. A stronger surveillance network involving controlling outbreaks of certain diseases and preventing their spread is essential in case of massive earthquakes to maintain a healthy community.

The population control is the crucial step in protecting and minimizing pollution of the environment because rapid population growth dilutes and defeats all the future plans and public welfare programs. The anti- pollution initiatives such as the banning of plastic bags, no dumping of waste into rivers or no burning waste in public places needs civic consciousness and the fear of fines and prosecution will act as a deterrent. The emergence of eco-consciousness in the world is picking up fast due to some scientific advancements, continued government supports, public participation, and transparent actions through numerous measures and schemes. The results of multidisciplinary research and application development, economic principles, public health ethics, and individual and population benefit should form the foundation for environmental policy making and this helps to disseminate viable and alternative practices to boost the global green development. Proper environmental planning, building engineering and management, use of renewable energy sources,

afforestation, and construction of sewage treatment plants could contribute to world welfare systems. Organizing nature camps, workshops, tree-planting and other events for ecological restoration can lead to long- term environmental benefits.

The establishment of central pollution control boards (CPCB), environment conservation enforcement administration (ECEA) and special operations group (SOG) to carry out detailed analysis of air, water and soil samples from different zones and recommend short-term solutions to prevent further pollution and long-term measures for environmental sustainability. An independent, autonomous body, such as a center for science and environment (CSE) can conduct environmental audits of industries and announce green rating in terms of their performance and compliance compared to the global benchmark. The 3Cs, coordination, cooperation and communication among different countries plays a pivotal role in enhancing the global ecosystem. Strict legislative measures need to be enforced to curb the menace of different types of pollution. “Act Responsible, Think Sustainable” is one of the sustainability slogans that is sending the right message to those committed to the pursuit of sustainable development goals. There is a need to create awareness in students at an early stage of life about the importance of protecting the environment and the dangers of global warming or irreversible climate change or irreparable damage [24-26]. Environmental activism is growing and that has become evident in the environmental justice movement [27]. The bilateral and multilateral relations among countries and continents as well as motivation to manage their networks in a way that maximizes their environmental interests is a challenge [28]. Air quality guidelines limit

set by world health organization (WHO) and environmental protection agency (EPA) distinguishes low pollution, moderate to heavy pollution and serious pollution categories [29].

It is essential to publish the list of various contaminants in air, water and soil and their maximum contaminant levels (MCLs) allowed for a particular application to have controls on pollutant emissions. Toxic release inventory (TRI) and air quality index (AQI) has been developed by EPA and this will help us in developing more environmentally friendly commercial solvents or control some of the many materials that can cause air pollution. Air quality monitoring requires us to carry out real-time data analysis on air pollution in a cost-effective manner using metal oxide sensors at different locations or by mounting on vehicles. Clearly, we have much to learn about proper air, water, and soil management to prevent a serious threat to human health due to contamination of ground and surface water, troposphere and stratosphere air as well as topsoil and subsoil layers. There is a need for distinctive issue-based approach to pollution and dedication to showcase the history of pollution that ranges from traditional pollution patterns to contemporary pollution because of needs and compulsions leading to cross-contamination situation.

NUCLEAR RADIATION POLLUTION

Electricity, being the lifeline of the economy, is an essential need for manufacturing, agriculture and services sectors. The high electricity price cause adverse economic impacts on these

sectors and it will affect the common man in daily life. Therefore, it is essential to pay special attention to ensure efficient and economical power generation, transmission and distribution.

The future state of global energy production and consumption depends on the combined application of nuclear, natural gas, hydroelectric, biomass, solar-thermal and solar-photovoltaic, and geothermal resources [30]. We have to learn lessons from the mistakes of previous nuclear power plant accidents to prevent the harmful effects from recurring, as the use of nuclear energy provide complimentary resource. There is a need to study health effects of exposure to radiation such as alpha and beta particles, gamma rays, X-rays, cosmic radiation and neutrons on the present generation and also cumulative effects of actions today over future generations. The destruction of the Japanese city of Hiroshima, by nuclear bomb, in 1945, instantly killing one lakh people is a grim reminder of the gravity of nuclear war. This nuclear radiation causes congenital defects, mental retardation, immune system destruction and cancers. Radiation-induced DNS transformation can lead to cancer. Containment of radioactive products that are dangerous for thousands of years is the most pressing challenge. Clean-up of contaminated areas, disposition of excess nuclear materials and dismantling of nuclear weapons also contaminate the environment and threatens human health.

The Chernobyl disaster in 1986, involving an explosion and fire, released large quantities of radioactive particles into the atmosphere, and the long-term effects like cancer are still being investigated. The earthquake and tsunami triggered a Fukushima nuclear accident in 2011 forced more than 3 lakh people to move away from the place and it is a tough task to contain the 300 metric

tons of radioactive groundwater leaking into the Pacific. There is a need to adopt new technologies taking into consideration adequate safety measures to meet the energy needs in the 21st century and beyond. Today, protective shielding consisting of lead and other dense metals is used to absorb much of the radiation in the place of work and low- and high-level radioactive waste (LLRW & HLRW) disposal methods are adopted.

The three principal aspects of paying particular attention to the steps on the way of natural processes, having profound mental reflection on the causes or implications of the observed phenomena, and performing theoretical investigation using advanced computational methods and exact experimentation based on modern experimental techniques should provide proper direction to the development of natural science and technology [21]. The successful investigator will provide a platform for modern researchers interested in the subject and set in motion a clean process that would have truly global significance. It is essential to strive to obtain an adequate number of solutions of problems and the clean-up the world activities would also contribute towards a greener planet. The general objective is to identify a variety of underlying factors or potential causes that could be contributing to the environmental issues and offer management plans and lifestyle changes, leading to better health of the people and benign environment. Creating social awareness, widespread environmental education and contributing to conservation of biodiversity as long-term measures will help strengthen enforcement of environmental safety standards, improve air, water and soil quality

and prevent different types of pollution on our pathway to preserve human health and environmental sustainability [3].

The climate change across the planet and global warming could reduce agricultural production and pose the risk of food supply in the future decades. The green chemistry initiative promotes the design and application of chemical products, processes and systems that are compatible with human health and the environment, though the contribution of the chemical industry to pollution is only a small part of the whole picture [Fig. 3]. The major directions involved in the recent research activities include finding alternative starting materials, reagents, transformations, reaction conditions and final products to achieve a more environmentally benign processes, products and systems.

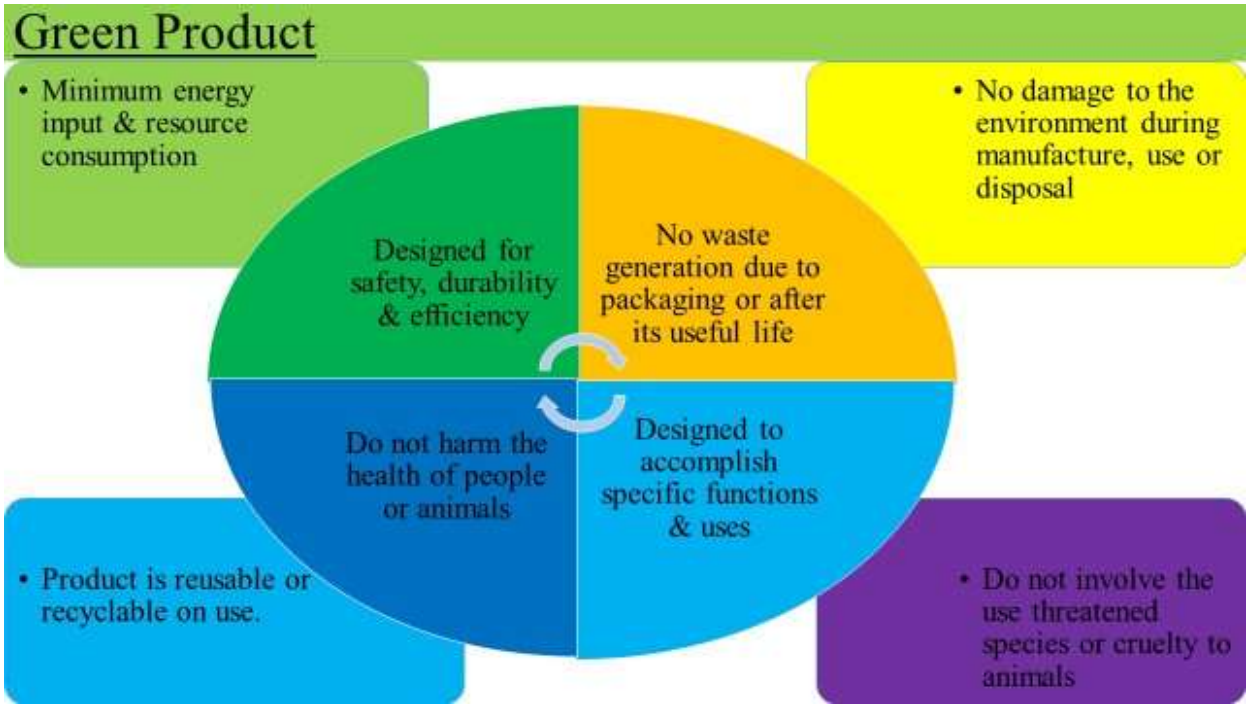

Fig. 3. The major green chemistry principles that can improve environmental quality.

TRAJECTORY OF TOXICOLOGY AND TOXIC LEVELS

The consequences of environmental exposure on human health depends on activation of biochemical reactions leading to a variety of physiological effects. The discipline of toxicology involves the study of adverse biological effects of physical (temperature, radiation) and chemical agents (carbon monoxide, benzene vapor) on living organisms. There are several factors such as the

age, sex, chemical species, dosage as well as absorption, distribution, metabolism and excretion mechanisms determine the overall effect of a particular toxic chemical in a given situation [12].

A toxic screen test is one of the most commonly used diagnostic blood test. It screens the blood for the presence of poisonous substances such as alcohol, amphetamines, antidepressants, antipsychotic drugs, hallucinogens, narcotics and tranquilizers. Some bacteria that invade our body produce poisons that enter the blood stream to cause life-threatening infection such as toxic shock syndrome. The effects of exposure of chemicals can be broadly classified into 'chronic (long-term) toxicity' that describes the adverse health effects from repeated exposures that occurs over a longer time period (months or years) (e.g. cancer or allergic reactions) or 'acute (short-term) toxicity' that result in adverse health effects immediately after exposure (hours) (e.g. burns from contact with concentrated mineral acids, hydrogen cyanide, phosgene). Chronic lead toxicity may occur from common sources such as lead-based paint in the home, lead smelting and refining or battery manufacturing work at the workplace or combustion of leaded gasoline in the environment. The excessive lead intake in children affects the brain and behavior, and increased blood lead concentrations in adults often resulting in hematological abnormalities. It is a cumulative poison that can cause a wide variety of neurological problems.

The most commonly used therapeutic chelating agent for mobilizing lead is ethylenediamine tetraacetic acid (EDTA) that forms a soluble complex that is excreted through the kidney system of the body. Acute metal toxicity commonly occurs from thallium salts used in rat poison, arsenic

trioxide used as herbicides or the misuse of methylmercury compounds as fungicides in seed treatment. Mercury can enter our body system by inhalation of its vapor, contact with the skin and ingestion of foods or water contaminated with it. Toxic effects include damage to the brain, lungs and kidneys and severe poisoning results in a neurological syndrome called Minamata disease. The acute or chronic mercury poisoning is treated using chelating agents such as dimercaprol and penicillamine that binds to mercury and eliminated from the body through subsequent urinary excretion.

The arsenic absorption from the gastrointestinal tract, ultimately results in its accumulation in the skin, nails and hair. It can be effectively mobilized by dimercaprol (2,3-dimercapto-1-propanol) that can then be eliminated from the body through urine. Other heavy metals that will accumulate in hair follicle include cobalt, chromium, cadmium and tungsten. Many of the reactions that proceed as per certain scheme using the pure chemicals in the laboratory may be different when a natural mix of these chemicals react under the actual conditions of environment. It is important to recall the fact that there is an optimum dose for all essential elements. When an element is insufficient, it results in deficiency disorders, but when it is present in excess, it exerts toxic effects resulting in different types of disorders. For instance, in Parkinson’s disease, copper is present in less than normal while in Wilson’s disease it is present in excess quantities. Screening for prenatal effects of environmental chemicals, including carcinogens with experimental animals is commonplace and such prenatal exposure to toxins may result in birth defects and developmental

deficits. While high level toxicity may be a sign that the environment is getting damaged, the adverse effects leading to a spectrum of ailments vary from person to person, the concentrations and chemical components of pollutants and the method of measurement also matters, and global effort is required to drastically reduce the extent of pollution.

ABSORPTION ROUTES AND HEALTH EFFECTS

There are several possible pathways of absorption of toxic chemicals into our body system and there is a need to understand general concepts in toxicology. The common avenues of exposure include inhalation of gases, aerosols or powder, ingestion by mouth via contaminated fingers, direct absorption by skin contact or damage or by splashes into the eyes or injection in homicidal poisoning. Thus, the most common routes of absorption of most toxicants are the gastrointestinal tract, respiratory tract and dermal routes. Further, uptake by humans depends on the rate of transport across dermal layers, lung membranes and rate of degradation within the human body and dispersion depends on density, water solubility, volatility and melting and boiling points of the chemicals concerned.

The toxicity testing methods include whole animal testing (in vivo), testing of isolated cells or tissues (in vitro) and in a computer simulation (in silico). Cellular studies have become popular in the last decade because of controllability and low cost. However, they are less reliable than animal studies and extrapolation of results to humans is more challenging. Further, ethical concerns limit

the application of testing methods to clinical trials in humans or exposure in human populations. The median lethal dose, LD50 is the dose required to kill half the members of a tested population (mice or rats) after a specified test duration. The LD50 value indicates relative toxicity of a substance, and it depends on the method of administration. There is a wide spectrum of relative toxicity among the chemical compounds: highly toxic (extremely hazardous), moderately toxic (highly hazardous), slightly toxic (mildly hazardous) and practically non-toxic (less hazardous).

For instance, methyl isocyanate is extremely toxic to humans from acute exposure and water is practically non-toxic and botulinum toxin is one of the most toxic while sugar is one of the least toxic. The relative toxicity of compounds varies within a particular class and DDT is more toxic than malathion, but less toxic than parathion among the insecticides. Organophosphates are more acutely toxic than organochlorine types of pesticides. Depending on the target organ systemic toxicity effect, they are classified as hepatotoxins, nephrotoxins, neurotoxins, hematopoietic toxins, pulmonary toxins and reproductive toxins [10,23]. Other measures of toxicity based on impacts of chemical exposure on the targeted tissue, organ or system include mortality (death), teratogenicity (ability to cause birth defects), carcinogenicity (ability to cause malignant tumors) and mutagenicity (ability to cause heritable change in the DNA). The agents which deprive the tissues of oxygen by displacing or diluting atmospheric oxygen or altering the biological processes that uses oxygen are called asphyxiants. The substances that tend to build up in the body as a result of repeated chronic exposures are known as cumulative poisons. A hematopoietic toxin affects the formation of blood cells while

a hepatotoxin causes damage to the liver cells. A reproductive toxin can harm the gonads, fetus or organs while genotoxins can alter the chromosome structure or number. A neurotoxin may affect neuron functions by inducing cell death, disrupting electrical mechanism or altering neurotransmitter activity.

Further, the biochemical mechanism may be different at low and high doses. The precise molecular mechanism of metal toxicity is uncertain in many cases and there is no effective treatment option either. Though chromium metal is an essential element, it is carcinogenic in Cr(VI) state and occupational exposure in electroplating industry poses risk of health hazards. Zero-valent mercury is highly toxic when inhaled as it can pass through the lung into the blood stream easily. Occupational exposure data indicate that industrial chemicals such as vinyl chloride causes lever cancer and benzene causes cancer and is often linked to leukemia. When more than one hazardous substance are present at the same time, the resulting effect can be greater than the effect predicted for the individual species.

The modern instrumental methods of analysis such as atomic absorption and emission spectrometry, X-ray fluorescence, inductively coupled plasma emission spectrometry, neutron activation analysis and other equipment with advanced features have been contributing to provide meaningful results in assessing exposure to toxic chemicals. The common symptoms of possible overexposure include eye discomfort, breathing difficulty, dizziness, headache, nausea, vomiting and skin irritation. The chemicals affect humans, causing problems such as physical deformity,

respiratory problems, hormonal disturbances, reproductive disorders, kidney damage, skin diseases, gynecological problems, central nervous system disorders, cancers of the liver, blood, and throat and unconsciousness and even death.

The major pathways of elimination of chemicals from our body include urinary excretion route and gastrointestinal tract excretion route. Other less common routes of excretion of chemicals include sweat, saliva, hair, nails, tears, milk, exhalation, and biliary excretion. The pharmacokinetic model considering the absorption, distribution, biotransformation, and excretion processes as a function of time is extremely useful in monitoring biological and environmental impacts and to arrive at reasonable dose-response relationships [18]. It is important to develop a deeper and more comprehensive understanding of the toxicological implications of ecosystems by considering it as a complex mixture of several chemicals in different concentrations. A firm understanding and application of the underlying green chemistry and green engineering principles fuel scientific progress and technological breakthroughs [3,22].

SAFETY PRECAUTIONS INVOLVING HAZARDOUS PRODUCTS

It is important to read the chemical safety information available in Safety Data Sheets (SDS) on the existing chemical catalogue and follow the recommendations for safe use and disposal of the materials that we use in the laboratory experiments [31]. For example, the common gases can be categorized as simple asphyxiants (N2, CO2), toxic asphyxiants (CO, HCN, H2S) and irritant gases

(Cl2, NH3, NO2, O3, SO2, HCl) and their toxic effects depend on several factors such as duration of exposure, history of health condition, concentration of the substance, age of the individual and the organ system affected. Further, the effect of irritant gases in the respiratory tract depends on their ability to denature proteins, water solubility, and lyophilic character. These potential occupational hazards could be minimized or eliminated by taking appropriate safety precautions while working, such as the use of personal protective equipment, improved design and maintenance, and proper interdisciplinary training in safety aspects and impacts.

We have to blend the right benchmark principles of safety into work practice by controlling our own thoughts and a host of more specific actions in the right safety spirit. Further research on the toxicology of chemical compounds is required to have a better understanding of toxic mechanisms and to have effective clinical medical practice to treat environmental and occupational exposure to such chemicals. The quality, effectiveness and safety of medicines and quality of services in the pharma sector are of crucial importance and circulation of spurious drugs can lead to major side effects in generally healthy people and adverse medical consequences in patients with other health complications. Therefore, stringent penalty for manufacture and sale of such drugs should be implemented, enforcing good manufacturing practices. The recent developments in genetically modified crops suggest that a detailed study of the long-term adverse effects of such products as potato, corn and apples on human health can indicate their usefulness in our daily lives [32].

The use of calcium carbide in artificial ripening of mangos produces acetylene gas that is a potential human carcinogen and toxic to aquatic organisms and it is better to use ethylene gas from the food safety point of view. It is essential to phase out the use of CFCs in refrigerators and auto air- conditioning systems eventually and alternatives such as hydrofluorocarbons (HFCs), 1,1,1,2-Tetrafluoroethane (C2H2F4) should be used by all the manufacturers. Annual limit on the mass per unit volume for fine particles with diameters less than 2.5 μm in the air should be set to 15 μg/m3, as part of ambient air quality standards [29]. All industrial effluents should be subjected to suitable treatment and smokestacks must be installed to trap smoke particles. Occupational safety and health administration (OSHA) law and regulations, recommends daily permissible noise level exposure and other workplace health and safety standards [17]. The iceberg model of toxic chemicals contains a small portion of compounds proven to be harmful at the top, slightly larger portion of partially proven cases, large chunk being not yet recognized cases in the middle, and finally many at the bottom will never be recognized due course due to difficulties of detection. Today, many university, industrial and government laboratories are involved in environmental research efforts and the major advances in this interdisciplinary topic may lead to practical solutions to the problem of hazardous waste.

BIOLOGICAL RESPONSE AND TOXICITY ASSESSMENT

The possible dangers of nanoparticles are due to the high surface to volume ratio, which can make them highly reactive and they can penetrate through cell membranes in biological systems, causing unknown interactions in real-world scenarios. The silver nanoparticles used in socks to reduce foot odor are released on washing that may destroy beneficial bacteria in the soil that help in breaking down organic matter. The respirable suspended particulate matter (RSPM) is an indicator of pollution in the air. The particles smaller than about 10 micrometers (PM10), can settle in the lungs and cause health problems, while those having size smaller than 2.5 micrometers (PM2.5), tend to penetrate into the gas exchange regions of the lung, and very small particles (< 100 nanometers) may pass through the lungs to affect other organs. There is a safe and dangerous level for every substance (toxicant or benign compound) depending on the dose-response graph where experimental data of different amounts of substance administered are plotted against frequency of some measurable physiological effects.

In general, higher dosage cause toxic effects in the organism while excessive dosage lead to lethality. The larger or steeper slope implies a toxic compound with a smaller range between the effective and toxic doses. The shape and slope of the curve could indicate toxicological end point, toxic dose, lethal concentrations, and lowest observed adverse effect level. The extrapolation of results for the effect of exposure to environmental chemicals is more challenging. Any extrapolation of results regarding physical and chemical properties from one nanoparticle to another closely related

one must take into considerations based on a quantitative structure activity relationship model (QSARs) [33].

Therefore, it is essential to develop specific approaches to testing their effects on human health and the environmental impact [34, 35]. There is a need to collect reliable data on exposure for environmental chemicals and response result to obtain information that help in categorizing and comparing the safety of different compounds and take proper risk management actions. The hazard identification by cellular or animal studies and chemical structure-property relationship is the first step in the risk management. The acceptable daily intake is calculated based on extrapolating relevant doses for humans from animal studies.

The exposure assessment must consider the frequency, duration, severity, and route in a population segment. The risk characterization based on the intensity and nature of an effect helps in the formulation regulatory process for implementation. Today, identification of toxicants is done through high-throughput screening of suspected compounds with known toxicity related targets and understanding their biotransformation mechanisms within the human body. The metabolically distinct distribution mechanisms can have an influence on the action of a toxicant. Relevant information and appropriate models to identify toxicological hazard and risk assessment help us to solve specific sustainable chemistry problems pertaining to health and the environment. The study of toxicity and resistance potential of selected test microorganisms could reveal the genetic basis or biochemical mechanisms of resistance.

The bioconcentration of pesticides in fish and biomagnification or bioamplification at the top of the food chain due to consumption of larger quantities of smaller animals affect the environment. For instance, dramatic decline in the population of some birds such as eagles, vultures, sparrows and falcons is caused by high concentrations of pesticide DDT in earlier studies or continued use of a harmful pain relief drug, diclofenac, a non-steroidal anti-inflammatory drug to treat cattle, was responsible for the great increase in bird mortality. The catastrophic decline of vulture numbers around 2006, has stabilized in the recent past. There is a need for a comprehensive environmental evaluation of veterinary drugs, careful planning to remove all known poisons, biodiversity management strategies, a ban on the use of toxic drugs, minimum consumption of natural resources, management of the sewage system and other ecological diversity conservation efforts.

The information on specific structural features of foreign chemicals that influence biological response (toxic tissue injury) on exposure helps us in understanding the adverse interactions between chemicals and biological systems and to reduce potential toxicity during the synthesis of new compounds by modifying functional groups. Sometimes, the toxicity of different isomers may be drastically different just like the therapeutic activity of certain isomers. The chemical safety assessment of emerging chemical technologies would have an impact on worker safety and the environment. The contamination of food with chemicals has to be determined to prevent the amount of poison we consume in the name of food. The rise of many diseases could be related to the contaminants present in processed food products from bread to branded items. It is important to

create awareness about safe foods and the processed food products containing food additives, preservatives, colorants, and flavors must be assessed for their potential long-term toxicity risk. A proper food safety mechanism, including stronger food regulations, strict enforcement, proper labeling, stringent quality control, and monitoring the entire food chain from farm or factory to the fork is necessary to prevent harm caused by unsafe food intake.

It is essential to create awareness about the importance of living in harmony with nature and organic farming practice provides a holistic approach to prosperity and the environment. It is extremely important to collect human data on accidental or routine exposure to chemicals and obtain meaningful information from critical analysis and proper interpretation of data in such cases. The range of chemicals could include environmental pollutants, industrial compounds, petrochemicals, pesticides, pharmaceuticals, hazardous wastes, and chemical warfare agents. The study of possible interactions of drug formulations in liquid or suspension form with plastic bottles over a period of time could indicate their potential toxic effects in humans. This will help us to understand real-world toxicological issues and to find out appropriate ecofriendly solutions. A new study on the oil spill in the Gulf of Mexico has found higher levels of many oil-related compounds like polycyclic aromatic hydrocarbons and volatile organic compounds, indicating the need for comprehensive chemical analysis of seafood samples and review of seafood safety.

ECO-TOXICOLOGICAL ASPECTS AND ADVERSE EFFECTS

Ecotoxicology deals with the study of the effects of toxic substances on ecosystems. It is essential to assess the environmental damage from pollution on plants and animals and predict the consequences of human activities on various ecosystems. The tools of assessment range from toxicity tests of individual chemicals on organisms, modern instrumental analysis to detect the presence of toxicants, and field surveys to characterize the damaged ecosystem. Hazardous substances with properties that make them dangerous or potentially harmful to the environment must be classified into extremely hazardous, highly hazardous, mildly hazardous and less hazardous types. The negative impact on the environment could include adverse effects on river basins, water, air and soil quality, wildlife and biodiversity and on forests. Alkaline soils can neutralize the acid deposition and can withstand acid accumulation without adverse ecological effects for a longer time.

Some areas are particularly vulnerable to acid deposition depending on a combination of climatic and geologic factors. The effects of acidification can be observed in lakes where sudden increase in acidity can produce severe chemical shocks to aquatic life. The gradual forest decline in some parts of the planet has been linked to acid rain and other air pollutants in woodlands. Acid rain can also affect the yields of certain crops, cause damage to some materials (Al, Cu, Ni, Marble, and Limestone), pose visibility problems and human health effects. Persistence of chemicals in the environment depends on the rates of atmospheric oxidation, aqueous hydrolysis, microbial degradation, photolysis and adsorption processes.

The environmental condition-toxicity relationships play an important role in determining the response of organisms. It is practically feasible to test a few representative species in the food chain and sample chemicals under controlled laboratory conditions, considering the complexity of the ecosystem where testing of the billions of species on this planet is impractical. Though LD50 is a common measure of toxicity, it does not consider toxic effects that are serious but not lethal and chronic toxicity effects. Further, cross-species extrapolations from animals to humans may impose some limitations and in certain cases a chemical relatively safe in rats may be highly toxic to humans. It is important to recall the old adage that “even nectar is a poison if taken in excess." It is known that table sugar administered in high doses can be toxic with high LD50 value. Nickel is an essential trace element in some animal species; it has toxic properties in high doses and one of its compounds, nickel tetracarbonyl, is a probable human carcinogen. Methylmercury present in fish is much more toxic than inorganic mercury found in other food products. Aspirin, when taken in large doses can lead to poisoning. The transformation of one species to another by processes in the environment has to be taken into consideration.

The environmental survey around the world using a multistage representative sample design will have long-term environmental implications and there is a need for a global welfare program. We will be in a position to relate the impacts of a chemical product, process or system to its effects in the environment, after establishing a reliable database containing information about the impact of chemical species on different organisms and the test methods adopted in such cases. It is now

considered important to adopt a reliable and a cumulative environmental impact assessment (EIA) of all development projects rather than using stand-alone treatment. The expert committee can study and recommend or reject the projects that have potential to cause a significant impact on the environment. The detailed study of every aspect of ecotoxicology from interactions between small particles to their effect on ecosystems, people and materials in our daily life and measurement of the impact of these particles as they fly through the environment help us in better understanding of the subject matter. We must focus on combining exhaustive academic and industry knowledge with advanced analytics to develop environmental models for setting and achieving global green global outcomes (Fig. 4). A mutually profitable long-term partnership, continuous support and cooperation among people in different fields such as software, medical, food processing and mechanical engineering fields is useful and important.

Performance improvements in activities like environmental engineering tasks, processes, and service operations using technology, products and systems, would result in value creation and transformation. A long-term vision and strategy for sustainable development, adopting modern practices and improving technology, quality and safety standards, good work environment, and mechanisms to improve operating efficiencies will help in taking more concerted global action to address the climate change challenge.

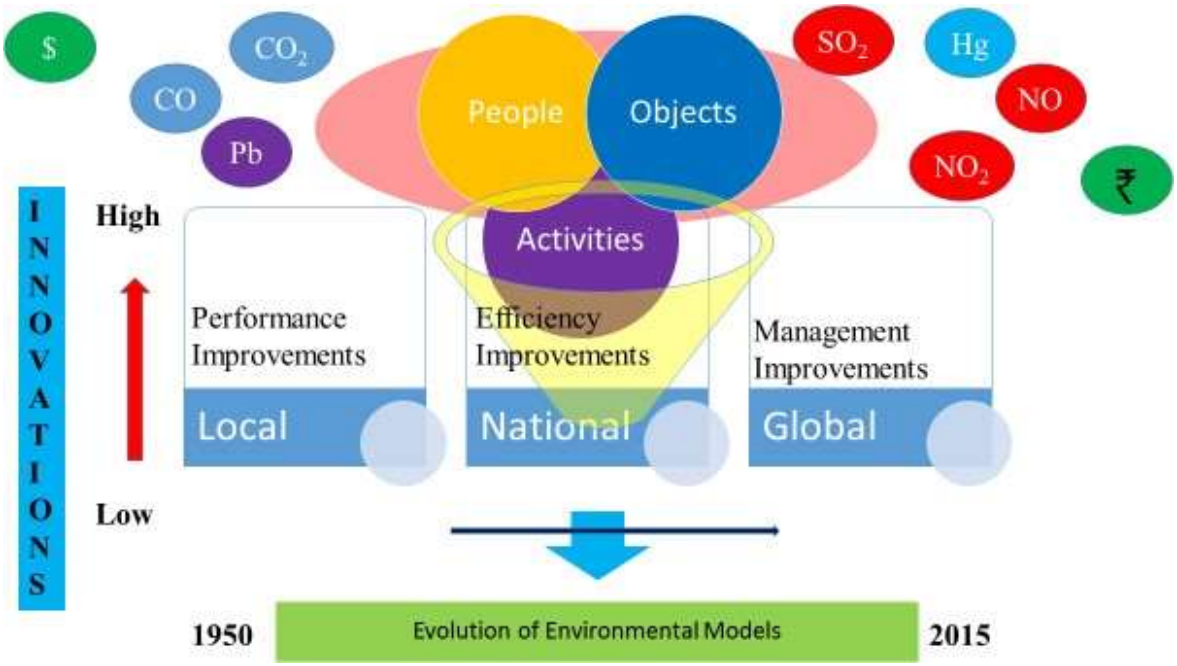

Fig. 4. Different categories of improvements and innovations at various levels in the evolution of environmental models.

INCIDENTS AND ACTIONS REQUIRED

Ariel spraying of an organo-chlorine pesticide, endosulfan, on the cashew plantations in India as a measure to control the tea mosquito bug, resulted in acute poisoning killing many fish, frogs, crabs and other animals. This has also caused debilitating diseases and other health complications such as cancer, skin diseases and infertility due disruption of the endocrine system. Unfortunately, pesticide poisoning is the main form of farmers' suicide. Bhopal gas tragedy in India, due to deadly

methyl isocyanate (MIC) gas, in 1984, that killed nearly 4000 people and injured about 200,000 people should be the eye-opener for all the earlier events of loss of lives due to chemical products.

The Exxon Valdez oil spill in 1989 has resulted in killing many birds, fish and other marine species due to short-term effects of toxicity of various components and indirect long-term effects such as habitat loss or lack of food. The design, commercial application and use of processes and products should minimize the impact on human health and the environment when pursuing sustainable development. Adequate and timely actions along with awareness campaigns by mobilizing the masses are required by both the government and the general public to keep the pollution under control [Fig 5]. The disciplined individuals committed to the cause of pollution reduction can contribute in various capacities in taking the green global development to a new level. Similarly, creative collaborations on climate change projects among different countries in the world will have long lasting implications globally and can deliver the expected dividends that reflect the emergence of strong ecosystem.

To achieve socioeconomic and scientific objectives, strong direct functional links must be built between academic institutions and other sectors to ensure effective cross-sectoral collaboration. Green and sustainable manufacturing are actually applicable to several sectors such as automobile, construction, chemicals, electronics, power, and consumer goods and there is an urgent need to evolve a strategy to spread an operational framework on a collaborative basis. Reliable and strategic partnerships between different countries in certain key sectors such as water supply and waste

management, food service management, transportation, power transmission and distribution, space cooperation, nuclear energy and defense, and urban infrastructure development is required to make significant overall progress.

It is important to have a memorandum of understanding (MoUs) between the collaborating nations or institutions, including clauses on investment commitments, sharing of responsibility and liability, and quality control and timely delivery. The establishment of enforcement directorate (ED) and carbon footprint exchange agreements at the global level would have enormous consequences to promote a better climate for life. The intergovernmental panel on climate change (IPCC) is the leading international body for the assessment of climate change and they have published the fifth assessment report [36]. The ecological movement across the world for a greater growth-environment balance is gaining momentum in the recent past. Today, collective and coordinated effort is a prerequisite to undertake different activities to drastically reduce pollution, minimize use of our precious natural resources and protect the environment. The inspiration to sustain the environmental reform campaign comes from the active participation of a large number of people and dedicated efforts by communities, civil society groups and organizations.

Fig. 5. Summary of actions required with strong close links to boost productivity and growth without environmental damage that will benefit all.

The following critical aspects need to be considered for the production and use of chemical products, and functioning of other systems on the pathway to sustainability:

1. Maintain a safe operation of chemical industries with a light ecological footprint and improve existing safety and security measures.
2. Risk assessment of toxic compounds used or produced to reduce impact on the environment.
3. Location of chemical plants away from heavily populated settlements.

4. Protection plans for workers and residents in case of disaster and proactive measures to minimize damages.
5. Pollution prevention at the source, recycling and disposal in that order, in an environmentally safe manner.
6. Global level action plan for achieving ecological restoration and sustainable development that will have profound implications and new enforcement strategies.
7. Budget allocation and commitment from management in implementation of pollution control and prevention programs.
8. Increasing sources of renewable energy and decreasing use of dwindling resources.
9. Reforestation programs and forest conservation efforts as part of sustainable management of forests.
10. Decrease global carbon footprints due to the transportation, residential and manufacturing sectors.
11. Use of eco-friendly technologies and sustainable agricultural practices for better results in crop production and for preventing extensive ecosystem damage due to development pressure.
12. Conduct research on less toxic chemical products, greener alternative processes, catalysis, kinetics and reaction engineering from benign environmental perspective.
13. Carry out life cycle analysis of a particular product or process to reduce the environmental impacts, at different stages of the overall process or use.

14. Develop green technologies and create a reaction system that can be scaled for production using tools like reaction conditions, catalysts or reactors, to improve reaction performance and reduce the environmental footprint.
15. Conduct study on the environmental contamination and toxic effects of human exposure of unburned hydrocarbons, nanomaterials and other particulate matter.
16. Proper environmental laws and procedures, transparency in functions and policy implementation aspects to prevent ecological disasters and to take forward the sustainable growth agenda for action with growing global connectivity.
17. Review of environmental clearances of mega-projects that would adversely impact aquatic and terrestrial biodiversity.
18. Strengthening safety base and establishing mass contact to create more awareness about sustainability aspects and impacts.
19. Attract more investments by nations in environmental protection and tackling environmental problems.
20. Establishing a global green network to advance knowledge and promote state-of-the-art technologies and distinct ideological perspectives to have a clean environment.

CONCLUSIONS

We have to look beyond our limited need and condition and sustainability is a prerequisite for any development paradigm and there is a link between the basic chemical principles and practical environmental issues. Harmful inorganic and organic chemicals discharged from agriculture, industry, transport, mining and urban centers as well as heat, noise, light and nuclear radiation contribute to particular environmental pollution issues. The root causes of pollution include human population explosion, rapid industrialization and urbanization, overexploitation of nature and natural phenomenon.

The study of the nature and quantity of specific pollutants, effects on humans and animals, sources, reactions and pathways, assessment and pollution control methods will help us to have more meaningful connect with life and nature. Technological solutions involving efficiency, ecological conservation, environmental laws and regulations, and healthier lifestyles help us to prevent pollution problems and adopt a more sustainable way of living. Ecofriendly design of chemical products, processes and systems that reduce or eliminate the generation or use of hazardous substances help in control of environmental pollution.

The active participation of every citizen is required in controlling different types of pollution and to witness the journey of impressive overall growth in the near- and long-term future with the delicate balance between economic growth and ecological security. The construction of energy-efficient buildings, efficient transportation systems, efficient lighting programs, good manufacturing

practice regulations, use and disposal of toxic chemicals and nanoproducts, and incentives to industries to reduce emissions will go a long way in improving the confidence of people across the globe and to address key challenges ahead through innovative techniques and interdisciplinary practice. Long-term measures are a necessity to benefit the global economy as a whole and corrective actions for creating a sustainable planet are required where there are some early warning signs [37-41].

There are many ways in which we can reduce our individual environmental footprint by adopting one or more sustainable personal practices and at the collective level, it can make a huge difference with the power of multiplying effect. The second international conference on evaluation of climate change and development was held in 2014. Such conferences on climate change and global development can offer serious and adequate recommendations so that the reasonable needs of people at all levels from diverse fields are taken care of without conflicts and contradictions and to balance private interest with the larger interest of society.

It is important to promote human activities that reflect universal values and contributes to the common good of the global community in addition to their personal development, as a true measure of ‘green growth’ is sustainability and social stability. It is essential to develop socially and environmentally responsible individuals and leaders by taking a holistic view of living in harmony with nature. Sharing universal and scientific knowledge will bring about unity in thought in diversity on this transformative journey towards sustainable development.

The consequences are evident in the fragile ecology and with proper planning depending on specific geographical conditions, their impact can be reduced. In this context, it is essential to develop humanitarian ethics in business practice that advances the common good of human development considering eco-sensitive zones and a positive attitude toward biodiversity, and prosper within society. The green development model will be successful in future decades by following the growth trajectory different from the past and depending on individual contributions and collective and comprehensive development efforts taking into consideration the parameters of the environment. The important components of sustainable development include environmental education and awareness, stabilization of population, conservation of ecological diversity, control of air, water and soil pollution, recycling of wastes and residues, use of renewable energy resources and planning of integrated use of ecosystems. It remains to be seen whether the identification of hazards and risks from chemical species to environmental, animal and human health, political will to build a green globe and implementing green initiatives through several steps in the regulatory process would eventually lead to the sustainability of the planet.

REFERENCES

1. Klaassen, C.D. Ed., Casarett & Doull's Toxicology: The Basic Science of Poisons, Mc Graw-Hill, New York, 2008.
2. http://sis.nlm.iih.gov/enviro/toxtutor/toxl (accessed June 2020).
3. Johnson, D.E., G.L. Anderson. Green Chemistry and Toxicology. Chapter 11 in Green Chemistry and Engineering: A Pathway to Sustainability. M. Abraham, A.E. Marteel- Parrish, (Eds). New York, Wiley & Sons, 2014, 325-349.

4. http://chemlabs.uoregon.edu/safety/toxicity.html (accessed June 2020).
5. R. Luttge, Microfabrication for Industrial Applications, Elsevier, Oxford, 2011.
6. www.esrl.noaa.gov/csd/assessments/ozone (accessed June 2020).
7. www.ifc.org/.../Final - Phosphate Fertilizer Plants.pdf (accessed June 2020).
8. S.S. Brown, Ed. Clinical Chemistry and Chemical Toxicology of Metals, Elsevier, Amsterdam, 1977.
9. Richter, Beyond Smoke and Mirrors: Climate Change and Energy in the 21st Century, Cambridge University Press, New York, 2010.
10. S.S. Brown, D.S. Davies, Eds. Organ-directed Toxicity Chemical Indices and Mechanisms, Pergamon, Oxford, 1981.
11. E. Pooley, The Climate War: True Believers, Power Brokers, and the Fight to Save the Earth, Hyperion, New York, 2010.
12. F.J. Verheijen, "Photopollution: Artificial light optic spatial control systems fail to cope with. Incidents, causation, remedies". Experimental biology, 1985, 44, 1–18.
13. P. Cinzano, P. F. Falchi, C.D. Elvidge, K.E. Baugh, "The artificial night sky brightness mapped from DMSP Operational Linescan System measurements" 2000.
14. M. Wautelet, Nanotechnologies, Institution of Engineering and Technology, London, 2009.
15. J. Kim, Nanomaterials, Apple Academic Press Inc., Oakville, 2010.
16. C. Walters, E. Pool, V. Somerset. Nanotoxicology: A Review, Toxicology - New Aspects to This Scientific Conundrum, Sonia Soloneski and Marcelo L. Larramendy, IntechOpen, 2016, DOI: 10.5772/64754.
17. https://www.osha.gov/llaw-regs.html (accessed June 2020).
18. G.F. Nordberg, Ed., Effects and Dose-response Relationships of Toxic Metals, Elsevier, Amsterdam, 1979.
19. P.D. Williams, G.H. Hottendorf, Eds., Comprehensive Toxicology, Elsevier, Amsterdam, 1997.
20. A. Lyubimov, Encyclopedia of Drug Metabolism and Interactions, John Wiley and Sons, New Jersey, 2012.
21. B. Reisfeld, A. Mayeno, Eds. Computational Toxicology, Vol.II, Springer Science, New York, 2012.
22. P.T. Anastas, M.M. Kirchhoff, Origins, Current Status, and Future Challenges of Green Chemistry, Acc. Chem. Res. 2002, 35, 686-694.
23. A.M.Richard, C.Yang, R.S. Judson, Toxicology Mechanisms and Methods, 2008, 18, 103-118.
24. P. Buell, J. Gerald, Chemistry in Environmental Perspective, Prentice Hall, New Jersey, 1994.
25. T.G. Spiro, W.M. Stigliani, Chemistry of the Environment, 2nd Edn., PHI Learning Pvt. Ltd. New Delhi, 2009.
26. D. Tilman, C. Lehman, Human Caused Environmental Change: Impacts on Plant Diversity and Evolution, 2001.

27. H. Christopher, Foreman, Jr., The Promise and Peril of Environmental Justice, Brookings Institution Press, Washington, D.C., 1998.
28. www.unep.org/pdf/recycling_from_e-waste_to_resources.pdf (accessed June 2020).
29. www.epa.gov/air/criteria.html (accessed June 2020).
30. A. Srivastava, I. Roy, Bio-Nano-Geo-Sciences, Ane Books Pvt. Ltd. New Delhi, 2009.
31. https://www.msds.com/ (accessed June 2020).
32. J. Freedman, Genetically Modified Food: How Biotechnology Is Changing What We Eat, The Rosen Publishing Group, 2009.
33. T.W. Schultz, M.T.D. Cronin, J.D. Walker, A.O. Aptula, Journal of Molecular Structure, 622, 2003, 1-22 (QSARs).
34. www.euro.who.int/data/assets/pdffile/0005/78638/E90038.pdf (accessed June 2020).
35. Chellaney, Water, Peace and War- Confronting the Global Water Crisis, Oxford University Press, New Delhi, 2015.
36. www.ipcc.ch › 2019.
37. G.D. Friedman, Primer of Epidemiology, 3rd Edn., McGraw Hill, New York, 1988.
38. A.K. De, Environmental Chemistry, 6th Edn., New Age International Ltd., New Delhi, 2006.
39. G.J. Miller, Living in the Environment, Wadsworth Publ. Co., California, 1994.
40. Shvedova, A.A. Kagan, V.E., Fadeel, B. Annu. Rev. Pharmacol. Toxicol. 50, 2010, 63- 68.
41. M. Fan, C –P., Huang, A.E. Bland, W. Wang, L. Slimane, I. Wright, Eds., Enviro-nanotechnology, Elsevier, Oxford, 2010.