International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 9 Issue 11 Series II || November 2020 || PP 59-64

Role of Green Chemistry in Reducing Environmental Pollution and Chemical Waste

Dr Krishan Kumar Arya
Assistant Professor Department of Chemistry, Government Model Degree College ArniyaBulandshahr U. P.

Abstract: *People face major challenges because environmental destruction and excessive chemical waste production create problems for traditional chemical methods. The traditional synthesis methods require dangerous chemical substances and harmful solvent materials together with processes that consume excessive power which results in serious damage to both the environment and the economy. Green chemistry establishes a sustainable solution that actively prevents pollution through the development of safer chemical substances and environmentally safe industrial methods. The research demonstrates how green chemistry helps decrease environmental pollution and chemical waste through its use of safe solvents and its development of atom-efficient reactions and renewable feedstocks and waste-reducing technologies. The study investigates practical uses across different industrial sectors while assessing their environmental and economic benefits. Green chemistry despite facing difficulties with scalability and costs and public knowledge proves to be the most practical method for achieving sustainable chemical development and maintaining environmental health.*
Keywords*: Traditional Chemical Methods, Traditional Synthesis Methods, Green Chemistry, Waste-Reducing Technologies, Renewable Feedstocks etc*

I. Introduction

1.1 Environmental Pollution: An Escalating Global Issue

Environmental pollution has become one of the most significant concerns confronting contemporary society, mostly because industrialisation and urban growth and unsustainable manufacturing methods have increased their economic activities. Pollution from chemical production and pharmaceuticals and agrochemicals and textiles and petroleum industries has created severe environmental damage to air and water and soil resources[1]. The environment accumulates three types of hazardous materials which include persistent organic pollutants and poisonous heavy metals and chemical residues that do not decompose, which results in harmful effects for both biodiversity and climate stability and human health[2]. Traditional chemical processes focus on achieving maximum output together with operational efficiency, which creates environmental problems through the production of waste materials and harmful emissions and damage to natural ecosystems. The combined impact of these activities has created more regulatory oversight while increasing global awareness about sustainable industrial development practices.

1.2 Generation of Chemical Waste and Its Environmental Consequences

The environmental impact from chemical waste occurs because the waste contains substances that are poisonous and corrosive and combustible and permanent. The traditional synthetic methods require standard chemical compounds together with organic solvents that evaporate and processes which consume high energy to create waste materials that become difficult to handle and dispose properly. The failure to manage chemical waste properly creates pollution problems for aquatic systems and damages soil quality while dangerous substances enter the food chain through bioaccumulation and biomagnification. The financial burden which waste management and regulatory compliance and site cleanup activities create proves that traditional chemistry-based methods fail to deliver successful results. The existing problems demonstrate that society needs to develop innovative solutions which prevent pollution at its source instead of relying on traditional end-of-pipe solutions.

1.3 Necessity of Green Chemistry as a Prophylactic Approach

Green chemistry has developed into a new scientific framework which focuses on preventing pollution and reducing waste while creating safe chemical products and processes. Green chemistry starts its sustainability practices at the molecular design stage which differs from traditional methods that handle waste after its

[1]Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press.https://global.oup.com
[2] Anastas, P. T., & Eghbali, N. (2010). Green chemistry: Principles and practice. Chemical Society Reviews, 39(1), 301–312. https://doi.org/10.1039/B918763B

creation[3]. Green chemistry promotes the adoption of environmentally friendly solvents and renewable starting materials and energy-efficient chemical reactions and industrial processes. This practice enables the chemical industry to reduce its environmental footprint. The organization supports sustainable development because more its preventive strategy maintains overall economic stability while protecting natural resources.

1.4 Objectives

The current study intends to:

1. The study investigates how green chemistry methods help decrease environmental pollution and chemical waste generation.
2. The study investigates how green chemistry principles improve the environmental performance of chemical processes.
3. The study demonstrates how green chemistry provides practical benefits in both industrial and environmental applications.
4. The study investigates existing challenges and potential pathways that will enable organizations to adopt green chemical methods at scale.

II. The concepts of Green Chemistry

The principles of green chemistry provide complete guidelines for developing chemical products and processes which require less hazardous materials or produce no dangerous substances. The twelve principles of the system provide sustainable and safe chemical handling methods which extend throughout the entire duration of chemical existence because they target the primary sources of pollution. The fundamental principle of this approach demands that chemists must stop pollution through waste reduction because waste management after disposal remains less efficient and more expensive than waste prevention methods[4]. The principle of atom economy requires chemical processes to use all materials in their final product because this practice reduces both waste and by-product production[5].

The development of less hazardous chemical synthesis methods leads to chemical reaction pathways which enable the use of safe materials with low toxic effects on both human beings and the planet. The implementation of safer solvent systems together with auxiliary substances leads to waste reduction because traditional organic solvents create hazardous volatile substances which are difficult to dispose of properly.

The energy-efficient chemical processes that operate at standard atmospheric pressure and room temperature require less energy while generating reduced greenhouse gas emissions. The use of renewable feedstocks Instead of running out of raw materials for production renews our capacity to safeguard environmental resources through resource preservation for future use[6]. The process of catalysis enables waste minimization through its capacity to enhance operational productivity while generating less waste when compared to standard chemical methods that require permanent material resources. The design of compounds that fulfil performance criteria and fully degrade after their useful period adheres to these key design principles. The system enables real-time pollution control through its ability to track and manage operations which prevent harmful chemical emissions. Green chemistry approaches pollution control and chemical waste reduction through scientific methods which transform how chemicals are developed and manufactured and used.

III. Origins of Environmental Contamination from Traditional Chemistry

Industrial processes that rely on traditional chemistry methods have created environmental pollution problems because they use hazardous raw materials and their chemical reactions lack efficiency and their waste treatment systems fail to work properly. The chemical production facilities release industrial effluents that typically contain high concentrations of acids and alkalis and heavy metals and dyes and organic pollutants[7]. The release of untreated or poorly treated wastewater into water bodies results in the destruction of aquatic

[3]Sheldon, R. A. (2016). Green chemistry, catalysis and valorization of waste biomass. Journal of Molecular Catalysis A: Chemical, 422, 3–12. https://doi.org/10.1016/j.molcata.2015.10.013

[4]Clark, J. H., Farmer, T. J., Herrero-Davila, L., & Sherwood, J. (2016).Circular economy design considerations for research and process development in the chemical sciences. Green Chemistry, 18(14), 3914–3934. https://doi.org/10.1039/C6GC00501B

[5]Jiménez-González, C., Poechlauer, P., Broxterman, Q. B., Yang, B. S., am Ende, D., Baird, J., … Keybl, J. (2011). Key green engineering research areas for sustainable manufacturing. Organic Process Research & Development, 15(4), 900–911. https://doi.org/10.1021/op200097d

[6]Sheldon, R. A. (2017). The E factor 25 years on: The rise of green chemistry and sustainability. Green Chemistry, 19(1), 18–43. https://doi.org/10.1039/C6GC02157C

[7]United Nations Environment Programme. (2011). Towards a green economy: Pathways to sustainable development and poverty eradication. UNEP.https://www.unep.org

ecosystems and the reduction of dissolved oxygen and the creation of serious threats to both human and animal health.

The use of hazardous solvents in traditional chemical operations creates a major risk of environmental contamination. Industrial processes extensively employ volatile organic compounds which include benzene and toluene and chloroform and dichloromethane as solvents for reactions and agents for purification. The substances emit high volumes of air pollution because their volatility allows them to escape into the atmosphere which worsens photochemical haze. The main problem with these materials arises from their combination of airborne toxins and high volatile rates which creates disposal challenges. The contamination of soil and groundwater resources increases because unintentional spills and improper solvent disposal practices.

The chemical industry creates greater environmental damage through its traditional synthesis methods because those methods generate toxic by-products. Various processes utilize stoichiometric reagents which create significant amounts of undesired byproducts that include salts and sludge and persistent organic pollutants. The byproducts display degradation resistance which forces treatment facilities to use energy-consuming methods for their disposal. The chemicals in question will persist within the environment for extended periods which results in continuous environmental contamination.

The chemical contaminants exhibit persistent environmental presence while accumulating through food chains which heightens their ecological effects. Chlorinated organics and heavy metals accumulate in organisms and multiply via the food chain, leading to chronic toxicity, endocrine disruption, and loss of biodiversity. The existing challenges demonstrate that traditional chemistry presents fundamental operational flaws while creating a demand for sustainable chemical solutions.

Source	Examples	Environmental Impact
Industrial effluents	Acids, dyes, heavy metals	Water pollution, aquatic toxicity
Hazardous solvents	Benzene, chloroform	Air pollution, groundwater contamination
Toxic by-products	Sludge, salts, POPs	Soil degradation, waste disposal burden
Persistent chemicals	Chlorinated compounds	Bioaccumulation, long-term toxicity

Table 1:Major Pollution Sources from Conventional Chemistry, Source: Researchers Findings

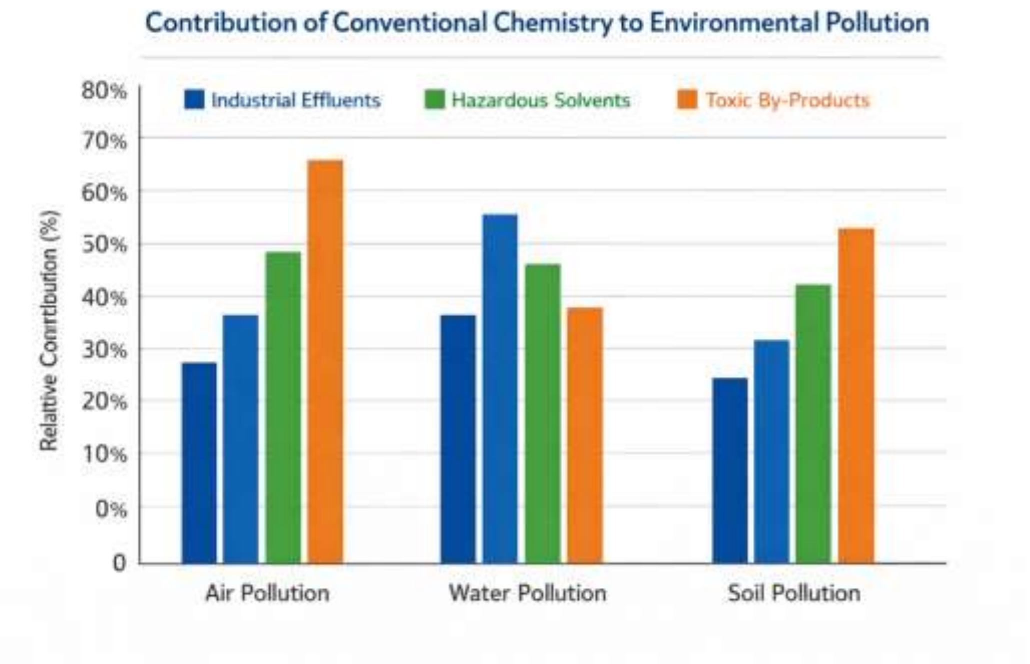

Figure 1: Environmental pollution contributions chart, Researchers Findings

IV. The Contribution of Green Chemistry to Pollution Mitigation

Green chemistry serves as a vital approach which helps to reduce environmental pollution through its fundamental assessment of chemical product and process design together with their operational methods. Green chemistry establishes its main focus on preventive methods which reduce dangerous material production at its source instead of working to decrease pollution after it has already taken place. The implementation of design-based solutions which replaced control-based solutions has shown success in achieving reduced emissions together with minimized waste production and restricted hazardous substance release into environmental elements such as air and water and soil[8]. The main way which green chemistry helps to reduce pollution involves its support for environmentally safe solvents and reaction media.

The typical attributes of conventional organic solvents include their high volatility and toxic properties which lead to their persistent environmental presence that results in significant air and water contamination[9]. Green chemistry supports the use of sustainable solvent options which include water and supercritical carbon dioxide and ionic liquids and bio-based solvents. The alternatives which exist reduce emissions linked to solvents while they simultaneously enhance safety for workers and create more efficient processes for waste handling and recycling operations.

The removal of dangerous materials through improved synthesis techniques enables factories to prevent pollution by utilizing safer methods which produce better results. The methods decrease the creation of toxic intermediate substances together with unwanted chemical by-products which reduces pressure on wastewater treatment facilities[10]. The concept of atom economy forms the core of this approach because it drives manufacturers to achieve maximum use of their raw materials during production. The process delivers high atom economy results which create minimal waste that directly reduces solid and liquid waste produced by traditional stoichiometric methods.

The use of renewable feedstocks stands as an essential method for reducing pollution levels. Green chemistry achieves two benefits through its shift from petroleum-based raw materials to biomass-derived resources. Renewable feedstocks create products that are easier to decompose and less dangerous which leads to a decrease in environmental pollution that lasts over time.

The green chemistry solutions work together to create production methods which generate less pollution and protect natural ecosystems while achieving greater sustainable development. Green chemistry provides a scientifically sound and practical framework for reducing pollution in many chemical sectors by incorporating cleaner solvents, efficient synthesis pathways, atom-economical reactions, and renewable resources.

V. Green Chemistry Strategies for Waste Reduction

The primary purpose of green chemistry is to reduce waste through the development of chemical processes which achieve higher productivity and lower material waste. Process intensification functions as an effective method which enables organizations to achieve higher production outputs through the optimization of their reaction conditions and equipment and process design[11]. The implementation of single-operation systems together with continuous-flow processes instead of batch processing methods enables chemical production facilities to achieve process intensification which results in reduced energy consumption and faster reaction times and decreased waste generation. The study of catalysis is very important for dealing with waste because it can make reactions more selective and more efficient[12]. Catalytic techniques enable chemical reactions to occur at milder conditions which require less reagent material than traditional stoichiometric methods.

The use of solvent-free methods together with alternative reaction systems represents a key green chemistry approach for achieving waste reduction. The elimination or reduction of solvents leads to direct waste reduction because solvents represent a major portion of chemical waste generated during traditional methods. The use of solvent-free reactions together with solid-state synthesis and mechanochemical techniques enables researchers to achieve waste reduction through solvent elimination while achieving decreased emissions and simplified purification methods[13]. Green chemistry requires the use of recyclable solvents or eco-friendly solvents for situations which require solvent use.

The combination of real-time waste monitoring and analytical control systems serves as essential tools for waste prevention. The system enables continuous assessment of reaction development through its analytical methods which enable immediate response to prevent excessive reaction or unwanted byproducts or waste of

[8]Lancaster, M. (2016). Green chemistry: An introductory text (2nd ed.). Royal Society of Chemistry.https://www.rsc.org

[10]Constable, D. J. C., Jimenez-Gonzalez, C., & Henderson, R. K. (2007). Perspective on solvent use in the pharmaceutical industry. Organic Process Research & Development, 11(1), 133–137. https://doi.org/10.1021/op0601765

[11]Kümmerer, K. (2010). Sustainable chemistry and the precautionary principle. Green Chemistry, 12(6), 1127–1135. https://doi.org/10.1039/B926098N

[12]European Commission. (2019). The European Green Deal. Publications Office of the European Union.https://commission.europa.eu

[13] Poliakoff, M., Fitzpatrick, J. M., Farren, T. R., & Anastas, P. T. (2002). Green chemistry: Science and politics of change. Science, 297(5582), 807–810. https://doi.org/10.1126/science.297.5582.807

materials. Waste reduction exists as a primary element of sustainable chemical design because these green chemistry techniques implement waste reduction as a key requirement.

VI. Practical Applications/Case Studies

The industrial sectors prove the effectiveness of green chemistry-based principles through their successful implementation here which decreases pollution & chemical waste while maintaining economic stability. The chemical manufacturing industry has experienced a substantial reduction in hazardous waste generation as a result of the implementation of solvent substitution and catalytic processes[14]. A significant number of large-scale producers have substituted stoichiometric reagents with recyclable catalysts which has led to cleaner reaction profiles and reduced the need for effluent treatment. The continuous-flow technologies have achieved better performance through two improvements which include a decrease in material losses and an upgrade in process control capabilities.

Green chemistry has been instrumental in the optimisation of synthetic pathways for active pharmaceutical constituents in the pharmaceutical sector. Pharmaceutical companies have reduced their waste production through process redesign work which uses fewer solvents and improves atom utilization in their multi-step processes. The use of aqueous reaction media together with biocatalysts improves process safety while creating products with higher purity. The solution also decreases the toxic nature of the by-products. The development enables drug companies to comply with strict environmental regulations.

The environmental persistence of pesticides and fertilizers decreased because scientists created safer production methods and developed new sustainable agricultural materials. Green chemistry-based formulations achieve their goals through selective effects which enable faster material degradation while maintaining agricultural output and preventing environmental contamination of water and soil areas.

The polymer industry implements bio-based materials and biodegradable polymers to demonstrate how green chemistry delivers sustainable environmental benefits to industrial operations. The use of renewable plant-based monomers in specific applications has replaced petroleum-based materials which helps to decrease plastic waste and carbon emissions. The case studies demonstrate how green chemistry moves from theoretical concepts to practical applications which provide industry-specific solutions that can be expanded to multiple sectors.

VII. Good for the environment and the economy

Green chemistry functions as an economic and environmental solution because it provides permanent methods for chemical creation through its sustainable design and production methods. Green chemistry works better for the environment because it uses renewable feedstocks and energy-efficient methods to reduce emissions and hazardous waste and natural resource consumption. The chemical industry because of its operational practices produces reduced environmental impacts while achieving sustainable development objectives established by international standards[15].

Green chemistry solutions generate substantial economic benefits because they enhance operational efficiency through reduced raw material consumption and decreased waste treatment expenses. Businesses benefit from clean-up measures which create safe workplaces and protect them from future liabilities while decreasing their insurance and compliance costs. Green chemistry helps companies achieve environmental compliance through its active process of meeting environmental standards. The approach establishes operational risk reduction which prevents penalties and operational restrictions. The examination of green chemistry through its entire product life cycle demonstrates that it safeguards both environmental and economic assets from product creation until product disposal. The extended value of this strategy establishes it as a valuable asset for companies in their long-term operational initiatives.

VIII. Obstacles and Constraints

The widespread use of green chemistry brings various challenges which need to be resolved despite its proven benefits. The scaling of green chemistry methods from laboratory success to industrial production presents major challenges. The process of scaling up production creates common problems which include difficulties in achieving reaction efficiency and maintaining catalyst stability and managing process control[16].

[14]rost, B. M. (1991). The atom economy—A search for synthetic efficiency. Science, 254(5037), 1471–1477. https://doi.org/10.1126/science.1962206

[15] Hessel, V., Kralisch, D., Kockmann, N., Noël, T., & Wang, Q. (2013). Novel process windows for enabling, accelerating, and uplifting flow chemistry. Chemical Engineering & Technology, 36(3), 391–402. https://doi.org/10.1002/ceat.201200642

[16] Zimmerman, J. B., Anastas, P. T., Erythropel, H. C., & Leitner, W. (2020). Designing for a green chemistry future. Science, 367(6476), 397–400. https://doi.org/10.1126/science.aay3060

The development of green substitutes for hazardous chemicals and solvents faces technological challenges because current solutions lack proper availability and existing infrastructure fails to support advanced catalytic and continuous-flow operations. Small and medium-sized businesses face economic obstacles which hinder their implementation efforts because they must deal with high initial costs and uncertain short-term financial returns. Industry professionals and policymakers lack essential knowledge and skills which obstruct their ability to implement green chemistry methods into standard practices, thus showing a need for increased educational and training initiatives.

IX. Prospective Developments and Research Trajectories

The future of green chemistry depends on technological advances and supportive government regulations. The research fields of catalysis and biotechnology and nanomaterials and artificial intelligence-based process optimization will make sustainable chemical processes more effective and efficient. The faster adoption of green chemistry methods will result from stronger implementation of green chemistry standards in environmental laws and industrial regulations because such rules will create financial rewards and clear environmental performance standards. The future development of green chemistry depends on educational progress and innovative achievements which will create environmentally responsible chemists through university programs and professional training courses. The complete potential of green chemistry for sustainable development needs continuous research work and collaboration between academic institutions and corporate entities and government agencies.

X. Conclusion

Green chemistry establishes a new approach which combines sustainable practices with core scientific principles to reduce environmental pollution and chemical waste. Green chemistry enables chemical companies to reduce their environmental footprint through its waste management approach which uses safer materials and efficient energy systems and renewable energy sources. The research demonstrates how it helps decrease pollution and waste production while delivering both environmental and economic benefits. The combination of ongoing technological progress and regulatory support creates new pathways for expanded technology implementation despite existing challenges related to scalability and affordability and public knowledge. Green chemistry functions as a vital scientific and industrial method which enables societies to achieve permanent environmental protection together with sustainable development.

Bibliography

[1]. Anastas, P. T., & Eghbali, N. (2010). Green chemistry: Principles and practice. Chemical Society Reviews, 39(1), 301–312. https://doi.org/10.1039/B918763B

[2]. Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press. https://global.oup.com

[3]. Clark, J. H., Farmer, T. J., Herrero-Davila, L., & Sherwood, J. (2016). Circular economy design considerations for research and process development in the chemical sciences. Green Chemistry, 18(14), 3914–3934. https://doi.org/10.1039/C6GC00501B

[4]. Constable, D. J. C., Jimenez-Gonzalez, C., & Henderson, R. K. (2007). Perspective on solvent use in the pharmaceutical industry. Organic Process Research & Development, 11(1), 133–137. https://doi.org/10.1021/op0601765

[5]. European Commission. (2019). The European Green Deal. Publications Office of the European Union. https://commission.europa.eu

[6]. Hessel, V., Kralisch, D., Kockmann, N., Noël, T., & Wang, Q. (2013). Novel process windows for enabling, accelerating, and uplifting flow chemistry. Chemical Engineering & Technology, 36(3), 391–402. https://doi.org/10.1002/ceat.201200642

[7]. Jiménez-González, C., Poechlauer, P., Broxterman, Q. B., Yang, B. S., am Ende, D., Baird, J., … Keybl, J. (2011). Key green engineering research areas for sustainable manufacturing. Organic Process Research & Development, 15(4), 900–911. https://doi.org/10.1021/op200097d

[8]. Kümmerer, K. (2010). Sustainable chemistry and the precautionary principle. Green Chemistry, 12(6), 1127–1135. https://doi.org/10.1039/B926098N

[9]. Lancaster, M. (2016). Green chemistry: An introductory text (2nd ed.). Royal Society of Chemistry. https://www.rsc.org

[10]. Poliakoff, M., Fitzpatrick, J. M., Farren, T. R., & Anastas, P. T. (2002). Green chemistry: Science and politics of change. Science, 297(5582), 807–810. https://doi.org/10.1126/science.297.5582.807

[11]. rost, B. M. (1991). The atom economy—A search for synthetic efficiency. Science, 254(5037), 1471–1477. https://doi.org/10.1126/science.1962206

[12]. Sheldon, R. A. (2016). Green chemistry, catalysis and valorization of waste biomass. Journal of Molecular Catalysis A: Chemical, 422, 3–12. https://doi.org/10.1016/j.molcata.2015.10.013

[13]. Sheldon, R. A. (2017). The E factor 25 years on: The rise of green chemistry and sustainability. Green Chemistry, 19(1), 18–43. https://doi.org/10.1039/C6GC02157C

[14]. United Nations Environment Programme. (2011). Towards a green economy: Pathways to sustainable development and poverty eradication. UNEP. https://www.unep.org

[15]. Zimmerman, J. B., Anastas, P. T., Erythropel, H. C., & Leitner, W. (2020). Designing for a green chemistry future. Science, 367(6476), 397–400. https://doi.org/10.1126/science.aay3060