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Future of Environmental Integrated Management: A Review of Advancements

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Abstract

Integrated environmental management has revolutionized the field of environmental conservation and management. Being a multidisciplinary approach, integrated environmental management coordinates economic growth with environmental sustainability by incorporating multidisciplinary strategies and stakeholder collaboration. Over the past decade, IEM has progressed significantly. Although its principles and frameworks have been effectively addressing complex environmental concerns, but it is still facing different issues in its implementation. Various advancements in technology, sustainable practices and circular economic models are being investigated to cope with these problems. The deployment of Internet of Things (IoT) networks, advancements in artificial intelligence (AI) and machine learning (ML), and the adoption of blockchain technology, have the ability to enhance the precision and efficiency of environmental monitoring and management. Additionally, Nature-Based Solutions (NBS) and green infrastructure have emerged as a critical strategy for addressing climate change, enhancing biodiversity, and improving urban sustainability. Adoption of circular economy and resource efficient models are one of the leading roads towards a green society. Further research on reaching carbon neutrality, industrial symbiosis, and resource resilience will undoubtedly result in a sustainable and circular society.

Keywords: Environmental management, Technological advancement, Current Trends, Tools for IEM, Sustainability, Environmental governance

Full length review article

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1. Introduction

The "Integrated environmental management" or IEM is a very broad interdisciplinary term used for environmental management. Firstly, the word "integrated" refers to the combination and unification of different components to form a coherent and well-coordinated system. It implies to the thoughtful integration of several elements to accomplish a specific objective or purpose. Environmental management is the process of initiating, planning, implementing, and controlling various strategies, policies, and technologies to regulate human impact on the environment, ensuring that natural resources are used sustainably and that ecological health is maintained. Environmental management can be applied at any level whether it be global, regional, or local level. Together "integrated environmental management" can be defined as a comprehensive and multifaceted approach that provides a broad framework for the assessment and management of environmental impacts and aspects related to an activity, product, or service at each stage and can be adopted by all sectors of society. A wide range of government and non-government organizations, as well as people with various interests and viewpoints, are usually involved in IEM [1]. The concept of environmental management gained public popularity and awareness in 1962, after the publication of Rachel Carson on the effects of pesticides on human health. From then on, the environmental management system continued to evolve towards betterment. The integration of the environmental management system with ecological, social, and economic studies has formed a new holistic framework called integrated environment management or IEM, which has opened new horizons in the field. Its significance resides in its comprehensive strategies and adaptive management practices to tackle intricate environmental concerns [2]. Though numerous problems are being faced in its implementation, still IEM plays a crucial role in successfully resolving present and future environmental issues, contributing to a resilient and sustainable community [3].

In this article, we will discuss the future of Integrated environmental management, keeping in mind its current status and some of the challenges faced. And give an insight into how we can formulate new and efficient interdisciplinary methodologies using scientific, technological, regulatory, and participatory methods for environmental management and conservation.

2.Evolutions in Integrated Environmental Management:

Over the years, various efforts have been made for the efficient management of environmental resources. After successfully making and implementing a policy, all its pros, cons, and limitations are studied to develop an even better strategy covering all environmental aspects. Some of the major highlights of IEM from the year 2010 to the present are described here. In 2010, a UN conference was held in Cancun, Mexico which focused on adapting strategies to cope with the issues of rapid climate change. The Cancun Agreements of 2010, adopted during COP16, became a guiding principle for subsequent environmental policies and frameworks [4]. Similarly, the International Association for Impact Assessment (IAIA) released guidelines for social impact assessment, emphasizing the significance of planning projects and making decisions while concurrently taking economic, social, and environmental concerns into account [5-6]. At the same period, the use of remote sensing and Geographic Information Systems (GIS) in IEM began, providing more accurate natural resource mapping, monitoring, and management [7]. The significance of integrated methods to sustainable development was emphasized by the United Nations Conference on Sustainable Development in 2012[8], which led to the development and adoption of the Sustainable Development Goals (SDGs) in 2015[9]. To better address environmental issues, 17 Goalsof the Sustainable Development Goals (SDGs) approved by the UN called for the restoration of the global partnership for sustainable development as well as the reinforcement of implementation strategies. The implementation of these SDGs provided new opportunities for the advancements of IEM [10]. The early usage of unmanned aerial vehicles (UAVs) and drones for environmental monitoring was one example of how technology advanced. It opened new possibilities for data collection and surveying at distant and inaccessible areas [11-13].Artificial intelligence (AI) and machine learning (ML) were also first incorporated into environmental management at that time. The 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 approved the Paris Agreement, which represents a global commitment to combat climate change through integrated initiatives including corporations, civil society, and governments[14-15]. Other developments, included the increased use of IoT devices in tracking biodiversity and soil, air, and water quality and condition assessment in real-time[16].Likewise, Big data analytics increased the capacity to handle and evaluate enormous volumes of environmental data from many sources, enhancing the precision and dependability of environmental evaluations.In 2017, the Global Pact for the Environment took place which was a landmark for the rapidly developing relationship between human rights and the environment. It aimed to emphasize integrated management techniques while unifying various environmental laws to enhance global environmental sustainability [17-18]. The European Green Deal, which was proposed in December 2019, was a comprehensive strategy to achieve climate neutrality by 2050. It aims to reform the economy of the EU for a sustainable future by implementing policies including decreasing greenhouse gas emissions, developing renewable energy, and encouraging a circular economy [19-20]. Later, the COVID-19 pandemic interrupted global environmental management programs, but it also brought attention to the interdependencies of human health, ecosystems, and the economy, prompting calls for more integrated approaches to sustainability. But in efforts to meet the targets set by the European Green Deal, EU climate law was passed which became legal binding in 2021. During this time, different technological advancements including the use of AI, IoT, big data, and blockchain technology took place for better environmental assessment, analysis, and recording of environmental data. UN Climate Change Conferences, also known as conferences of parties, COP 26 (2021, Glasgow), COP 27(2022, Sharm El-Sheikh), and COP28 (2023, Dubai) played their part in environmental conservation and management. The main goal of COP 26 was to limit temperature rises to 1.5 degrees Celsius. It also focused on using efficient and green fuels band reducing the use of coal and fossil fuels for reduced emissions, more climate funding, and the use of advanced technology to reach climate targets [21]. COP27 aimed to advance the implementation of the Paris Agreement with a strong focus on adaptation and resilience, loss and damage, and climate finance. Significant progress was made in establishing the Loss and Damage Fund to support vulnerable nations. The summit also stressed the importance of public participation and digital innovation in environmental management, showcasing tools for engaging citizens and enhancing data collection [22]. COP28 is expected to consolidate global efforts toward integrated environmental management and drive further policy commitments. Anticipated focuses include accelerating technological innovations for climate action, enhancing international cooperation, and implementing adaptive management strategies. The conference aims to build on the progress of previous COPs, with a strong emphasis on sustainable development and resilient infrastructure [23]. Similarly, many other efforts are being made for the promotion of conservation and management of the environment, creating a road map to a green and sustainable life.

3 Major tools used in IEM:

Following are some of the frameworks that are currently being used for environmental management[24-25].

3.1 Environmental Management Systems (EMS):

Environmental Management Systems are the frameworks that provide important guidance for an organization to manage their environmental aspects systematically. Their job includes the development of such policies which show their dedication to the protection of their environment. After identifying a problem, roles, and objectives are established for the complete implementation and monitoring of the rules set by it. Thus, it can be said that the organization’s structure, working, practices, policies, and resource and energy management are fully optimized by EMS ensuring the efficiency and effectiveness of the system as well as the organization [26].

3.2 Environmental Impact Assessment (EIA):

Environmental Impact Assessment is used to determine how a product, process, or service affects the environment. Its main goal is identifying and predicting the harmful environmental effects and devising ways to minimize them as much as possible. It takes the role of stakeholders into account and ensures the consideration of social and economic factors in addition to environmental effects. The objective is to prevent environmental degradation in order to support sustainable development [27].

3.3 Geographic Information Systems (GIS):

Geographic Information systems are computer-based systems that are used to collect, store, analyze, and manage spatial or geographic data. GIS provides 3D models and maps for the complete visualization and understanding of data and patterns for its users, aiding in important decision-making. GIS provides informative data in a variety of disciplines, including public health, transportation logistics, environmental monitoring, urban planning, and disaster management, to help with better decision-making, efficient resource management, and ecological assessment [28].

3.4 Remote Sensing:

Remote sensing is a method that uses satellites, drones, or airplanes to collect data about objects or regions from a distance. Radiated or reflected light or heat radiation is identified and quantified during the procedure. Remote sensing is a key component of many scientific fields, such as meteorology, forestry, geology, agriculture, and environmental monitoring. This makes land use, vegetation health, water bodies and atmospheric variables mappable and observable. Remote sensing improves the ability to make informed decisions and implement effective management strategies by providing a comprehensive and accurate overview of environmental conditions over large areas[29].

3.5 Artificial Intelligence (AI) and Machine Learning (ML):

The growing importance of artificial intelligence in the field of environmental management is undeniable. Big data enables the collection and analysis of vast and complex environmental data from a variety of sources, including social media, IoT devices, and remote sensing. Using artificial intelligence and machine learning, these data are analyzed simultaneously, which provides information on consumption patterns, optimizes the use of resources, combats uncertainty factors, and predicts future trends to improve environmental management. However, further research is still needed for its optimized performance [30].

3.6 Life Cycle Assessment (LCA):

Life Cycle Assessment (LCA) is a systematic methodology for the evaluation of environmental impacts of a product, process, or service throughout its entire life cycle [31]. In this process, assessment from raw material extraction through production, utilization, and disposal is carried out. Various factors which affect the environment like energy consumption, greenhouse gas emissions, water usage, and waste generation, are identified according to some set standards and managed during LCA. This allows policy and decision-makers to gain a full understanding of the situation and contribute to the development of more sustainable products and procedures by highlighting improvement opportunities [32].

3.7 Stakeholder Engagement:

In integrated environmental management or IEM, stakeholder engagement refers to the active participation of every relevant party in the decision-making process, including corporations, non-governmental organizations (NGOs), local communities, government agencies, and other interest groups [33]. Every party either it be government or the public has to play its part to ensure that all the related concerns are being considered and addressed [34-35].. Thus, resulting in more thorough and efficient environmental management strategies [36].

3.8 Nature-Based Solutions (NbS):

In integrated environmental management (IEM), nature-based solutions (NbS) refer to the use of ecosystems and natural processes in managing environmental problems and improving sustainability. These methods exploit the inherent flexibility and adaptability of ecosystems to benefit both people and the environment. Wetland restoration, reforestation, green infrastructure, and sustainable agricultural methods are a few examples of such solutions [37]. In addition, NbS often provides more benefits, such as habitat restoration and biodiversity protection, at lower costs than traditional engineering and infrastructure solutions. Stakeholders can simultaneously achieve multiple goals such as community resilience, socio-economic growth and environmental protection by engaging NbS in IEM initiatives. Overall, NbS represents a holistic and sustainable approach to environmental management, consistent with principles [38].

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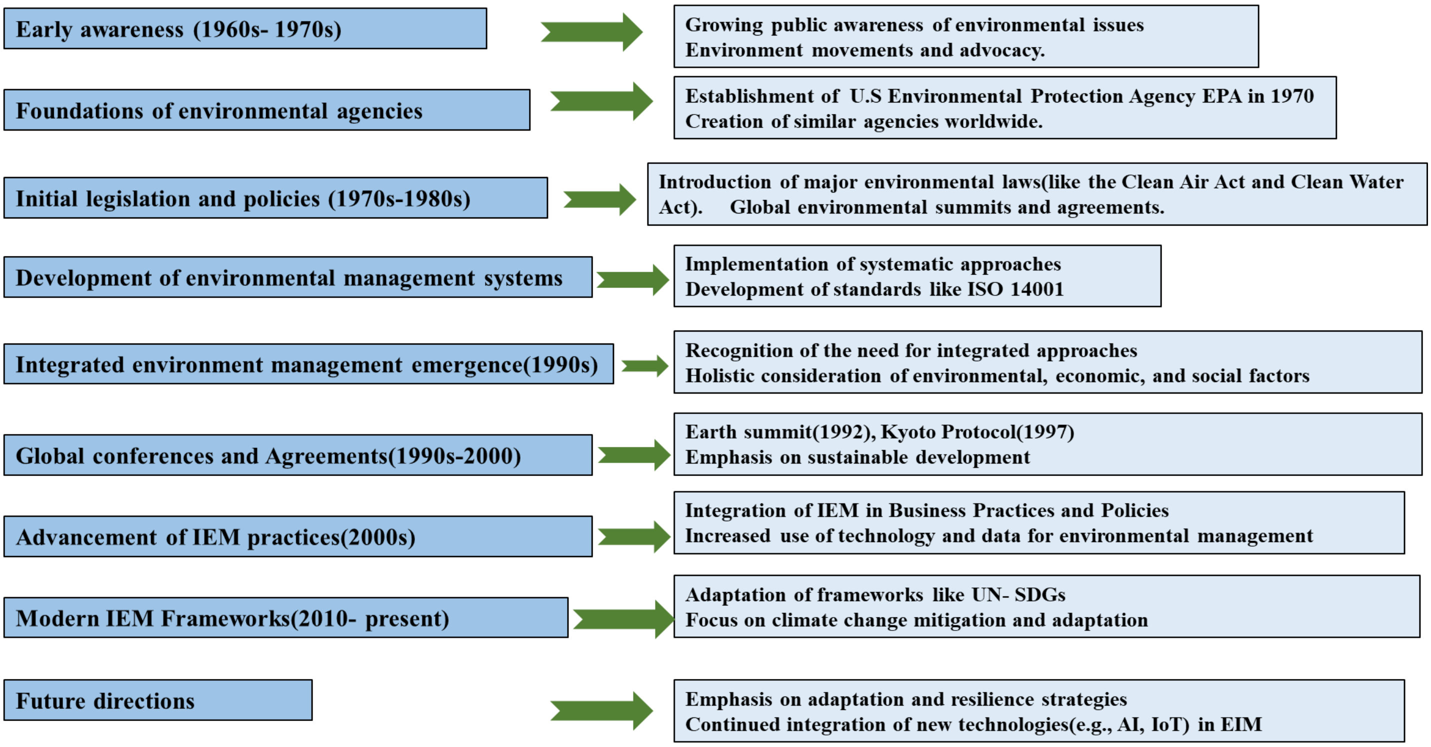

Figure 1: Brief Historical Background of IEM

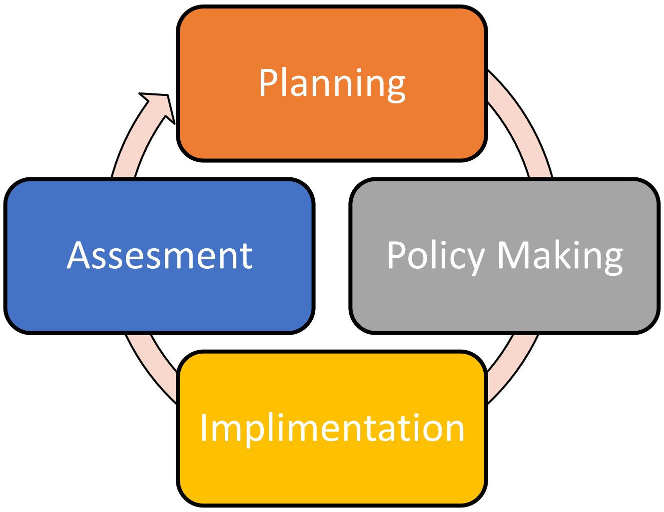

Figure 2: Schematic Diagram of Environmental Management System

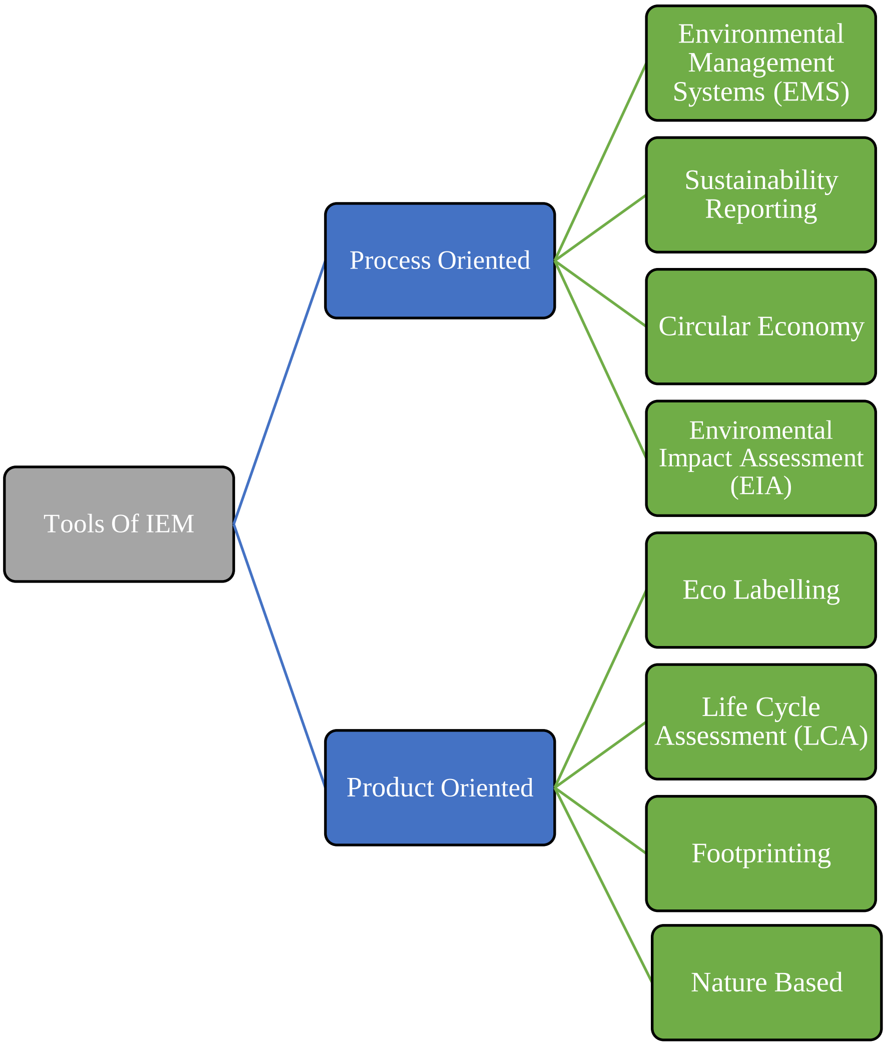

Figure 3: Classification of Some Tools of IEM

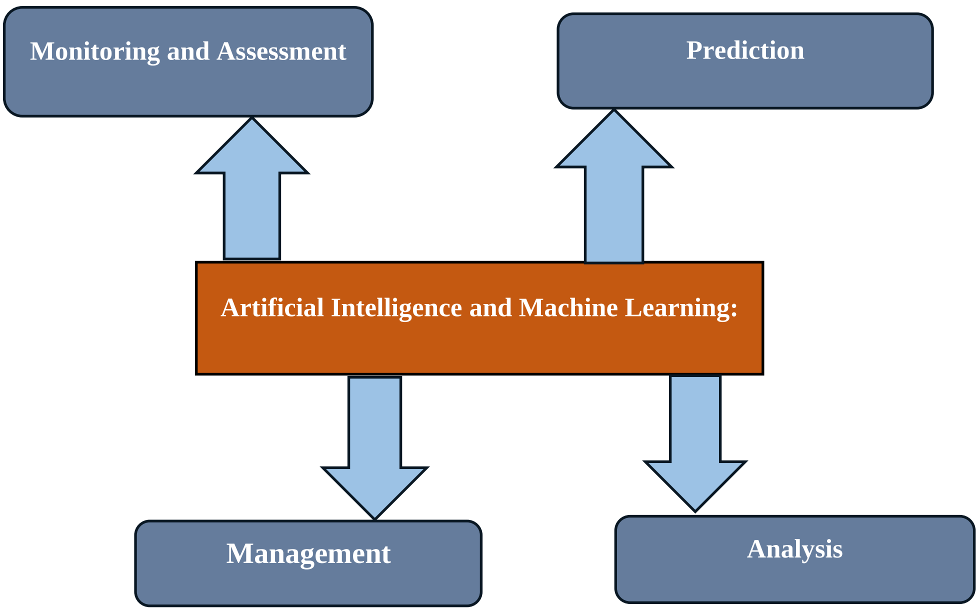

Figure 4: Role of AI and ML in IEM

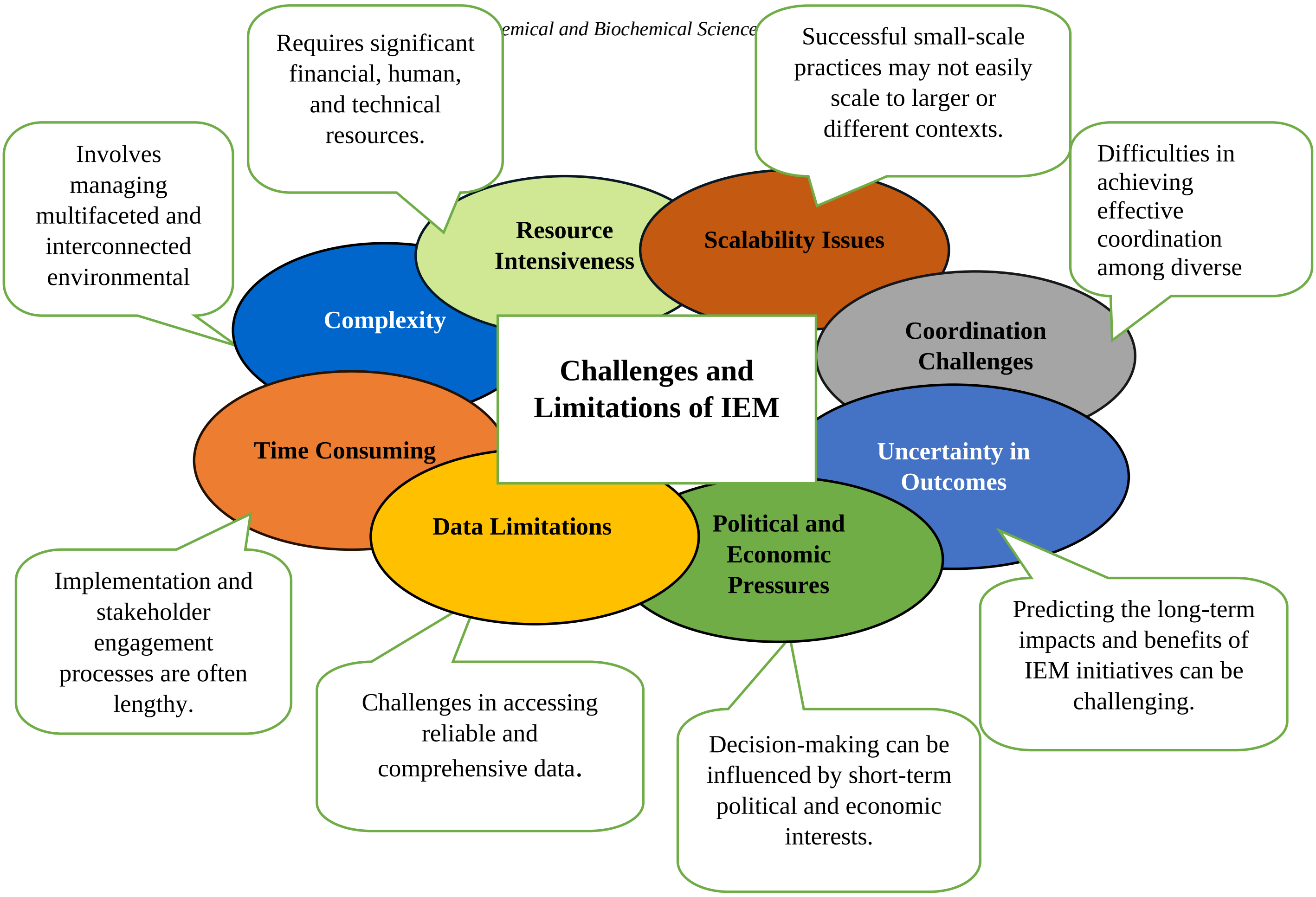

Figure 5: Challenges and Limitations of IEM

3.9 Circular Economy Practices:

Circular economy practices involve the formulation and implementation of strategies that focus on the minimization of waste of resources, increasing their efficiency, and adopting sustainable usage and production patterns[39].

3.10 Eco-Labeling:

In Integrated Environmental Management (IEM), eco-labeling is the process of certifying and labeling goods and services that adhere to certain environmental criteria, thereby reducing the negative environmental impacts. These eco-labels are given out according to some set standards for the identification of eco-friendly products and services and for encouraging sustainable production and consumption processes. Eco-labeling in IEM contributes to the achievement of larger environmental goals by lowering the overall ecological footprint, and increasing consumer and company understanding of environmental issues. This approach helps integrate environmental factors into market dynamics, credibility, and positive information for the consumers[40].

3.11 Sustainability Reporting:

Sustainability reporting in integrated environmental management (IEM) means the systematic disclosure of an organization's environmental, social and financial results. This report provides stakeholders with transparent information about the organization's environmental system, which allows the identification of deficiencies and corrective actions to improve them[41].

Common frameworks for sustainability reporting are the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB). By regularly documenting and reporting on sustainability efforts, organizations can track their progress, identify areas for improvement, and increase accountability. Sustainability reporting also helps build trust among stakeholders such as customers, investors and regulators by demonstrating commitment to environmental protection and corporate social responsibility. This practice supports informed decision-making and promotes continuous improvement in sustainability performance[42].

3.12 Strategic Environmental Assessment (SEA):

SEA is a sequential type of environmental impact assessment that can deal with policy, plan, or program levels. Different in-depth assessments based on different levels can be carried out by Strategic Environmental Assessment. SEA is becoming more and more recognized as a crucial strategy for putting the idea of sustainable development into practice since it makes it possible to apply the sustainability principle to everything from individual projects to policies[43].

4. Challenges and Limitations of current IEM systems:

IEM tells how to manage different activities without having a negative impact on the environment. The difficulty in IEM arises due to the following reasons (i) collection, management, and analysis of different types of information and datasets (ii) to project data over time in order to fill in chronological gaps or create predictions (iii) taking into account the uncertainties of applied models and policies (iv) to compare and extend available data across spatial landscapes (v) the conversion of data into more useful forms that support policy decisions (vi) assessment of whether a policy or system is useful harmful or need more adaptations[44].

5.Future of Integrated Environmental Management:

5.1 Technological Advancements:

Multiple technology developments will probably transform integrated environmental management (IEM) in the future. These innovations will improve the efficiency and sustainability of environmental issue monitoring, management, and mitigation. The following important developments are anticipated to have a big impact:

5.1.1 Artificial Intelligence (AI) and Machine Learning (ML):

Artificial Intelligence (AI) and Machine Learning (ML) can play revolutionary roles in enhancing the efficiency, accuracy, and effectiveness of Integrated Environmental Management (IEM).Environmental impact assessment and life cycle assessment which are some of the basic tools of IEM but are extremely time-consuming and meticulous, can be done efficiently using AI[45].

For sustainable agricultural practices, AI technologies can be used for predictive modeling, data analysis, and precision farming, to maximize crop yields, limit resource inputs, and lessen environmental effects[46]. It can also improve irrigation, fertilizer use, and pest management through the analysis of soil conditions, weather patterns, and crop health data for organic farming[47-48].

By the combination of AI and waste management system, an automated and efficient system can be obtained that can provide a framework for reusing, recycling, and minimizing waste production[49-50].From monitoring energy and resource consumption to their analysis, management, and forecasting of environmental threats, AI technologies provide novel and modern approaches throughout different sectors in a variety of fields [51-52].

More advancements in AI will enable us to form proficient systems and strategies that will play their part in the conservation, monitoring, management, and of natural resources, waste, pollution, and renewable energy sources[53-54].

5.1.2The Internet of Things

There are several obstacles to the deployment of sensors and IoT systems, including increased energy consumption, the production of pollution and E-waste, and their high prices. Still, research is being done to create more precise, less expensive, and green sensors[55]. A green IoT will help in the conservation of environmental resources, increase energy efficiency, and decrease carbon footprint through proficient techniques. For example: Drone technology is one of the major IoT technologies that led us to a more favorable IEM. They can travel to far places for environmental, climate, and pollution monitoring and reduce the e-waste by wireless recharging. Further research can lead to the development of more such devices that can monitor, gather, analyze, and store data economically and efficiently. For a sustainable and human-friendly environment, e-waste from these smart devices should be reduced as much as possible. Automated and collaborative IoT devices should be adopted in many sectors like waste and pollution management, traffic control, communication, and big data analysis[56-57].

In addition to that, A suitable infrastructure is usually required to store, process, or analyze the vast amounts of data created by IoT devices and social media. It will also provide instructions for appropriate automated actions depending on the insights gleaned. Owing to the expenses linked with this kind of infrastructure, the "platform as a service" business model is gaining traction. Amazon Web Services (AWS), Microsoft Azure, Thing Worx IoT Platform, IBM's Watson, Cisco IoT Cloud Connect, Salesforce IoT Cloud, Oracle Integrated Cloud, and GE Predix are a few of the leading IoT platforms available today. Future technologies are expected to revolve around database management, cloud computing, and analytics. As the cost of sensors is predicted to drop, the demand for cloud computing will rise quickly[58]. The integration of AI, IoT, blockchain technology and other emerging technologies will be a revolutionary step in many fields including IEM[59].

5.1.3Geographic Information Systems (GIS) and Remote Sensing

The current study included a thorough analysis of the role that remote sensing plays in evaluating various water security concerns in addition to other uses. From mobile GIS in the field to scientific analysis of production data at the farm manager's office, GIS is becoming an increasingly significant part of agriculture production worldwide. It helps farmers increase productivity, reduce expenses, and manage their land more effectively [60].

5.1.4Technologies for Renewable Energy

Environmental problems including global warming, climate change and ozone layer depletion are getting worse, more catastrophic, and more lethal. More industrialized and developing nations are working together to boost the use of renewable energy technology to address the issue. In order to achieve this, a variety of studies and inventions must be made, and the introduction of newer techniques and parts is greatly appreciated for the production of electricity based on renewable energy that is more economical and efficient. If the recommendations are taken into account, it is thought that the majority of the constraints associated with each renewable energy source can be resolved in the near future. In addition to technological improvement, favorable legislation, incentives, low costs and societal acceptability are needed to reap the benefits of renewable energy. In these areas, governments and non-governmental groups must be heavily involved. To guarantee appropriate resource selection and deployment of renewable energy depending on region, more study incorporating these aspects is also required[61].

5.1.5 Genomics and Biotechnology

Environmental Genomics (EG) based techniques have a great deal of potential for monitoring ecosystems and can currently meet the majority of the needs of monitoring programs. Adopting EG regularly is undoubtedly a paradigm change, but this technical advance will allow for the necessary up scaling to satisfy changing global monitoring requirements while overcoming the constraints of existing morpho-taxonomy approaches. Without a doubt, EG-based techniques will open the door to an ecosystem monitoring framework that is faster, more efficient, repeatable, and semi-automated[62].

Whatever the planned implementation approach, a more seamless transition will result from the following significant advances in science, technology, and society: (a) Experts, stakeholders, and regulators working together to create transdisciplinary and cooperative monitoring campaigns would make it easier for monitoring programs to close the gap between science and policy. (b) Regardless of the intended implementation strategy to be decided in future monitoring campaigns, a collection of reference morphological and molecular data in parallel, at least in a subset of reference points or during a transition period, will assure backward and forward compatibility of time series data sets. (c) To fully complete reference sequence databases, more representatives of the known biodiversity from a larger geographic area must be added. (d) It is necessary to provide a reference database structure for de novo strategies. To formally develop knowledge about the sensitivity of OTUs or ASVs to disturbance, a crucial prerequisite is the capacity to compare them with reliability in monitoring programs. (e) It is yet unknown at which taxonomic resolution level (haplotype, species, genus, family, order, class) HTS readings are most useful as genetic bioindicators in a particular circumstance. (f) It will be crucial to use rigorous experimental designs to separate the effects of natural (seasonal) variation from disturbance-induced community changes to identify novel genetic bioindicators in complex communities. (g) To create a structural and functional community metrics-based implementation approach, a foundational and repeatable research set is needed. A more widely applicable monitoring strategy that is less restricted by database and geographic coverage constraints will likely be established as a result of this project[63].

5.1.6Blockchain Technology

Blockchain technology stores data in an open network of digital blocks enabling transparent and safe data sharing across organizations It has the power to completely transform a wide range of sectors, including healthcare, finance, and supply chain management. Blockchain technology has the potential to address issues related to environmental sustainability. By tracking a product's origin, blockchain technology can help guarantee that it is made in an environmentally responsible manner. It can also be applied to develop incentive schemes that promote environmentally friendly behavior. However, there are a number of drawbacks to using blockchain technology. Blockchain, for instance, may need a lot of electricity, which may be bad for the environment. Due to being in the early stages of development, it still has significant legal and technological obstacles to be solved. In general, blockchain technology holds great promise for assisting in the resolution of environmental sustainability problems[64].

5.2 Sustainable Practices and Innovations:

Sustainable practices and Innovations include Nature-Based Solutions (NBS) and green infrastructure, which are essential components of Integrated Environmental Management (IEM). NBS harnesses natural processes to address environmental challenges, while green infrastructure integrates natural elements into urban settings to provide sustainable infrastructure services. Together, they enhance resilience, support biodiversity, improve water management, and promote human well-being. Integrating these approaches into IEM requires cross-sectoral collaboration, supportive policies, community involvement, and effective monitoring to create sustainable and resilient environmental management systems[65].

5.3 Circular Economy and Resource Efficiency:

The circular economy has been playing a major part in various sectors due to its principles like restoration instead of end-of-life concept, using renewable resources, bio-waste management, adopting a green and sustainable production and supply process, and many more[66]. The integration of principles of circular economy into IEM can transform the environment into a more sustainable one. Such a system will provide a closed-loop system that will focus on the manufacturing of products that can be reused, and recycled. This will result in minimizing waste thus increasing resource management[67]. Efforts should be made to spread awareness among the stakeholders and the general public about sustainability. Government policies and global collaboration will be required for any business to adopt circular practices. The Extended Producer Responsibility (EPR) can be expended by holding the manufacturers accountable for their products and asking them for sustainable design and waste reduction[68]. Adopting a no-waste approach using waste of one company as a raw material for other, will be a positive step toward environmental welfare and circular economy. Similarly further research in achieving carbon neutrality, industrial symbiosis, resource resilience, and urban mining will, surely, lead toward a sustainable and circular society[69].

6. Conclusions:

At the end of the discussion, we can state that integrated environmental management is both promising and uncertain. Modern technologies such as blockchain, artificial intelligence, ML, and IoT have revolutionized environmental monitoring and management in terms of accuracy, efficiency, and transparency. Environmental concerns are complex and dynamic, demanding the use of real-time data collecting, predictive analysis, and improved decision-making—all of which are achievable through technological advancements.

Green infrastructure and nature-based solutions (NBS) represent a paradigm shift for a sustainable and sustainable environment. These methods have many advantages, such as reducing climate change, increasing biodiversity and improving human well-being by harnessing natural processes and integrating them into ecosystem management and urban planning.

Strong legislative frameworks that promote interdisciplinary cooperation and long-term sustainability goals, including the Global Compact and the European Green Deal, increasingly help deliver these programs. Despite these encouraging advances, the IEM field still faces several challenges, such as protecting privacy and security, facilitating system interoperability across heterogeneous systems, and maintaining continued funding and public participation. To overcome these obstacles, we must constantly develop new ideas, collaborate across industries and implement flexible management plans that adapt to changing environmental conditions.

In conclusion, IEM can be critical to achieving a healthy balance between human activities and the environment by adopting technological advances and incorporating NBS and green infrastructure into all comprehensive management frameworks. Future environmental challenges and the well-being of the planet and its inhabitants depend on the continued development of IEM practices, supported by strong legislative commitments and broad stakeholder participation.

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