RESEARCH PAPER

Impact of Drugs and Pharmaceutical Products on Life Cycle Assessment of Medical Healthcare Unit in India

Vikas Kumar[1]*, Umesh Gurnani[2], Vishwajeet Khan[3], Gaurav Gaurav[4]

[1]*PhD Scholar Department of Mechanical Engineering, University of Engineering and Management, Jaipur, India Pin 303807
[2]Associate Professor, Department of Mechanical Engineering, University of Engineering and Management Jaipur, India Pin 303807.
[3]Associate Professor, Department of Civil Engineering University of Engineering and Management Jaipur, India Pin 303807.
[4]Assistant Professor, Department of Mechanical Engineering Rao Birendra Singh State Institute of Engineering and Technology, Zainabad, India, 123411.

***Corresponding Author:** Vikas Kumar
*PhD scholar Department of Mechanical Engineering University of Engineering and Management, Jaipur, India, 303807
Email- vikasbugalia@yahoo.co.in

Abstract
Healthcare systems are essential for improving population health and supporting economic development; however, healthcare operations are increasingly recognized as significant contributors to environmental degradation through energy consumption, pharmaceutical use, and medical waste generation. Recent global assessments indicate that the healthcare sector contributes approximately 4–5% of total global greenhouse gas emissions, demonstrating that medical systems have a measurable environmental footprint comparable to that of major industrial sectors. Among the various contributors to healthcare environmental impacts, pharmaceutical products represent a critical component because their life cycle includes energy-intensive manufacturing processes, complex chemical synthesis, global transportation networks, and disposal of unused drugs. Life Cycle Assessment (LCA) is widely recognized as a comprehensive methodological framework used to quantify environmental impacts associated with products and services across their entire life cycle, from raw material extraction to final disposal. LCA has been increasingly applied in healthcare sustainability research to evaluate environmental impacts associated with hospital infrastructure, pharmaceuticals, and medical devices. Pharmaceutical products are particularly important in LCA studies because their production involves multiple stages of chemical processing, solvent usage, and energy-intensive manufacturing that contribute to greenhouse gas emissions, resource depletion, and ecotoxicological risks. This study evaluates the environmental impacts of drugs and pharmaceutical products within the life cycle of a medical healthcare unit in India using the Life Cycle Assessment framework. Environmental impact categories including climate change potential, fossil resource depletion, freshwater ecotoxicity, and human toxicity were analyzed using inventory data collected from healthcare operations. In addition to pharmaceutical consumption, the study also evaluates the environmental impacts associated with laboratory and diagnostic instruments used in pharmaceutical testing and clinical analysis. The results indicate that pharmaceutical production and diagnostic equipment contribute significantly to climate change potential and resource depletion within healthcare systems. These findings highlight the importance of integrating environmental sustainability into pharmaceutical management practices and hospital procurement strategies. The study contributes to sustainable healthcare research by providing empirical insights into the environmental footprint of pharmaceutical products in Indian healthcare systems.
Keywords: *Life Cycle Assessment (LCA); Pharmaceutical Environmental Impact; Healthcare Sustainability; Pharmaceutical Waste Management; Environmental Footprint; Sustainable Healthcare Systems*
How to cite this article: Kumar V, Gurnani U, Khan V, Gaurav G. Impact of Drugs and Pharmaceutical Products on Life Cycle Assessment of Medical Healthcare Unit in India. Int J Drug Deliv Technol. 2026;16(12s): 234-241. DOI: 10.25258/ijddt.16.12s.24.

1. Introduction

Healthcare systems play a vital role in maintaining public health, improving life expectancy, and supporting socio-economic development across the world. Hospitals, diagnostic laboratories, pharmaceutical supply chains, and medical research institutions collectively form the backbone of modern healthcare systems [1]. Despite their essential role in society, healthcare activities require large quantities of energy, materials, pharmaceuticals, and medical equipment, which can result in significant environmental impacts [2]. As global healthcare demand continues to increase due to population growth, urbanization, and rising disease burdens, the environmental footprint of healthcare systems has become an important issue for researchers and policymakers [3].

*Author for Correspondence: vikasbugalia@yahoo.co.in

Recent studies have demonstrated that the healthcare sector contributes substantially to global environmental emissions. According to Eckelman and Sherman, healthcare activities are responsible for nearly 4.4% of global greenhouse gas emissions, placing the healthcare sector among the major contributors to climate change [3]. These emissions originate from several sources, including hospital infrastructure energy consumption, medical equipment production, pharmaceutical manufacturing, and healthcare waste management [4]. Among these components, pharmaceuticals represent a particularly complex environmental challenge due to the chemical-intensive nature of drug production and the widespread distribution of medicines across healthcare systems [5].

Pharmaceutical products exert environmental impacts at multiple stages of their life cycle. The life cycle of pharmaceutical products typically includes raw material extraction, synthesis of active pharmaceutical ingredients (APIs), formulation of drugs, packaging, transportation, consumption within healthcare facilities, and disposal of unused or expired medicines [6]. Each of these stages involves energy consumption, chemical processing, and resource utilization that contribute to environmental emissions and ecological risks [7]. In particular, pharmaceutical manufacturing processes involve extensive chemical synthesis and solvent usage, which can lead to significant greenhouse gas emissions and waste generation [8].

Another major environmental concern associated with pharmaceuticals is the release of pharmaceutical residues into the environment. Several studies have reported the presence of pharmaceutical compounds in surface water, groundwater, and wastewater treatment plants, indicating that conventional wastewater treatment technologies may not effectively remove pharmaceutical contaminants [9]. These residues may accumulate in aquatic ecosystems and cause adverse ecological effects, including toxicity to aquatic organisms and disruption of microbial communities [10]. Furthermore, the presence of pharmaceutical compounds in the environment may contribute to the development of antimicrobial resistance, which has become a major global public health concern [11].

Life Cycle Assessment (LCA) has emerged as a widely accepted methodological framework for evaluating environmental impacts associated with products and processes throughout their life cycle [6]. LCA provides a systematic approach for quantifying environmental burdens such as greenhouse gas emissions, resource depletion, and toxic emissions associated with production and consumption activities [12]. The methodology has been standardized through international guidelines including ISO 14040 and ISO 14044, which define the principles, framework, and requirements for conducting life cycle assessments [13]. These standards provide a structured approach for analyzing environmental impacts across the entire life cycle of products and services.

In recent years, LCA has been increasingly applied in healthcare sustainability research to evaluate environmental impacts associated with hospitals, medical devices, pharmaceuticals, and healthcare services [7]. Studies have shown that LCA can provide valuable insights into environmental hotspots within healthcare systems and identify opportunities for improving sustainability in healthcare operations [14]. For instance, life cycle assessments of healthcare systems have revealed that pharmaceutical manufacturing and medical device production contribute significantly to healthcare carbon footprints [15].

India has one of the largest healthcare systems in the world and is also a major global producer of pharmaceutical products. The Indian pharmaceutical industry plays a critical role in supplying generic medicines to both domestic and international markets [16]. While the pharmaceutical sector contributes significantly to economic growth and healthcare accessibility, it also generates environmental impacts associated with chemical manufacturing processes, energy consumption, and waste generation [17]. The rapid expansion of healthcare infrastructure in India has further increased the demand for pharmaceuticals and diagnostic services, thereby intensifying environmental pressures associated with healthcare operations.

Hospitals and healthcare facilities rely heavily on pharmaceutical products and laboratory diagnostic instruments for patient care. Diagnostic laboratories require advanced instruments such as chromatographs, spectrometers, analyzers, and centrifuges to conduct clinical testing and pharmaceutical analysis [18]. These instruments consume significant amounts of energy and materials during operation, contributing to environmental impacts associated with healthcare systems. Evaluating the environmental footprint of pharmaceuticals and laboratory equipment is therefore essential for developing sustainable healthcare strategies.

Although several studies have examined environmental impacts associated with healthcare systems globally, limited research has focused specifically on the life cycle impacts of pharmaceuticals within healthcare facilities in developing countries such as India. Understanding the environmental impacts associated with pharmaceutical consumption in healthcare units is important for developing sustainable healthcare policies and environmental management strategies.

Therefore, the objective of this study is to evaluate the environmental impacts associated with drugs and pharmaceutical products within the life cycle of a medical healthcare unit in India using the Life Cycle Assessment framework. The study analyzes environmental impact categories including climate change potential, fossil resource depletion, freshwater ecotoxicity, and human toxicity associated with pharmaceutical consumption and laboratory activities. By identifying environmental hotspots within healthcare operations, this research aims to provide insights for improving environmental sustainability in healthcare systems.

2. Research Methodology

Life Cycle Assessment (LCA) was adopted in this study to evaluate the environmental impacts associated with drugs and pharmaceutical products used in a medical healthcare unit in India. LCA is widely recognized as a scientific method for assessing environmental impacts associated with a product system throughout its life cycle, from raw material extraction to final disposal [6][12]. The methodology enables comprehensive evaluation of environmental burdens including greenhouse gas emissions, energy consumption, resource depletion, and toxicity impacts [14]. Due to its systematic and internationally standardized framework, LCA has increasingly been applied in environmental evaluation of healthcare systems and pharmaceutical industries [19][20].

The methodological framework used in this study follows the internationally recognized guidelines described in ISO 14040 and ISO 14044 standards for life cycle assessment [13]. According to these standards, LCA consists of four major phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation of results [6]. These phases provide a structured approach for evaluating environmental impacts associated with pharmaceutical products and healthcare activities.

The primary objective of this research is to evaluate environmental impacts associated with drugs and pharmaceutical products used in a medical healthcare unit in India. The study also considers environmental impacts associated with laboratory and diagnostic instruments used in pharmaceutical testing and clinical analysis. The functional unit for the study represents pharmaceutical consumption and associated laboratory activities within a healthcare facility during the defined study period.

The system boundary for this research includes pharmaceutical production, drug transportation, pharmaceutical consumption within healthcare facilities, laboratory diagnostic processes, and waste management. These stages represent the major phases of the pharmaceutical life cycle within healthcare systems. Previous studies have highlighted that pharmaceutical manufacturing and distribution contribute significantly to environmental emissions due to energy-intensive chemical synthesis processes and global supply chain logistics [21][22][23][24].

The life cycle inventory analysis involves the collection and quantification of input and output flows associated with pharmaceutical activities. Inventory data include energy consumption, chemical usage, emissions to air and water, and resource consumption associated with pharmaceutical products and laboratory instruments. Inventory data used in this study were derived from healthcare operational data and environmental impact databases commonly applied in LCA studies [25].

The environmental impact categories considered in the present study are widely used in life cycle assessment research and represent major environmental concerns associated with industrial and healthcare activities [26]. These categories include climate change potential, fossil resource depletion, freshwater ecotoxicity, human toxicity, marine ecotoxicity, metal depletion, ozone depletion, particulate matter formation, and terrestrial acidification [27][28]. These impact indicators enable evaluation of environmental consequences associated with pharmaceutical consumption and laboratory operations.

Impact Category	Reference Unit
Agricultural land occupation	m^2a
Climate change	kg CO_2-eq
Fossil depletion	kg oil-eq
Freshwater ecotoxicity	kg 1,4-DCB eq
Human toxicity	kg 1,4-DCB eq
Marine ecotoxicity	kg 1,4-DCB eq
Metal depletion	kg Fe eq
Ozone depletion	kg CFC-11 eq
Particulate matter formation	kg PM10 eq
Photochemical oxidant formation	kg NMVOC
Terrestrial acidification	kg SO_2 eq

Table 1: Environmental impact categories considered in the study

The life cycle impact assessment phase converts inventory data into environmental impact indicators using characterization models. These models quantify the potential environmental damage associated with emissions and resource consumption. Impact assessment models such as ReCiPe and TRACI are commonly used in LCA studies to evaluate environmental impacts in standardized units [28][29]. These models allow comparison of environmental impacts across different categories and facilitate identification of environmental hotspots within the system.

The interpretation phase of LCA involves analysis of impact assessment results to identify key environmental contributors and evaluate their significance. Through this process, the study identifies major environmental impacts associated with pharmaceutical products and laboratory instruments within healthcare systems.

3. Results and Discussion

The life cycle assessment results indicate that pharmaceutical products and laboratory diagnostic instruments contribute significantly to environmental impacts within healthcare systems. The analysis reveals that several environmental impact categories are affected by pharmaceutical consumption, particularly climate change potential, fossil resource depletion, and ecotoxicity.

Impact Category	Result
Climate change	14.71 kg CO_2-eq
Fossil depletion	4.85 kg oil-eq
Freshwater ecotoxicity	0.028 kg 1,4-DCB eq
Human toxicity	0.0012 kg 1,4-DCB eq

Table 2-Environmental impacts associated with drugs and pharmaceutical products

3.1 Climate Change Impact

Climate change potential represents one of the most significant environmental impact categories associated with pharmaceutical production and healthcare activities. The analysis shows that pharmaceutical products contribute approximately 14.71 kg CO_2-equivalent emissions, indicating a substantial carbon footprint associated with pharmaceutical consumption. These emissions originate primarily from energy-intensive pharmaceutical manufacturing processes, transportation of medicines, and packaging materials used in pharmaceutical supply chains.

Previous studies have said pharmaceutical manufacturing as a major contributor to healthcare carbon emissions. Pharmacmilarly identifieeutical production involves multiple chemical synthesis steps, solvent usage, and purification processes that require significant energy input [30]. In addition, global pharmaceutical distribution networks require transportation and refrigeration, which further increase greenhouse gas emissions associated with pharmaceutical products [31].

3.2 Fossil Resource Depletion

Fossil depletion potential was observed to be 4.85 kg oil equivalent, indicating that pharmaceutical production ecosystems [35].

and distribution rely heavily on fossil fuel resources. Petrochemical feedstocks are commonly used in pharmaceutical synthesis and packaging materials, which contributes to fossil resource consumption [32]. Furthermore, energy required for pharmaceutical manufacturing and laboratory equipment operation is often generated from fossil fuel sources, thereby increasing fossil depletion impacts.

3.3 Ecotoxicity Impact

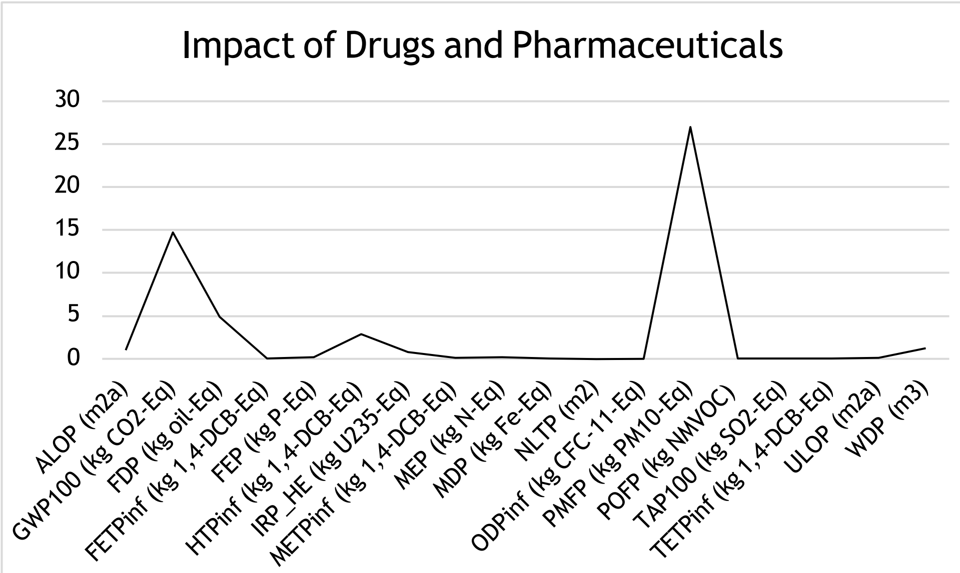
Freshwater ecotoxicity potential was observed to be 0.028 kg 1,4-DCB equivalent, indicating potential ecological risks associated with pharmaceutical residues released into aquatic environments. Pharmaceutical compounds entering water bodies may affect aquatic organisms and disrupt ecosystem functions [33]. Research has demonstrated that pharmaceutical residues can accumulate in aquatic environments and influence biological processes such as reproduction and growth in aquatic species [34].

Human toxicity potential was also identified as an environmental concern associated with pharmaceutical production and disposal. Chemical synthesis processes used in pharmaceutical manufacturing may release toxic substances that pose risks to human health and

Impact Category	Result
Climate change	1847 kg CO_2-eq
Freshwater ecotoxicity	1700 kg 1,4-DCB eq
Fossil depletion	362 kg oil-eq

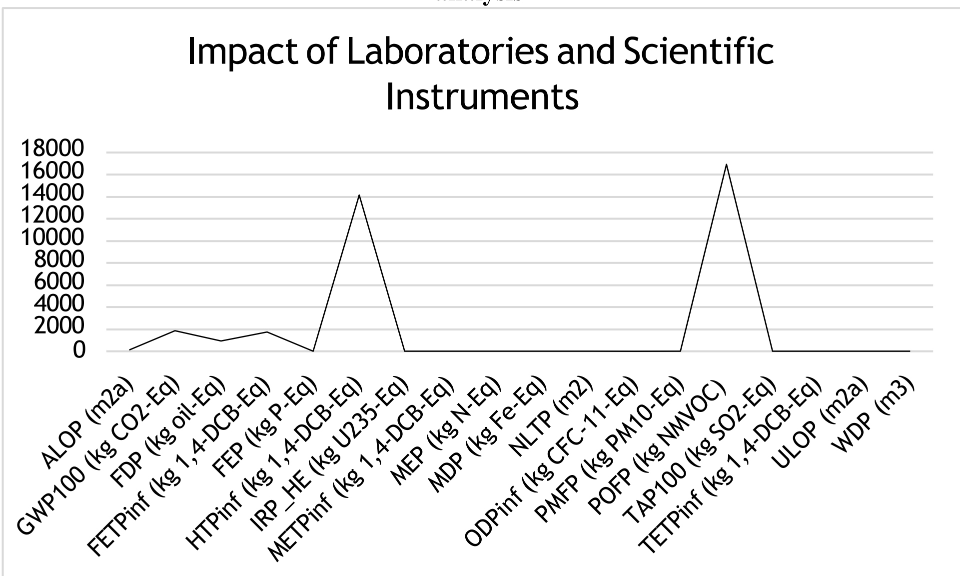
Table 3-Environmental impacts associated with laboratory and scientific instruments

Figure 1. Environmental impacts of drugs and pharmaceutical products used in the healthcare unit



The graphical representation shown in **Fig. 1** illustrates the environmental impact indicators associated with pharmaceutical products. Climate change potential exhibits the highest contribution among the evaluated categories, indicating that pharmaceutical manufacturing and distribution processes are major contributors to greenhouse gas emissions.

Figure 2. Environmental impacts associated with laboratory and scientific instruments used in pharmaceutical analysis



The environmental impacts of laboratory instruments are illustrated in **Fig. 2**. The results demonstrate that diagnostic laboratory equipment contributes significantly to climate change potential and freshwater ecotoxicity due to high electricity consumption and chemical reagent usage.

3.4 Environmental Impacts of Laboratory Instruments

The analysis indicates that laboratory and diagnostic instruments contribute significantly to environmental impacts within healthcare systems. Climate change potential associated with laboratory equipment was observed to be approximately 1847 kg CO_2-equivalent, which is substantially higher than impacts associated with pharmaceutical products alone. This finding highlights the energy-intensive nature of diagnostic laboratory operations.

Laboratory instruments such as chromatographs, spectrometers, centrifuges, and analytical devices require continuous electricity consumption and specialized materials for operation. These instruments are essential for pharmaceutical testing and clinical diagnostics but contribute to environmental impacts due to energy consumption and manufacturing processes [36].

Freshwater ecotoxicity impacts associated with laboratory equipment were also found to be significantly high. Chemical reagents, solvents, and laboratory waste generated during pharmaceutical analysis contribute to ecotoxicological impacts in aquatic environments if not properly treated [37].

3.5 Environmental Hotspots in Healthcare Systems

The results of this study indicate that environmental hotspots within healthcare systems are primarily associated with pharmaceutical manufacturing processes, laboratory diagnostic activities, and energy consumption in healthcare facilities [38]. Similar findings have been reported in previous life cycle assessment studies of healthcare systems, which highlight pharmaceuticals and medical equipment as major contributors to environmental impacts [39]

Reducing environmental impacts associated with pharmaceutical products requires implementation of sustainable practices such as green chemistry approaches, improved pharmaceutical waste management, and energy-efficient laboratory technologies. Green pharmaceutical manufacturing techniques can reduce chemical waste generation and energy consumption, thereby minimizing environmental impacts [40].

Healthcare institutions can also reduce environmental footprints by adopting environmentally responsible procurement policies and promoting rational drug usage. Efficient pharmaceutical inventory management and proper disposal of expired medicines can further reduce environmental contamination.

4. Conclusions

This study evaluated the environmental impacts associated with drugs and pharmaceutical products within the life cycle of a medical healthcare unit in India using the Life Cycle Assessment framework. The findings indicate that pharmaceutical products contribute significantly to environmental impacts including climate change potential, fossil resource depletion, and ecotoxicity.

Climate change potential was identified as the dominant environmental impact category associated with pharmaceutical consumption due to energy-intensive manufacturing processes and transportation activities.

Laboratory and diagnostic instruments used in pharmaceutical testing were also found to contribute significantly to environmental impacts because of high energy consumption and material requirements.

The results highlight the importance of integrating environmental sustainability into pharmaceutical management and healthcare operations. Adoption of green chemistry principles, energy-efficient laboratory technologies, and improved pharmaceutical waste management strategies can significantly reduce environmental impacts associated with healthcare systems.

The study provides valuable insights for policymakers, healthcare administrators, and environmental managers seeking to promote sustainable healthcare practices. Future research should focus on evaluating environmental impacts of healthcare systems using large-scale datasets and exploring innovative technologies for environmentally sustainable pharmaceutical production and waste management.

References

1. Eckelman, M. J., Huang, K., Lagasse, R., Senay, E., Dubrow, R., & Sherman, J. D. (2020). Health care pollution and public Health damage in the United States: an update: study examines Health care pollution and public Health damage in the United States. *Health Affairs*, *39*(12), 2071-2079.
2. McLean, M., Madden, L., Maxwell, J., Schwerdtle, P. N., Richardson, J., Singleton, J., ... & Horton, G. (2023). Planetary health: educating the current and future health workforce. In *Clinical education for the health professions: Theory and practice* (pp. 815-844). Singapore: Springer Nature Singapore.
3. Pichler, P. P., Jaccard, I. S., Weisz, U., & Weisz, H. (2019). International comparison of health care carbon footprints. *Environmental research letters*, *14*(6),064004.
4. Sherman, L. S., Blum, J. D., Keeler, G. J., Demers, J. D., & Dvonch, J. T. (2012). Investigation of local mercury deposition from a coal-fired power plant using mercury isotopes. *Environmental Science & Technology*, *46*(1), 382-390.
5. Kummerer K., *Annual Review of Environment and Resources*,2019.
6. Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., ... & Rydberg, T. (2011). Life cycle assessment: past, present, and future.
7. Laurent, A., Molin, C., Owsianiak, M., Fantke, P., Dewulf, W., Herrmann, C., ... & Hauschild, M. (2019). The role of life cycle engineering (LCE) in meeting the sustainable development goals–report from a consultation of LCE experts. *Journal of Cleaner Production*, *230*,378-382.
8. Donnelly, D. P., Rawlins, C. M., DeHart, C. J., Fornelli, L., Schachner, L. F., Lin, Z., ... & Agar, J. N. (2019). Best practices and benchmarks for intact protein analysis for top-down mass spectrometry. *Nature methods*, *16*(7), 587-594.

9. Bagnis, S., Boxall, A., Gachanja, A., Fitzsimons, M., Murigi, M., Snape, J., ... & Comber, S. (2020). Characterization of the Nairobi River catchment impact zone and occurrence of pharmaceuticals: Implications for an impact zone inclusive environmental risk assessment. *Science of the Total Environment*, *703*, 134925.
10. Ghirardini, A., & Verlicchi, P. (2019). A review of selected microcontaminants and microorganisms in land runoff and tile drainage in treated sludge-amended soils. *Science of the total environment*, *655*, 939-957.
11. Morrison, L., & Zembower, T. R. (2020). Antimicrobial resistance. *Gastrointestinal Endoscopy Clinics*, *30*(4),619-635.
12. Huijbregts, M. A., Steinmann, Z. J., Elshout, P. M., Stam, G., Verones, F., Vieira, M., ... & Van Zelm, R. (2017). ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *The international journal of life cycle assessment*, *22*(2),138-147.
13. Finkbeiner, M., Inaba, A., Tan, R., Christiansen, K., & Kluppel, H. J. (2006). The new international standards for life cycle assessment: ISO 14040 and ISO 14044. *The international journal of life cycle assessment*, *11*(2),80-85.
14. Hellweg, S., & Mila i Canals, L. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. *Science*, *344*(6188), 1109-1113.
15. Eckelman, M. J., Huang, K., Lagasse, R., Senay, E., Dubrow, R., & Sherman, J. D. (2020). Health care pollution and public Health damage in the United States: an update: study examines Health care pollution and public Health damage in the United States. *Health Affairs*, *39*(12), 2071-2079.
16. Singh, R., Singh, S., Kumar, A., Kulkarni, G. T., & Thakkar, A. R. (2023). Impact of Regulatory Policy Changes on Generic Drug Prices in the United States. *Indian Journal of Pharmaceutical Education & Research*, *57*(2).
17. Yadav, D., Singh, R., Kumar, A., & Sarkar, B. (2022). Reduction of Pollution through Sustainable and Flexible Production by Controlling By-Products. *Journal of Environmental Informatics*, *40*(2).
18. Sharma, P., Gaur, V. K., Sirohi, R., Varjani, S., Kim, S. H., & Wong, J. W. (2021). Sustainable processing of food waste for production of bio-based products for circular bioeconomy. *Bioresource Technology*, *325*, 124684.
19. Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The eco invent database version 3 (part I): overview and methodology. *The international journal of life cycle assessment*, *21*(9),1218-1230.
20. Fantke, P., Aurisano, N., Bare, J., Backhaus, T., Bulle, C., Chapman, P. M., ... & Hauschild, M. (2018). Toward harmonizing ecotoxicity characterization in life cycle impact assessment. *Environmental Toxicology and Chemistry*, *37*(12), 2955-2971.
21. Vikas Kumar, Vishwajeet Khan, Gaurav Gaurav. (2025). Impact of Medical Waste from a Healthcare Unit on Environment: An Organizational Life Cycle Assessment Study. Journal of Applied Bioanalysis, 11(6S), 162-167. https://doi.org/10.53555/jab.v11si6.1462
22. Kumar, V., Khan, V., & Gaurav, G. (2025). Environmental And Healthcare Issues Of Medical Waste. International Journal of Environmental Sciences, 11(11s),1093-1101. https://doi.org/10.64252/6fjwd193
23. Nantaba, F., Wasswa, J., Kylin, H., Palm, W. U., Bouwman,H., &Kummerer, K. (2020). Occurrence, distribution, and ecotoxicological risk assessment of selected pharmaceutical compounds in water from Lake Victoria, Uganda. *Chemosphere*, *239*, 124642.
24. Daughton, C. G. (2020). Wastewater surveillance for population-wide Covid-19: The present and future. *Science of the Total Environment*, *736*, 139631.
25. Reinhard, J., Wernet, G., Zah, R., Heijungs, R., & Hilty, L. M. (2019). Contribution-based prioritization of LCI database improvements: the most important unit processes in ecoinvent. *The International Journal of Life Cycle Assessment*, *24*(10), 1778-1792.
26. Kumar, V., Gaurav, G., Khan, V., Choudhary, S., & Dangayach, G. S. (2023). Life cycle assessment and its application in medical waste disposal. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2022.12.255
27. Kumar, Vikas, Gaurav Gaurav, Vishwajeet Khan, Sarita Choudhary, and G. S. Dangayach. "Life cycle assessment and its application in medical waste disposal." *Materials Today: Proceedings* (2023).https://doi.org/10.1016/j.matpr.2022.12.255
28. Huijbregts, M. A., Steinmann, Z. J., Elshout, P. M., Stam, G., Verones, F., Vieira, M., & Van Zelm, R. (2017). ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *The international journal of life cycle assessment*, *22*(2), 138-147.
29. Morelli, B., Hawkins, T. R., Niblick, B., Henderson, A. D., Golden, H. E., Compton, J. E., ... & Bare, J. C. (2018). Critical review of eutrophication models for life cycle assessment. *Environmental science & technology*, *52*(17),9562-9578.
30. Slater, B., & Michaelides, A. (2019). Surface premelting of water ice. *Nature Reviews Chemistry*, *3*(3),172-188.
31. Barratt, A., & McGain, F. (2021). Overdiagnosis is increasing the carbon footprint of healthcare. *bmj*, *375*.

32. Tukker, A., Pollitt, H., & Henkemans, M. (2020). Consumption-based carbon accounting: sense and sensibility. *Climate Policy*, *20*(sup1), S1-S13.
33. Jia, Y., Schmid, C., Shuliakevich, A., Hammers-Wirtz, M., Gottschlich, A., aus der Beek, T., ... & Hollert, H. (2019). Toxicological and ecotoxicological evaluation of the water quality in a large and eutrophic freshwater lake of China. *Science of the Total Environment*, *667*, 809-820.
34. Kummerer, K., & Clark, J. (2016). Green and sustainable chemistry. In *Sustainability Science: An Introduction* (pp. 43-59). Dordrecht: Springer Netherlands.
35. Arnold K., *Journal of Cleaner Production*, 2021.
36. Eckelman, M. J., Huang, K., Lagasse, R., Senay, E., Dubrow, R., & Sherman, J. D. (2020). Health care pollution and public Health damage in the United States: an update: study examines Health care pollution and public Health damage in the United States. *Health Affairs*, *39*(12), 2071-2079.
37. Celis-Hernandez, O., Cundy, A. B., Croudace, I. W., Ward, R. D., Busquets, R., & Wilkinson, J. L. (2021). Assessing the role of the “estuarine filter” for emerging contaminants: pharmaceuticals, perfluoroalkyl compounds and plasticisers in sediment cores from two contrasting systems in the southern UK. *Water research*, *189*, 116610.
38. Gaurav, Gaurav, Vikas Kumar, Sumit Gupta, M. L. Meena, G. S. Dangayach, and Manish Kumar Jindal. "Life cycle assessment of extraction of edible oil from mustard seeds: a case study of an oil industry." *Materials Today: Proceedings* (2023). https://doi.org/10.1016/j.matpr.2023.01.055
39. Pichler, P. P., Jaccard, I. S., Weisz, U., & Weisz, H. (2019). International comparison of health care carbon footprints. *Environmental research letters*, *14*(6), 064004.
40. Ziegler, C. G., Allon, S. J., Nyquist, S. K., Mbano, I. M., Miao, V. N., Tzouanas, C. N., ... & Zhang, K. (2020). SARS-CoV-2 receptor ACE2 is an interferon-stimulated gene in human airway epithelial cells and is detected in specific cell subsets across tissues. *Cell*, *181*(5), 1016-1035.