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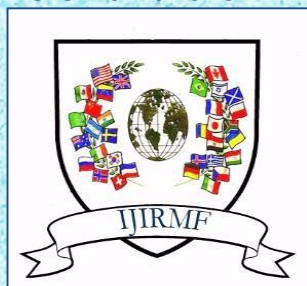
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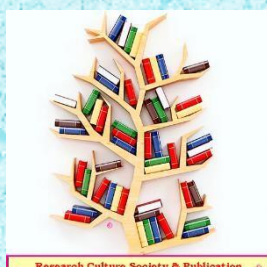
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Conference Special Issue - 61

October - 2025

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Dr. C. M. Patel

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About the organizing Institutions:

International Scientific Research Association is a registered and an esteemed research association working on to provide scientific research services, educational studies and activities at international level, also coordinate with other research organizations for the educational research events. Scientific Research Association as honorary partner of the ‘Research Culture Society’ with MoU – collaboration.

Eurasian Research Organization is an international scientific research organization registered with government bodies and united organizations. It is also a professional, autonomous, non-profit organization operating on an international scale. Along with other international organizations, Eurasian Research organization will also start up new research and teaching initiatives.

Research Culture Society (RCS) is a Government Registered International Scientific Research organization. Registered with several United or Government bodies. It is also an independent, professional, non-profit international level organization. RCS-ISRO shall also initiate and setting up new educational and research programs with other international organizations. Society has successfully organized 135+ conferences, seminars, symposiums and other educational programmes at national and international level in association with different educational institutions.

Objective of the International Conference:

International Conference on Agricultural Economics and Development aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results on all aspects of Sustainability, Green Environment, Agricultural Economics, Business and Development. It also provides a premier interdisciplinary platform for researchers, practitioners and educators to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields Sustainable Environment and Green Technology.

About the Conference :

ICSEGT-2025 is a good platform to bring together accomplished academicians, scientists, researchers, scholars and students to exchange and share their knowledge, experiences and research results on the aspects of advancements in Science, Agriculture, Engineering and Technology. This forum can & will spell a scholarly platform to network and discuss the practical challenges encountered and the solutions adopted in their respective domains worldwide. The Conference aims at providing an ambience that will be instrumental in taking our delegates and participants to the next level of their expertise in their profession.

Track 1 – Sustainable Environment.

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Track 3 – Green Technology & Sustainable Economy.

About the Special Issue / Conference Book:

Ensuring environmental sustainability means keeping our natural ecosystem in balance. Fighting pollution, taking drastic measures to reduce harmful emissions and waste, triggering positive and innovation-driven economic cycles as drivers to optimize, recycle and reuse resources.

Green technology is a broad word that refers to the application of science and technology to generate environmentally sustainable products and services. It is connected to clean-tech, which refers to goods or services that increase operational performance while lowering costs, reduce energy usage and waste, or decrease negative environmental effects. Green technologies cover a wide range of technologies that assist in reducing human influence on the environment and fostering long-term growth. The fundamental parameters for green technology are social equitability, economic feasibility, and sustainability.

The book epitomizes the potential of sustainable environment and green technologies for environmental management. It caters to the needs of researchers, environmentalists, microbiologists, agriculturalists and those who are interested in environmental stewardship and sustainability paradigms. The edited book is a collection of peer-reviewed scientific abstracts and papers submitted by active researchers in the International Scientific Research Conference. This book can be helpful to understand the various concepts of Sustainability, Green Environment, Agricultural Economics, Business and Development.

Dr. Jessica C.

Founder President, International Scientific Research Association.

Email : scientificresearchassociation@gmail.com



Message

Dear Colleagues !

I am grateful to co-organizing institutions, all the speakers, committee members and presenters of 'International Conference on Sustainable Environment and Green Technology' (ICSEGT-2025). The overwhelming response to the contributors was acknowledged in a very positive manner and it shows that the new age is very much eager to work with technical literature. The rising researcher and scholar from various institutions and in-house participants motivate us to improve ourselves.

We are currently in the era of science and green technology generation, the science and technology developments are working on to develop more the green technology and green energy generation that can provide sustainable solutions to various issues.

Here I am delighted that the series of conference on contemporary issues in Green Environment and Technology immensely required in the 21st century, it's all due to the valuable efforts of faculty members of computer science and engineering department.

I extend my best wishes for the editorial team of the special issue, at last I hope this technological literature interaction will be a source of inspiration to upcoming educationists, technocrats and stakeholders.

Jessica

ICSEGT - 2025 Conference Chair
Founder, International Scientific Research Association



Dr(hc) Rania Lampou
President, Eurasian Research Organization
Email : info@eurasianresearch.org

MESSAGE

Dear Colleagues!!!

I am glad to be the part of Organizational Committee of “International Conference on Sustainable Environment and Green Technology - 2025”, jointly organized by ‘International Scientific Research Association’ and Eurasian Research Organization, in collaboration with ‘Research Culture Society’ (11 – 12 October, 2025).

We have an exciting program at the conference that will allow participants a good platform to present their research work, extend networks, and future research directions. I hope that all participants will have a productive approach at this online conference.

I sincerely hope that this conference will deliberate and discuss all the different facets of this exciting topic and come up with recommendations that will lead to a better world.

I wish the conference great success.



Dr(hc) Rania Lampou
President, Eurasian Research Organization,

Dr.C. M. Patel

Director, RESEARCH CULTURE SOCIETY

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Message

Dear Professional Colleagues,

It is gratifying to note that 'International Scientific Research Association'; Eurasian Institute of Science and Technology (EU) in collaboration with 'Research Culture Society' (Government Registered Scientific Research organization) are organizing - 'International Conference on Sustainable Environment and Green Technology' during 11 – 12 October, 2025.

The aim of the conference is to provide an interaction stage to researchers, practitioners from academia and industries. The main objective is to promote scientific and educational activities towards the advancement of common citizen's life by improving the theory and practice of various disciplines of science, engineering & technology. Provide the delegates to share their new research ideas and the application experiences face to face.

I believe, this International Conference will help in redefining the strong connection between students and academicians from different institutions. An additional goal of this international conference is to combine interests and scientific research related to Sustainability, Green Environment, Agricultural Economics, Business Development, Engineering and Technology Development to interact with members within and outside their own disciplines and to bring people closer for the benefit of the scientific community worldwide.

My best wishes to the committee members, speakers and participants of this scientific conference ICSEGT-2025.

A handwritten signature in blue ink, appearing to read 'Dr. C. M. Patel', is positioned above the printed name.

Dr.C. M. Patel
Director, Research Culture Society.

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Dr. Jessica C., Founder President, International Scientific Research Association.

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Environmental Assessment of Heavy Metal Contamination in Gulf of Mannar, Thoothukudi Coast

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Abstract: Heavy metal pollution in marine areas has raised concerns about its possible influence on aquatic ecosystems and human health. The seawater was collected from the Therespuram coast in the Thoothukudi district, Gulf of Mannar region. This study aims to assess the concentration levels of selected heavy metals, including cadmium (Cd), lead (Pb), mercury (Hg), and copper (Cu) in seawater. Heavy metals were analysed using atomic absorption spectrophotometer. Concentrations of heavy metals were found to decrease in the order of $Cu > Pb > Cd > Hg$. The heavy metal concentration for cadmium was below the permissible limits as proposed by EPA. However, the concentration levels of copper, mercury and lead were higher than the recommended limits set by the EPA. Notably, the copper and lead levels were lower compared to a previous study. The increase in concentration in the present study might be due to land runoff and domestic waste discharge. Thus, the current study makes it extremely important to monitor heavy metal contamination, which will ultimately lead to advancements in domestic and industrial wastewater treatment techniques. This study contributes valuable baseline data for future ecological risk assessments and marine conservation strategies in the region.

Key Words: Atomic Absorption Spectrophotometer, Gulf of Mannar, Heavy Metals, Thoothukudi Coast

1. INTRODUCTION:

Over the past few years, heavy metal pollution of the aquatic environment has become widespread across the world. Heavy metal pollution in Indian coastal waters is a significant threat to aquatic resources^[1]. Heavy metals are one of the major contaminants that contribute to the global issue of marine environmental pollution. They are intrinsic, naturally occurring components of the aquatic environment in trace amounts. They originate in the oceans through both natural processes and anthropogenic activities. Natural processes, like soil erosion around mangrove forests, atmospheric inputs, and aeolian processes, set the background values, whereas anthropogenic inputs and rapid industrialisation and urbanisation in coastal regions are the main sources of pollution in the marine environment. Heavy metals are also increasingly introduced to the coastal environments through oceanic dumping and riverine discharge, where rivers that run through densely populated urban areas may carry them downstream^[2].



The Gulf of Mannar is recognised as India's first marine biosphere reserve and is home to almost 36,000 different kinds of plants and animals. The area is covered in mangroves, has sandy beaches, and has sea grass beds that are ideal for turtle nesting^[3]. Tuticorin Bay, which covers 56 square kilometers, is located on the Gulf of Mannar, Tamil Nadu, on India's southeast coast^[4]. Furthermore, the city is home to a number of both big and small-scale companies^[3]. The main sources of metal pollution along the Tuticorin coast are oil spills from fishing harbours, heavy metals discharged from fertiliser and chemical industries, large amounts of heated effluent and fly ash from thermal power plants, and the discharge and disposal of untreated domestic and industrial wastes and effluents from shrimp farms that are either untreated or partially treated^[5]. In the present investigation, heavy metals were analysed in the Therespuram coast in Thoothukudi district.

2. LITERATURE REVIEW:

The study of heavy metal distribution in coastal water and surface sediments is a key element in understanding the distribution levels and determining the source of anthropogenic influences on the marine ecosystem^[6]. Anand and Kala (2015)^[6] analyzed heavy metal concentrations in coastal water samples from Mandapam, Thoothukudi, Arumuganeri, and Kanyakumari across different seasons. Their findings revealed that nearshore waters showed elevated metal levels, suggesting significant input from human activities such as industrial discharge and domestic wastewater. The concentration of metals varied seasonally, influenced by factors like runoff and coastal currents. This variability highlights the dynamic nature of heavy metal distribution in coastal waters. The study emphasizes the importance of regular water quality assessments to track pollution trends in these regions.

Similarly, Hermalin and Glory (2016)^[3] assessed the heavy metal distribution of coastal water of Thoothukudi and reported that the study area was moderately contaminated with copper, lead and cadmium. These contaminants were mainly linked to human activities like industrial discharge and urban runoff. They also observed high nutrient levels in some areas, pointing to land-based sources of pollution. Furthermore, Rajaram *et al.*, (2020)^[5] evaluated the concentration of toxic metals caused by manmade activities in the coastal zone of Tuticorin in surface water and sediment samples and the results showed that the concentration of metals was higher during the mid-year season in both water and sediment samples.

Additionally, Mohanraj *et al.*, (2021)^[7] studied about the seasonal variation of heavy metals in the intertidal gastropod *Trochus radiatus* of Gulf of Mannar and they evaluated the surface seawater near Hare Island for heavy metal pollution and found that lead had the highest concentrations and cadmium was present in the lowest amounts in the surface seawater. Lastly, Saxena *et al.*, (2022)^[1] analysed heavy metals such as Cu, Zn, Pb and Cd in the water and sediment samples from the selected stations of Thoothukudi coastal waters, viz., Punnakayal, Therespuram and Vaippar, and found out the heavy metal concentrations were below the permissible limits as proposed by WHO (1989) and EPA (2014). Therefore, the present study therefore aims to update and expand upon previous findings to reflect the current environmental conditions of the region.

3. OBJECTIVES:

The objective of the present study is to analyse the heavy metal concentration of cadmium (Cd), lead (Pb), mercury (Hg), and copper (Cu) in the seawater sample of the Therespuram coast in Thoothukudi district. This study attempts to assess the levels of these elements to gain a better understanding of the presence and effects of these heavy metals on marine ecosystems.



4. METHODOLOGY:

The study area was Therespuram coast in Thoothukudi district. It is one of the main fishing harbours in the Tuticorin coast and heavily polluted by sewage and effluents from household wastes, hospital and slaughter-house wastes, etc^[5]. The samples for the present study were collected from Therespuram coast in Thoothukudi district. Sampling bottles were pre conditioned with 5% nitric acid and later rinsed thoroughly with distilled deionized water. At sampling site, the bottles were rinsed at least three times before sampling was done. Samples were placed in an ice bath and brought to the laboratory. Upon arrival in the laboratory, samples were acidified using concentrated nitric acid to prevent metal adsorption onto container walls and stored at 4°C until analysis. The samples were subjected to acid digestion following the method of FAO (1975)^[8]. The samples were digested with a mixture of concentrated nitric acid (HNO₃) and perchloric acid (HClO₄) in the ratio of 1: 2 until the formation of white residue at 100°C in a water bath. The cooled residue was dissolved completely by adding 1 N HCl and made upto 25ml with distilled water. The content was filtered by cotton wool, and the filtrate was subjected to metal analysis in atomic absorption spectrophotometer for the analysis of many of the trace metals like cadmium (Cd), copper (Cu) and lead (Pb), while the content of mercury (Hg) was analysed with a cold-vapour atomic adsorption spectrophotometer^[9]. The calibration curves were prepared separately for all the metals by running different concentrations of standard solutions. A reagent blank sample was analysed and subtracted from the samples to correct for reagent impurities and other sources of errors from the environment. The heavy metal concentration in sea water was reported as µg/l.

5. RESULTS:

Heavy metals such as cadmium (Cd), lead (Pb), mercury (Hg), and copper (Cu) in seawater were analyzed (Figure 1). The cadmium concentration was found to be 4.40±0.95 µg/l. Lead concentration in sea water sample was 17.6±1.05 µg/l. The concentration of mercury in the sea water was 1.07±0.34µg/l. The copper concentration in sea water was 22.02±1.03 µg/l. The mercury concentration was low compared to cadmium, lead and copper. Concentrations of heavy metals were found to decrease in order of Cu > Pb > Cd > Hg.

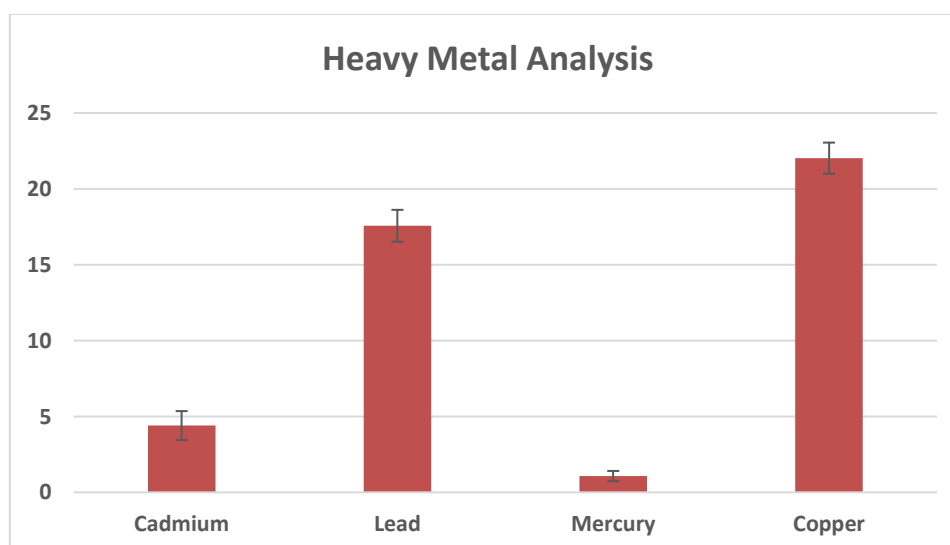


Figure 1: Heavy metal analysis in seawater



6. DISCUSSION :

Cadmium may enter the marine environment due to the geology of the catchment soil and runoff from phosphate-fertilised agricultural soils, as well as the disposal of nickel-cadmium-based batteries and cadmium-plated items. The primary source of cadmium in the coastal environment identifies both natural crustal origins and potential human sources. The primary natural causes include regional dust transport, mineral transport, rock weathering, and natural occurrences like volcanic eruptions and forest fires. Human development activities close to coastal areas, industrial effluent discharge, and local waste disposal are examples of anthropogenic inputs in coastal sediment^[10,11]. Cadmium toxicity caused Itai-Itai disease in Japan and can cause bone disease, anosmia and yellow discolouration of the teeth^[12,13]. According to international standards, the permissible limit for Cd in water is 0.01mg/l^[1] and EPA guidelines for the saltwater chronic criteria^[14] for cadmium is 7.9 µg/l. Therefore, in this study, the cadmium level was below the permissible limits. Comparable to the present study, Saxena *et al.*, (2022)^[1] reported the cadmium level varied from 0.004 to 0.019 ppm in the Therespuram region from the Thoothukudi coast, which is similar to the cadmium level in the present study.

Lead is a non-essential element. The sources of lead concentration in coastal environments include power plant operations, automobile exhausts, household sewage, agricultural runoff, cargo loading and unloading, harbour dredging, leaching from antifouling paints used in fishing boats, and leakage or unburned leaded fuel and diesel from vessels^[15,16]. This lead transported through the atmosphere and later settled in the seawater, subsequently wet and dry fallout in sediments. In seawater, it forms colloids that plankton can easily absorb. The high concentration of lead in the coastal regions is related to the input of industrial effluents from industries like industrial petrochemical, painting, thermal plant and other chemical industries, which are also exposed to wave and storm actions^[17]. The overall utilisation of motor fishing boats and automobiles has significantly increased, which is the cause of the higher lead level in the absence of any industry near the study sites^[18,19]. In this study, the lead concentration in sea water was higher than the recommended limits set by EPA^[14] which is 8.1 µg/l. The higher concentration of lead might be due to the domestic waste discharge^[1]. In contrast to the results of this study, Rajaram *et al.*, (2020)^[5] assessed the toxic metal contamination in the Tuticorin coast and found that the level of Pb ranged from 16.47±3.10 to 28.43±22.31 mg/l. Saxena *et al.*, (2022)^[1] reported the lead level varied from 1.517 to 3.264 ppm in the Therespuram region from the Thoothukudi coast, which is higher than the results of the current investigation.

Copper is an essential trace element for living organisms which allows the critical enzyme to function properly and assists the enzyme in transferring energy into the cells in the humans^[20]. However, higher copper uptake than needed is a double-edged sword that causes adverse effects^[21]. The effects include headache, vomiting, liver and kidney damage and Wilson's disease^[22]. Copper is frequently used in antibiofouling paints used in offshore engineering and on ship surfaces^[23]. The possibility for higher concentrations of copper is due to the usage of copper-based algaecides and herbicides used in the nearby agricultural land and surface runoff in these coastal areas during the inter-monsoon fall^[17]. The copper concentration in sea water was higher than the recommended limits set by EPA^[14] (3.1 µg/l). The increase in concentration of Cu in the present study might be due to land runoff, mechanical and chemical weathering of rocks, and additional components washed from the catchment areas through runoff and windblown dust, as also reported by Sankar *et al.*, (2010)^[13]. Similar to the present investigation, Rajaram *et al.*, (2020)^[5] evaluated the toxic metal contamination throughout the Tuticorin shoreline and observed that the copper levels varied between 1.45±1.33 to 10.02±8.88 mg/l. Saxena *et*



al., (2022)^[1] reported the copper level varied from 0.184 to 0.304 ppm in the Therespuram region from the Thoothukudi coast which is higher compared to the findings of this study.

Mercury levels slightly exceeded the EPA^[14] marine criterion of 0.94 µg/l. Mercury exposure poses a major risk to the health of several human organs, including the brain, liver, kidneys, and testicles, where it can cause histopathological alterations^[24]. Furthermore, according to several other research, environmental mercury exposure can potentially result in autoimmunity and blood mercury levels are higher in autoimmune disease patients than in healthy individuals^[25]. Regular monitoring and assessment of heavy metals in seawater should be carried out to protect the coastal environment from heavy metal contamination.

8. CONCLUSION:

The results showed that cadmium levels were within the safe limits set by EPA. However, copper, mercury and lead were found in higher amounts than recommended by EPA. Interestingly, the levels of copper and lead were actually lower than what was reported in an earlier study. This is due to land runoff and domestic waste discharge. The waste water and domestic sewage should treat and reused for agricultural and domestic purpose. Strict method of waste disposal control should be applied to ensure the safety of the environment and to safeguard the aquatic life. Monitoring Programs should continue to maintain the quality of aquatic environment.

REFERENCES:

1. Saxena, M., Padmavathy, P., Kumar, A., Katara, S., Singh, P., & Bhatt, A. J. (2022). Bioaccumulation of selected heavy metals in water and sediments of Thoothukudi coastal waters. *Journal of Experimental Zoology India*, 25, 1979–1985.
2. Samanta, P., Ray, N. N., & Singhal, S. (2024). Heavy metal concentration in marine water: An assessment of ONGC's blocks in Mumbai High Region, Arabian Sea. *Global Journal of Engineering and Technology Advances*, 21(02), 70–78.
3. Hermalin, P., & Glory, M. (2016). Assessment of heavy metal distribution of coastal water of Thoothukudi – Gulf of Mannar. *Golden Research Thoughts*, 6(3).
4. Asha, P. S., Diwakar, K., Usharani, A., & Prema, D. (2021). Investigations on selected ecological parameters of Tuticorin Bay, Gulf of Mannar, South-East Coast of India with emphasis on suitability for mariculture. *Indian Journal of Fisheries*, 68(3), 44–52.
5. Rajaram, R., Arumugam, G., Shanmugam, V., & Ganesan, A. (2020). Ecological risk assessment of toxic metals contamination in Tuticorin coast of Gulf of Mannar, Southern India. *Chemistry and Ecology*.
6. Anand, J. B. D., & Kala, M. J. S. (2015). Study on heavy metal distribution in the coastal environments along the foremost places of South-East Coast of India. *International Journal of Innovative Research in Science, Engineering and Technology*, 4(3), 1201.
7. Mohanraj, T., Sheeba, M., Cross, S. R. T. S., & Rajathy, T. J. (2021). Seasonal variation of heavy metals in the intertidal gastropod *Trochus radiatus* of Gulf of Mannar. *Open Journal of Marine Science*, 11, 92–102.
8. Food and Agriculture Organization of the United Nations. (1975). *Manual of methods in aquatic environment research: Part 10. Determination of heavy metals in marine sediments and waters* (FAO Fisheries Technical Paper No. 144). FAO.
9. US EPA (4). (1994). Method 245.1, Revision 3.0: Determination of Mercury in Water by Cold Vapor Atomic Absorption Spectrometry. Washington, D.C.: U.S. Environmental Protection Agency.
10. Kennish, M. J. (1996). *Practical handbook of estuarine and marine pollution* (525 pp.). Boca Raton, FL: CRC Press.



11. Fatoki, O. S., & Mathabatha, S. (2001). An assessment of heavy metal pollution in the East London and Port Elizabeth harbours. *Water SA*, 27, 233–240.
12. Sanders, T., Liu, Y., Buchner, V., & Tchounwou, P. B. (2009). Neurotoxic effects and biomarkers of lead exposure: A review. *Reviews on Environmental Health*, 24(1), 15–46.
13. Sankar, T. V., and Ashok Kumar, K. (2014). Food safety with special reference to seafood. *Practical Aspects of Seafood Safety* (eds Panda S K, Hassan F, Sanjeev S and Sankar T V.), 1-4.
14. U.S. Environmental Protection Agency. (1995). *Water quality criteria for protection of aquatic life: Saltwater chronic criteria* (EPA 822-R-95-005). Washington, D.C.: U.S. Environmental Protection Agency.
15. Abu-Hilal, A. H. (1987). Distribution of trace elements in nearshore surface sediments from the Jordan Gulf of Aqaba (Red Sea). *Marine Pollution Bulletin*, 18(4), 190–193.
16. Batley, G. E., & Brockbank, C. I. (1990). Impact of ocean disposal of dredged sediments from the RTA Glebe Island Bridge site—A coastal sediment survey (CSIRO Report FT/IR 050). Center for Advanced Analytical Chemistry—Division of Coal and Energy Technology.
17. Selvaraj, K., Ram-Mohan, V., Srinivasalu, S., Jonathan, M. P., & Siddartha, R. (2003). Distribution of non-detrital trace metals in sediment cores from Ennore creek, southeast coast of India. *Journal of Geological Society of India*, 62, 191–204.
18. Jonathan, M. P., & Ram Mohan, V. (2003). Heavy metals in sediments of the inner shelf off the Gulf of Mannar, Southeast coast of India. *Marine Pollution Bulletin*, 46, 263–268.
19. Jayaprakash, M., Jonathan, M. P., Srinivasalu, S., Muthu Raj, S., Ram-Mohan, V., & Rajeshwara Rao, N. (2008). Acid-leachable trace metals in sediments from an industrialized region (Ennore Creek) of Chennai City, SE coast of India: An approach towards regular monitoring. *Estuarine, Coastal and Shelf Science*, 76, 692–703.
20. Prashanth, L., Kattapagari, K., Chitturi, R., Baddam, V., & Prasad, L. (2015). A review on role of essential trace elements in health and disease. *Journal of Dr. NTR University of Health Sciences*, 4(2), 75–85.
21. Tvrda, E., Peer, R., Sikka, S. C., & Agarwal, A. (2015). Iron and copper in male reproduction: A double-edged sword. *Journal of Assisted Reproduction and Genetics*, 32(1), 3–16.
22. Mahurpawar, M. (2015). Effects of heavy metals on human health. *International Journal of Research-Granthaalayah*, 3, 1–7.
23. Raman, A. V., & Ganapati, P. N. (1983). Pollution effects on ecobiology of benthic polychaetes in Visakhapatnam harbour (Bay of Bengal). *Marine Pollution Bulletin*, 14, 46–52.
24. Zhou, F., Yin, G., Gao, Y., Liu, D., Xie, J., Ouyang, L., Fan, Y., Yu, H., Zha, Z., & Wang, K. (2019). Toxicity assessment due to prenatal and lactational exposure to lead, cadmium, and mercury mixtures. *Environment International*, 133, 105192.
25. Crowe, W., Allsopp, P. J., Watson, G. E., Magee, P. J., Strain, J., Armstrong, D. J., Ball, E., & McSorley, E. M. (2017). Mercury, as an environmental stimulus in the development of autoimmunity – A systematic review. *Autoimmunity Reviews*, 16, 72–80.



Green AI: A Path to Sustainable Cybersecurity in Data Centers

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Abstract : Modern data centers are the foundation of today's digital ecosystem, powering artificial intelligence (AI), cloud computing, and large-scale data processing. However, their intensive energy use and substantial carbon emissions pose serious environmental challenges. As AI systems become more prevalent, there is an urgent need for Green AI—an approach that prioritizes both environmental sustainability and cybersecurity. This paper investigates the convergence of Green AI and sustainable cybersecurity in data center operations. It examines strategies such as energy-efficient architecture design, renewable energy adoption, AI-driven workload and cooling optimization, and carbon footprint minimization. Furthermore, it emphasizes the integration of carbon-aware security frameworks that align data protection with sustainable energy practices. The findings highlight that AI-powered optimization, when coupled with renewable energy and secure system management, can create a balance between performance, resilience, and ecological responsibility.

Keywords: Green AI, Sustainable Cybersecurity, Data Center, Renewable Energy, Energy Efficiency, Carbon Footprint.

1. INTRODUCTION

In today's digital age, data centers serve as the invisible backbone of modern life, powering everything from cloud storage, online banking, and e-commerce to artificial intelligence and social media platforms. However, traditional data centers are notorious for their high energy consumption and significant carbon emissions, making them one of the largest contributors to the ICT sector's environmental footprint. This growing concern has led to the emergence of Green Data Centers (GDCs) — a new generation of facilities designed to operate with maximum efficiency and minimal environmental impact (Gupta et al., 2011) [2].

Green data centers integrate renewable energy sources such as solar, wind, and hydroelectric power to reduce dependency on fossil fuels. Advanced cooling methods like liquid cooling and free-air systems help lower electricity use, while AI-driven workload management ensures that computing power is used intelligently and efficiently. Technologies such as virtualization and machine learning optimize resource allocation by consolidating servers and minimizing idle time, leading to substantial energy savings.



Figure 1: Green AI Framework for Sustainable Data Centers

Industry pioneers including Google, Microsoft, and Amazon Web Services are taking major strides toward achieving carbon-free data center operations by 2030, setting global benchmarks for sustainability. These initiatives demonstrate how environmental responsibility and digital growth can go hand in hand. Moreover, frameworks like ISO 50001:2018 provide structured guidelines for continuous monitoring, energy management, and performance improvement, ensuring that efficiency gains are measurable and long-lasting (Al Kez et al., 2022) [10].

2. REVIEW OF GREEN DATA CENTER EFFICIENCY AND CARBON FOOTPRINT

Traditional data centers consume enormous power due to continuous server operation and complex cooling requirements. According to the International Energy Agency (IEA), global data center electricity demand reached approximately **460 TWh** in 2022, representing around 1.5% of total global electricity use [2].

A **Green Data Center (GDC)** employs technologies like **server virtualization**, **AI-based workload management**, and **energy-aware hardware** to enhance performance per watt. Performance metrics such as **Power Usage Effectiveness (PUE)** and **Carbon Usage Effectiveness (CUE)** help organizations evaluate sustainability outcomes [3].

Moreover, adopting **AI for workload prediction** can reduce idle computing resources by up to 40%, while **modular server infrastructure** enhances scalability and minimizes waste. By combining energy optimization with strong cybersecurity controls, data centers can mitigate both environmental and digital risks simultaneously.

Green Data Centers (GDCs) employ energy-efficient hardware, optimized airflow management, and AI-based monitoring tools to minimize environmental impact. Bilal et al. [1] highlighted that network traffic management and hardware virtualization can cut energy usage by 30%.

Table 1: Comparative Review of Data Center Efficiency Parameters

Efficiency Metric	Description	Typical Range	Reference
PUE (Power Usage Effectiveness)	Total power / IT equipment power	1.1 – 2.0	[23]
CUE (Carbon Usage Effectiveness)	CO ₂ emitted per unit of IT energy	0.2 – 0.5	[6]
WUE (Water Usage Effectiveness)	Water used per kWh of IT energy	1.8 – 3.5	[26]
DCiE (Data Center Infrastructure Efficiency)	IT Power / Total Facility Power	50% – 70%	[23]

In a green setup, cooling energy can be reduced to 20% or less using intelligent design and renewable power. Efficient power and cooling systems help in reducing **carbon footprints**. Studies such as those by Gupta et al. [2] and Sharma et al. [4] emphasize that using simulation tools (e.g., GDCSim) and modular architectures can optimize energy management and server utilization.

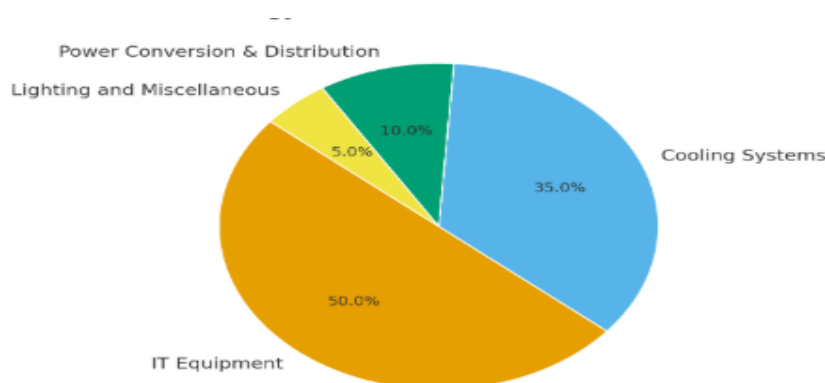


Figure 2: Energy Breakdown in Data Centers

This pie chart showing the **Energy Breakdown in Data Centers**, where IT Equipment consumes the largest share at 50%, followed by Cooling Systems at 35%, Power Conversion & Distribution at 10%, and Lighting & Miscellaneous at 5%.

3. METHODOLOGY

This research employs a qualitative and analytical methodology to examine the integration of Green Artificial Intelligence (AI) and sustainable cybersecurity in modern data centers. Secondary data was collected from peer-reviewed journals, industry reports, and international standards such as ISO 50001 and ISO 27001, covering publications from 2015 to 2025. The study involves synthesizing existing literature to identify trends, innovations, and research gaps related to renewable energy integration, AI-driven optimization, and carbon-aware security systems. Comparative analysis was conducted using key sustainability metrics such as Power Usage Effectiveness (PUE), Carbon Usage Effectiveness (CUE), and Water Usage Effectiveness (WUE) to assess performance and energy efficiency. Based on these findings, a conceptual framework was developed to integrate Green AI techniques with energy-efficient cybersecurity strategies, promoting secure, intelligent, and environmentally sustainable data center operations.

4. INTEGRATION OF RENEWABLE ENERGY RESOURCES IN GREEN DATA CENTER OPERATIONS

Integrating renewable sources into data centers has become vital for cutting carbon output and ensuring long-term, dependable operations. Facilities now combine renewables with grid power to keep systems stable while lowering energy footprints. Solar and wind are increasingly supported by hydro and geothermal options, giving centers cleaner and more predictable power. Together, these resources help data centers operate continuously while moving toward true environmental responsibility.

4.1 Solar Power in Green Data Centers

Solar power is becoming a leading clean-energy choice for data centers, offering reliable on-site electricity. Rooftop panels and solar microgrids help cut emissions and reduce long-term energy expenses. Stored solar energy keeps systems running even when sunlight is unavailable. Smart tools also predict solar output, allowing workloads to be scheduled more efficiently.

4.2 Wind Energy Integration in Data Centers

Wind energy provides a steady and effective power source for data centers, especially in regions with consistent wind flow. Many companies invest in wind farms to reduce their reliance on traditional grid electricity. This renewable source supports high computing demands with minimal environmental impact. When paired with solar and smart grid systems, it forms a resilient and flexible energy mix.

4.3 Hydroelectric and Geothermal Power Utilization

Hydroelectric power offers a constant, low-carbon energy supply that fits the needs of large data centers. Facilities near hydro plants benefit from reliable, round-the-clock electricity. Geothermal systems add further advantages by providing natural cooling and stable power from underground heat. Together, these sources deliver dependable, weather-independent energy that supports long-term sustainability.

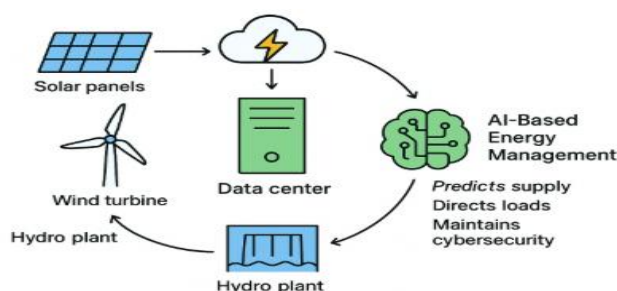


Figure 3: Renewable Energy Flow in a Green Data Center

- **Google** runs several data centers on **100% renewable energy**, using both solar farms and wind parks.
- **Microsoft** has committed to becoming **carbon negative by 2030**, meaning it will remove more carbon than it emits.

Integrating renewable energy into data center operations is a cornerstone of sustainability. Leading technology firms like Google and Microsoft have committed to operating on **100% renewable energy** through the deployment of **solar, wind, and hydroelectric** systems [4].

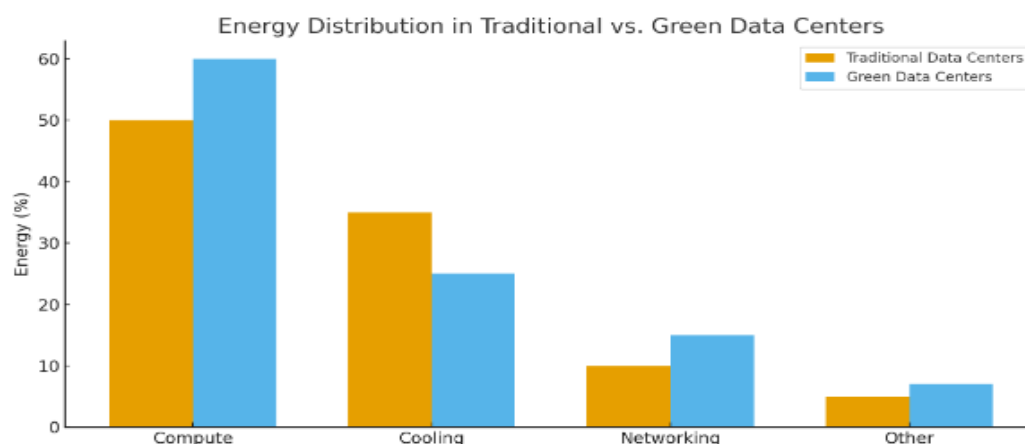


Figure 4: Energy Distribution in Traditional vs. Green Data Centers

This comparison shows how optimization and smart cooling significantly lower energy overhead.

5. STRATEGIES FOR DESIGNING AND OPERATING ENERGY-EFFICIENT DATA CENTERS

The sustainable design of a data center requires both smart architecture and intelligent operations. Today's data centers are no longer just storage hubs—they are complex digital ecosystems that must balance energy use, performance, and security. To make them sustainable, organizations are adopting innovative practices like server virtualization, AI-driven workload scheduling, advanced cooling technologies, energy-aware cybersecurity, and efficient data lifecycle management. These strategies together form the foundation of a greener and more responsible data infrastructure [1][4][13]

Table 2. Energy Efficiency Strategies in Sustainable Data Centers

Optimization Strategy	Typical Energy Reduction	Description
Virtualization	30–40%	Fewer active servers
AI-based Load Balancing	25%	Predictive resource allocation
Modular Cooling	20%	Targeted airflow
Liquid Cooling	40–50%	Efficient heat transfer



When implemented collectively, these strategies achieve a significant reduction in both operational cost and carbon footprint while maintaining secure and resilient infrastructures.

5.1 Server Virtualization and Consolidation

Server virtualization allows multiple virtual systems to run on a single machine, helping cut down the number of physical servers needed. This reduces power use, cooling demands, and overall operating costs. Consolidating workloads keeps servers active and efficient instead of wasting energy on idle equipment. The approach also adapts resources automatically, giving data centers flexible and sustainable performance.

5.2 Dynamic Workload Scheduling

Dynamic workload scheduling uses AI to decide where computing tasks should run for the best energy savings. By tracking temperature, power use, and performance, it shifts workloads to the most efficient servers. Heavy tasks can be moved to renewable-powered or cooler zones to lower energy strain. This smart coordination reduces waste and keeps systems running smoothly even during peak demand.

5.3 Free-Air and Liquid Cooling

Modern cooling techniques are helping reduce one of the biggest energy expenses in data centers. Free-air cooling uses naturally cool outdoor air to regulate temperatures, cutting reliance on traditional AC systems. Liquid cooling removes heat more effectively by circulating special fluids around components. Both methods improve efficiency, lower costs, and extend hardware life, making them essential for greener operations.

5.4 Energy-Aware Cybersecurity

Energy-aware cybersecurity focuses on protecting systems while keeping power use low. Lightweight and adaptable security methods adjust their intensity based on real-time risk levels. AI can streamline threat detection, reducing unnecessary scans without weakening safety. This approach maintains strong defense while supporting the energy goals of sustainable data centers.

5.5 Data Lifecycle Optimization

Data lifecycle optimization reduces the energy needed to store and manage growing amounts of information. Techniques like file deletion, compression, and deduplication prevent unused data from consuming power. Tiered storage places frequently used data on fast devices while shifting older files to low-energy archives. These strategies cut energy use, extend hardware lifespan, and lower digital waste.



Figure 5: Comparative Impact of Energy Optimization Technique

Together, these methods can cut energy costs by more than 50%, while maintaining high performance and data protection.

6. MEASURING AND EVALUATING ENERGY EFFICIENCY AND SUSTAINABILITY METRICS

Measuring and assessing energy efficiency is essential for promoting transparency and accountability in green data centers. These evaluations help organizations detect inefficiencies, monitor progress, and



comply with global sustainability standards like the GHG Protocol, ISO 50001, and LEED certification. Core performance metrics such as Power Usage Effectiveness (PUE), Carbon Usage Effectiveness (CUE), and Water Usage Effectiveness (WUE) measure energy efficiency, carbon emissions, and water management respectively. PUE reflects the energy used by IT equipment, CUE connects energy use to carbon output, and WUE tracks water consumption in cooling systems. Consistent monitoring and open reporting drive compliance, innovation, and continuous improvement in sustainable operations. Three core sustainability metrics are commonly used based on following keys.

6.1. Power Usage Effectiveness (PUE)

Power Usage Effectiveness (PUE) is the most widely recognized metric for assessing how efficiently a data center uses energy. It measures the ratio between the total facility power and the energy actually consumed by IT equipment. The closer the PUE value is to 1.0, the more efficient the data center's operation. Leading companies like Google consistently monitor PUE to ensure maximum power utilization for computing rather than for cooling, lighting, or other auxiliary systems. This metric promotes continuous improvement by allowing managers to identify inefficiencies and optimize energy distribution in real time.

6.2. Carbon Usage Effectiveness (CUE)

Carbon Usage Effectiveness (CUE) extends beyond energy efficiency by measuring the carbon emissions associated with a data center's power consumption. It expresses the amount of carbon dioxide released per unit of IT energy used, offering insight into the facility's environmental footprint. A lower CUE value indicates greater reliance on renewable energy sources such as solar, wind, or hydropower. This metric is vital for organizations aiming to achieve carbon-neutral or carbon-free operations. For example, two centers may share identical PUE values yet differ significantly in CUE if one draws from coal-based electricity while the other uses renewables.

6.3. Water Usage Effectiveness (WUE)

Water Usage Effectiveness (WUE) evaluates how efficiently a data center uses water to support cooling and energy systems. It is defined as the volume of water consumed per kilowatt-hour of IT power used. With water scarcity emerging as a global concern, WUE helps organizations assess and minimize the environmental impact of their cooling strategies. Many facilities are now adopting air-cooled or closed-loop systems to conserve water without compromising performance. In line with The Green Grid (2024) recommendations, WUE should be analyzed alongside PUE and CUE for a comprehensive understanding of sustainability performance.

Table 3. Sustainability Metrics Overview

Metric	Description	Ideal Value	Significance
PUE	Total energy / IT energy	≤ 1.2	Measures energy efficiency
CUE	Carbon emissions / IT energy	≤ 0.3	Tracks emission control
WUE	Water use / IT energy	≤ 0.5	Encourages water conservation

Reporting these metrics annually helps organizations benchmark their sustainability progress and identify areas for improvement. Some data centers now use **blockchain-based reporting** for transparent, verifiable data sharing.

7. ADVANCED COOLING OPTIMIZATION METHODS IN GREEN DATA CENTERS

Cooling has always been one of the biggest energy concerns in data centers, often responsible for around 35–45% of total electricity use [8]. Traditional air-conditioning systems work nonstop, even when they are not needed, which leads to high energy bills and carbon emissions. To overcome this challenge, modern data centers are adopting smart and sustainable cooling methods. These systems are designed to adjust automatically to temperature and humidity changes inside the facility, helping to maintain ideal conditions while cutting energy waste. Below are some of the most effective and eco-friendly cooling innovations that are shaping the future of green data centers.



Table 4: Cooling Technique vs. Energy Savings

Cooling Technique	Energy Savings	Maintenance Complexity
Traditional HVAC	0%	Low
Free-Air Cooling	20–30%	Medium
Liquid Cooling	40–50%	High
AI-Driven Thermal Control	55–65%	Medium-High

7.1 Liquid Immersion Cooling

Liquid immersion cooling keeps servers cool by submerging them in a safe, non-conductive liquid that absorbs heat far more efficiently than air. This method removes the need for heavy air conditioning and reduces the use of noisy cooling fans. Because temperatures stay stable, the hardware experiences less strain and lasts longer. Overall, it offers a cleaner, quieter, and more energy-efficient cooling solution for modern data centers.

7.2 Hot/Cold Aisle Containment

Hot and cold aisle containment improves airflow by separating cool intake air from the hot exhaust released by servers. Equipment is arranged in alternating rows, with barriers preventing the two air streams from mixing. This setup helps cooling systems deliver cold air directly to where it’s needed most. As a result, energy use drops significantly while internal temperatures remain steady and controlled.

7.3 AI-Driven Temperature Control

AI-based temperature control adjusts cooling in real time by studying live data from sensors across the data center. Instead of wasting energy on uniformly cooling the entire space, the system targets specific hotspots. This approach minimizes unnecessary power consumption while keeping equipment safe and stable. AI can also align cooling activity with renewable energy availability, improving both efficiency and sustainability.

7.4 Free-Air Cooling

Free-air cooling uses naturally cool outside air to maintain safe temperatures inside the data center, reducing dependence on mechanical air conditioners. When weather conditions allow, filtered outdoor air replaces or supplements traditional cooling systems. This method cuts energy use dramatically, especially in cooler climates. Along with lowering costs and emissions, it improves system reliability by preventing heat-related failures.

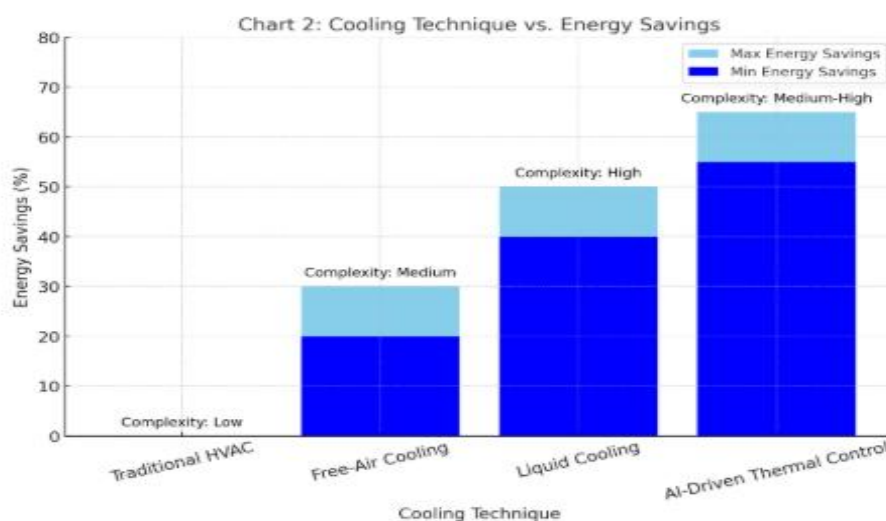


Figure 6: Smart Cooling Optimization in Green Data Centers



AI not only improves energy use but also ensures **cyber-physical safety**, monitoring for thermal anomalies that might signal a cyberattack on cooling systems. Optimized cooling not only saves energy but also extends hardware life and reduces the risk of downtime or thermal failures.

8. CHALLENGES AND FUTURE DIRECTIONS

Although progress toward greener and more secure data centers has been significant, several barriers still limit full adoption. True sustainability demands advanced technology, major financial commitment, and strong global cooperation. Balancing security, performance, and energy efficiency remains a major challenge. The sections below outline the key obstacles that must be addressed to achieve truly sustainable digital infrastructure.

8.1 High Initial Investment

Building green data centers often requires expensive renewable systems, such as solar arrays, wind units, and modern cooling solutions. These technologies reduce costs over time, but the upfront price can be difficult for smaller organizations to manage. Integrating renewables with older power systems adds even more financial strain. Despite incentives, the cost gap between short-term budgets and long-term sustainability slows global adoption.

8.2 Interoperability and Standardization

Different regions use varying sustainability metrics, making it difficult to compare performance across data centers. This lack of standardization limits cooperation and complicates renewable integration. Inconsistent measures also affect transparency and long-term planning. Unified frameworks and shared reporting methods could help streamline progress and improve accountability worldwide.

8.3 Cybersecurity Vulnerabilities

As data centers become more interconnected through IOT, AI, and smart grids, they face growing cybersecurity risks. These interconnected systems create more entry points for attackers, threatening stability and data integrity. A breach can disrupt energy management or even cause operational downtime. New AI-driven security tools aim to protect systems without adding heavy energy demands.

8.4 AI Energy Demand

AI helps optimize data center operations, but training and running large models require substantial energy. Some model-training processes can produce emissions comparable to long-term vehicle use. Even with more efficient chips, rising worldwide AI demand increases overall power consumption. Researchers now focus on “Green AI,” which promotes tools and algorithms that use fewer resources.

8.5 Renewable Variability

Solar and wind power support cleaner operations, but their natural fluctuations create reliability challenges. When sunlight or wind drops, data centers often turn to non-renewable backups. Energy storage and hybrid systems help, but remain expensive and limited. AI-based forecasting can match workloads with renewable availability, though storage and battery concerns still slow wider adoption.

8.6 Cost Barriers

Even with long-term savings, green infrastructure requires major initial investments that many organizations struggle to afford. Upgrading hardware, retraining staff, and redesigning workflows add to the expense. Limited financial support and slow payback periods discourage sustainability projects. Many companies rely on hybrid models, but broader incentives are needed for global-scale transformation.

8.7 Data Privacy vs. Energy Efficiency Trade-offs

Securing data often requires encryption, redundancy, and backups, all of which increase energy use. These protections can conflict with efforts to reduce power consumption in green data centers. Idle redundant systems and frequent encryption processes add unnecessary load. Emerging energy-efficient



encryption and AI-driven security are being developed to protect privacy without undermining sustainability.

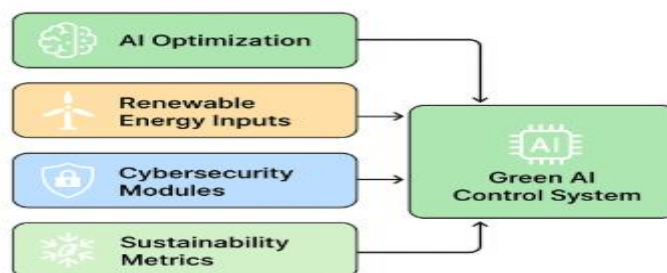


Figure 7: Future green data center innovation framework

Future directions involve **AI-driven intrusion detection** systems that balance speed, accuracy, and low energy use. There is also growing interest in **quantum-secure algorithms**, which may one day offer ultra-secure, energy-efficient encryption. **Self-healing cyber defense systems** that align with low-carbon operational goals.

9. OPPORTUNITIES FOR FURTHER RESEARCH AND INNOVATION

There are vast opportunities for further research and innovation in developing smarter, more energy-efficient Green Data Centers. Future studies can focus on integrating AI-driven automation, IoT-based monitoring, and edge computing for real-time energy optimization. Research can also explore new cooling technologies and sustainable materials to reduce environmental impact. Advancements in renewable energy storage and carbon-neutral operations hold great potential. Green AI provides a unique opportunity to unify sustainability and cybersecurity innovation. Future advancements may include:

9.1. Carbon-Aware Security Frameworks

Carbon-aware security frameworks aim to deliver strong protection while using energy efficiently. Traditional systems consume power continuously, even during low threats. By scheduling security tasks during high renewable energy availability, data centers can reduce carbon emissions. AI-driven models adjust operations to align with green power sources. This approach ensures cybersecurity supports environmental sustainability.

9. 2. Blockchain-Based Renewable Energy Trading

Blockchain enhances secure and transparent renewable energy trading among data centers. Its decentralized structure prevents fraud and cyberattacks while enabling smart contracts for automatic green energy exchange. By removing intermediaries, it cuts costs and improves efficiency. New energy-efficient algorithms further reduce blockchain's power use. Thus, it promotes both cybersecurity and sustainability.

9. 3. AI-Powered Predictive Maintenance

AI-driven predictive maintenance ensures efficient and secure data center operations. Machine learning analyzes system data to detect cyber threats or hardware faults early. Abnormal energy use or temperature can signal vulnerabilities or intrusions. Timely action prevents downtime and energy waste. This proactive approach strengthens both security and sustainability.

9. 4. Edge Computing Integration

Integrating edge computing with cybersecurity builds a stronger and more sustainable digital infrastructure. By processing data near its source—such as IoT devices or local sensors—edge systems minimize data transmission to central servers, reducing both energy consumption and cyber risks. This localized approach enhances privacy, decreases latency, and limits potential attack points. When powered by renewable microgrids, edge nodes can operate securely even during network disruptions.



Combining AI-driven security analytics at the edge with green data centers fosters an ecosystem that is both energy-efficient and cyber-resilient.

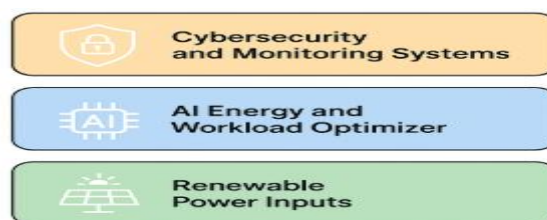


Figure 8: Framework for Sustainable, Secure Data Centers

Continued interdisciplinary collaboration across AI, cybersecurity, and environmental sciences will drive the evolution of **next-generation sustainable data centers**.

10. CONCLUSION AND OUTCOMES

The transformation of Green Data Centers reflects a crucial step toward integrating sustainability, efficiency, and cybersecurity in modern digital infrastructure. By integrating renewable energy systems, AI-driven automation, and intelligent cooling, these centers reduce carbon emissions while maintaining strong security and performance. The use of carbon-aware cybersecurity frameworks and blockchain-enabled energy trading enhances both energy efficiency and data protection. AI-powered predictive maintenance further improves operational resilience by identifying potential equipment failures and cyber threats early. Metrics such as PUE and DCiE provide clear benchmarks for tracking sustainable and security performance. This study concludes that combining green technologies with advanced cybersecurity solutions leads to improved energy efficiency, reduced operational costs, and greater data resilience. The findings suggest that the future of data infrastructure lies in eco-secure models, where environmental responsibility and digital protection progress together in harmony (Singh & Gupta, 2024; Capozzoli et al., 2018). It establishes that future data centers must combine eco-friendly technologies with robust cybersecurity to ensure a sustainable, secure, and intelligent digital ecosystem.

REFERENCES

- [1] K. Bilal, S. U. Khan, and A. Y. Zomaya, "Green data center networks: Challenges and opportunities," *Proc. 11th Int. Conf. Frontiers Inf. Technol.*, IEEE, 2013.
- [2] S. K. S. Gupta et al., "GDCCSim: A tool for analyzing green data center design and resource management techniques," *Proc. IGCC'11*, 2011.
- [3] A. Sari and M. Akkaya, "Security and optimization challenges of green data centers," *Int. J. Commun. Netw. Syst. Sci.*, vol. 8, no. 12, 2015.
- [4] P. Sharma et al., "Design and operational analysis of a green data center," *IEEE Internet Comput.*, vol. 21, no. 4, pp. 16–24, 2017.
- [5] SiCortex, "Green computing performance index," 2011.
- [6] L. Wang and S. Khan, "Review of performance metrics for green data centers," *J. Supercomput.*, vol. 63, no. 1, 2011.
- [7] A. Hammadi and L. Mhamdi, "A survey on architectures and energy efficiency in data center networks," *Comput. Commun.*, vol. 40, pp. 1–21, 2014.
- [8] T. Wang et al., "A general framework for performance guaranteed green data center networking," *IEEE GLOBECOM*, 2014.
- [9] The Green Grid, "Using virtualization to improve data center efficiency," 2009.
- [10] D. Al Kez et al., "Exploring the sustainability challenges facing digitalization and internet data centers," *J. Cleaner Prod.*, vol. 371, 2022.



- [11] Y. Zhang et al., “GreenWare: Greening cloud-scale data centers,” *Proc. Middleware’11*, 2011.
- [12] W. McNamara et al., “Best practices for creating the green data center,” *ASHRAE Journal*, Oct. 2008.
- [13] A. Nagarathinam et al., “Green data centers: A review of current trends and practices,” *Technology-Driven Business Innovation*, vol. 1, pp. 251–264, 2024.
- [14] R. Mata-Toledo and P. Gupta, “Green data center: How green can we perform?” *J. Technol. Res.*, vol. 2, pp. 1–8, 2010.
- [15] M. Ghamkhari and H. Mohsenian-Rad, “Energy and performance management of green data centers,” *IEEE Trans. Smart Grid*, vol. 4, no. 2, 2013.
- [16] G. I. Meijer, “Cooling energy-hungry data centers,” *Science*, vol. 328, 2010.
- [17] K. Ebrahimi et al., “A review of data center cooling technology,” *Renew. Sustain. Energy Rev.*, vol. 31, 2014.
- [18] Z. Song et al., “Data center energy and cost saving evaluation,” *Energy Procedia*, vol. 75, 2015.
- [19] R. Wu et al., “Energy efficient optimization for green data center based on cloud computing,” *Proc. Nat. Conf. Electr. Electron. Comput. Eng.*, 2015.
- [20] I. Goiri et al., “GreenSlot: Scheduling energy consumption in green data centers,” *Proc. SC’11*, 2011.
- [21] K. Bilal et al., “A taxonomy and survey on green data center networks,” *Future Gener. Comput. Syst.*, vol. 36, 2014.
- [22] M. Xu et al., “Greening data center networks with throughput-guaranteed power-aware routing,” *Comput. Netw.*, vol. 57, 2013.
- [23] C. Belady et al., “The Green Grid data center power efficiency metrics: PUE and DCiE,” *The Green Grid Consortium*, 2008.
- [24] J. Brandon, “Going green in the data center,” *Processor*, vol. 29, no. 39, 2007.
- [25] L. Lannelongue et al., “Green algorithms: Quantifying the carbon footprint of computation,” *Adv. Sci.*, vol. 8, no. 12, 2021.
- [26] J. Wan et al., “Sustainability analysis of green data centers with CCHP and waste heat reuse,” *IEEE Trans. Sustain. Comput.*, vol. 6, no. 2, 2020.
- [27] T. Bhattacharya and X. Qin, “Modeling energy efficiency of future green data centers,” *Proc. Int. Green Sustainable Comput. Workshops, IEEE*, 2020.
- [28] Shehabi et al., “United States Data Center Energy Usage Report,” *Lawrence Berkeley National Laboratory*, 2016.
- [29] International Energy Agency (IEA), “Data Centres and Data Transmission Networks,” *IEA*, Paris, 2022.
- [30] M. Patterson, “The Effectiveness of Data Center Energy Metrics,” *Intel Corporation Technical Report*, 2020.
- [31] Google Sustainability Report, “Carbon-Free Energy for Data Centers,” *Google*, 2023.
- [32] J. Wu et al., “Cyber-Physical Security in Renewable-Powered Data Centers,” *IEEE Access*, vol. 9, pp. 18905–18917, 2021.
- [33] S. Singh and A. Gupta, “AI-Based Optimization in Sustainable Cloud Infrastructure,” *Journal of Green Computing*, vol. 8, no. 3, pp. 55–63, 2024.
- [34] ISO 50001:2018, “Energy Management Systems — Requirements with Guidance for Use,” *International Organization for Standardization*.
- [35] A. Capozzoli et al., “Cooling Systems in Data Centers: Energy Analysis and Performance Optimization,” *Applied Energy*, vol. 232, pp. 120–136, 2018.
- [36] T. Strubell, A. Ganesh, and A. McCallum, “Energy and Policy Considerations for Deep Learning in NLP,” *ACL Proceedings*, 2019.



Sustainability Summit: Fostering a Sustainable Environment

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Abstract: *The accelerating collapse of our natural atmosphere - as introduced by climate variation, biodiversity destruction, water scarcity, and contamination - poses one of the profound accusations to mankind in the 21st century. In reply, sustainability summits have risen as inevitable stages for discourse, cooperation, policy-making, and novelty among governments, cultured society, academia, and merchandise. This paper examines the multifaceted nature of sustainability summits in cherishing a sustainable atmosphere, exploring their dynamic, restrictions, and best exercises. Beginning with a reconsideration of current scholarship on sustainability novelty, environmental leadership, society attitude, the argument recognises main mechanisms by which summits can catalyse function: wisdom sharing, rule fixing, networking, policy manufacture, finance mobilization, and common cognition. The main body evokes ultimate thematic fields including sustainable development goals (SDGs), tech innovation and clean energy, circular economy, leadership and stakeholder engagement, and behavioural change. The exploration traces on case studies and experimental exploration - such as the acceptance of sustainability novelties in hospitals in Pakistan, transformational guidance in hospitality in China, and pedagogical interferences in STEM education - showing how summits can behave not just as rhetoric but as devices for modest environmental results. Objections are also evaluated: logistical and economic confines, danger of summit exhaustion, the void between promises and execution, injustice in participation, and the scarcity for inclusive, righteousness-oriented aspects. The ending underlines that for summits to actual cherished sustainability, they must be designed to bridge divisions (global/local, rich/poor), center science with policy, establish tangible and modest objectives, and assure follow-through. Policymakers, summit constituents, and participants are urged to inflect responsibility, leverage novelty, and prioritise community-led function. The paper contributes to realising how universal discourses can conduct to fruitful environmental transformations when underpinned by stern planning, inclusive exercise, and sustained function.*

Keywords: *Sustainability summits, Environmental leadership, Sustainable development goals, Circular Economy, Stakeholder Engagement, Behavioural Change.*

1. INTRODUCTION:

Sustainability has uplifted from being a buzzword to an indispensable universal obligatory. The world's ecosystems are under unpalatable torment: ascending intentness of greenhouse gases are warming the planet; species are vanishing at frightful rates; freshwater provisions are under stress; and contamination of wind, space, and stream bulldozes human wellness and ecological unity. In this context, universal and provincial summits focused on sustainability have become eventual fields for greeting interconnected environmental emergencies. Summits - from the United Nations' conferences to scholastic, merchandise, or sector-specific forums - offer absolute positions for stakeholders to share wisdom, formulate policy, mobilize provisions, and hold themselves responsible. However, the



usefulness of such summits relies not just on oration or lecture, but on translating undertakings into function. Constructing summits that cherish authentic advancement towards environmental sustainability claims more than entire discourses; it demands a skeleton that bridges science, penetration, community cooperation, and technology. Moreover, summits must debate with problems of right: some communities endure the scorched earth of environmental decline, yet often have the least sound in worldwide forums. Sustainable development goals (SDGs) underline that environmental hygiene, social equity, and financial enhancement are inalienable, and any summit focussed on sustainability must mirror that combination. This paper takes steps to explore how sustainability summits can cherish a sustainable environment. Main queries include: what are the methods by which summits pay to environmental results? What thematic precedences and novelties are arising in current investigation and exercise? What are the general barriers, and how have different agents investigated to surpass them? By illustrating current experimental practice, event instances, and theoretical knowledge, this paper aims to retail both the undertakings and traps of sustainability summits. It discusses that well-schematic summits can function as catalysts for diversity - if they pay attention to inclusivity, follow-through, responsibility, and classification with example-based accomplishments. In performing so, summits can transform environmental rhetoric into lasting exercise, supporting to steer societies towards resilience, sustainability, and righteousness.

2. ANALYSIS:

The Role and Significance of Sustainability Summits:

1. Historical Evolution of Environmental Summits:

The role of summits in sustainability cannot be admired without reflecting their chronologic origins. The 1972 Stockholm Conference was the first chief worldwide case where environmental problems were put on the universal agenda. This was pursued by the 1992 Earth Summit in Rio de Janeiro, which launched Agenda 21, a design for sustainable progress, and established the concept that financial enhancement and environmental safeguard must go together. Later cases such as the Johannesburg Summit (2002) and Rio+20 (2012) amplified these precedences, while the Paris Climate Agreement (2015) exhibited that summits can reach in lawfully fastening skeletons. At the provincial and native levels, academics, NGOs, merchandises now host sustainability summits fitted to sectoral problems such as renewal strength, stream management, or knowledge for sustainable improvement. This change portrays that summits are no longer enclosed to diplomats but encircle grassroots agents.

2. Defining Sustainability Summits as Catalysts:

Sustainability summits serve as catalysts by providing -

- (a) Deliberative Spaces: where various stakeholders partake in discourses.
- (b) Knowledge Platforms: where fresh scientific inventions and best exercises are divided.
- (c) Commitment Forums: where administration and merchandises promise to resort to sustainable exercises.
- (d) Norm-Setting Arenas: where unity on universal standards - such as carbon neutralism or rotational organization ethics - are founded.

These summits function on diverse ranges (native, provincial, universal) and across diverse branches (weather, activity, stream, nourishment, knowledge). Their energy lies in the fact that they inspire collaboration across silos and favour formulate general objectives.



Mechanisms by Which Summits Foster Sustainability:

1. Knowledge Sharing and Scientific Communication:

Summits simplify the translation of complicated scientific exploration into policy discourse. For instance, the Intergovernmental Panel on Climate Change (IPCC) reports are frequently introduced or practised in such stages, consenting policymakers to realise the recent climate science in a digestible mode. Without summits, exploration inventions hazard remaining limited to academic journals.

2. Networking and Partnerships:

A key act of summits is shaping cross-sectoral fellowships. Governments, NGOs, merchandises, and academics occasionally conduct in similar places. By meeting at summits, they set up cooperations, start collective programs, and impart finance mechanisms. For example, the Mission Innovation association on pure activity was commenced at COP21, where 24 governments undertook to double clean energy R&D appointments.

3. Policy Formulation and Agenda Setting:

Summits can impact policy from hand to hand. The Paris Agreement is a key instance of how international summits can prepare fastening skeletons. At national levels, taking part in international workshops frequently pressures governments to classify national policies with global regulations - such as renewal strength objectives or carbon neutrality undertakings.

4. Mobilization of Financial aid Technical Resources:

Summits often function as fields for economic commitments. For example, improved nations pledged to mobilize \$100 billion yearly to help rising countries with climate adaptation and mollification (though accomplishment has crawled). Likewise, summits develop advantages for merchandises to circulate sustainability investments.

5. Raising Public Awareness and Shaping Norms:

Summits are high-appointment cases extensively dressed by the media. The remark helps extend knowledge among inhabitants, merchandises, and governments. They influence attitude obliquely by depicting communal rules - what was once calculated elective (e.g., renewal strength assumption) is increasingly noticed as an ethical and financial requisite.

Thematic Priorities in Contemporary Sustainability Summits:

1. Sustainable Development Goals (SDGs) Integration:

The UN's 2030 Agenda with its 17 SDGs forms the spine of most summit agendas nowadays. Central objectives combined with environmental sustainability include -

SDG 6 (Clean Water and Sanitation)

SDG 7 (Affordable and Clean Energy)

SDG 11 (Sustainable Cities and Communities)

SDG 12 (Responsible Consumption and Production)

SDG 13 (Climate Action)

SDG 15 (Life on Land)

Summits increasingly underline how these objectives interrupt, emphasizing that advancement in one field (e.g., energy) often relies on progress in others (e.g., water, infrastructure).

2. Technological Innovation and Clean Energy:

Technological resolutions govern summit discourses. Main novelties include -



- (a) Solar, wind, and hydro ability propagation.
- (b) Soft robotics and bioinspired technology for ecosystem regeneration and governance.
- (c) Carbon capture and storage (CCS) technologies.
- (d) Sustainable agriculture technologies such as precision farming and vertical farming.

A study in Pakistan hospitals remarked that restoring sustainability novelties (simplicity, trialability, relative benefit) raised environmental sustainability and diminished provision extravagance.

3. Circular Economy and Resource Efficiency:

Round economy ethics - reduce, reuse, recycle, redesign - are increasingly major. For example, the European Union's Circular Economy Action Plan (2020) was heavily influenced by summit discourses. Summits underline fruitful merchandise frames such as product take-back schemes, waste-to-energy technologies, and closed-loop manufacturing.

4. Leadership and Stakeholder Engagement:

Leadership is eventual in translating summit undertakings into function. Current exploration in China demonstrates that environmental transformational leadership significantly impacts sustainable attitudes among workers in the hospitality segment. Leaders who encourage green emotion and inherent inspiration can enhance organisational alteration.

5. Behavioural and Cultural Change:

Sustainability is not only about policy but also about human standards and attitudes. Lessons demonstrate that compassion for nature and sympathy correlate sharply with pro-environmental attitudes. Summits that centre cultural propagations - storytelling, indigenous aspects, morals - are more fruitful in mobilizing long-term behavioural alteration.

6. Education, Youth, and Capacity Building:

Youth summits and student conferences have flourished as potent places for environmental circulation. Education assemblies within summits emphasize sustainability literacy, interdisciplinary meditation, and novelty. For instance, STEM students involved in question-based study announced statistically meaningful profits in sustainability standards.

Challenges in Sustainability Summits:

1. The Implementation Gap:

One of the most stationary critiques is the void between rhetoric and function. Undertakes made in summit announcements are frequently non- fixture, leading to faint accomplishment. For instance, the commitment of \$100 billion per year for rising lands has not been fully dignified.

2. Equity and Justice Issues:

Environmental collapse disproportionately influences vulnerable societies, yet they are frequently illustrated in summits. For example, indigenous wisdom, though critical for biodiversity preservation, is occasionally given enough position in interlocution. Equity thoughts - climate justice, gender justice, intergenerational equity - must become prime.

3. Summit Fatigue and Duplication:

With different overlapping conferences (climate, biodiversity, energy, oceans), stakeholders occasionally realise exhaustion. Replication without substantive results hazards undermining reliability.

4. Financial and Logistical Constraints:

Taking part in worldwide summits can be expensive for impoverished countries and grassroots associations. Virtual options post-COVID have developed availability but also elevated digital divide problems.

5. Resistance to Behavioural Change:

Even with wisdom and infrastructure, attitude alteration remains hard. Governments turn to lobbying by potent crafts; residents frequently undergo lifestyle variation (e.g., minimising car usage, dietary switches). Summits need to center behavioural science to maintain this interference.



Best Practices and Recommendations:

1. Clear, Measurable Goals:

Summits should launch SMART objectives (Specific, Measurable, Achievable, Relevant, Time-bound). Instead of obscure undertakings, countries should promise quantifiable goals, e.g., reduce emissions by 40% by 2030.

2. Inclusive Participation:

Assuring various tones - Global South, indigenous peoples, youth, women - emphasizes justice and usefulness. Technology can help enlarge fellowship by providing hybrid ideals.

3. Bridging Global and Local Action:

Assurance must be localised. Summits should assist municipal governments and communities to accomplish penetration at base level, providing finance and industrial experience.

4. Scaling up Innovations:

Effective pilot projects displayed at summits must be measured. For example, originalities in extravagance regulation or renewal strength should be divided across boundaries with economical techniques.

5. Embedding Behavioural Science:

Summits should use behavioural science - social norms, nudges, incentives - to develop sustainable healthy lifestyles. Consciousness perspectives must evoke not only reasoning and thought but also to standards and affections.

6. Accountability and Transparency:

Mechanisms such as independent governance, yearly improvement reports, and online panels can confirm undertakings are stressed. Transparency creates faith and restrains greenwashing.

3. CASE STUDIES:

1. Pakistan's Healthcare Sector:

Hospitals in Pakistan receiving sustainability novelties (waste commutation, energy competency) exhibited that novelty consistency and trialability quicken acceptance. This shows summits should underline effective, reference-tangible resolutions.

2. Hospitality Sector in China:

Exploration expresses that transformational guidance cherishes sustainable exercises, with workers showing green benevolence and inherent inspiration. Summits can thus underline guidance teaching as a chief instrument.

3. STEM Education in Higher Learning:

Explorative educational learning demonstrated important advancements in sustainability standards when students were involved in interdisciplinary lessons. Summits should replicate this through youth forums and workshops.

4. European Circular Economy Action Plan:

The EU's CEAP arose from comprehensive summit discourses. It has led to new policies on ecodesign, waste reduction, and sustainable textiles. This exhibits how summit discourses can directly impact provincial policy skeletons.

5. COP21 and the Paris Agreement:

The Paris Agreement is the most remarkable event where summit diplomacy led to a fastening skeleton. Although partial, it has impacted national climate regulations globally, drawing the ability of summits when combined with responsibility.



4. CONCLUSION:

Sustainability summits hold extensive undertaking as devices of environmental advancement. They simultaneously bring different agents, simplify wisdom modification, set rules, mobilise provisions, and catalyse promises that might otherwise remain crumble. Yet the dynamic is understood only if summits are more than symbolic: if their results are reasonable, their sharing inclusive, their promises lucid, and their follow-through powerful. From the experimental events calculated - ranging from novelty acceptance in hospitals, guidance in hospitality segments, to sustainability knowledge in STEM - it is clear that fruitful summits are those which mingle technological and policy novelty with moral standards and behavioural alteration. They associate universal objectives to native truths, assuring that resolutions are grounded in the associations where advancements are required most.

Going onwards, summit promoters and policy composers should frame these forums to offer obvious function designs, with obligation and timelines; ensure suitable finance to help accomplishment beyond the summit; inflict mechanisms for responsibility; confirm appeal across geography, social rank, and era; leverage novelty but also social regulations and standards; and hold motivation beyond the case itself. In sum, cherishing a sustainable environment via sustainability summits is not merely about collecting consents - it's about improving ceaseless, inclusive, science-based, modest variation. With contemplative models and performed accomplishment, sustainability summits can become fundamental tools in the worldwide attempt to protect environmental health, assure social righteousness, and create a lively future for all.

REFERENCES :

1. Sachs, Jeffrey D. *The Age of Sustainable Development*. Columbia University Press, 2015.
2. Caradonna, Jeremy L. *Sustainability : A History*. Oxford University Press, 2014.
3. Khan, Ali Junaid, et al. "Adoption of Sustainability Innovations and Environmental Opinion Leadership: A Way to Foster Environmental Sustainability through Diffusion of Innovation Theory." *Sustainability*, vol. 14, no. 21, 2022, article 14547.
4. He, J., et al. "Fostering Sustainable Hospitality Practices to Meet UN-SDGs." *PLOS ONE*, 2024.
5. Ballarotto, G., et al. "Feeling the Nature to Foster Sustainability: The Mediating Role of Self-Compassion and Compassion in Pro-Environmental Behaviours." *Sustainability*, vol. 17, no. 1, 2025, article 351.
6. United Nations. "Transforming Our World: The 2030 Agenda for Sustainable Development." United Nations, 2015, <https://sdgs.un.org/2030agenda>.
7. UNEP. "Global Environment Outlook - GEO-6: Healthy Planet, Healthy People." Cambridge University Press, 2019, <https://www.unep.org/resources/geo-6>.
8. World Bank. *World Development Report 2020: Trading for Development in the Age of Global Value Chains*. World Bank, 2020, <https://www.worldbank.org/en/publication/wdr2020>.
9. Intergenerational Energy Agency (IEA). "World Energy Outlook 2023." IEA, 2023, <https://www.iea.org/reports/world-energy-outlook-2023>.
10. UNFCCC. "The Paris Agreement." United Nations Framework Convention on Climate Change, <https://unfccc.int/process-and-meetings/the-paris-agreement>.



How much is enough: Analyzing the Relocation Model of Sariska Tiger Reserve with other important Tiger Reserves in India

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Abstract: Voluntary relocation of villages located within the Critical Tiger Habitat (core) of Tiger Reserves, remains one of the most significant conservation interventions for creating 'inviolable spaces' for tigers. The basic relocation framework in India follows the revised guidelines issued by National Tiger Conservation Authority in 2008 consisting of Option I (Cash Package) and Option II (Land Package); State Governments, however, retain the discretion to expand these models with additional measures such as livelihood support, infrastructure development, and financial assistance. The outcome of village relocation process itself and its further impact on the tiger habitat thus vary from State to State, depending on the operational procedures followed in that particular area. Hence, the level of success is relative and varies among States. Till 2024, out of the 848 villages and 89808 families in 54 tiger reserves, 257 villages and 25007 families have been relocated. Around 591 villages comprising of 64801 families are still residing within the tiger reserves. Therefore, the process of relocation cannot be assigned a tag of complete success or complete failure. The shifting of villages is a challenging task dependent on multiple factors of trust-building among the Department and the villagers, inter-agency cooperation and post relocation support provided to the community. This study, while focusing on Sariska (Rajasthan), compares its relocation model with those implemented in prominent Tiger Reserves in Madhya Pradesh, Maharashtra, Karnataka and West Bengal. The purpose of the study is to critically evaluate these models and explore the question: what constitutes "enough" for a relocation to be deemed successful? The study further examines whether fixed parameters can be established to assess the level and limits of success in voluntary village relocation within Tiger Reserves. Understanding the parameters of 'successful relocation' is essential not only for India's tiger conservation strategy but also for global debates on balancing human rights with large carnivore recovery.

Key Words: Voluntary Village Relocation, Critical Tiger Habitat, Inviolable Space, National Tiger Conservation Authority (NTCA), Cash package, Land package.

1. INTRODUCTION:

Relocation of people from the Protected areas is based on the hypothesis that human use of natural resources depletes their availability (Alexander, Prasad & Jahagirdar, 1989). NTCA has established that tiger occupancy of forest was dependent on availability of wild prey and low impact on the habitat.



Good source populations of tigers were found in areas devoid of human impacts and NTCA established that it is essential to have minimum inviolate area of 800-1200sq.kms to support a population of 20 breeding tigresses.

Global estimates range from 8.5-14.4 million persons that have become--either voluntarily or not-displaced for conservation purposes (Feldman, Geisler & Silberling, 2003) though the major gaps in the basic information in the WCMC database, it is difficult to estimate the number of displaced as a result of establishment of protected areas. In India, roughly 1500 villages consisting of 3,25,00 people resided in the Core/buffer zones of the Tiger Reserves (Tiger Task Force Report 2005). Out of 848 villages consisting of 89808 families in the Core Areas of 54 Tiger Reserves in India, 257 villages with 25007 families have been relocated since the initiation of Project Tiger on April 1, 1973. 591 villages with 64801 families are in the process or still to be relocated (NTCA Report 2024).

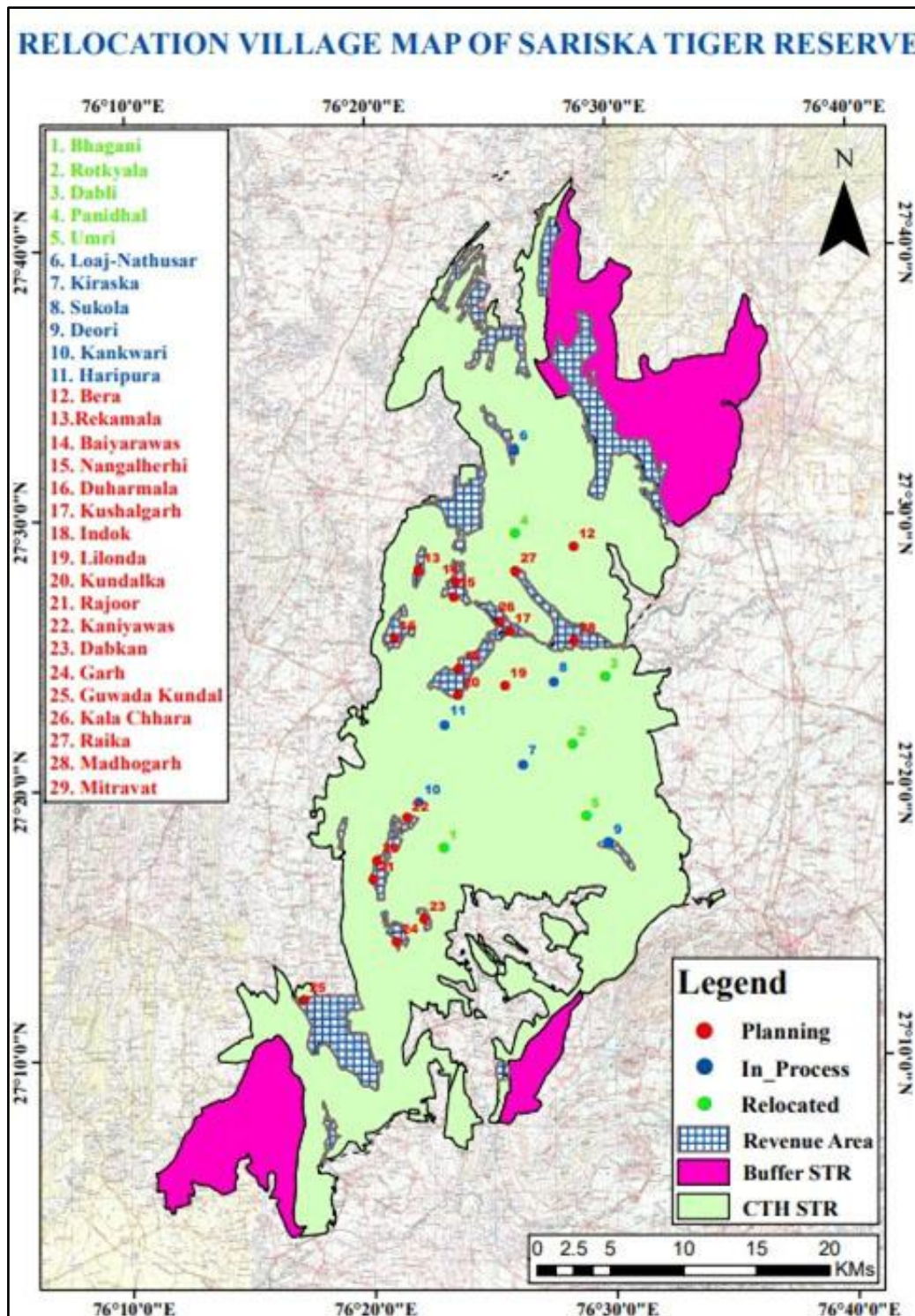
The extermination of all its tigers till 2004 in Sariska Tiger Reserve by poaching gangs, highlighted the issue of relocation of villages from Tiger Reserves in the country, which has over 75%% of the wild tiger population in the world among tiger range countries. In fact, the State Empowered Committee formed by the Government of Rajasthan in 2005, highlighted in its report, that villagers residing in the core area of the tiger reserve, informed the poachers about the movement of the tigers in the specific area of the forest, as they were aggrieved of their cattle killed by the tigers .They cooperated with the poachers for eliminating the tiger.(page 17-18, SEC Report 2005).Consequently the Committee emphatically proposed for rehabilitation of the villages with utmost priority. Simultaneously, the Tiger Task Force, commissioned by the Government of India, after the Sariska imbroglio in 2005, called for priority to be given to resettlement of villages from core areas of tiger reserves for the long-term survival of the species (Ministry of Environment and Forest, Tiger Task Force Report 2005).

Consequently, relocation was taken on priority and the revised guidelines for relocation of villages were issued in 2008 by National Tiger Conservation Authority (NTCA).

In the First Management Plan of Sariska Tiger Reserve (STR) approved by the Chief Wildlife Warden, Padam Shri Kailash Sankhala (1978-1982), mention has been made about the relocation of two guadas, Kalighati and Slopka in 1966-67, to the existing villages. The use of relocation as a PA management tool, took a more organized form in 1976, when relocation of villages, Karnakawas and Kiraska took place. The land was identified at Bandipul, Dulawa and Sirawas but several relocated families returned to resettle close to an existing village Kundalaka, where they established a new village- Naya Kundalka. Sariska Tiger Reserve witnessed relocation of village Kiraska in 1976 to Sirawas but due to ill-conceived displacement policy, the villagers returned to the Kiraska mala, putting a jolt to the efforts for the next 31 years, when Bhagani was relocated in 2007. Out of the 29 villages inside the CTH of the Sariska Tiger Reserve, 11 villages are being considered for relocation on priority basis. 5 villages (Bhagani, Umri, Rotkela, Panidhal and Dabli) have already been completely relocated, Bhagani being relocated in 2008. Later Umri in 2011, Rotkela in 2012-13, Panidhal and Dabli in 2020-21, were shifted (Fig. 1)



Figure 1: Relocation map of Sariska TR



Very good work has also been done in the sector of village relocation in Satpura Tiger Reserve in Madhya Pradesh, where 49 villages (including 13 in buffer areas) consisting of 5136 families have been relocated since 2005, creating more inviolate space for the tigers of Satpura and offering a better resettlement package, improving the health and livelihood status of the people after relocation There



are numerous examples of exemplary work being done in the area of village relocation but nevertheless, the challenge to offer a better uplift in the living standards of the relocated people, is always a daunting task for the conservationists in the field (Ghate, & Beazley, 2007).

The present study concentrated on a comparison of the relocation strategy of Sariska Tiger Reserve with other relocation models in some of the Tiger Reserves of the country.

Study Area:

Nestled in the world's oldest Aravalli Mountain ranges, STR is the westernmost limit of the Tiger distribution in India.

STR (76017'E to 760 34'E and 2705'N to 27033'N) is situated in the Aravalli and lies in the semi-arid part of Rajasthan. It became a wildlife sanctuary in 1958 and a Tiger Reserve in 1979. The total Area of the Tiger Reserve is 1203.33 sq.kms with a CTH of 881.11 sq.kms and a buffer of 332.22 sq.kms. The terrain is undulating, hilly in nature and possesses numerous valleys with two large malas (plateaus), Due to the historic decision of the first reintroduction of tiger from Ranthambore to Sariska in 2008, and successful translocations of 11 tigers from Ranthambhore Tiger Reserve between 2008 to 2023, the population of tigers presently in Sariska has crossed 40.

There were 29 villages located inside the Critical tiger Habitat of Sariska tiger reserve of which 11 were situated in the preliminary notified National Park area. About 10000 people in these villages along with 19132 livestock, live inside the STR. These people are traditional pastoralist communities who totally depend on forests for their livelihood. Villagers in Sariska Critical Tiger Habitat (CTH/Core) depend totally on forests for their livelihood. Traditionally a pastoralist community, their main source of income is selling milk and its products like —Mawa & Ghee. The economy of villagers of Kankwari, Kiraska, Lilunda and Kundalka is totally dependent on animal husbandry, while villagers of Dabli, Sukola and Haripura also work as daily wage labourers in adjoining areas. More than 80% of the income of an average household still comes from the sale of milk, mawa & ghee, while 20% comes from their secondary occupations like daily labourers, drivers, farmers, govt. service etc. The villages like Dabli, Deori and Raikamala (located on the boundary of the reserve), being revenue villages have some agricultural land in core area, where they mainly grow wheat, corn, oat, mustard and gram. The economy literally subsists on the edge.

2. RESEARCH METHOD :

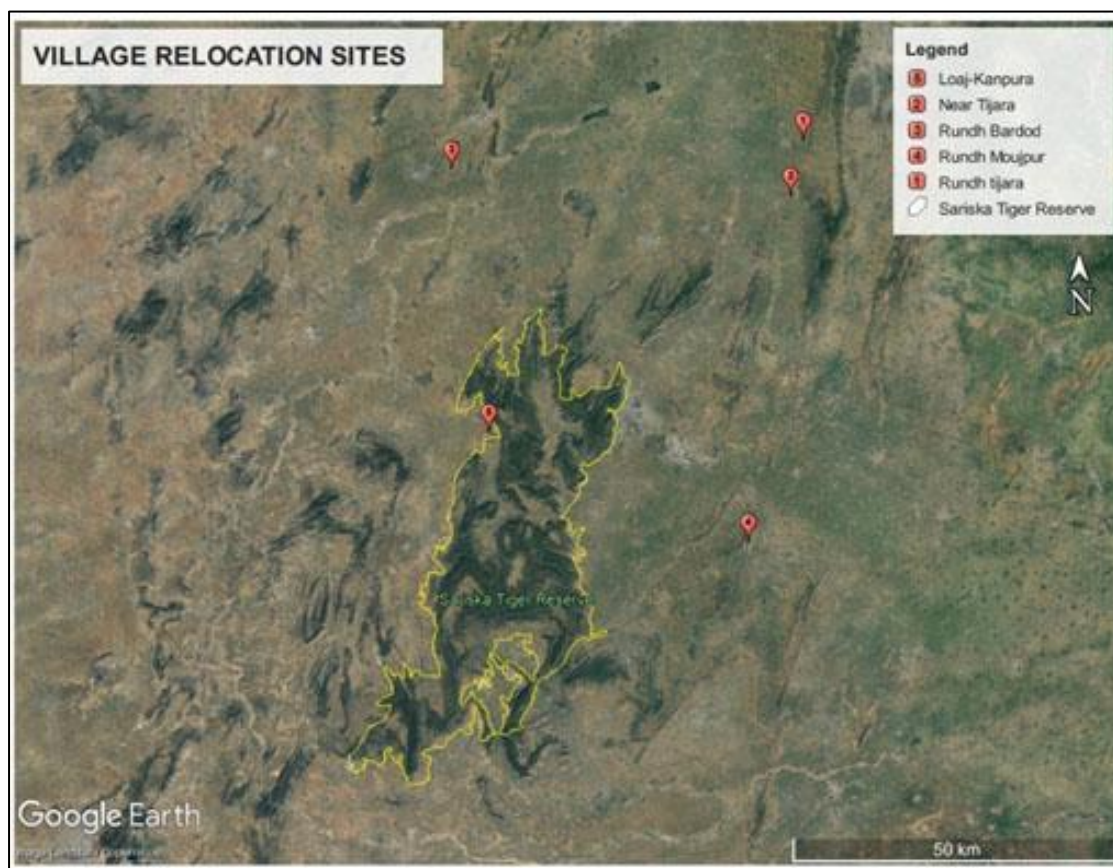
Primary data on sources of livelihood, number of earning members, secondary occupations, income and expenditure estimates, assets and infrastructure, of relocated as well as original population was collected by questionnaire-based survey using Semi-structured, un-structured and focus group interviews having open-ended and close ended questions

Secondary information from Office of Field Director, Sariska Tiger Reserve and relocation strategies of important Tiger Reserves of the country, including relocation policies of the States were also collected.

A survey of the relocated families from Sariska at 5 locations (Nangli Rund, Mojpur Rund, Tijara, Loj Kanpura and Maliyarjat) (Fig 2) was done by informal interactions and questionnaire survey. As per the IRR model (Cernea 2002) displacement risks of landlessness, joblessness, homelessness, marginalization, food insecurity, increased morbidity, loss of access to common property resources and

community disarticulation was also studied and analysed w.r.t. the families relocated in these five locations. Samples have been selected broadly under two categories to cover families relocated in option 1 (cash Package) and option 2 (land package).

Figure 2: Settlement sites of relocated villages



The Sariska relocation model:

In STR, after the unsuccessful attempt in 1976, post tiger poaching era of 2004, relocation of four villages from the core area, was set as a pre-requisite of tiger re-introduction by the NTCA. A small village Bhagani (21 families), though in the periphery of the tiger reserve, was selected and the process of relocation re-started in 2006. After several meetings and voluntary consent of the villagers for relocating on a forest land, Nangli roondh in Behror tehsil, almost 100 kms away from Sariska in Alwar District, and the village was finally settled on 1 lakh per family package under the State Relocation Policy of 2002. As per the State Policy, original land holding + 1 hectare land was to be provided to each displaced family. Agricultural land was allotted to a minimum economic holding (MEH) of 4 acres (1.6 hectares) of un-irrigated land or 2 acres (0.8) hectare irrigated land, even to landless farmers and 5400 sq. ft (60x90 ft.) and free residential plot with basic facilities of safe drinking water, roads, community building, electricity and pucca housing was provisioned. Due to paucity of funds, dovetailing under different government schemes of State and Government of India, was done. By the time this was being executed a revised package for village relocation/ rehabilitation was issued by the NTCA in 2008, which provided two options of Cash package and land packages follows:



- Option 1- Payment of entire amount (Rs.10 lakhs per family now increased to 15 lakhs in 2021) to the family in case the family opts so, without involving any rehabilitation/relocation process by the Forest Department.
- Option II- Carrying out relocation/rehabilitation of village from protected area/ tiger reserve by the Forest Department. (Land Package- Land procurement [2 hec.]/development etc.,)

Consequently, with the revision of the package, the village relocation took pace and as per data of the Forest Department, out of the 11 villages prioritised for relocation from the core area, 5 have been completely relocated since 2007 and 6 villages have been partially relocated. Out of 1471 families in the 11 villages, 1041 families have been relocated (511 in Option 1 and 691 under option II). 269 families have not given their voluntary consent, due to insistence of inclusion of their children who have crossed the age of 21 now, but were minors at the time of the socio-economic survey in 2008-2011.

A modification in the State Relocation Policy of 2002 was issued in September 2022, where the land value was assumed to be calculated based on the assumption that every family possessed 1.6 hectares of un-irrigated (or 0.8 hectares of irrigated land) and 5400 sq. ft of residential land. Consequently, the DLC rate was calculated for the village within the tiger reserve and based on the amount arrived, proportionate land was proposed to be given outside the tiger reserve (as per the DLC rate of the land outside the tiger reserve). Families to be relocated, were to be given land equivalent to the value arrived at, using the above formula. This led to very less area of land compared to 1.6 hectares given to villagers and led to halt in the relocation process in the new villages. The villages which were already under progress continued to use the 2002 policy. The State Government is in the process of revisiting the modification based on the feedback of the District Relocation Committee. The present status of relocation in STR is shown at Table 1.

Table 1. Status of village relocation in STR

S.No.	Village Name	Total Families	Consent given			Consent not given	Family relocated till Nov 2024	Year of relocation
			Option 1	Option 2	Total			
Completely Relocated Villages								
1	Bhagani	21	0	21	21	-	21	2007-08
2	Umri	93	39	54	93	-	93	2020-21
3	Rotkyala	52	49	3	52	-	52	2012-13
4	Panidhal	24	0	24	24	-	24	2020-21
5	Dabli	132	118	14	132	-	132	2020-21
	Total	322	206	116	322	0	322	
Partially Relocated Villages								
6	Sukola	64	17	25	42	22	42	2009
7	Kraska	210	132	38	170	40	131	2011
8	Devri	191	73	26	99	92	95	2011
9	Kankwadi	173	41	104	145	28	145	2008
10	Haripura	78	10	46	56	22	50	2011
11	Loj Nathusar	123	16	107	123	0	121	2022
		310	16	229	245	65	135	2023
	Total	1149	305	575	880	269	719	
Grand Total		1471	511	691	1202	269	1041	

The relocation models adopted in States of Madhya Pradesh, Maharashtra, West Bengal, and Karnataka was studied and compared with the Sariska relocation model.



Satpura Tiger Reserve:

Satpura Tiger Reserve relocation model received the NTCA Award for Excellence in relocation of villages twice in 2011-12 and 2016. 49 villages have been relocated till 2024 from Satpura Tiger Reserve.

Out of 5136 families in 49 villages, 3507 were relocated under Option 1 (68.3 %) and 1629 (31.7 %) under Option II. The first village relocated was Dhain from Bori Range in 2004-05. 91 families were relocated under Option II (land Package) spending 91 lakhs (1 lakh/family). The next village relocated was Bori in 2009-10, from the same range, with 117 families but spending 10 lakhs/family, amounting to 1170 lakhs under Option II, due to the revised relocation package of NTCA of 2008.

The same package of NTCA is being implemented by the Satpura authorities and the whole process is very transparent, structured and organised. Apart from pre-relocation engagement including undertaking entry point activities for the villagers, the grievance redressal mechanism at three levels, i.e., Redressal at Forest guard level, then Range Officer level, ACF and finally DCF/FD level, Jan sunwai/ public hearings by District Collector every week and Samasya Kalyan Shivirs at cluster level by Forest Department and all line departments in the district, is very effective in hand holding and trust building efforts of the relocated villagers.

In accordance to the Hon'ble Supreme Court order of 28th January 2019 in IA No.3924 of 2015 in WP© 202/1995, 3910.57 hectares of forest land has been diverted for relocation and 3145 hectares has been denotified to legally enable the relocated families for ownership and make them eligible for benefits of different government schemes.

Satpura Tiger Reserve has initiated the handholding of the relocated villagers under the Option I, though it is not obligatory on part of the Park Management to do it. In villages relocated under Option-I, where funds were limited, all basic facilities have been provided through convergence of and engagement with civil society organisations working in the area. Under Option-I, in which the villagers are free to settle anywhere, development is not the mandate of the park management. But the park management facilitated development in Option-I villages and helped them to select and settle in one place. In these villages, the park coordinated with district administration and other NGOs to provide the basic amenities like roads, electricity, drinking water facilities, etc. As the park management is also sensitive to their issues in the new locations, it used Park Development Fund to provide basic facilities and conducted various livelihood training sessions for the villagers. An electricity sub-station (4.5 crores) was also installed and operationalised through the MP Minor Forest Produce Federation fund, which has ensured electricity in 23 villages and infused trust and confidence in the people relocated and to be relocated. Another very important initiative by the Park Management, was the support taken under Corporate Social Responsibility, (CSR) in relocation of the villages, on financial literacy, health and nutrition, livelihood improvement, water conservation (Punjab National Bank Foundation, NatWest Foundation, Reliance Foundation, CII, donations by local companies, etc.).

The funds have been mobilised from different sources other than NTCA and included funding from Madhya Pradesh Minor Forest Produce Federation, Tribal Welfare Department apart from CAMPA and State Government contribution.



Maharashtra Model

In the Tadoba-Andhari Tiger Reserve (TATR), village relocation and rehabilitation are conducted in accordance with the Maharashtra Government's Rehabilitation Government Resolution in November, 2012, and subsequent related resolutions, as well as guidelines from the Central Government. Since 2003, TATR has undertaken the systematic relocation of six villages from its core area: Boteyzari (2007), Kolsa (2007 and 2022), Navegaon (Ramdegi) (2013), Jamni (2014), and Palsagaon Singru (2019). Rantalodhi is currently undergoing the rehabilitation process. Out of 1137 families, 1170 families have been relocated since 2007. (Option I: 427 families. Option II: 582 families).

In Maharashtra, families agreeing to relocate are given the same amount of 15 lakhs as per revised guidelines of NTCA. But landowners are given additional compensation from the State Government (Ghate, 2005), unlike in Sariska, where there is no compensation for land owned by people opting for relocation under Option I.

Option 1:

- All eligible families get 15 lakhs in two instalments (1+14) as a package amount.
- After the valuation of property, land is compensated @ 4 times the ready reckoner (given by sub registrar).
- Immovable property (house, trees, etc) is calculated at 2 times the valuation given by the concerned department. e. g. 1) House PWD 2) Fruit Trees-Agricultural dept 3) Teak and other-Forest Department.

Option 2:

- All the land-holders and landless families are provided 2 hectares of land per family. If the land is available in the command area of the irrigation project, then such land shall be allotted else the Collector can allot such land from grazing land, e- class land.
- 180 sq. mtr. plot for house construction + Rs 3 lac for house construction + Rs 75000 for Misc expenses.
- Forest Department can purchase private land for allotment (by following due procedure).

Additionally, families opting for option 2, will get valuation of land (as per ready reckoner) + 30% solatium. (Here land means land and other immovable property attached to it as per MLRC) other immovable property would be treated similarly.

In Melghat Tiger Reserve out of the 33 villages in the Critical Tiger Habitat, 19 villages have been completely relocated from 2001 to 2020 and 6 villages are in progress. Out of a total of 5140 families, 4708 families have been relocated. 95% (4468) of the total families were relocated under Option I (Cash package families) and only 5% (240) under Option II. It is pertinent to mention that in Melghat Tiger Reserve, out of 10 lakhs given under option I to the villagers, 1 lakh was retained by the Forest Department in some villages in a society formed by relocated villagers, for purchase of land, preferably government land at concessional rates, and then distributed to the cash package families. This relieved the relocated villagers of searching land and helped the department to relocate the families as a cluster,



which paved way for dovetailing other government schemes at a convenient location (Sekar, 2015). The State Government has also provided relief to the Option I families, by a government resolution to return the 1 lakh/family in lieu of land purchased by the Forest Department, sending a very positive message to the yet to be relocated families and also testifies the sensitivity of the Government towards the process of relocation.

Karnataka Model:

In the Bhadra Tiger Reserve, 16 villages consisting of 736 families were located within the Sanctuary. The Project for relocation was prepared in 1992 to acquire 861 acres of revenue land of these villages and to relocate it outside the Sanctuary. 431 families from 10 villages have been relocated by acquiring 708 acres land. In Bhadra, Government issued the Rehabilitation and Resettlement package benefits by Land acquisition and compensation under the Land Acquisition Act (Government of Karnataka, 2002). The relocated families are included in the list of beneficiaries, based on eligibility, for providing benefits of different central and state government schemes, especially of the tribal department, which actually elevates the package to many times, when converted to monetary terms.

West Bengal Model

Buxa Tiger Reserve (BTR) is the 15th Tiger Reserve in the country situated in the Alipurduar district of West Bengal. Total geographical area of the tiger reserve is 760.86 sq.kms. The core/critical tiger habitat occupies 417.55sq.kms. Though evidences suggest only one tiger in the reserve, the recent relocation of two villages Gangutia and Bhutiya Basti, has highlighted the commitment of the State Government, which can be an inspiration in the relocation models of other States. All 191 families of Gangutia and 51 families of Bhutiya Basti, chose Option I (Cash package of 15 lakhs). Due to the coordination of other departments, the land department identified and allocated 0.08 acres of land to each family, for building a house and creating kitchen gardens, a benefit provided in addition to the 15-lakh compensation under Option I by the State Government. Till now, 151 families of Gangutia and 51 families of Bhutiya have been given 0.08-acre land. Homestay loan was also provided to ensure livelihood sustainability by the Government.

Comparison between Tiger Reserves:

Based on the following data a comparison was drawn between the different models while assigning parameters based on which the success could be assessed.

PARAMETERS	SARISKA	RANTHAMBORE	TADOBA ANDHERI	MELGHAT	BUXA	SATPURA
Number of Complete villages relocated out of CTH	5/29 (17%)	8/68 (12%)	5/6 (83%)	19/33 (58%)	2/15 (13%)	36/36 (100%)
No. of families complete relocated	322/ 4115	732/9229	926//1170	4468/5140	242/1019	4006/4006



Total no. of families relocated (including partially relocated villages)	1041	1787	1137	4708	242	5136
Option I: Option II	1:1.35	1:0.58	1: 1.36	1:0.05	1:0	1:0.46
Impact on Tiger population growth (2006-2022)	0 to 24+	32 to 57	34 to 97	30 to 57	0 to 1	39 to 50

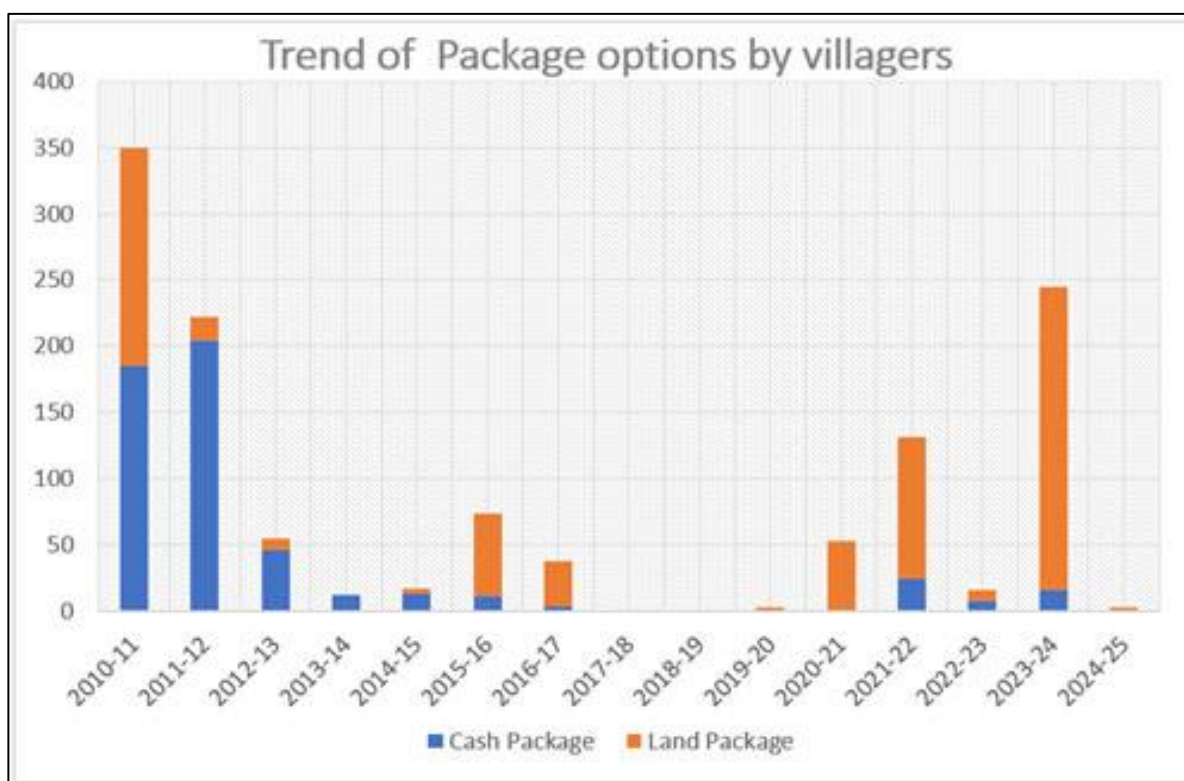
3. DISCUSSION :

The Sariska relocation commenced from 2007. Similar has been the case for relocation in all tiger reserves mainly because of the recommendation of the Tiger Task Force Report in 2005 post -Sariska crisis, that finally paved way for paradigm shift in focus towards village relocation and issuance of revised relocation package by NTCA. In the same span of 17 to 18 years different areas as analysed above, have performed differently. The pace of relocation in Satpura has been particularly exemplary. Around 50 villages have been relocated in the last 17 years whereas, 5 villages in Sariska, 8 in Ranthambore, 19 in Melghat, 2 in Buxa and 5 villages in TATR, have been completely relocated. Where Satpura has been completely freed of human habitations in the CTH, TATR has also created inviolate spaces by relocation of 5 out of 6 villages. Sariska on the other hand, is still facing a challenging task of relocation and has been able to relocate 5 completely and 6 partial villages out of 29 villages.

The relocation models being implemented in the different tiger reserves in India, presents more or less uniformity in enforcement but the difference in outcomes can be inferred mainly due to structured plan, motivated team and the dedication of the Field officers along with co-ordination with the District Administration. The Sariska relocation progress is slow compared to the other 5 tiger reserves, mainly due to some factors of high land value in National Capital region (NCR), almost negligible handholding of cash package families, less conversion of forest land into khatedari lands, etc (Jain, & Sajjad, 2016). The other States like Maharashtra and West Bengal have gone a step ahead by contributing additional support in the form of fund and extra land to the families. The slow progress in Sariska, can be attributed to reluctance of the people coupled with lot of adversities, compared to other tiger reserves. While it cannot be denied that the convergence of schemes, poor grievance redressal mechanisms and dissatisfaction of the villagers, still in the tiger reserve, for non-inclusion of their children who have now crossed the eligible age for including as a separate family, after the survey of 2008-2011, remains to be major impediments, it is also a fact that the District land rates fixed in Alwar being in NCR, is extremely high. The data revealed that what initially started as a positive trend has now reached a point of stalemate with gradually less interest in the cash package of 15 lakhs (Fig 3).



Figure 3: Trend of the cash package vis a vis land package in the last 15 years



Biologists and social scientists often have different ways of asserting an argument on relocation. Whereas biologists tend to assess the issue of relocation in terms of viability of habitats, ecosystems and endangered species, social scientists in sharp contrast, tend to visualise the issues of equity and justice as central to sociological and historical analysis of conservation processes. Dowie (2011) argued whether conservationists are sacrificing human-welfare and well-being for the sake of what can be termed as *imperial conservation*. Karanth (2007) had analyzed a relocation and resettlement project in India's Bhadra Wildlife Sanctuary and draws out insights for improving conservation practices related to resettlement efforts

A negative program of action signifies a more aggressive pursuit of conservation through protected areas and efforts to increase the size of PAs and the rigor with which they are protected, would likely result in even in higher rates of displacement. A positive program of action would address the core criticisms of conservation-induced displacements. It would focus on specific examples in which displacement-related grievances are addressed in an exemplary manner, adopt a policy to avoid involuntary displacements as far as possible, convert involuntary displacement into voluntary agreements to move, and where such options are impossible, design compensation packages that would ensure that those suffering displacement are left 'no worse off' as a result of protected area creation. (Agrawal & Redford, 2009).

As in other Tiger Reserves, the pace has been generally satisfactory ranging from 50 -100% since 2006-07 but in Rajasthan the progress has been very slow, ranging from 15-20%. The trust and confidence of the villagers on the Department seems to be low due to factors of pending land rights, State Relocation policy changes of 2022 not agreeable to the villagers thereby causing an impediment in the



progress, high land value and consequently less inclination towards option I (Jain, & Sajjad, 2015). Some of the other Tiger Reserves have succeeded in establishing good coordination with the district authorities for convergence of schemes, pooling of funds from other Schemes. The special effort of Satpura in pooling CSR funds for improving the quality of life of the relocated villagers and of Melghat/Tadoba, wherein the State Government had issued liberal compensation in terms of 4 times of the DLC rate for compensation of land to Option I families, additional homestead land to Option I families in Buxa, exhibit positive steps for relocation.

Questionnaire survey and secondary data of relocation in Sariska Tiger Reserve revealed that the land purchased by the villagers under Cash Package of 10 lakhs till 2021 and 15 lakhs after 2021, was on average 0.5 hectares (0.13 – 1.2) which was actually 1/3rd of the amount of land offered in the land package (1.6 hectares). In other States, though the land bought by the Option I families, would be less than 2 hectares that is being offered in the Option II, but the area of land is higher than in Sariska because of the high land value in National Capital region, thereby minimising the eight risks as envisaged in the IRR model of Cernea.

4. CONCLUSION :

Since its inception Project Tiger has expanded from nine tiger reserves covering 18,278 sq.kms to 58 tiger reserves encompassing 84,587 sq.kms, the number of villages in these tiger reserves pose a significant conservation challenge in creating “inviolable spaces” for the expanding population of tigers. Most of the habitats are surrounded and interspersed with unsustainable land use patterns and developmental projects and an impediment to animal movement. Out of the estimated tiger population of 3682 (SE 243), the most significant increase in the tiger population was observed in Central India landscape and the Shivalik Hills and Gangetic Plains, mostly occupied by Madhya Pradesh, Maharashtra, and Uttarakhand. The prioritisation of village relocation in these landscapes and other ones, need to be taken up with liberal policies of the State Governments, doing the extra bit, for self-reliance and self-sustenance of the families relocated outside the tiger reserve (Meena, 2015). The study indicates that while in some states, the motivation and the effort is commendable while in some tiger reserves, more needs to be done, especially Sariska, for presenting a better bargain to the villagers. It is also emphasised that ‘one size does not fit all’ and looking into the land prices outside the tiger reserve, the productivity of the land with the water availability for agricultural practices, the degree of difficulty varies within tiger reserves. Moreover, the trend of Option I vis a vis Option II, is gradually changing in tiger reserves, especially Sariska, indicative of the challenge of ascertaining more isolated forest lands/revenue lands for resettlement. The tiger population increase in the tiger reserves also suggest that though relocation of villages is an important contributing attribute but even with 20% relocation results in Sariska and Ranthambore, the population has grown showing co-existence with preservation of core natal areas in some pockets. It is also a fact that all the villages in the Core Areas of the Tiger Reserves may not get relocated and hence a prioritisation of the villages to free the areas in tiger reserves to act as source areas, may be the immediate requirement.

In a most recent study (Mandal et. al., 2013) it was shown that there cannot be a simple straight procedure for relocation; there needs to be priorities with reference to multiple factors, both anthropogenic and ecological. Voluntary village relocation cannot be weighed on a fixed scale; the process involves human beings and their wills. Thereby many requirements vary from one place to another, in this case from one Tiger Reserves to another. A completely successful relocation is a conservational dream yet to achieve. In this study the same issue has been highlighted while comparing



between the different models adopted. Through the study understanding of the most crucial effort and the requisite area of interference was tried to achieve. Conservation is a global goal, more such in areas ruled by the top predators like Tiger and Lion. However, the proper sustainable management and achieving a balance between human habitation and undisturbed wilderness is the aim of voluntary village relocation. With due understanding of the area specific requirement more effective result thus can surely be obtained it terms of a promising posterity through sustainable conservation practices.

REFERENCES:

1. Agrawal, A., & Redford, K. (2009). Conservation and displacement: an overview. *Conservation and society*, 7(1), 1-10.
2. Alexander, K. C., R. R. Prasad and M. P. Jahagirdar (1989). "Relocation of tribals from tiger reserves: policies and principles of rehabilitation." *Journal of Rural Development (Hyderabad)*, 8(5): 441-455.
3. Cernea, M.M. (2000). Risks, safeguards and reconstruction: A model for population displacement and resettlement. In: Cernea, M.M. & McDowell C. (eds.) Risks and Reconstruction: Experiences of Resettlers and Refugees. *The World Bank: Washington DC*.
4. Dowie, M. (2011). Conservation refugees: The hundred-year conflict between global conservation and native peoples. *MIT press*.
5. Feldman, S., Geisler, C., & Silberling, L. (2003). Moving targets: displacement, impoverishment, and development*. *International Social Science Journal*, 55(175).
6. Ghate, R. & Beazley, K. (2007). Aversion to Relocation: Myth or Reality? *Conservation and Society*, 5(3): 331-334.
7. Government of India (2005). Joining the Dots. Report of the Tiger Task Force. Ministry of Environment and Forests, Government of India, New Delhi.
8. Government of India (2004). Centrally Sponsored Beneficiary Oriented Scheme for Tribal Development (BOTD). Compendium of guidelines and circulars issued by the Directorate of Project Tiger. Ministry of Environment and Forests, Government of India, New Delhi.
9. Government of India (2004). Status of village Relocation, NTCA. Ministry of Environment and Forests, Government of India, New Delhi.
10. Government of India (2022). Status of village Relocation, NTCA. Ministry of Environment and Forests, Government of India, New Delhi.
11. Government of Karnataka (2002). Forgotten villages - the story of resettlement of villages from the Bhadra tiger reserve. Deputy Commissioner, Chikmagalur. Karnataka.
12. Ghate, R. (2005). "Tadoba-Andhari tiger reserve: Relocation versus wildlife preservation." *Economic and Political Weekly*, 40(46): 4807-4809.
13. Jain, P. and H. Sajjad (2015). "Analysis of willingness for relocation of the local communities living in the Critical Tiger Habitat of the Sariska Tiger Reserve, India." *Local Environment*, 1-11.
14. Jain, P. and H. Sajjad (2016). "Household dependency on forest resources in the Sariska Tiger Reserve (STR), India: Implications for management." *Journal of Sustainable Forestry*, 35(1): 60-74.
15. Karanth, K. K. (2007). "Making resettlement work: The case of India's Bhadra Wildlife Sanctuary." *Biological Conservation*, 139(3-4): 315-324.



16. Mandal, D., Nigam, P., Malik, P. K. & Habib, B. (2024). Putting ducks in a row: Village resettlement prioritization from inside tiger reserves and its implication in achieving global conservation goals for India. *Journal of Wildlife Science*, Online Early Publication, 01- 09.
17. Meena, M. L. (2015). "Relocation and livelihood concerns of sariska tiger project, Rajasthan: A pride or plight?" *Space and Culture, India*, 3(2): 72-80.
18. Sekar, N. (2016). "Tigers, Tribes, and Bureaucrats: the voluntariness and socioeconomic consequences of village relocations from Melghat Tiger Reserve, India." *Regional Environmental Change*, 16: 111-123.



Analytical Study on Environmental Pollution and Control Management ; Issues and Challenges

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Abstract: Environmental pollution is one of the major challenges that India is facing today as elsewhere in the world, endangering human health and lives, biodiversity and ecosystems stability. As the country develops rapidly in next industrial phase, pollutions levels have reached its peak, leading to serious environment degradation. As per latest report, Pollutions kills more than 8 millions peoples worldwide in 2017. India, the second most largest populated nation in the world, ranked first among the top ten nations in the world where premature death occurred due to pollution, and second in the top ten nations in the world where premature death occurred due to air pollution. The World Air Quality Report 2018 by IQAir and Greenpeace revealed that 15 of the 20 most polluted cities globally were in India. *Gurugram*, was the worst air quality city in the world and *Delhi* as the most polluted capital city across the world. In 2024, India was the fifth-most polluted country in the world, with an annual average particulate matter (PM) concentration of more than 10 times the World Health Organization's recommended limit. This paper examines and analysis the various types, sources, and impacts of environmental pollutions and explores the key policies adopted for pollution control and management globally with special emphasis to Indian context. Through this paper, an effort has been made to address the challenges being faced in pollution control and management. The study concludes with some key suggestive measures or recommendations for effective, efficient, and robust pollution control and management.

Key Words: *Environmental Pollutions, Types, Causes and Effects, Challenges in Pollution Control and Management*

1. INTRODUCTION:

The environmental challenges that humanity is currently facing are not isolated to any specific region or nation; it is a global issue. The threat of ecological disasters impacts not just certain regions of the world but affects the entire planet, The extensive scientific evidence regarding *climate change, global warming, acid rain, ozone layer depletion, loss of biodiversity, deforestation, species extinction, and various types of pollution* demonstrates a global influence that required new approaches to human restraint and international collaboration to tackle these problems.

Environmental pollution stands as one of the most critical challenges India is currently facing, similar to many regions around the globe, viz., air pollution, water pollution, land or soil pollution, noise pollution, thermal pollution, radioactive pollution, and plastic pollution.etc. As the nation progresses rapidly through its next phase of industrialization, pollution levels have surged to unprecedented heights, resulting in severe environmental degradation. According to recent reports, pollution was responsible for the deaths of more than 8 million people globally in 2017. India, being the second most populous country in the world, holds the highest number of premature deaths linked to pollution, recording 2,326,771 fatalities, and ranks second in terms of premature deaths caused by air pollution, with 1,240,529 fatalities. The World Air Quality Report 2018, by IQAir and Greenpeace, indicated that 15 out of the 20 most polluted cities worldwide were located in India. *Gurugram* was noted as most



polluted city in the world, with an annual average concentration of PM_{2.5} at 135.8 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$), while *Delhi* was identified as the most polluted capital city globally, with an annual average PM_{2.5} concentration of 113.5 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). In 2024, India ranked as the fifth-most polluted country in the world, with an average PM_{2.5} concentration of 50.6 micrograms per cubic meter, which is ten times higher than the limit recommended by the World Health Organization.

2. LITERATURE REVIEW:

Gupta & Kumar (2020), *Environmental Pollution and Sustainable Development in India*, pointed that environmental pollution poses one of the most complex and critical challenges in India's path to development. Literature highlights a conflicting between economic development and environmental protection, where immediate development objectives frequently overriding sustainability goals.

Narain S. & Bell R.G. (2019). *Environmental Governance in India*, highlighted that pollution manifests in various forms viz, air, water, soil, and noise and is closely linked to health deterioration, loss of ecosystem, and socio-economic disparities. Despite having a robust legal and institutional framework, India continues to grapple with alarming pollution levels This literature review compiles research on environmental pollution and control management in India, analyzing its causes, effects, policy responses, technological intervention, and persistent gaps in governance.

Guttikunda, S. K., & Jawahar, P. (2020), *Urban Air Pollution Trends in India; Analysis and Mitigation*, emphasized that air pollution has emerged as a significant concern for public health and the environment. Key contributors include industrial and vehicles emissions, coal-based power plants, biomass combustion, dust from construction activities.

Jain et al.,(2020), *Evaluating India's Air Quality Management Strategies; The case of NCAP*, pointed that the National Clean Air Programme (NCAP), initiated in 2019, aims for a 20–30% decrease in particulate matter (PM_{2.5} and PM₁₀) levels by 2024. Nonetheless, literature highlights, that implementation remains inconsistent across cities due to insufficient monitoring systems and weak local capacities

Chakrabarti, S., & Mitra, S. (2021), *Governance and environmental management in India; Institutional challenges*, highlighted that despite the presence of advanced legislation, pollution control and management in India encounters enforcement barriers. Key challenges consist of lack of robust monitoring systems, inadequate collaboration among agencies, a shortage of skilled personnel, and gaps in data. Financial constrains hinder the functional ability of Pollution Control Boards, especially at the state level.

However, there are numerous gaps in both research and policy regarding environmental pollution control and management in India.

3. AIMS AND OBJECTIVES OF THE STUDY:

1. To examine and analyse the various Types, Sources and Impacts of environmental pollution.
2. To explore and analyse the key Environmental Policies adopted for Pollution Control and Management Globally with a special focus on the Indian context.
3. To address the Issues and Challenges in Pollution Control and Management.
4. To suggest or recommendation for more effective, efficient and robust environmental Pollution Control and Management.
5. To create mass public awareness and education about the environmental issues

4. Definitions of Environmental Pollution

Pollution, which refers to the release of harmful substances or energy into the environment, disturbs the natural equilibrium and leads to negative impacts on living organisms, ecosystems and environment. Section 2(c) of the Environment Protection Act (EPA)1986 defines, 'Environmental Pollution' as any 'Environmental Pollutant' presence in the environment. Further, Section 2(b) of EPA 1986 defines,



‘Environmental Pollutant’ as present of ‘any solid, liquid or gaseous substance in such concentration which is injurious to environment. There are other pollutants, which is beyond the definition of EPA 1986, such as heat energy, noise, and nuclear radiation, that are not substances. Environmental pollution has evolved from a localized concern to a global issue, evident in cross-border air pollution, climate change, global warming, ocean acidification, and significant declines in biodiversity.

5. Types of Environmental Pollutions : The various types of pollutions are :-

1. Air Pollution

Air pollution refers to the contamination of the air by gases, particulate matter, and biological substances. It can be described as an imbalance in air quality that results in harmful effects. Air pollution is one of the most critical types of pollution. Key contributors to air pollution include: emissions from industries, emissions from vehicles, practices in agriculture, natural sources (wildfires, volcanic eruptions, and dust storms), burning fossil fuels (like coal, oil, or natural gas), hazardous off-gassing, and releases from radiation or nuclear accidents, etc. Air pollution contributes to global warming, acid rain, increasing temperatures, erratic rainfall, and droughts around the globe, complicating life for everyone. The effects of air pollution encompass respiratory illnesses and cardiovascular issues, including asthma and lung cancer.

2. Water Pollution

Water is the ‘elixir of life’, essential to the life of every living thing on earth, whether human, animal, plants or micro-organisms. Water pollution occurs when harmful substances contaminate rivers, lakes, oceans, and groundwater. The effects of water pollution have been devastating to all living things on earth. The key sources of water pollution are: *Industrial waste or effluents, Sewage and waste water, Municipal stream, Agricultural runoff, Marine Dumping and Oil Spills, Radiological Spills or Nuclear incidents, Illegal Dumping* (materials or objects within water bodies), *Biological contamination*, etc. Impacts of water pollution include *ecosystem disruption, reduced potable water supply, and damage to aquatic biodiversity*. Water pollution also has a negative impact on the entire food chain as it has a significant impact on people who depend on water for their sustenance. The spread of *water-borne diseases* such as *cholera* and *diarrhoea* has also increased across the globe.

3. Soil or Land Pollution

Soil and land pollution arises from the accumulation of toxic substances that degrade soil quality and fertility. Land and soil pollution refers to the earth’s natural environment, which includes deforestation, the removal of tree cover, the release of untreated toxic materials into the land, the disposal of unhygienic and harmful waste, and the pollution of the earth’s natural elements. Land pollution not only impacts the natural surrounding on the ground but also affects the purity and quality of underground water. Major sources of soil or land pollution include: *Excessive use of Chemicals, Industrial waste disposal, Acid rain and atmospheric deposition, Mining and logging practices, Garbage at road, Unlawful disposal of waste in natural environments, Oil spills, Deforestation, Radiation spills or nuclear accidents*, etc. Soil contamination leads to *reduced agricultural productivity, food insecurity, bioaccumulation of toxins in crops, and loss of soil biodiversity*.

4. Noise Pollution

Noise pollution is a form of pollution that is invisible but can cause psychological problems such as stress, hypertension and hearing impairment and hence called as ‘the slow killer’. It is a gift of modern industrial civilization that is invading the environment at an alarming rate. Major sources of noise pollution are *noise produced by machines in industries, noise from planes, helicopters, motor vehicles, construction or demolition, noise from human activities* such as *sports events or concerts, loud music* etc. Excessive noise from industries, transportation, and urban development affects both humans and wildlife. Chronic exposure leads to hearing impairment, stress, cardiovascular issues, and reduced productivity.



5. Thermal and Radioactive Pollution

Thermal or Heat pollution is caused by the accumulation of heat in the environment over long periods of time. This can be caused by *large industrial plants, deforestation, air pollution* and more. It increases the temperature of the earth, causing extreme climatic changes and the death of wildlife. Some examples of thermal pollution include increased lake water from nearby production (cooler water is used to cool the plant, then pumped back into the lake) and increased temperatures in areas with a lot of concrete or vehicles (usually in cities). Thermal pollution results from the discharge of heated water or air, mainly from power plants and industrial facilities, disrupting aquatic life.

Radioactive pollution is a form of pollution caused by *nuclear plant failures, improper waste disposal and accidents*. It can lead to *cancer, infertility and blindness*, as well as *birth defects*. It can also *sterilize soil* and affect the air and water. The *Chernobyl (US)*¹ and *Three Mile Island incidents (1979)*² have shown that radioactive fallout affects humans, animals, plants and fauna in the same way as x-rays and atomic reactor plants. Radioactive pollution stems from nuclear accidents, improper disposal of radioactive waste, and mining of radioactive ores. It poses long-term health hazards, including cancer and genetic mutations.

6. Plastic Pollution

Plastic pollution is a modern global crisis. Plastic pollution obstructs rivers and oceans, endangers aquatic life, and enters the food chain via microplastics. Its management is especially challenging due to the persistence of plastics in the environment.

7. Causes of Environmental Pollution : The major causes of Environmental Pollutions are:

1. Rapid and Unsustainable Industrial Development

Industry is the engine of growth and development for a modern society. However, it has also been found to be one of the major contributors to environmental pollution and degradation in the country. After independence, steps were taken to develop industries in the country. However, industrialization has brought with it the issue of environmental pollution. Industrial waste is directly discharged into the water courses, making them unsuitable for human consumption. Liquid waste is the most common type of waste discharged into the aquatic environment. Oil and gas from petro-chemicals are also discharged into the water. Tanning, paper and pulp manufacturing processes release colouring waste into the water. The chemical substances present in the industrial water can pollute the physical composition of the water courses. As a result of industrialization and urban development, the environment has deteriorated significantly.

2. Rapid and Unplanned Urbanisation

Rapid and unplanned growth of urbanisation has also contributed to the pollution and degradation of the human environment. This is due to the continuous migration of the poor from the villages and small towns to the cities. Now, over a fifth of the nation's population lives in urban areas. As a result, the urban population of the metropolitan cities is growing day by day. The slums are a major issue of the big cities and a major contributor to the environmental degradation.

3. Uncontrolled Growth of Population

Overpopulation increases demand for resources and generating more waste. The environment is constantly changing due to the fact that the earth is finite and the world's population is infinite. With India being the second largest populated country in the world after China, the problem of population growth is a global issue. As the population grows, so does the demand for natural resources such as

¹ It was the worst and costliest nuclear disaster in human history, costing an estimated US 700 billion 1986.

² It was the worst nuclear accident in USA where a nuclear meltdown of Unit 2 reactor (TM1-2) of the Three Mile Island Nuclear Generating Station, USA on 28 March 1979 released radioactive gases and iodine into the environment.



water, air, land, soil and forest. This increases the need for food, housing, and cultivation, while also increasing the demand for minerals, water, and energy. This has a negative impact on the environment, leading to an increase in chemical use, the use of pesticides, deforestation, pollution, and heavy traffic.

4. Poverty

Poverty also adversely affect the environment. The word 'poverty' refers to the condition where an individual or family cannot attain a basic standard of living. Due to poverty, people exploit the natural resources to satisfy essential needs such as food, fuel, and housing. Indeed, poverty and necessity are among the leading contributors to pollution. Consequently, it is vital to take measures to eradicate poverty.

5. Lack of Environment Awareness

It's true that our education system has a significant impact on the quality of the environment. Environmental problems, which are global issues, are hardly known to the general public. The lack of awareness about the environment issues is considered to be a major cause for environmental pollution instead of degradation. Environmental pollution can be curbed to considerable extent only by raising environmental awareness among the people.

The Hon'ble Supreme Court has issued directions to cinema and exhibition halls to display slides containing information and messages on the environment, free of charge, to disseminate information on the environment. The court expressed its opinion that the environment education should be made a compulsory subject in schools and colleges through a graded system for general mass awareness.³

6. Others Factors :

Other factors that contribute to environmental pollution and environmental degradation are: *Deforestation, Uncontrolled use of fossil fuels, Over exploitation of natural resources, Uncontrolled or Indiscriminate use of technology, Uncontrolled use of pollutants, Poor disposal of sewage, waste water, and solid waste management, Failure to control ionizing radiation emissions, Poor management of electromagnetic energy and noise, Poor sound and heat management, Unsustainable agricultural practices, and Weak enforcement of environmental laws, etc.*

8. Effects of Environmental Pollutions : Some of the main effects of pollutions include:

1. Environmental Degradation

The environment is the first victim of pollution, whether it is in the air or water. As Carbon dioxide levels rise in the atmosphere, smog forms, which blocks sunlight from reaching the Earth's surface, preventing plants from photosynthesising. Gases like Sulphur dioxide and Nitrogen oxide caused acid rain. In the case of Oil spill, water pollution can kill several species of aquatic life.

2. Ecosystems and Biodiversity Loss

Pollutants destroy ecosystems, disrupt food chains, and lead to the extinction of species. The acidification of oceans endangers coral reefs, whereas pesticides diminish the populations of pollinators that are vital for agriculture.

3. Climate Change and Global Warming

One of the significant impacts of pollution is climate change. Global warming is a glaring example of it. Greenhouse gas emissions, such as carbon dioxide, methane, nitrous oxide, and chlorofluorocarbon, are the main factors driving global warming, resulting in rising sea levels, extreme weather phenomena, and the degradation of arable land. Every day, new industries are emerging, new vehicles are entering the roads, and trees are being felled to make space for new homes. All these activities, whether directly or indirectly, lead to an increase in carbon dioxide levels in the atmosphere resulting the melting of polar ice caps, which raises sea levels and endangers individuals residing in coastal regions.

³ M.C.Mehta v. Union of India, AIR 1992 SC 382.



4. Ozone Depletion

The ozone layer is a lean layer of air in the atmosphere that shields the Earth from ultraviolet radiation. Human activities, such as the release of substances like CFCs into the atmosphere, have caused a depletion of the ozone layer.

5. Infertile Land

Pollution affects not only the health of people, but also the health of the environment, plants, fruits and vegetables, rivers and ponds, forests and animals, on which they depend for their survival. It is essential to control pollution because nature, wildlife and man are precious gifts to humanity. The constant use of pesticides and insecticides can make the soil infertile. The plants may not grow properly. The chemicals produced from the industrial waste are released into the water flowing resulted the quality of the soil is also affected.

6. Socio-Economic Consequences

Pollution diminishes agricultural output, harms infrastructure, and raises healthcare expenses. Developing countries face unequal burden due to limited resources available for controlling pollution.

7. Effect on Human Health

Pollution affects the health of people by destroying their respiratory system, cardiovascular system and neurological system. Pollution is directly linked to diseases such as asthma, cancer, cardiovascular ailments, and neurological disorders. The World Health Organization estimates that 7 million premature deaths annually are attributed to air pollution alone.

I. Environmental Pollutions : Global Impact

New data indicates that pollution remains the primary cause of premature deaths globally, responsible for 8.3 million fatalities in 2017 (nearly one in seven deaths). These fatalities stem from exposure to hazardous air pollution, water pollution, soil pollution, and chemical pollution. This analysis relies on findings from the Institute for Health Metrics and Evaluation (IHME) Global Burden of Disease Study 2017. The findings estimate the overall number of premature deaths to be between 7 million and 10 million, with air pollution alone contributing to 5 million of these deaths. The World Health Organization (WHO) states that air pollution is attributed to 7 million premature deaths.

II. Environmental Pollution : Indian Context

India, the second most populous country in the world, appears on both lists of the top 10 countries with the highest pollution-related death in 2017, and second highest deaths due to air pollution, as well as 10 highest death rate of 174 per 1 lac population. According to the World Air Quality Report 2018 by IQAir and Greenpeace, 15 out of the 20 cities with the worst pollution globally were located in India. Gurugram had the poorest air quality in the world, while Delhi was identified as the most polluted capital city worldwide. As of 2024, India was reported to be the fifth-most polluted nation in the world, with an average PM2.5 concentration of 50.6 micrograms per cubic meter, which exceeds the World Health Organization's recommended limit by ten times.

9. Key International Environmental Policies for Pollution Control and Management

1. The Stockholm Conference 1972 : The UN Conference on Human Environment 1972 is considered as the origin of modern era of environmentalism. This conference laid down the rules on which the nation across the world shall enact the laws to protect and promote the global environment.

2. The Rio-Summit 1992: The UN Conference on Environment and Development (UNCED) reiterated the decision taken at Stockholm Conference and showed to the world the path of Sustainable Development.

3. The Paris Agreement 2015

The Paris Agreement is a legally binding international treaty addressing climate change, which was adopted by 196 parties at the UN Climate Change Conference (COP21) in Paris on December 12, 2015. It entered into force on November 4, 2016. The main goal of the agreement is to limit global warming to well below 2 degrees Celsius and to aim for a target of 1.5 degrees Celsius, relative to pre-industrial levels.



4. Montreal Protocol 1987

The Montreal Protocol is an international treaty adopted in 1987, recognized as one of the most effective environmental agreements in history, being the first and only UN treaty to achieve universal ratification by all 197 member states of the UN. The primary goal of the Montreal Protocol is to eliminate the use of substances such as chlorofluorocarbons (CFCs) and other compounds that deplete the ozone layer. Almost 100 chemicals are governed by this agreement, encompassing CFCs, halons, and various substances that deplete ozone levels. It outlines schedules for phasing out production and use of these substances, with different timelines for developed and developing countries. This agreement has played a vital role in recovery of the ozone layer and has exemplified the importance of being flexible and adaptable in response to emerging scientific knowledge and challenges.

5. Basel Convention (1989)

The Basel Convention 1989 is an international agreement to control transboundary hazardous waste movement.

6. The Kyoto Protocol 1997

The Kyoto Protocol is an international accord linked to the United Nations Framework Convention on Climate Change (UNFCCC) that mandates developed nations to cut their greenhouse gas emissions. It was officially adopted in Kyoto, Japan, in 1997, with the first commitment period running from 2008 to 2012. A key feature of the protocol is its legally binding emission reduction targets for the countries involved. The main objective of the Kyoto Protocol is to combat climate change by lowering greenhouse gas emissions, especially from developed nations.

7. Sustainable Development Goals (SDGs)

The UN Sustainable Development Summit 2015 which was held in New York has adopted the 2030 Agenda for Sustainable Development, comprises of 17 Sustainable Development Goals (SDGs). This is a Global Action Plan aimed at eradicating poverty, safeguarding the planet, and guaranteeing peace and prosperity for everyone by the year 2030. The Summit address interconnected global issues and challenges, adopting the 17 Sustainable Development Goals (SDGs).

10. Key Environmental Policies in India for Pollution Control and Management

India has a comprehensive policies framework system for pollution control and management, with key policies like *the Water Act 1974*⁴, *the Air Act 1981*⁵, *the Environment Protection Act of 1986*, etc. These policies are implemented through various institutions, including the Ministry of Environment Forest and Climate Change (MoEFCC), Central and State Pollution Control Boards (CPCB & SPCBs), and the National Green Tribunals (NGTs).

1. The Wildlife Protection Act 1972 :

This act aims to protect wild animals, plants, and their habitats.

2. The Water (Prevention and Control of Pollution) Act 1974 : This law addresses water pollution and aims to maintain the quality of water resources and to prevent, control and abatement of water pollution. Under this Act the Centre and States Pollution Control Boards were established.

3. The Air (Prevention and Control of Pollution) Act 1981: The fundamental objectives of this Act is to prevent, control and abatement of air pollution.

4. The Environment (Protection) Act 1986. This is an umbrella legislation of environmental law in India. The Act empowers the Centre government with wide powers and functions in relating to environmental protection.

5. The Public Liability Insurance Act 1991 : The Act aims to provides relief and compensation to the victim of the environmental pollution.

⁴ The Water (Prevention and Control of Pollution) Act 1974.

⁵ The Air (Prevention and Control of Pollution) Act 1981.



6.Environment Impact Assessment (EIA) Notification : This notification requires environmental impact assessments for various development projects.

7. The National Green Tribunal Act 2010. This Act established special fast tract environmental court, the National Green Tribunals (NGTs) with 5 Benches in India with New Delhi as its Principal Bench and regional benches in Pune (Western Zone Bench), Bhopal (Central Zone Bench), Chennai (Southern Zone Bench) and Kolkata (Eastern Zone Bench). The National Green Tribunals (NGTs) was established on 18th October 2010 with objective to effectively and expeditiously resolve cases related to environmental protection and the conservation of forests and other natural resources and all the environmental disputes that involve multi-disciplines issues.

7. Environment Policy 2006 : This policy emphasizes sustainable livelihoods, partnerships among stakeholders, and regulatory reforms.

11. Challenges in Pollution Control and Management

Environmental pollution control and management faces numerous challenges, which includes the following :-

- **Fragmentation Policies Framework:** Overlapping laws or multiple agencies often handle similar environmental issues with limited coordination, leading to inefficiencies and delays.
- **Weak Enforcement:** Despite of strong environmental laws and policies, enforcement or implementation can be inconsistent due to factors like lack or insufficient of resources, corruption, and political interference which can hinder progress. Weak institutional capacity and corruption.
- **High Costs of Pollution-Control Technologies.** High costs of pollution control technologies is one of the major challenges particularly for the developing countries.
- **Balancing Development and Conservation:** Rapid industrial development and economic growth can put immense pressure on natural resources, making it difficult to balance development needs with environmental protection. The pursuit of economic growth can often conflict with environmental protection efforts.
- **Lack of Public Awareness and Participation in Rural and Underdeveloped Regions:** Environmental decisions are often made without meaningful input from affected communities, undermining the legitimacy and effectiveness of governance. Limited understanding of environmental issues and inadequate opportunities for public involvement in decision-making can undermine policy effectiveness.
- **Lack of Global Cooperation :** To effectively addressed transboundary and global environmental challenges, such as climate change, global warming, biodiversity loss and pollutions, require international cooperation and coordination which sometimes lack.
- **Lack of Coordination Among Stakeholders:** Inadequate or lack of collaboration among stakeholder and agencies pose major challenge in effective pollution control and management.
- **Climate Change, Pollution & Waste Management:** India, in particular, is highly vulnerable to climate change impacts, requiring robust adaptation and mitigation strategies. Air, water, and land pollution, along with waste management challenges, pose significant threats to human health and ecosystems.
- **Inconsistent Data and Monitoring:** Inconsistent data and inadequate monitoring infrastructure hinder the effective implementation and enforcement of environmental policies.
- **Lack of Integration:** Environmental considerations are not always integrated into other sector policies, leading to inconsistencies and missed opportunities.
- **Limited Resources:** Insufficient funding, human resources, and technical capacity can impede effective environmental management.
- **Resistance From Industries and Vested Interests:** Non-compliance of rules, regulations and court orders by the industries and vested interests are major causes for environmental degradation.



- **Lack of Environmental Governance at the Local Level:** Ineffective participation at local level in environmental decision-making, Delays in transfer of funds to the Municipalities, Poor capacity of Municipalities, Lack of Integrated approach at ULB level, 74th Constitutional Amendment have not been included in some states legislation, Lack of Municipal Adaptation of environmental governance at local levels, etc.

12. CONCLUSION

Environmental pollution has become one of the most significant and critical issues of the 21st century, threatening human health, biodiversity, and the stability of ecosystems. The acceleration of industrialization, urbanization, and population growth has led to an increase in pollutants released into the air, water, and soil. Since 1970s, India's institutional and policy framework for pollution control and management has undergone substantial development. The Water (Prevention and Control of Pollution) Act of 1974 and the Air (Prevention and Control of Pollution) Act of 1981 formed the basis for institutional supervision. The Environment (Protection) Act of 1986 granted the central government authority to establish standards and enforce compliance. The Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs), created under the Water Act, act as the main bodies for implementation. The establishment of the National Green Tribunal (NGT) in 2010 marked a notable transition towards specialized environmental adjudications. While the NGT's proactive initiatives have improved environmental jurisprudence, there are still deficiencies in local enforcement. There is a lack of coordination among the Ministry of Environment Forest and Climate Change (MoEFCC), various line ministries, and local authorities. Although the 74th Constitutional Amendment aimed to empower Urban Local Bodies (ULBs) through decentralization, financial and technical constraints obstruct effective pollution control. Technological innovations are vital in India's fight against pollution. It underscored the significance of clean technologies like zero-liquid discharge systems, biofiltration techniques, air quality monitoring devices, and green infrastructure for stormwater management. The use of renewable energy sources, especially solar and biogas, has been linked to further advantages in decreasing pollution and mitigating carbon emissions. Community participation plays a vital role in managing and controlling pollution. Efforts initiated by local communities, such as campaigns for waste segregation, citizen-led air quality monitoring, and initiatives to restore local watersheds, have shown considerable success when backed by institutional support. The Swachh Bharat Mission (SBM) significantly raised awareness and enhanced sanitation access, though it has been criticized for focusing more on construction rather than promoting encouraging in behavior.

Despite progressive legislation, India encounters challenges in enforcing pollution control and management. Major challenges include, lack of effective monitoring systems, poor inter-agency cooperation, a deficiency of qualified personnel, and gaps in data. Financial constraints hinder the operational capacity of Pollution Control Boards, particularly at the state level.

The emphasis is on sustainable development, technological advancements, policy frameworks, and community involvement as vital tools for combating environmental degradation. Environmental pollution poses a significant threat to the survival and well-being of both present and future generations.

Effective control and management require a comprehensive strategy that integrates scientific knowledge or technology, policy initiatives or legislation, economic incentives, education, and public participation. To address the complexities of environmental issues or deterioration requires robust global cooperation, clear goals, and robust institutional capacity, alongside grassroots action, to secure a sustainable future. The way forward calls for innovation, political commitment, and a collective transition towards sustainable lifestyles.

13. RECOMMENDATIONS/ SUGGESTIVE MEASURES

- **Enhanced Policy Development or Regulatory Frameworks and Institutions :** To establish effective environmental policies, and to enact comprehensive and integrated environmental laws while equipping regulatory agencies with the necessary resources and authority.



Current monitoring systems primarily target traditional pollutants, there is a growing need for comprehensive frameworks to assess risks related to emerging contaminants like microplastics, nanomaterials, and pharmaceutical residues. There is an urgent requirement for a rigorous evaluation of the effectiveness of policies.

- **To Strengthen Institutional Framework:** To define clear roles and responsibilities for various institutions engaged in environmental management, ensuring they have adequate resources and authority.
- **To Encourage Stakeholder Participation:** To guarantee the involvement of all stakeholders by facilitating equitable participation, including local communities, in environmental decision-making.
- **To Encourage Public Awareness and Participation:** To educate the public, fostering community participation in decision-making processes, and guarantee transparency.
- **To Incorporate Environmental Considerations into all Policies:** To ensure that environmental goals are integrated throughout various sectors such as agriculture, energy, and transportation.
- **To Promote Sustainable Practices and Green Technologies:** To support research and development of environmentally friendly technologies, promote eco-friendly innovations, and adopting sustainable resource management strategies.
- **To Enhanced International Cooperation:** To strengthen international agreements and promote global cooperation to address transboundary and global environmental challenges effectively.
- **To Achieve Sustainable Development :** To safeguard the environment and incorporate environmental conservation as a vital component of the developmental process.
- **To Improve Data Collection:** there is a lack of long-term data linking pollutants exposure to health effects in different regions. Future research should combine epidemiological, economic, and ecological data to support evidence-based policymaking.
- **To Monitor and Enforcement:** To efficiently monitor environmental situations and enforce environmental laws.
- **Transparency and Accountability:** To ensure transparency and accountability in the processes. environmental decision-making.
- **To Strengthen Local Level Institutions. The local institutions need to be more strengthen with sufficient powers and resources, who need to take a comprehensive approach to promote sustainable development at the local level.**

REFERENCES

1. International Conventions/Conferences/Treaties/Agreement on Environment Protection

- United Nations.(1972). *Report of the United Nations Conference on Human Environment, Stockholm, 5-16 June 1972.*United Nations.
- United Nations.(1992). *Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-16 June 1992.* United Nations.
- United Nations.(1997). *Kyoto Protocol to the United Nations Framework Convention on Climate Change 1992,* United Nations.
- United Nations. (2002). *The Report of the World Summit on Sustainable Development Johannesburg, South Africa, 26 August - 4 September 2002.* United Nations.
- United Nations. (2015). *The Paris Agreement.* UN Climate Change Summit (COP21).
- United Nations. (2015). *Transforming Our World, The 2030 Agenda for Sustainable Developmen (17 Sustainable Development Goals).* United Nations.
- The Basel Convention (1989). *The Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Disposal.* United Nations Environment Programme.



2. Environmental Legislations in India

- The Wildlife (Protection) Act 1972 (No. 53 of 1972).
- The Water (Prevention and Control of Pollution) Act 1974 (No.6 of 1974).
- The Forest (Conservation) Act 1980 (No.69 of 1980).
- The Air (Prevention and Control of Pollution) Act 1981 (No.14 of 1981).
- The Environment (Protection) Act 1986 (No.29 of 1986).
- The Public Liability Insurance Act 1991 (No.6 of 1991).
- The Biodiversity Act 2002 (No.18 of 2003).
- The National Green Tribunal Act 2010 (No.19 of 2010).

3. Environmental Rules/ Regulations/Policies in India

- The Hazardous Wastes (Management and Handling) Rules in 1989,
- The Manufacture, Storage and Import of Hazardous Chemicals Rules 1989.
- The Chemical Accidents (Emergency Planning, Preparedness and Response) Rules 1996.
- The Biomedical Wastes (Management and Handling) Rules in 1998,
- The Recycled Plastics (Manufacture and Usage) Rules 1999,
- Environment (Siltation for Industrial Projects) Rules 1999,
- The Municipal Solid Wastes (Management and Handling) Rules in 2000.
- The Noise Pollution (Regulation and Control) Rules 2000.

4. Environmental Law Books

- Divan S. & Rosencranz A, (2022), *Environmental Law and Policy in India*; 3rd Edition 2022, Oxford University Press, United Kingdom.
- Leelakrishnan P. (2008). *Environmental Law in India*, 3rd Edition .2008, Lexis Nexis, India.
- Myneni S.R. (2022), *Environmental Law*, 4th Edition 2022, Asia Law House, India.
- Shanthakumar S.(2005), *Introduction to Environmental Law*, 2nd Edition 2005, Lexis Nexis, India.
- Tripathi, S.C (2015), *Environmental Law*, 6th Edition.2015, Central Law Publication, India.
- Upadhaya J.J. (2018). *Environmental Law*, 5th Edition 2015, Central Law Agency, India.

5. Law Journal/ Articles/ Reports

- CPCB (2021). *Status of Water Quality in India*. Central Pollution Control Board.
- Chakrabarti S. & Mitra S. (2021). *Governance and environmental management in India: Institutional challenges*. Environmental Policy and Law.
- Gupta A. & Kumar R. (2020). *Environmental pollution and sustainable development in India*. Environmental Science and Policy.
- Guttikunda S. K. & Jawahar P. (2020). *Urban air pollution trends in India: Analysis and mitigation*. Atmospheric Environment.
- IQAir and Greenpeace (2018), *The World Air Quality Report 2018*
- Jain N., Sharma S. & Agarwal R. (2020). *Evaluating India's air quality management strategies: The case of NCAP*. Environmental Research Letters.
- Joshi A. & Kumar S. (2020), *Status and challenges of municipal solid waste management in India: A review*. Cogent Environmental Science.
- Kaur R. & Singh P. (2020). *Evaluating the Swachh Bharat Mission: Achievements and limitations*. Indian Journal of Public Administration.



- MoEFCC (2019). *National Clean Air Programme*. Ministry of Environment Forest and Climate Change Government of India.
- MoHUA (2022). *Annual Report on Solid Waste Management in Urban India*. Ministry of Housing and Urban Affairs.
- Narain S. & Bell R.G.(2019). *Environmental Governance in India*. World Bank Publications.
- Pollution and Health Metrics (2019): *Global, Regional and Country Analysis Report 2019*, Global Alliance on Health and Pollution, Geneva, Switzerland.
- Rani M. & Bhatnagar N.(2020). *E-waste management in India: Emerging policy and practice challenges*. Resources, Conservation and Recycling.
- TERI (2020). *Wastewater Management in Urban India: A Review of Challenges and Opportunities*. The Energy and Resources Institute.
- Tripathi V., Mishra P. & Jain A.(2022). *Innovations in environmental technologies: Indian advances and challenges*. Current Science.
- Upadhyay S. & Jain N. (2021), *Role of National Green Tribunal in environmental protection in India*. Indian Journal of Law and Environment.
- WHO (2021). *Air Pollution and Health 2021*. World Health Organizations.

6. Web Reference

- <https://www.indiascienceandtechnology.gov.in/listingpage/air-pollution-india-status-and-challenges>.



Investor Perspective on Derivatives of Commodities Market as Tool of Investment for Sustainable Economy

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ABSTRACT: *The growing emphasis on sustainability and responsible investment has reshaped financial markets, compelling investors to evaluate instruments that balance profitability with long-term economic stability. This paper explores investor perspectives on derivatives within the commodities market as strategic tools for fostering a sustainable economy. The study explores how these financial instruments might improve market efficiency, control risk, and promote sustainable resource allocation by looking at futures, options, and swaps related to critical commodities. The research emphasises the changing role of commodity derivatives as mechanisms supporting price stability, transparency, and resilience in global supply chains rather than just as speculative instruments through a combination of literature review, investor sentiment analysis, and market trend evaluation. The results imply that derivatives can make a significant contribution to sustainable economic development when they are in line with frameworks for responsible investing and environmental, social, and governance (ESG) principles. The paper concludes by proposing policy and regulatory measures that could enhance investor confidence and ensure derivatives markets contribute positively to sustainability goals.*

Keywords: *Investor Perspective, Portfolio Diversification, Sustainable Economy.*

1. INTRODUCTION

In recent years, the global financial landscape has undergone a paradigm shift toward sustainability-driven investment strategies. Investors, policymakers, and financial institutions increasingly recognize the need to align financial instruments with the broader goals of economic stability, environmental preservation, and social responsibility. Within this context, the commodities market—historically viewed as a domain for price discovery, hedging, and speculative gains—has acquired renewed significance. Commodity derivatives such as futures, options, and swaps are now being examined not only as instruments for managing price volatility but also as potential enablers of sustainable economic growth.

The dynamics of the commodities market are inextricably linked to real economic activity, particularly in sectors such as energy, agriculture, and metals. These industries are essential to reaching the Sustainable Development Goals (SDGs) of the UN, particularly those that deal with poverty alleviation, climate action, and responsible production and consumption. Therefore, it is essential to



comprehend how derivatives work in directing investments towards effective resource allocation and sustainable commodity production. Derivatives provide options for investors to reduce risk exposure, diversify their portfolios, and promote long-term sustainability goals.

Excessive speculation in commodity derivatives can lead to price distortions and social inequities, particularly in essential commodities like food and energy. Conversely, well-regulated derivative markets improve liquidity, stabilize prices, and facilitate the efficient transfer of risk, thereby strengthening economic resilience. The balance between these underscores the importance of examining investor perceptions, motivations, and strategies in utilizing derivatives within a sustainability-oriented framework. The interplay between investment motives, market efficiency, and sustainable development, highlighting the evolving role of financial innovation in shaping a responsible global economy. The study aims to add to the conversation about how derivative markets might evolve from simply profit mechanisms to catalysts for long-term economic transformation by combining theoretical insights with empirical facts.

CONCEPTUAL FRAMEWORK

INVESTOR PERSPECTIVE: An investor's perspective is a market outlook based on the anticipated returns and risks of potential investments. It means how the investor envisions or sees the different investment avenues. It refers to mind-set of investor who prioritize long-term financial goals over short-term gains.

PORTFOLIO DIVERSIFICATION: Portfolio diversification is a key financial strategy designed to minimize risk by investing in a variety of asset types, each responding differently to market fluctuations which reduces exposure to risk and enhances long-term financial preparedness.

SUSTAINABLE ECONOMY: Sustainable economy aims to meet the needs of the present without compromising the ability of future generations to meet their own needs, balancing economic growth with environmental protection and social equity.

OBJECTIVES OF THE STUDY

To study the impact of annual income on investor perspective on derivative instruments of commodity markets for sustainable economy.

HYPOTHESIS

H_0 = There is no relationship between investor perspective and annual income.

2. REVIEW OF LITERATURE

Baker C., “Derivatives and ESG” (2022) observed that financial markets are increasingly developing innovative, ESG-related derivatives and relying upon these instruments to hedge ESG-related risks. Derivatives can also facilitate access to the tremendous amounts of capital necessary for the transition to a cleaner energy future and to the objective of net zero emissions by 2050 of governments around the world.

Kumar S., “ESG derivatives and factoring sustainability in investment management” (2023) explored how sustainability objectives intersect with derivatives markets. The applicability of derivatives explicitly tied to ESG factors play a role in promoting climate risk management and social justice.

Varsani H.D., Chitkara D., Ishihara Y. and Mahmood R., “ESG and climate reporting with derivatives” (2024) observed that asset managers are increasingly considering derivatives not just for hedging or return generation but also for aligning exposures with ESG goals. They examined different



types of investors who participate in commodity derivatives markets, how they form expectations and how institutional constraints shape strategies.

3. RESEARCH METHODOLOGY

Methods of Data collection

Data was collected from primary and secondary sources. Primary data was collected in the form of structured questionnaires; which were distributed among 50 respondents and 49 were received duly completed.

Secondary data was collected through articles, books, journals, newspaper and internet.

Sampling method and Sample size

Convenience Sampling Method was adopted to select respondents. The study was conducted with 50 respondents and 49 were received duly completed.

Analysis of data

Classification and tabulation of data and regression co-efficient technique were performed using MS Excel and SPSS.

4. DATA ANALYSIS

Table 1: Socio-economic profile of respondents

S. No.	Category	No. of respondents	% of respondents
1	Age group		
	21-30	25	51.02
	31-40	21	42.86
	41-50	02	4.08
	Above 50	01	2.04
	Total	49	100
2	Gender		
	Male	21	42.86
	Female	28	57.14
	Total	49	100
3	Qualification		
	School Level	09	18.37
	Graduate	16	32.65
	Post graduate	14	28.57
	Professional	10	20.41
	Total	49	100
4	Occupation		
	Private employee	33	67.35
	Public employee	13	26.53
	Self-employed	03	6.12
	Total	49	100
5	Annual income		
	Below 300000	08	16.33
	300001-500000	24	48.98
	500001-700000	15	30.61
	Above 700000	02	4.08



	Total	49	100
6	Marital status		
	Married	13	26.53
	Unmarried	36	73.47
	Total	49	100

Source: Primary data

Table 2: Awareness of Derivatives of Commodities Market

S. No.	Concerns	No. of respondents	% of respondents
1	Website	11	22.45
2	Newspaper/Magazine	04	8.16
3	Relatives/Friends	06	12.25
4	Financial Advisors	25	51.02
5	Advertisement	03	6.12
	Total	49	100

Source: Primary data

Table 3: Preferred Type of Derivative Instrument

S. No.	Method	No. of respondents	% of respondents
1	Forwards	04	8.16
2	Futures	15	30.61
3	Options	30	61.23
	Total	49	100

Source: Primary data

Table 4: Influence of Derivative Instruments for Sustainable Economy

S. No.	Instruments	No. of respondents	% of respondents
1	Strongly influences	18	36.73
2	Somewhat influences	30	61.23
3	Not influences	01	2.04
	Total	49	100

Source: Primary data

Table 5: Reasons for preferring Derivative Instruments by respondents

S. No.	Advantage	Rank order					Score	Rank
		1	2	3	4	5		
1	Sustainable Economy	12	9	9	6	13	148	2
2	Risk management	33	11	2	3	0	221	1
3	Portfolio diversification	2	11	13	13	10	129	3
4	Arbitrage opportunities	1	4	14	16	14	109	5
5	Return Enhancement	1	14	11	11	12	128	4

Source: Primary data

Table 6: Relationship between investor perspective and annual income

Personal Variable	Regression Coefficient (β)	t-value	Significance Level (p-value)	Significant / Not Significant
Annual Income	0.482	3.216	0.002	Significant



Source: Computed from Primary Data

The above table shows that investor perspective has positive and statistically significant relationship with annual income. The regression coefficient suggests that as annual income increases, the investor's favourable perception of derivative instruments also rise. This implies that higher-income investors are more aware of, and more inclined to use, derivatives as investment tool supporting a sustainable economy.

5. FINDINGS AND SUGGESTIONS

- 32.65% of respondents are graduates.
- 48.98% of respondents have annual income from ₹300001 to ₹500000.
- 42.86% of respondents are in the age group 31-40.
- 51.02% of respondents got awareness of derivative instruments of commodity markets from financial advisors.
- 61.23% of respondents use options as preferred type of derivative instrument.
- 61.23% of respondents feel that derivatives of commodities market somewhat influences sustainable economy.
- Respondents have ranked reasons for preferring derivative instruments of commodity markets such as risk management, sustainable economy, portfolio diversification, return enhancement and arbitrage opportunities.
- Annual income of respondents have influence on investor perspective on derivative instruments of commodity markets.
- Increased literacy would reduce reliance on intermediaries and promote more informed decision-making.
- Regulatory bodies can also consider providing tax incentives or margin benefits for participation in certified ESG-compliant derivatives. Periodic policy reviews should be undertaken to ensure that market mechanisms support both price stability and sustainable resource allocation.

6. CONCLUSION

The present study examined the relationship between investor perspectives and the use of derivative instruments in the commodities market, with a focus on their role in promoting a sustainable economy. The findings indicate that investors increasingly recognize derivatives—particularly options and futures—as valuable tools not only for risk management and portfolio diversification but also for supporting long-term sustainability objectives. Most respondents associated derivatives with the potential to enhance economic stability by improving market efficiency, ensuring price transparency, and facilitating efficient resource allocation.

Empirical analysis revealed a significant relationship between annual income and investor perspective, suggesting that higher-income investors possess greater awareness, accessibility, and confidence in using derivatives for sustainable investment purposes. This underscores the importance of income and financial literacy as key determinants of participation in derivatives markets. Furthermore, investors rated risk management and sustainable economic contribution as their primary motives for engaging with commodity derivatives, highlighting a shift from purely speculative behavior toward responsible investment practices.

The study concludes that well-regulated and transparent derivative markets can play a constructive role in advancing sustainability goals when integrated with Environmental, Social, and Governance (ESG) principles. However, for derivatives to serve as genuine instruments of sustainable



development, there must be a concerted effort among regulators, exchanges, and investors to promote awareness, design ESG-linked products, and strengthen market integrity.

In essence, the evolution of the commodity derivatives market from a speculative domain to a strategic platform for sustainable investment reflects the growing alignment between financial innovation and social responsibility. By embedding sustainability considerations into derivative trading and investment decisions, markets can effectively contribute to building a resilient, inclusive, and sustainable global economy.

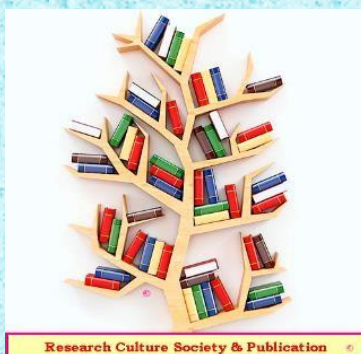
REFERENCES

1. Baker C. (2022), “Derivatives and ESG”, American Business Law Journal, Vol. 59, No. 4, pp. 725-772.
2. Kumar S. (2023), “ESG derivatives and factoring sustainability in investment management”, Academy of Marketing Studies Journal, Vol. 27, No. 3, pp. 1-14.
3. Varsani H. D., Chitkara D., Ishihara Y. and Mahmood, R. (2024), “ESG and climate reporting with derivatives”, MSCI Research & Insights, Vol. 2, pp. 42-65

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