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Table of Content

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PHYSICAL AND CHEMICAL DEVELOPMENT TRENDS OF DOMESTIC WASTE LEACHATE CONCENTRATE TREATMENT TECHNOLOGY

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Abstract: Concentrate is a secondary pollutant produced by the membrane separation process during the treatment of domestic waste leachate. It contains a large amount of refractory organic matter, heavy metals and inorganic salts. This article focuses on the removal effect of physical and chemical treatment technology on pollutants in concentrated liquid and the advantages and disadvantages of each treatment technology. This paper can provide a reference for the scientific management of concentrated liquid.
Keywords: Concentrate; Landfill leachate; Recharge; Coagulation; Evaporation

1 PHYSICAL AND CHEMICAL TREATMENT AND DISPOSAL TECHNOLOGY OF CONCENTRATED LIQUID

With the significant improvement of people's living standards and economic level, the generation of urban domestic waste has grown rapidly. According to statistics, the global urban domestic waste generation is approximately 2.01 billion t/a, and is expected to reach 3.4 billion t/a by 2050. In 2019, my country's domestic waste removal volume reached 204 million tons, an increase of 6.81% compared with 2015. Currently, landfill is one of the main disposal methods of municipal solid waste. Compared with incineration and composting, landfilling has the advantages of simple process, lower cost, and is suitable for processing many types of waste. It is favored in most developing countries. However, after domestic waste is landfilled, a series of physical, chemical and Biochemical reactions produce landfill leachate. It is estimated that each ton of domestic waste produces approximately 0.1 t of leachate during the landfill cycle.

In my country, in order to meet the national standard "Pollution Control Standard for Domestic Waste Landfills" (GB 16889-2008) and the pollutant discharge requirements in various local standards, leachate usually adopts the method of "pretreatment + biochemical method + membrane treatment", especially the “pretreatment + MBR + NF + RO” process, has been widely used in leachate treatment plants of different treatment scales [1]. While meeting pollutant emission standards, the nanofiltration and reverse osmosis membrane separation processes will produce a concentrated liquid (referred to as concentrated liquid) with a volume ratio of 10% to 30%. This concentrated liquid is enriched in various refractory organic matter and heavy metals. and inorganic salts. How to handle and dispose of concentrated liquid has become one of the environmental issues that need to be solved urgently. To this end, this article focuses on analyzing the research and application progress of physical and chemical treatment technology in the treatment and disposal of concentrated liquids, and discusses the advantages and disadvantages of each treatment process.

Because traditional physical and chemical processes have the characteristics of low cost, easy operation, and high efficiency, they are widely used in the treatment and disposal of concentrated liquids. At present, the physical and chemical treatment and disposal methods of concentrated liquid mainly include recirculation method, evaporation method, solidification/stabilization method, coagulation sedimentation method, etc. [2].

1.1 Reinjection Method

For small treatment scale (<100 t/d) and economically underdeveloped areas, the recirculation method is one of the most commonly used disposal methods for concentrated liquid because of its simple operation, economical and reasonable. The recirculation method is to recirculate the concentrated liquid from the surface of the landfill or inside the landfill to the landfill. It uses the physical and chemical effects of the landfill and the biological metabolism of plants and microorganisms to absorb and degrade the concentrated liquid. Organic matter is intercepted and degraded. Previous studies have shown [3] that the recirculation of concentrated liquid increases the production of landfill gas and methane produced by waste degradation. It is speculated that 20% of the organic matter in the concentrated liquid participates in the methane production process. However, recent studies have found that as the landfill time increases, the number of recharges of concentrated liquid increases, which will gradually weaken the ability to reduce organic matter, salt, etc. in the effluent after recharge, affecting the water quality characteristics and microbial community structure of the leachate. At the same time, It will also have an impact on the stability of the landfill [4]. Studies have also confirmed that pollutants in the concentrate will accumulate in the leachate and reach high concentrations, especially volatile fatty acids, ammonia nitrogen and COD. Changes in these water quality parameters will interfere with the separation performance of the MBR membrane system, leading to membrane fouling and scaling problems, which in turn will lead to increased energy consumption [5].

1.2 Evaporation Method

The evaporation method uses external energy to evaporate the water in the concentrated liquid and reduce the volume of the concentrated liquid. The principle is a physical process in which volatile substances and non-volatile substances are separated from each other through liquid-gas conversion. During the evaporation treatment process, the volume of the concentrated liquid can be reduced by more than 90%, and the residual liquid after enrichment is mainly humus and soluble salts as well as a small amount of heavy metals [5]. Generally speaking, the evaporation system is only sensitive to the pH value of the incoming water, which depends on the corrosion resistance of the materials used to make the evaporator to acidic leachate. Due to the corrosive effects of acids and salts, the maintenance and continued use of the equipment are affected. There are serious limitations, and the treatment cost is high, and the water treatment is also affected [6]. In addition, from the perspective of recent practical engineering applications, the subsequent treatment and disposal of the residual liquid produced by evaporation is one of the problems faced by most leachate treatment companies.

1.3 Curing/Stabilization Method

Solidification is the process of converting contaminated liquid waste or waste into a physically durable concrete material that reduces permeability to prevent hazardous contaminants from entering the environment. The solidification/stabilization process mainly produces stable solid substances by mixing hazardous waste with binders such as cement to ensure the safe transportation and storage of waste [7]. Che Ning et al.[8] studied the leaching characteristics of pollutants when the concentrate and fly ash are solidified. The results show that replacing water with the concentrate has no significant impact on the strength of the solidified body. In addition, the leaching concentrations of organic matter and heavy metals meet the leaching toxicity requirements and can be used as building materials. In recent years, some people have also studied high-strength cement to replace ordinary cement and reduce the cement dosage ratio to reduce the volume of the solidified body. However, based on existing research results, it is difficult to estimate the long-term stability and service life of these solidified bodies [9]. For concentrates with a high content of heavy metals, low content of biodegradable substances, and easy formation of complexes, solidification and stabilization treatments can be selected.

1.4 Coagulation and Sedimentation Method

The coagulation sedimentation method mainly adds chemicals to flocculate the organic pollutants in the concentrated solution through electroneutralization, compressed electric double layer, adsorption bridging, net capture and sweep, etc., and then removes them through solid-liquid separation. A method of suspending solids and colloids in water. The pollutant treatment efficiency of this process is mainly affected by factors such as the water quality of the concentrate, the properties of the coagulant, water temperature conditions, and operating conditions, among which the type and dosage of the coagulant play a decisive role [10]. Long et al. [11] studied the removal effects of different types of coagulants on pollutants in concentrated liquids. The results showed that compared with ferrous chloride, ferrous sulfate, and polyaluminum chloride, ferric chloride has a greater effect on COD. It has the highest removal rate and can reduce the COD concentration in the concentrated solution from 4000 mg/L to 718 mg/L. However, it has recently been discovered that the coagulation and sedimentation method is generally used as a pretreatment link in the concentrate treatment process, especially to remove refractory organic matter, such as humus.

2 CONCLUSION

At present, concentrated liquid is one of the main by-products in the leachate treatment process, and physical and chemical treatment and disposal technologies such as recirculation method and evaporation method have been studied. However, based on existing research, various physical and chemical treatment technologies are not practical in practice. There are still certain disadvantages or defects in application. In the future, combined treatment processes should be considered, such as physical chemistry + biochemistry, physical chemistry + advanced oxidation, etc., to improve the removal efficiency of pollutants and reduce treatment costs.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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RESEARCH AND DEVELOPMENT OF ECOLOGICAL INTEGRITY ASSESSMENT TECHNIQUES FOR ESTUARINE ENVIRONMENTS

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Abstract: Estuaries are important transition areas connecting freshwater and marine environments and play an important role in maintaining biodiversity and ecosystem services. The ecological integrity of estuaries is critical to the sustainable management and conservation of ecosystems. This article conducts a bibliometric analysis on the ecological integrity evaluation of estuaries, focusing on the evaluation methods and index selection of estuary ecological integrity evaluation. It mainly includes physical and chemical indicators, biological indicators and socioeconomic indicators. The importance of selecting different indicators for the evaluation of estuary ecological integrity is systematically analyzed through case studies. Finally, it was pointed out that some problems still faced in the evaluation of estuary ecological integrity were pointed out, and several suggestions were put forward to address these problems.
Keywords: Ecology; Aquatic ecology; Estuarine ecology; Marine environment

1 BIBLIOMETRIC ANALYSIS OF ESTUARY ECOLOGICAL INTEGRITY

In a broad sense, an estuary refers to the junction area formed when a river merges into a receiving water body, and is the transition zone between a river and a receiving water body. According to the different water receiving bodies, estuaries can be divided into types such as estuaries entering the sea, estuaries entering the lake, estuaries entering the reservoir and tributary estuaries. The term's etymology comes from the Latin word "Aestus", meaning "tidal". The narrow concept of estuary only includes areas affected by tides and runoff, that is, estuaries that enter the sea [1]. The estuaries appearing in this article all refer to estuaries in a narrow sense. As the junction where fresh water and sea water meet, the estuary is an important area where land and marine ecosystems are interconnected. It not only carries the material exchange between the basin and the ocean, but also has the characteristics of river and marine ecosystems [2]. Due to its unique geographical and environmental conditions, the estuary area often becomes an economically developed and densely populated area [3]. In recent years, with the development of economy and society and population growth, estuary areas have been affected by a series of man-made stress factors, resulting in increased sediment, nutrient and pollutant loads, and habitat degradation [4-5]. They change the community composition and species diversity of the estuary area, destroy the ecological functions of the estuary, and also have a huge impact on the ecosystem services that the estuary can provide [6], seriously restricting the development of the estuary area. Therefore, it is of great significance to evaluate the integrity of the estuary ecosystem. In this regard, water environment quality is one of the important evaluation indicators. Various methods such as water quality index and pollution index can be used to evaluate the environmental quality of the estuary [7]. Aquatic ecological integrity evaluation is a quantitative and systematic evaluation method. It is a comprehensive and comprehensive evaluation of the structure, function and process of the ecosystem, which can provide scientific basis for ecological protection and management. Research on the integrity of aquatic ecosystems is an international hot spot, and maintaining the health and stability of aquatic ecosystems has become the goal and management strategy of countries around the world [8].
The concept of ecological integrity originates from ecology, and its development can be traced back to the mid-20th century. In 1949, Leopold first proposed the concept of "land ethics". He believed that "it is correct for human activities to develop in the direction of protecting the integrity, stability and beauty of biological communities. On the contrary, it is wrong [9]." However, he did not The integrity he mentioned was further explained; in 1981, Karr and Dudley gave the first clear definition of ecosystem integrity. Integrity is a health dimension that reflects the ability of an ecosystem to maintain its organization (structure and function). The degree to which an ecosystem maintains its natural state, stability and self-organization ability under external disturbance provides an effective tool [10]; in the early 1990s, the Organization for Economic Cooperation and Development (OECD) established The Pressure-State-Response Framework (PSR) was developed, which was used to establish ecological environment assessment index systems in various countries [11]; in 1989, Rapport proposed that an ecosystem with good integrity should have the ability to maintain its own organizational structure Integrity and the ability to self-recover after being stressed [12]; in 1992, Costanza summarized the definition of ecosystem integrity, that is, the ecosystem should be disease-free, stable or recoverable, while maintaining diversity or complexity, and has the potential for vitality or growth, while maintaining an automatic balance between the system and its elements [13]. At present, domestic and foreign scholars have carried out a large number of studies on the evaluation of water ecological integrity, and their research scope covers multiple ecosystems such as rivers [14-15], wetlands [16-17], lakes [18], and reservoirs [19] . However, most ecological integrity assessment studies are conducted in rivers and streams. Since the ecological characteristics of estuarine ecosystems are

relatively complex and are greatly affected by human activities, there are relatively few studies on their integrity assessment [20]. This article will focus on the methods, index selection and weight allocation of estuary ecological integrity assessment, aiming to provide reference for the protection and management of estuary ecosystems.

In order to understand the current development process of research on estuary ecological integrity evaluation, as well as the emerging trends in the research frontier, methods such as cluster analysis, emergent analysis, and literature collection were used, and the knowledge graph tool CiteSpace was used to analyze the relevant aspects of estuary ecological integrity evaluation. A bibliometric analysis of the literature was conducted, which mainly summarized the annual changes in publications in the past 30 years, and determined the main subject categories; as well as identified emerging research hotspots, and finally predicted development trends.

1.1 Search Methods and Data Sources

This article selects the core collection database in the Web of Science (WOS) database as the source of research data. The document type is: article, the time span is set to 30 years, and the search time includes articles published from 1993 to January 1, 2023. , search using keyword combinations linked by Boolean operators "AND" and "OR", the search formula is: TS = ("Estuar *") AND ("ecological quality" OR"ecological integrity"OR"ecological health") . The obtained documents were identified and screened, and 590 records were finally identified, and their data sources were analyzed.

At the same time, CNKI data is selected as the Chinese literature database. Document type selection: papers, time span is not limited, and CNKI professional search tool is used. The search formula is: SU= ("estuary" * "ecology") and SU= ("health" + " "Completeness"), 52 records were obtained. After identifying and filtering the search results, only 29 relevant documents were obtained. Due to the low sample size, the imported software analysis could not obtain effective results, so this analysis only used the WOS database Literature was retrieved as data source.

1.2 Analysis of the Number of Articles Published Over the Years

Statistically analyze the number of articles published each year in the field of estuary ecological integrity assessment, and obtain the number of articles published over the years (Figure 1). The results show that the research interest in estuary ecological integrity evaluation has been increasing year by year in the past 30 years. In the first few years, from 1994 to 1999, only a small amount of literature was published. Starting from 2000, the number of articles published gradually increased, increased rapidly in 2005, and has remained at a high level since then. Especially after 2007, the number of published articles increased year by year, showing an exponential growth trend. The number of published articles reached a peak in 2012. According to Rocha et al. [21], the possible reason is the academic community’s evaluation of aquatic ecological integrity. The attention has become more and more intense, and some journals have even published special issues for it. For example, Biologia Acuatica published a special issue on ecological quality in 2012. In 2021 and 2022, the number of published articles reached 53 and 58 respectively, further demonstrating the rapid development momentum of this field. Judging from the general trend, research on estuary ecological integrity evaluation has continued to grow in the past 30 years, showing an increasing trend year by year, indicating that this field has received widespread attention and has important research value and practical application in the field of ecological environment significance.

1. 3 Keywords and Emergence Analysis

Figure 1 shows the occurrence time and duration of each keyword, reflecting the length of influence of the keyword in the research field. In addition, it should be noted that the blue line in the table represents the entire research period (2002-2023), and the red line represents the duration of the citation burst [22-23]. In addition, in order to more accurately explore the research topics in the field of estuary ecological integrity assessment and grasp its development rules, we divided the development from 2002 to 2023 into three periods. The current stage can be summarized as concept exploration of ecological integrity assessment (2002-2009), ecological indicator monitoring and ecological integrity assessment framework construction (2010-2016), ecological risk assessment and pollutant source tracing (2017 -2023). At this stage of exploring the concept of ecological integrity assessment, scholars are not very clear about the concept of ecological integrity, and they mainly focus on specific indicators such as water quality conditions for water bodies; at this stage of constructing the ecological indicator monitoring and ecological integrity assessment framework, researchers realize that water bodies It is inseparable from the ecosystem, and began to study the integrity of water ecology from a holistic perspective, pay attention to comprehensive assessment and management, and began to use various models to simulate the evolution of ecosystems; in the ecological risk assessment and pollutant source tracing stages, Scholars have conducted a series of studies on ecological risk assessment and the spatial and temporal distribution of trace metal elements, aiming to reveal the impact of pollutant distribution on ecosystem integrity.

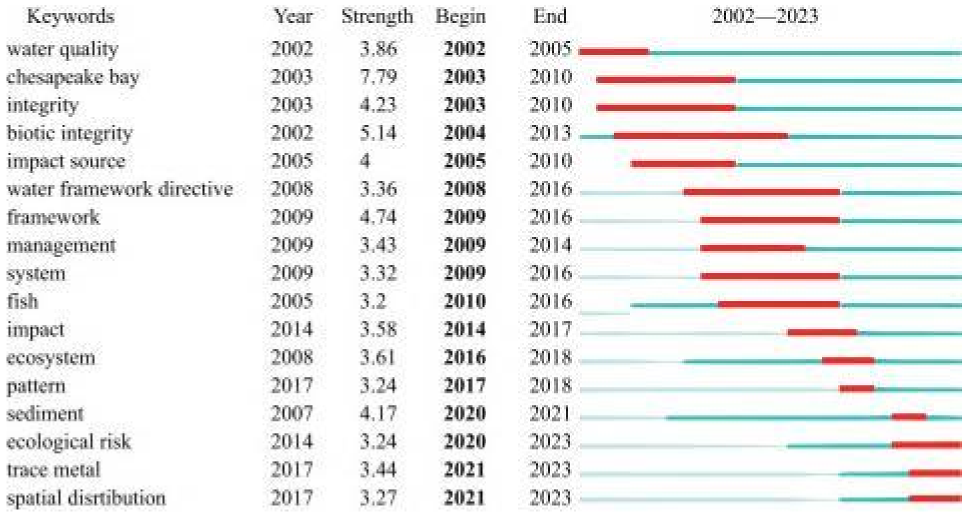

Figure 1 Time map of the top 17 keywords with emergent intensity in the field of estuary ecological integrity assessment

Note: The greater the value of emergence intensity, the faster the research interest of the keyword grows during this period; the start time and end time represent the time when the keyword emergence begins and the emergence ends respectively; the red segment in the timeline represents the explosive growth of keyword research. time period.

2 SELECTION OF ESTUARY ECOLOGICAL INTEGRITY EVALUATION INDICATORS

Estuaries show unique differences compared with other water bodies, mainly reflected in water mixing, tidal influence, sedimentation, ecosystem complexity, concentration of human activities, and salinity changes. According to the research of Elliott and Quintino [24], estuaries are places where fresh water and sea water meet each other, which leads to the complexity of hydrological and chemical characteristics. The effect of tides has a significant impact on the water level and flow in the estuary area, further increasing the complexity of hydrodynamics [25]. In addition, according to Stevenson and Kennish [26], the sedimentation phenomenon in the estuary area is caused by the slowdown of river water velocity, which has a profound impact on the evolution of topography and landforms. The ecosystem in the estuary shows extremely high complexity, supporting a rich variety of biological species due to the interaction of freshwater and saltwater [27]. Finally, the estuary area is a hotspot of human activities. Activities such as fishing, shipping, and urban development make this area a complex system in which natural and human factors interact. These differences make estuaries a key area of multidisciplinary research in ecology, geography, and hydrology, which are of far-reaching significance for understanding the functions and responses of complex aquatic ecosystems and promoting sustainable development.

The selection of estuary ecological integrity evaluation indicators is a key step in the research on estuary ecological integrity evaluation, and plays a decisive role in the scientific nature of subsequent evaluation results. In order to enable the estuarine ecosystem integrity assessment to solve practical problems and provide scientific basis for management decision-makers, it is necessary to select indicators based on the characteristics of the ecosystem [28]. Appropriate evaluation indicators should accurately reflect the key factors of ecosystem integrity [29]. The selection of estuary ecological integrity evaluation indicators should follow the following principles: indicators should be able to reflect the integrity status of the estuary ecosystem [30] and be able to accurately and reliably measure changes in the estuary ecosystem; indicators should be comparable [31] and be able to Comparisons should be made between different estuarine ecosystems; indicators should be operable [32] and can be measured through existing technical means. In addition, when selecting estuary ecological integrity evaluation indicators, a variety of indicators should be comprehensively considered, including water quality indicators, fish indicators, benthic biological indicators and heavy metal indicators in sediments, etc., to comprehensively and accurately assess the ecological integrity of the estuary. [33]. Combined with existing research, currently scholars mainly divide estuary ecological integrity evaluation indicators into three categories: physical and chemical indicators, biological indicators and socioeconomic indicators. Among them, biological indicators are the most commonly used indicators, because one component of evaluating ecological integrity is measuring biological integrity, which usually emphasizes the analysis of plankton, benthic organisms, macroalgae, and fish.

2.1 Physical and Chemical Indicators

When it comes to the assessment of estuarine ecosystems, physicochemical indicators are an essential part. Physical indicators are a direct measure of the physical environmental conditions of the estuary (such as water quality, sediment quality, and hydrology) [34] and help detect changes caused by human influence. Chemical indicators are used to evaluate the content and pollution of chemical substances in the estuary water. situation. Commonly used physical and chemical indicators in estuaries are shown in Table 1. The specific characteristics and functions of the estuary under study require careful consideration when selecting physicochemical indicators for estuarine ecological integrity assessment. For example, the hydrodynamics of an estuary, such as the magnitude and timing of tidal exchanges, can affect the suitability of certain indicators for assessing ecological integrity [35]. Tide is a crucial driving force in estuarine ecosystems, and its regularity has a profound impact on ecosystem structure and function. Scholars have emphasized the critical role of tides on estuarine hydrodynamics and hydrology. According to the research of Galois et al. [36], changes in water flow caused by tides have a significant impact on estuary sediment transport, dissolved oxygen distribution, and material circulation in the ecosystem. Under extreme meteorological events, tidal patterns may change, further affecting the stability and adaptability of estuarine ecosystems. In addition, research by Smith and Hollibaugh [37] showed that tides also have a significant impact on the spatial distribution and abundance of microorganisms and benthic organisms in estuarine ecosystems. Similarly, the specific characteristics of estuarine habitats, such as the type and distribution of vegetation, will also affect the selection of physical and chemical indicators to measure changes in habitat quality and quantity [38]. Furthermore, the selection of physicochemical indicators should be guided by the overall goals and objectives of the ecological integrity assessment, including the specific management issues that the assessment is intended to address. For example, if the main management goal is to reduce nutrients entering an estuary, then nutrient indicators such as nitrogen and phosphorus concentrations may be more meaningful than other indicators because nitrogen and phosphorus are the 2 major nutrients for biological growth and they are The concentration in the water body directly affects the growth and reproduction of algae and other organisms [39]. Excessive nitrogen and phosphorus can lead to eutrophication and trigger algal blooms. Estuary areas are often more prone to eutrophication due to the intersection of fresh water and seawater and intense human activities. It should be noted that any single indicator cannot reflect the full picture of the ecological integrity of the estuary, and a set of complementary indicators should be used to provide a more comprehensive assessment [25]. The selection of physicochemical indicators should also be regularly reviewed and updated to ensure that they continue to be relevant and effective in assessing ecological integrity. The selection of physical and chemical indicators in the ecological integrity evaluation of estuaries is not significantly different from that in other aquatic ecosystems.

Table 1 Commonly used physical and chemical indicators for estuary ecological integrity evaluation

Indicator type	Contains indicators	Indicator role
Hydrological indicators[14,16,40]	Salinity, substrate, depth, flow characteristics, flow deviation, tidal range and sediment transport rate, average rainfall, flood intensity index, proportion of annual runoff entering the sea, etc.	Provides information on estuarine circulation and sedimentation processes
Physical indicators Geomorphological indicators	Shoreline erosion, sedimentation rates and channel stability, etc.	Indicates the physical processes that shape estuarine environments and provide important habitat for aquatic species
Chemical indicators[14,43-45]	pH, dissolved oxygen, ammonia nitrogen, nitrate, phosphate, heavy metals, biochemical oxygen demand, etc.	Provide information on water pollution levels, nutrient content, accumulation of harmful substances, etc.

2.2 Biological Indicators

In addition to physicochemical indicators, biological indicators are also crucial for assessing the ecological integrity of estuaries, as they provide information on the impact of environmental stressors on biological communities and can help us understand biodiversity, ecological processes and ecosystem stability Sex[46]. These indicators typically involve measurements of species richness, species composition, and biodiversity in ecosystems. For example, species diversity index can be used to evaluate the number and relative abundance of different species in estuarine ecosystems, which helps to understand the interactions between various organisms and the allocation of ecological niches in estuarine ecosystems. Indicators such as species composition can more specifically describe the biological composition of the estuarine ecosystem, including fish, zooplankton, phytoplankton, benthic organisms, etc., and evaluate their ecological functions. Benthic invertebrates, phytoplankton, and fish are often used as biological indicators for estuarine ecological integrity assessment because they are sensitive to changes in water quality and habitat conditions [47] .

In specific applications, Ma Tingting et al. [48] selected multiple indicators, including the phytoplankton Shannon-Wiener index, to comprehensively assess the integrity of the main estuaries in the Taihu Lake Basin in my country; Hallett et al. [49] used the fish community index to quantify Ecological status of estuaries in southwestern Australia; Kido[50] used the stream biological integrity index to evaluate the integrity status of 18 streams in Hawaii, USA, and confirmed this by sampling and analyzing 39 locations (including 6 estuary sections). effectiveness of this method. However, it is worth noting that due to the existence of the estuary quality paradox [24, 51], that is, due to the high variability of the physical and chemical properties of estuaries, compared with other freshwater or marine ecosystems, estuarine biological communities are less resistant to environmental pressures. More acceptable. Under the same stress conditions, freshwater or marine ecosystem species may regard it as an environmental stress, while estuarine organisms have negligible impact on them due to their high tolerance. Le et al. [33] pointed out that some common endemic species in estuaries include special fish, crustaceans, and plant species with high salt tolerance that can survive in the transition zone between fresh water and sea water. In terms of adaptive strategies, some studies have shown that estuarine biota often exhibit a high degree of adaptability to changing salinity, water temperature, and hydrodynamic conditions. This may include changes at multiple levels such as behavioral adaptation, physiological adaptation, and genetic adaptation [52]. For example, fish species in some estuarine areas may exhibit migratory behavior under different salinity conditions to adapt to seasonal changes in the waters. Therefore, when selecting biological indicators (species composition, biodiversity, etc.) based on the structural characteristics of the estuary to evaluate the ecological integrity of the estuary, the error caused by this situation on the evaluation results should be taken into consideration. In order to solve the impact of the estuary quality paradox on the evaluation results, many scholars have proposed some corresponding solutions. For example, Elliott and Quintino [24] pointed out that we cannot rely too much on the structural characteristics of the ecosystem to identify the degree of stress that human activities have on estuarine ecology. Instead, it is necessary to combine structural characteristic indicators with functional characteristic indicators, and Hess et al. [53] found that using foraminiferal monitoring methods to detect environmental disturbances in estuaries can effectively solve the problem of estuary quality paradox.

2.3 Socioeconomic Indicators

Socioeconomic indicators can reflect the interrelationship between the estuary ecosystem and human activities. It includes the consideration of social and economic activities around the estuary, which have a direct or indirect impact on the integrity of the estuary ecosystem. According to Rapport et al. [54], the selection of socioeconomic indicators should be based on their impact on and dependence on ecosystem services, as well as their interaction with ecological indicators. Through literature search, the most commonly used socioeconomic indicators include population density, land use, agricultural and industrial activities, and water resource utilization [55]. Population density is an important socioeconomic indicator, which represents the ratio of population to area in the area surrounding the estuary. Increased population density often means increased demand for land and water resources, which may lead to increased land development and water use, thereby impacting estuarine ecosystems. Research shows that estuaries in areas with high population density often face greater pollution pressure and resource pressure, which may lead to reduced water quality, habitat degradation, and loss of biodiversity [56]. At the same time, the land use patterns in the surrounding areas of the estuary have a profound impact on the integrity of the estuary ecosystem. Different land use types may have different impacts on estuarine ecosystems. For example, urbanization and agricultural expansion may lead to the reduction of habitats such as wetlands and mangroves, thereby affecting biodiversity and ecological functions [57]. Proper planning and management of land use is one of the important measures to maintain the ecological integrity of estuaries. Agricultural activities can pollute estuarine waters through the use of pesticides and fertilizers, especially when farmland runoff enters estuaries. Industrial activities may discharge harmful substances and wastewater, causing direct negative impacts on estuarine ecosystems. Water resource utilization is also a key indicator for evaluating socioeconomic impacts. Water is a key element of estuarine ecosystems and a basic need for agriculture, industry and urban life. Excessive utilization of water resources may lead to excess nutrients in the water body, triggering algae blooms and deteriorating water quality, including reduced salinity, changes in nutrient dynamics, increased sedimentation, and disruption of physical processes such as tidal mixing and scouring. Negatively affecting estuarine ecosystems [58], these changes may adversely affect biodiversity, impair ecosystem services such as fisheries and coastal protection, and undermine the overall function of estuaries. Salinity is an important indicator for assessing the impact of reduced seawater flow, because when it deviates from the natural balance it signals an increase in ecological stress. Monitoring salinity levels provides us with valuable information to help us understand the extent and severity of this flow reduction and is a key parameter in understanding the ecological consequences for estuarine biodiversity, ecosystem services and overall functioning of balanced water resources use and Protecting estuarine ecosystems is an important issue in socioeconomic planning and management. Balancing water resource utilization and protecting estuarine ecosystems are important issues in socioeconomic planning and management. Since estuaries are closely related to human activities and economic development, compared with other aquatic ecosystem integrity assessments, socioeconomic indicators have a greater impact on the evaluation results when evaluating estuary ecological integrity. The selection is an integral part of the evaluation process.

3 ESTUARY ECOLOGICAL INTEGRITY EVALUATION METHOD

Ecosystem integrity assessment methods can be divided into two categories: indicator species method and indicator system method. The indicator system method can be further subdivided into methods such as comprehensive indicator evaluation method, analytic hierarchy process, principal component analysis method and entropy weight method [42]. When evaluating ecosystem integrity, multiple ecological indicators are often used, and their weighted scores are integrated through mathematical methods to form a comprehensive indicator system to describe the structure and function of the ecosystem [44]. In recent years, a large number of specific quantitative methods have been used in the practical application of the indicator system method, and multiple methods are used in combination and cross-wise, not limited to a single fixed method system. Since the indicator species method is usually applicable to a single ecosystem and requires a large amount of species measurement data, while the indicator system method is not limited by the number or type of ecosystems or data sources, the latter is currently used for ecological integrity assessment methods. It is more extensive than the former [59].

3.1 Indicator Species Method

The indicator species method is one of the two main assessment methods for evaluating ecosystem integrity. This method is mainly based on the number of dominant species, key species and sensitive species in the community to analyze environmental changes and assess the integrity of natural ecosystems. It includes three categories: biological index method, diversity index method and biological integrity index method. In 1981, Karr and Dudley proposed an evaluation method based on the Fish Integrity Index (F-IBI) [10], and later developed the Benthic Integrity Index (B-IBI) and Algae Integrity Index. Index (D-IBI)[60]. At present, IBI evaluation methods have included a variety of biological groups, such as phytoplankton [61-62], macrobenthos, fish and algae [63]. The IBI is mainly used to assess the integrity of aquatic ecosystems based on fish and zooplankton [64-66], while the Shannon-Weaver Biodiversity Index is generally used to assess the integrity of aquatic ecosystems based on phytoplankton and zooplankton [67] . Benthic macroinvertebrate communities are the most consistently emphasized biotic component of aquatic ecosystems when developing methods to assess biotic integrity. There are currently a large number of methods, including a variety of indices, indicators and evaluation tools [68]. Due to the specificity of the estuary itself, not all indicators can be applied to the ecological integrity evaluation of the estuary. For example, AZTI's marine biotic index (AMBI) and benthic biotic index (BENTIX), and other indices designed to determine stress are related to the abundance of tolerant species, and estuarine waters due to their Unique ecological characteristics, such as high natural organic matter content, are typical of tolerant species. These characteristics may cause the application of indices such as AMBI and BENTIX in estuarine waters to produce inaccurate results, that is, it is mistakenly believed that the ecological status of the estuary has been downgraded. Furthermore, due to the low species diversity in estuarine waters, some indices (such as AMBI and biomass quality index (BQI)) may not be used or calculated because their thresholds for use or calculation are reached.

Although the indicator species method was developed in the early days and widely used in ecosystem integrity assessment, in the estuary ecosystem integrity assessment, there are also cases where fish community index and zooplankton integrity index are used to assess ecological conditions [48-49] . However, the indicator species method also has certain limitations, as follows: depending on the identifiability of the species, this method requires accurate identification and classification of benthic organisms, but some species may be difficult to identify or classify, resulting in poor assessment Inaccuracy; relies on the consistency of environmental conditions. This method assumes that certain species only occur under specific environmental conditions. If environmental conditions change, the reliability of these species will also be affected; affected by human interference, Human activities have had extensive and complex impacts on ecosystems, which may interfere with the survival and distribution of benthic organisms, thus affecting the accuracy and effectiveness of the indicator species method. Therefore, compared with composite ecosystems, the indicator species method is more suitable for evaluating natural ecosystems that are rarely disturbed by human activities.

3.2 Indicator System Method

The indicator system method is based on ecosystem characteristics and service functions, and uses mathematical methods to determine the integrity of the ecosystem. This method combines multiple indicators, including ecosystem structure, functional succession process, ecological services, etc., and reflects the integrity status and change trend of the ecosystem. For example, Jiang et al. [69] used multi-source remote sensing data and field measurements, and adopted a comprehensive evaluation method to study the ecological integrity and changes of the Jiulong River Estuary from 2004 to 2009. Compared with the indicator species method, the indicator system method can reflect the transformation of ecosystem integrity assessment at different scales. It is a more comprehensive and comprehensive ecosystem integrity assessment method. It is also the most widely used ecosystem integrity assessment method at home and abroad. Evaluation method[70]. The main steps of the indicator system method are shown in Figure 3. Indicator selection and indicator weight allocation are two very important key steps. The relevant content of indicator selection has been discussed in Section 2 of this article. This section mainly introduces the methods related to indicator weight allocation.

In the evaluation of estuary ecological integrity, different evaluation indicators may have different effects on the evaluation results. Therefore, it is necessary to more accurately consider the contribution of each indicator through reasonable weight distribution, so as to comprehensively reflect the integrity status of the estuary ecosystem. . At present, in the ecological integrity evaluation, the methods commonly used by scholars include the analytic hierarchy process, the entropy weight method, the fuzzy comprehensive evaluation method, and the gray correlation analysis method. Among them, the analytic hierarchy process calculates the weight of each indicator through the hierarchical structure model and judgment matrix; the entropy weight rule uses the information entropy principle and the entropy weight criterion to determine the weight of indicators; the fuzzy comprehensive evaluation rule uses the concepts and algorithms of fuzzy mathematics to The indicators are converted into fuzzy numbers and comprehensively evaluated; the basic idea of the gray correlation analysis method is to find out the correlation between different indicators by calculating the correlation between indicators, thereby identifying indicators of relative importance. The principles and applicability of the above methods.

3.3 Differences in Ecological Integrity Assessment Methods Between Estuaries and Other Water Body Types

A major difference between estuaries and other freshwater ecosystems is that the estuary environment is highly variable, including physical and chemical changes in salinity, substrate, depth, fine particles, and maximum turbidity zones rich in organic matter [41]. In addition, estuaries are also subject to human impacts, including water pollution, changes in estuary surface size, and channel management [74]. Due to frequent human activities, the estuary area has been disturbed by river management, construction, industry, agriculture, and urbanization. These disturbances are more serious than inland ecosystems. Based on the characteristics of the estuary ecosystem, there are differences between the ecological integrity evaluation of estuaries and the ecological integrity evaluation of other water body types. The evaluation object of estuary ecological integrity assessment is the estuary and its surrounding sea areas and coastal zones, while the evaluation object of inland ecological integrity assessment is the ecosystem in inland areas. The evaluation of estuary ecological integrity needs to consider the special environment and species composition of the estuary ecosystem. The evaluation indicators include factors such as hydrodynamic conditions, seawater and river water quality, species diversity, land use and human activities. The evaluation of inland ecological integrity evaluation Indicators mainly include factors such as land use, vegetation cover, soil quality, biodiversity and hydrological conditions. In addition, because the estuarine ecosystem is at the junction of land and sea, data acquisition is relatively difficult and requires data from multiple departments and fields. The evaluation process is more complex than that of inland ecosystems.

To sum up, the ecological integrity evaluation of estuaries is mainly reflected in three aspects compared with the ecological integrity evaluation of other water bodies: (1) differences in evaluation objects and their own characteristics; (2) differences in selection of evaluation indicators; (3) data acquisition Differences in difficulty.

4 RESEARCH CASES OF ESTUARY ECOLOGICAL INTEGRITY ASSESSMENT

At present, scholars at home and abroad have done a lot of research on the ecological integrity evaluation of estuaries. In these studies, most indices are calculated based on species community composition and ecosystem structural and functional attributes, combined with multiple independent indicators. For example, Ferreira [75] considered the physical characteristics and biochemical characteristics of the estuary, combined with independent indicators such as water quality characteristics, dynamics, sediment characteristics, and anti-interference ability, to construct a comprehensive evaluation system for ecological integrity. Borja and Dauer [76] pointed out that when different indicators covering various responsive ecological and community characteristics are combined together, more accurate and comprehensive assessment results will be obtained. Among the indicator groups, species richness-composition indicators are the most widely used in current indices. Among them, indicator species or taxa related to estuary quality characteristics usually dominate the index.

Generally speaking, foreign research on the evaluation of estuary ecological integrity is relatively in-depth, involving many aspects, including the application of physical, chemical, and biological indicators, model simulation methods, and research on comprehensive evaluation methods. For example, research in European and American countries focuses on using comprehensive evaluation methods to combine multiple ecological indicators to comprehensively assess the integrity and functions of estuarine ecosystems. For example, Chiu and Wu [77] developed a statistical modeling method for the latent health factor index (LHFI), which combines multiple ecological indicators, including water quality, habitat, and biodiversity, to conduct a comprehensive assessment of estuarine ecosystems. In addition, foreign scholars have also applied remote sensing technology to the evaluation of estuary ecological integrity, using high-resolution satellite data and geographic information systems to conduct refined research on the spatial distribution and changes of estuary ecosystems [78]. In China, the research trend of estuary ecological integrity evaluation has gradually expanded from single biological indicators to multi-disciplinary comprehensive evaluation. Many studies focus on establishing an evaluation system and index system suitable for China's unique estuaries, such as studies on the Yangtze River Estuary, Yellow River Estuary, etc., emphasizing the comprehensive consideration of the impact of specific environmental conditions such as tides and salinity on the evaluation results [43,45]. At the same time, domestic scholars have also begun to pay attention to the impact of socioeconomic factors on estuarine ecosystems, and gradually introduced socioeconomic indicators to comprehensively evaluate the ecological integrity of estuaries [28].

At present, domestic scholars have established an appropriate evaluation index system based on the characteristics of my country's estuaries. Sun Tao and Yang Zhifeng [79] pointed out that the integrity of the estuary ecosystem should comprehensively consider three aspects: environmental quality, biological quality, and the impact on the watershed and humans; Peng Tao and Chen Xiaohong [14] considered the environmental, ecological, and socioeconomic aspects A total of 17 indicators were selected from 3 aspects to evaluate the ecosystem integrity status of typical estuaries in the Haihe River Basin; Liu Chuntao et al. [40] improved the PSR model and established the DPSRC model, from "driving force-pressure-state-system response"Control" five aspects to evaluate the ecological integrity level of Liaohe Estuary; Hui Xiujuan et al. [80] used principal component analysis to comprehensively reflect the physical and chemical characteristics of water bodies, aquatic life characteristics, water body hygiene characteristics, and habitat environmental characteristics; Dong Junjie et al. [15] By comprehensively integrating indicators such as bank slope stability, riverbank vegetation coverage, and the degree of artificial interference in the riparian zone, the integrity of the riparian zone in the river section from Yuehe Mouth to Shihe Mouth was evaluated; Niu Mingxiang et al. [43] based on the PSR model, from the Yellow River Based on the biological ecology, environmental quality, social economy, management measures and human health of the estuary area, 50 evaluation indicators were selected to construct an evaluation index system for the ecosystem integrity of the Yellow River estuary area; Zhang Rui et al. [81] based on the fish in the Yellow River estuary waters Based on the characteristics of the regional composition, 12 evaluation indicators were proposed from the aspects of fish species composition, breeding symbionts, fish tolerance and nutritional structure, etc., and an evaluation index system for the fish biological integrity index in the Yellow River estuary waters was constructed and formulated. evaluation criteria.

In summary, foreign research has made great progress in the evaluation of estuary ecological integrity, but there are still some differences in the understanding of the connotation of ecological integrity [82]. Domestic research, based on learning from foreign research, has formed an evaluation index system and methods suitable for China's estuarine wetlands, but it is still necessary to strengthen the comprehensive evaluation of river ecosystems and habitat research. Table 2 lists some relevant research cases on ecological integrity evaluation by domestic and foreign scholars. Future research can learn from foreign experience, strengthen cooperation and exchanges in domestic and foreign research, and jointly promote the development of the field of estuary ecological integrity assessment.

5 PROBLEMS AND PROSPECTS

Evaluating the ecological integrity of an estuary is a complex task involving multiple ecological factors, evaluation indicators and evaluation methods. Although many studies have made progress in this field and established various evaluation systems and methods, there are still some problems that need to be solved.

(1) Complex structure and ecological integrity challenges

Estuarine ecosystems have attracted much attention due to their complex structures. Biodiversity and structural complexity complicate the evaluation of ecological integrity, which requires comprehensive consideration of various biotic and abiotic factors. The estuarine system is composed of three main parts: land, rivers and oceans, including a wide range of biotic and abiotic components. There are complex interactions and feedback mechanisms between these components. The biodiversity and structural complexity of the estuarine system increase the ecological Challenges of integrity assessment.

(2) The impact and complexity of human activities are increasing

The impact of human activities on estuarine systems cannot be ignored. Activities such as water pollution, coastline development, and fishing have serious impacts on the ecosystem, and may even lead to irreversible changes in the ecosystem. How to identify the response relationship of human activities to the ecological integrity of the estuary puts forward higher requirements for evaluation work.

(3) Inconsistency in evaluation methods limits comparison and comprehensive evaluation

The lack of consistent and standardized evaluation methods globally or even nationwide makes the evaluation of estuarine ecosystems face greater limitations in cross-national and cross-regional comparisons and overall comprehensive evaluation. The lack of universally accepted evaluation standards and methods leads to insufficient comparability of evaluation results between different regions and countries, thus hindering a consistent and comprehensive understanding of global estuarine ecosystems.

Based on this, in the future ecological integrity evaluation of estuaries, we should focus on the following aspects: 1) Comprehensively consider various factors and select appropriate evaluation indicators and methods to comprehensively and accurately assess the integrity of the estuary ecosystem. Including multiple indicators, such as species diversity, ecosystem functions and ecosystem services; 2) Establish a comprehensive ecological monitoring network. The network should cover multiple key areas, including water quality, soil, vegetation, animal communities, etc., to ensure comprehensive coverage of all aspects of the ecosystem. The long-term accumulation of monitoring data will help to gain a deeper understanding of the actual effects of human activities and help identify key factors related to changes in biological integrity; 3) Develop estuary-related standards. Data sharing and exchange should be promoted, unified evaluation standards and methods should be researched and developed, comparative and comprehensive evaluation of estuary ecological integrity evaluation should be achieved, and the protection and sustainable development of estuary ecosystem should be promoted.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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THE EVOLVING TREND OF MOBILE INTEGRATED DOMESTIC SEWAGE TREATMENT EQUIPMENT

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Abstract: With the rapid development of science and technology in our country, domestic sewage treatment equipment is also gradually upgraded, and underground or semi-underground integrated domestic sewage treatment equipment is increasingly widely used. However, for the treatment of domestic sewage in temporary construction camps and post-disaster reconstruction camps, underground treatment equipment has shortcomings such as large area and easy idle resources. In contrast, mobile domestic sewage treatment equipment has the advantages of convenience, resource saving, and high flexibility, and has good application prospects in emergency treatment of domestic sewage. The article summarizes the treatment technology of mobile integrated domestic sewage treatment equipment in recent years; introduces the specific structure and treatment effect of mobile domestic sewage treatment equipment with physical and chemical methods, biological methods, combined technology and constructed wetlands as core technologies; Compare mobile and underground domestic sewage treatment devices from the perspective of resource utilization and long-term planning, highlighting the flexibility, economical and practicality of mobile domestic sewage treatment devices; by analyzing the situation of rural domestic sewage treatment, we can predict the future of rural domestic sewage treatment The model was discussed, and the operation mode of coexistence of small sewage treatment plants and mobile domestic sewage treatment units was proposed. The development trend of mobile domestic sewage treatment units was prospected, with an emphasis on the advancement of advanced catalytic oxidation and membrane separation processes. It has important theoretical and practical guiding significance.
Keywords: Domestic sewage; Mobile treatment device; Sewage treatment; Technological progress; Integration

1 INTRODUCTION TO MOBILE INTEGRATED DOMESTIC SEWAGE TREATMENT TECHNOLOGY

With the rapid development of my country's economy, farmers' living standards continue to improve, and water consumption is also gradually increasing. According to the "China Urban and Rural Construction Statistical Yearbook 2021" released by the Ministry of Housing and Urban-Rural Development, the domestic water consumption in organized towns is 649,082. 0.79 L, but the treatment rate of rural domestic sewage is only 61. 95%. The level of environmental protection construction in rural areas does not match the level of economic construction, and the random discharge of domestic sewage has led to increasing water pollution problems [1-2]. If the drainage pipe network is used to collect and process rural domestic sewage in a unified manner, it will increase the financial burden and is economically undesirable. Underground integrated sewage treatment equipment has the advantages of easy installation, low operating costs, and low construction investment, and is suitable for rural domestic sewage treatment [3-4]. However, for the temporary storage of domestic sewage in construction camps and post-disaster reconstruction camps, underground integrated sewage treatment equipment still has limitations. This is because underground integrated sewage treatment equipment is difficult to move and cannot be disassembled, and it cannot follow the construction after the construction is completed. The team evacuated, resulting in a waste of resources. In comparison, mobile domestic sewage treatment equipment has the advantages of small footprint, simple equipment, high treatment efficiency and can be moved at any time, and is suitable for the treatment of this type of wastewater. In addition, as the efficiency of water treatment processes gradually increases, the size of sewage treatment equipment gradually decreases, which greatly increases the mobility of integrated domestic sewage treatment equipment and will have more extensive application scenarios in the future. Therefore, it is necessary to summarize the technology of existing mobile domestic sewage treatment equipment to provide a theoretical basis for subsequent upgrades of mobile domestic sewage treatment equipment.

Domestic sewage can be divided into black water and gray water according to its source. Black water consists of feces, urine and toilet flushing water, while gray water consists of bathing water, toilet sewage, laundry water and kitchen water [5]. Domestic sewage usually has the characteristics of large fluctuations in water quality and quantity, poor concentration, and high nitrogen and phosphorus content [6], and usually contains a large amount of suspended solids, dissolved organic matter, and microorganisms. At present, mobile integrated domestic sewage treatment equipment is mainly used for the treatment of dispersed sewage (rural domestic sewage, temporary campground storage sewage).

The core processes of existing mobile integrated domestic sewage treatment equipment can be divided into two categories: biological treatment and physical and chemical treatment based on principles (Table 1). Biological treatment mainly includes anoxic-aerobic (AO) series processes, biofilm methods and their derivative processes, and physical and chemical treatment mainly includes membrane separation technology, coagulation precipitation, electrocoagulation, advanced catalytic oxidation and its derivative processes. The mechanisms and characteristics of each process are as Table 1.

Table 1 Core treatment process of mobile integrated domestic sewage treatment equipment

principle	processing technology	Advantage	Disadvantages
biological treatment	AO series process	High efficiency, simple process, low operation and maintenance costs	It is difficult to satisfy the nitrogen and phosphorus removal effects at the same time
	biofilm method	Strong impact load resistance and low sludge production	Less operational flexibility
Physical and chemical treatment	Membrane separation technology	easy to use	Membrane production costs are high and easy to pollute
	coagulation sedimentation	easy to use	The treatment effect is poor and often used as pretreatment
	electrocoagulation	High phosphorus removal efficiency	higher cost
	advanced catalytic oxidation	High COD and ammonia nitrogen removal efficiency	Higher energy consumption

1.1 AO Series Process

The AO process is a relatively common domestic sewage treatment process and a type of activated sludge process. The denitrification reaction is carried out in the anoxic tank, reducing nitrate and nitrite into nitrogen and removing it from the sewage. In addition, it can also degrade macromolecules into small molecules to improve the treatment effect of the subsequent aeration tank. Nitrification reaction occurs in the aeration tank to degrade organic matter in sewage. Anaerobic anoxic aerobic (AAO) is to add an anaerobic tank in front of the anoxic tank in the AO treatment process. The main function of the anaerobic tank is to make the returning phosphorus-accumulating bacteria anaerobically release phosphorus, thereby strengthening the phosphorus removal of the reaction facility effect[7]. Hu Junfu et al. [8] used a two-stage AO biological contact oxidation process to treat rural domestic sewage, using flexible biological ropes as biological fillers to improve the adhesion properties of the biofilm and reduce the generation of sludge. The final COD, ammonia nitrogen, and total phosphorus in the effluent were All have reached the Class A discharge standard of the "Pollutant Discharge Standard for Urban Sewage Treatment Plants".

1.2 Biofilm Method

The purification mechanism of the biofilm method is as follows: When sewage flows through the biofilm reactor, microorganisms attach to the filler and grow to form a biofilm. When the sewage flows through the biofilm, the microorganisms come into contact with pollutants in the sewage, completing the purification of the sewage.. The mainstream processes of biofilm method include aerated biological filter, biological turntable, etc. Aerated biological filter is a treatment process developed in the 1980s based on biological filter and biological contact oxidation method [9]. Bao Muping[10] designed a sewage treatment plant with aerated biological filters as the core. Flocculants were added to the high-density sedimentation tank to improve the incoming water quality. After several months of debugging, the effluent water quality reached the "Urban Sewage Treatment Plant Pollution Class A standard of the National Chemical Emission Standards (GB 18918-2002). The difference between the biological turntable and other biofilm processes is that both the disk and the water flow are moving. The AAO process is completed every time the turntable rotates, and the nitrogen and phosphorus removal effect is good [11]. Wei Zhenzhou et al. [12] used the biological turntable method to treat domestic sewage in small towns. The daily water treatment volume was 1500 m3. After passing through the grille, cyclonic grit chamber, and biological turntable, the effluent COD, ammonia nitrogen, total phosphorus, and total nitrogen were all averaged. It reaches the Class I B standard of the "Pollutant Discharge Standard for Urban Sewage Treatment Plants".

1.3 Membrane Separation Technology

Membrane separation technology is a physical and chemical treatment process. Its separation principle is to selectively pass the components in the sewage by generating a pressure difference on both sides of the membrane. When sewage flows through the separation membrane, one or more substances are selectively permeable, and the remaining substances are intercepted to achieve the purpose of separation and purification [13]. Currently, membrane separation technologies that are commonly used in the field of sewage treatment include microfiltration, nanofiltration, ultrafiltration, reverse osmosis, and electrodialysis [14]. Wang Donghe et al. [15] used electrolytic coupling membrane separation technology to treat marine domestic sewage. The water treatment volume can reach 64 m3/d, and the effluent water quality meets the requirements of the IMO. MEPC. 227 (64) resolution. This method selects microfiltration membrane separation technology, in which the membrane separator uses polyvinylidene fluoride hollow fiber membrane modules.

1.4 Electrocoagulation

Physical and chemical methods are used to treat organic matter in sewage, mainly including filtration, coagulation, electrochemical treatment, etc. Among them, coagulation and filtration treatment can not only target wastewater with low organic matter content and high suspended matter content, but also serve as pretreatment measures for high COD wastewater. Electrocoagulation usually uses iron or aluminum as the anode, and a polymerization reaction occurs under alkaline conditions to generate hydroxide precipitation. During the precipitation process, the effluent quality is further improved through net trapping [16]. Long Kui et al. [17] used electrocoagulation-electrolysis coupling technology to treat ship domestic sewage. Electrocoagulation was used as a pretreatment process to treat sewage, and electrolysis was used as an advanced treatment method to further improve the effluent quality. COD was removed under appropriate conditions such as pH and electrolysis time. The rate can reach 93%.

1.5 Advanced Catalytic Oxidation

In recent years, advanced catalytic oxidation technology has been considered an efficient and reliable sewage treatment technology, and its main purpose is to remove certain new pollutants, such as pesticides, food additives, drugs, etc. [18]. Advanced catalytic oxidation oxidizes pollutants by generating a sufficient amount of hydroxyl radicals [19] and can be used for the treatment of domestic sewage. It mainly includes electro-Fenton, electrocatalysis and photocatalysis. The specific characteristics are shown in Table 2.

Table 2 Advantages and Disadvantages of Advanced Catalytic Oxidation Treatment Process

processing technology	Advantage	Disadvantages
Electric Fenton	Lower cost and good treatment effect	Need to work within a narrow pH range
Electrocatalysis	Strong anti-pollution ability and high energy utilization rate	higher cost
Photocatalytic	Mild reaction conditions and strong oxidizing ability	The effect is limited by multiple factors such as the transmittance of the solution, the nature of the catalyst, and the wavelength of light.

1.5.1 Electric fenton
Electro-Fenton technology uses Fe^{2+} and H_2O_2 produced by electrolysis as Fenton reagents. The two interact to generate hydroxyl radicals.
It should be as formula (1) [20].
$Fe^{2+} + H_2O_2 + H^+ = Fe^{3+} + H_2O + \cdot OH$ (1)
The hydroxyl radicals generated by the electro-Fenton method can efficiently remove COD and ammonia nitrogen in sewage. Zhang Feng et al. [21] used the electro-Fenton method to remove COD and phosphorus from nickel plating wastewater. The mass concentration of COD_{Cr} and phosphorus in this type of wastewater can reach 2 000 mg/L and 1 000 mg/L. At pH value = 3, The reaction was carried out for 40 minutes at a current density of 10 mA/cm^2, so that the COD_{Cr} and phosphorus removal rates in the solution were 84. 7% and 91. 5% respectively.

1.5.2 Electrocatalysis
Electrocatalytic oxidation technology can treat domestic sewage with high COD_{Cr} and high ammonia nitrogen. During the electrolysis process, a redox reaction occurs, which degrades the organic matter in the sewage [22-23]. Huang Yanfeng et al. [24] used the electrochemical combined membrane bioreactor (MBR) process to treat domestic sewage from offshore platforms, and the treatment effect was best under the conditions of a plate spacing of 2 cm, a current of 52 A, and an electrolysis time of 2 h., the operating cost of the entire device is 67.96 yuan/d, the final degradation rate of COD_{Cr} is 87%, and the effluent water quality meets the requirements of the IMO. MEPC227(64) resolution.

1.5.3 Photocatalysis
The principle of photocatalysis is that under ultraviolet or visible light irradiation, electrons on the surface of semiconductor materials are excited from the valence band to the conduction band, thereby forming reactive oxygen species, such as superoxide anion radicals, singlet oxygen and hydroxyl radicals [25]. Ren Chunyan et al. [26] used photo-electric coupling catalysis to reduce COD_{Cr} in domestic sewage, operating at a current density of 600 A/m^2, an operating current of 940 A, and an ultraviolet radiation intensity of 50 $\mu W/cm^2$ for 60 d., the water treatment capacity of the entire pilot scale can reach 24 m^3/d, and the COD_{Cr} mass concentration of the effluent is stable below 125 mg/L, which meets the requirements of IMO. MEPC. 227 (64) resolution.

1.6 Combination Technology

Combining the above single-stage treatment process into a multi-stage treatment process can improve the sewage treatment effect. MBR is a new process that combines membrane separation technology with biological treatment units. The unique MBR flat membrane module is placed in the aeration tank, and the water after aerobic aeration and biological treatment is filtered through the filter membrane by a pump. Extraction, using membrane separation equipment to intercept activated sludge and macromolecular organic matter in the biochemical reaction tank, eliminating the need for a secondary sedimentation tank, can greatly increase the concentration of activated sludge [27]. MBR is usually used in conjunction with other processes to treat sewage, using membrane separation components instead of secondary sedimentation tanks to achieve mud-water separation. Xu Jianyu et al. [28] used AO combined with MBR technology to treat domestic sewage in the faculty park. Compared with the conventional sequential intermittent activated sludge treatment process, the effect of nitrogen and phosphorus removal was improved. Because

MBR was used instead of the secondary sedimentation tank, it saved use of land and reduce energy consumption. The effluent quality after commissioning can reach the Class I B discharge standard of the "Pollutant Discharge Standard for Urban Sewage Treatment Plants". Zuo Yanjun et al. [29] combined coagulation, AO and MBR processes to treat domestic sewage. They first used the coagulation process to remove suspended large particles in the sewage, then used the AO process to remove nitrogen and phosphorus, and finally used the MBR process to strengthen The effluent water quality reaches the Class A discharge standard of the "Pollutant Discharge Standard for Urban Sewage Treatment Plants". There are also studies that couple biological treatment technology with ecological treatment technology to form biological-ecological combination technology. In the past, microorganisms were used to degrade organic matter, and in the latter case, artificial wetland technology was used to carry out deep nitrogen and phosphorus removal. Combining the technical advantages of each other, the quality of effluent water was further improved [30].

2 CLASSIFICATION OF MOBILE INTEGRATED DOMESTIC SEWAGE TREATMENT EQUIPMENT

Based on different domestic sewage treatment processes, mobile integrated domestic sewage treatment equipment can be roughly divided into 4 types, namely treatment equipment with physical and chemical methods, biological methods, combined technology and other technologies (such as constructed wetlands) as the core process. It mainly includes coagulation filtration, membrane separation technology, advanced catalytic oxidation, AO series processes, biofilm methods, constructed wetlands and their combined processes. The characteristics are shown in Table 3.

Table 3 Characteristics of conventional mobile integrated domestic sewage treatment equipment

processing technology	Core craftsmanship	Advantage	Disadvantages
Physical Chemistry	coagulation, filtration	Lower cost, simple operation and maintenance	Poor processing effect
	Membrane separation technology	Good treatment effect, simple operation and maintenance, small footprint	Membrane costs are high and easy to pollute
	Photocatalysis/Electrocatalysis	Good treatment effect, high effluent quality, small footprint	The device is complex and the operation and maintenance costs are high
biological methods	AO, AAO	Low cost, simple operation and maintenance	It occupies a large area and requires sludge return
	biofilm method	Low cost, no sludge backflow, strong impact load resistance	Some processes require backwashing
Combination technology	AO+MBR	High effluent quality	Large floor space and high operation and maintenance costs
other	Artificial wetland	Low cost, beautifying the environment	Poor treatment effect and small water volume

2.1 Treatment Equipment with Physical and Chemical Methods as the Core

Equipment based on physical and chemical methods usually treats gray water, that is, sewage such as washing, washing vegetables, and bathing water, rather than black water with high CODCr and high ammonia nitrogen. This type of gray water can be recycled after coagulation, filtration, and sterilization. Luo Kongcheng [31] invented a mobile sewage filtration truck for gray water treatment. The entire device mainly consists of a mixing box, a submersible pump, a water outlet pipe, a filter box, a water discharge pipe, a blower, an iron pipe, a jet head and an air outlet pipe. The core processing technology is filtration. First store the gray water in the sewage tank, then start the water pump, suck the sewage into the filter box for filtering, and then discharge it into the mixing tank after filtering. At the same time, turn on the blower for stirring. The treated water can be used again.

In addition, domestic sewage from ships can be collected in categories and discharged into the urban sewage collection system for treatment after docking. Wei Helei [32] invented a mobile residential ship domestic sewage treatment device, which collects black water and gray water separately, and regularly disinfects and sterilizes the two types of sewage to prevent the growth of germs. Each collection bin is equipped with an alarm system that will sound an alarm when the capacity exceeds 80%. The device collects sewage by gravity alone, without the need for other equipment.

For the treatment of black water, physical and chemical processes such as microfiltration and ultrafiltration can be selected. In the design of mobile sewage treatment equipment, there are many choices for microfiltration and ultrafiltration processes, because this process takes up very little space and can achieve good sewage treatment effects. Forbis-stokes et al. [33] designed a mobile septic water treatment device to treat black water in septic tanks in Indian cities and empty the septic tanks in a timely manner for subsequent use. The core processes of this device are adsorption, microfiltration and ultrafiltration. After the sewage passes through a mesh fabric to remove large particles, it enters a fiberglass container composed of sand and pebbles for filtration, and then passes through an activated carbon adsorption device to further remove suspended matter in the water. At the same time, the activated carbon can also absorb organic matter and ammonia nitrogen in the sewage, further improving the water quality.. After that, the sewage passes through microfiltration and nanofiltration devices in sequence to realize sewage reuse. After the entire device operates stably, the removal rates of CODCr, total suspended solids and total coliforms are 81%, 80% and 98.4% respectively, reaching the discharge standards of Indian sewage treatment plants.

Wang Lei et al. [34] invented a movable photocatalytic sewage treatment device, which can effectively treat domestic sewage and industrial wastewater. It mainly consists of a water inlet pipe, a photocatalytic filler rod, an outlet pipe, a sewage pump, a mobile platform, and a fixed It consists of racks, etc. According to the different quantity and quality of sewage water, photocatalytic filler rods of different specifications and models can be selected to improve the purification efficiency. The photocatalytic filler rod adopts a translucent shell and uses sunlight for photocatalytic treatment of sewage during the day. It can use a built-in light source for photocatalysis at night. Generally speaking, this process has lower energy consumption, higher processing efficiency, and strong adaptability to impact loads.

2.2 Treatment Equipment with Biological Methods as the Core

Biological sewage treatment equipment is cheap, effective and widely used. Similarly, in the selection of core processes for mobile sewage treatment units, biological processes such as AO, AAO, and MBR are usually given priority. The structure of this type of device usually consists of a grille, a regulating pool, a core process pool, and a disinfection pool. Among them, the function of the grille is to remove floating substances in the sewage, the function of the regulating tank is to uniform the water quality and quantity, the removal of most organic matter and ammonia nitrogen is completed in the core process tank, and finally the function of the disinfection tank is to disinfect and sterilize.

Li Tianyuan [35] developed an intelligent mobile rural sewage treatment device with the core process of AO. Treatment process: The device inhales sewage and performs anaerobic reaction after it reaches the designated liquid level, and then adds an aeration head for aeration to perform aerobic reaction. The whole process is automated. The central box sends instructions to each unit according to the preset data, and the device can run according to the program.

Xin Haibo et al. [36] designed a mobile sewage treatment device with AAO technology as the core. The entire device consists of a regulating tank, anoxic tank, aerobic tank, sedimentation tank, and disinfection tank, and can be used for the treatment of small-scale domestic sewage. The aerobic tank of the mobile sewage treatment device adopts multi-stage segmented contact oxidation, which reduces the reaction load step by step and improves the system's ability to withstand impact loads.

Wang Linghang et al. [37] developed a mobile sewage treatment vehicle based on the AAO process, which consists of a filter press box, an anaerobic box, anoxic box, and an aerobic box. The device is convenient and fast, and can perform secondary treatment of incompletely treated sewage. Among them, the filter press box can be divided into a pressure water area and a water filter area. The water pressure area is composed of pressure blocks and air bags, and the water filter area is adsorbed by an activated carbon layer. A UV lamp is hung on the top of the final aerobic box for disinfection and sterilization.

Wang Yuming et al. [38] developed a movable black and odorous water treatment equipment with aerated biological filter and biological turntable technology as the core, which can treat the overflowing domestic sewage in the drainage pipe network and the black and odorous water in the surrounding ponds. for processing. The entire device consists of a coagulation reaction tank, a sedimentation tank, a regulating tank, an aerated biological filter, and a biological turntable. Fenton's reagent is added to the coagulation sedimentation tank for oxidation treatment. The device is connected to an external solar power generation system and is suitable for the treatment of small-scale black and odorous water bodies. The effluent can reach the Class A emission standard of the "Pollutant Discharge Standard for Urban Sewage Treatment Plants" (GB 18918-2002).

2.3 Mobile Combined Technology Processing Equipment

The water quality and quantity of domestic sewage fluctuate greatly and change significantly with the seasons. In order to maintain the stability of effluent water quality, combined technologies are usually used to treat sewage. Zhong Xudong et al. [39] developed a mobile rural sewage emergency treatment device to temporarily treat domestic sewage. The effluent water quality can reach the Class I B standard of the "Pollutant Discharge Standard for Urban Sewage Treatment Plants" (GB 18918-2002), and can be used for Greening and irrigation. The device consists of a regulating pool, an anoxic pool, an aerobic pool, and an MBR. The size of the device is 7. 28 m × 2. 13 m × 2. 18 m. The hydraulic retention time in the anoxic pool and the aerobic pool is 8 h.. The cleaning box is responsible for cleaning the MBR, and the pipeline is cleaned by adding sodium hypochlorite through the dosing box.

Zhou Jiazheng et al. [40] developed a unit-type membrane biodegradation mobile sewage treatment station. The core treatment device is a biological treatment tank and a hollow fiber membrane filtration device. The structure design is reasonable and compact, and can effectively treat sewage without producing activated sludge. The biological treatment tank is equipped with an aeration tank, a sedimentation tank, and a disinfection and decolorization tank. The domestic sewage first passes through the fence basket to remove floating substances, and then enters the aeration tank for aeration and oxidation. After sterilization and decolorization, it enters the tubular hollow fiber filter for filtration. treatment to improve effluent quality.

Wang Xiaoli et al. [41] developed a mobile integrated sewage treatment equipment, which is composed of modularized mobile treatment devices. The entire device integrates mixing reaction, water distribution and aeration, which can realize integrated sewage treatment and is suitable for treating small-scale rural domestic sewage. The water quality after treatment by this device reaches the surface water quality standard III and can be directly discharged or reused. The mobile integrated device is mainly composed of a hydrolysis acidification tank, a contact oxidation tank, an MBR tank, a disinfection tank, and a sludge tank. The hydrolysis acidification tank contains elastic fiber composite filler to increase the amount of microorganisms and improve the treatment effect. The hydrolysis acidification tank mainly degrades organic matter into small molecular substances such as fatty acids, and can also perform denitrification reactions under anoxic conditions. The contact oxidation tank is connected to the MBR membrane to reduce the production of activated sludge. The microorganisms attached to the oxidation tank undergo oxidative metabolic reactions to remove pollutants in the sewage. Biochemical oxygen demand (BOD), CODCr and other indicators are also reduced in the treatment tank.. In addition, the nitrification reaction will also occur in the oxidation tank, and the nitrification liquid will flow back to the hydrolysis acidification tank through the return pipeline for denitrification. Disinfection is carried out by adding chlorine dioxide into the disinfection pool.

Zhao Bolton [42] developed a mobile emergency domestic sewage treatment equipment. Different from the above-mentioned device, this device combines biological methods with physical and chemical methods, and is mainly composed of a crushing device, a sand and gravel layer, activated carbon and a photovoltaic power generation device. Domestic sewage first passes through the crushing device to crush larger objects into fine particles, and then flows into the anaerobic chamber for treatment. Different from the above-mentioned device, the anaerobic chamber of this device contains photosynthetic bacteria and fluorescent tubes. Photosynthetic bacteria can decompose organic matter in sewage under conditions of light and anaerobic conditions. After anaerobic treatment, it enters the filter chamber for treatment. The quality of the effluent water is further improved through activated carbon adsorption. The fluorescent tube, crushing motor, and stirring motor of the device are all connected to the photovoltaic power generation device.

2.4 Mobile Constructed Wetland Treatment Equipment

In the design of mobile sewage treatment equipment, constructed wetland technology is rarely used. This is because constructed wetlands occupy a large area and have poor treatment effects. However, constructed wetlands have the characteristics of triple degradation mechanism (substrate, plants, microorganisms) and low energy consumption, which makes this technology have significant advantages in treating domestic sewage, especially in terms of nitrogen and phosphorus removal.

European countries such as Belgium often hold music festivals. Music festival venues usually do not have drainage systems or the capacity of the drainage systems is insufficient, making it difficult to deal with the domestic sewage temporarily generated by the music festivals. Lakho et al. [43] developed a mobile domestic sewage treatment equipment with constructed wetland technology as the core. The mobile device processes black water and gray water through a constructed wetland, and then flows into the drinking water regeneration system to regenerate pure water. It not only solves the problem of domestic sewage pollution, but also recycles water resources. The mobile facility uses a trailer as a carrier, with water inlet tanks installed on both sides and a water level sensing device, which can realize automatic water inflow. The incoming water flows into the wetland through the perforated pipe network. The entire device process consists of constructed wetlands, ultrafiltration, and reverse osmosis. The sewage first passes through a constructed wetland for denitrification and phosphorus removal, and then passes through an activated carbon adsorption device to remove large particulate matter to prevent the subsequent ultrafiltration device from clogging. Ultrafiltration-reverse osmosis removes remaining organic pollutants. Finally, after disinfection and sterilization, the water quality can be improved. Meet drinking water requirements. After adjustment and optimization of the device, the removal rates of CODCr, BOD, total suspended solids, total nitrogen, and total phosphorus can reach 90%, 95%, 97%, 24.7%, and 76%.

Zehnsdorf et al. [44] developed a mobile treatment device with reed roots as the main treatment unit, which is used to treat temporary urban wastewater (for example, domestic sewage from temporary construction sites, domestic sewage from tourist campsites, temporary camping after disasters) local domestic sewage, etc.). The device uses a reaction chamber composed of reed roots as the core treatment process, using plants and microorganisms attached to the plants to treat sewage. Since the reaction roots are relatively dense, the treated wastewater usually requires pretreatment in order to prevent clogging. Therefore, this mobile facility is usually used in conjunction with other pretreatment measures, and the treatment load can reach 1 200 L/d.

3 CHARACTERISTICS OF MOBILE INTEGRATED TREATMENT EQUIPMENT FOR DOMESTIC SEWAGE

3.1 Advantages of Mobile Integrated Treatment Equipment

For dispersed sewage in remote areas or domestic sewage in temporary construction campsites, if the drainage system is not installed or the drainage system has insufficient carrying capacity, it is easy to cause sewage leakage and affect the surrounding environment. The extensive laying of pipelines to remote areas will also cause a waste of resources. In view of the above situation, mobile domestic sewage treatment equipment has irreplaceable advantages. Compared with underground treatment equipment, mobile sewage treatment equipment has the advantages of high treatment efficiency, small footprint, convenient management, and small sludge output. It does not cause waste of resources and is suitable for treating temporary wastewater [45]. Mobile integrated devices have the following advantages when treating domestic wastewater.

3.1.1 Save pipe network laying costs

Remote areas usually have fewer households and are far away from urban sewage treatment plants. If urban drainage pipelines are forcibly laid, the economic benefits will be low and the pressure on the financial department will also increase. In comparison, mobile sewage treatment equipment has low construction prices and low operating costs. It has unique advantages in treating a small amount of domestic sewage in remote areas. It can adopt different processes for treatment according to local water quality and quantity conditions, and has high flexibility.

3.1.2 Save resources

For domestic sewage discharged from temporary construction or shelter camps, if an underground or semi-underground treatment device is built, the temporary treatment device will remain idle after the construction is completed and the disaster has passed, resulting in a waste of resources. Compared with mobile processing facilities, this underground device will occupy a larger area, require more initial investment, and consume more manpower and material resources. Using mobile sewage treatment equipment will save resources and meet the requirements of sustainable development.

3.2 Disadvantages of Mobile Integrated Processing Equipment

Mobile sewage treatment equipment is characterized by convenience and speed. Therefore, the treatment capacity of the device is limited and it is not suitable for treating large-scale wastewater. The underground device has many structural units, a high water treatment capacity, strong impact load resistance, and low operation and maintenance costs [46]. In comparison, the treatment process of mobile sewage treatment equipment is usually related to the membrane process, which requires regular maintenance and flushing. In order to improve the treatment effect, dosing (coagulant) is usually required. Therefore, the operation and maintenance costs are relatively high.

3.3 Application Status of Mobile Integrated Processing Equipment

According to the "China Urban and Rural Construction Statistical Yearbook 2021" released by the Ministry of Housing and Urban-Rural Development, the annual domestic water consumption, sewage treatment plant processing capacity and sewage treatment devices (integrated treatment devices) of organized towns across the country in the past ten years are summarized, as shown in the table As shown in 4, various indicators show an increasing trend year by year. It is worth noting that the processing capacity of sewage treatment devices in organized towns is similar to that of sewage treatment plants, indicating that integrated domestic sewage treatment devices are widely used in towns and villages.

Table 4 Statistics on domestic sewage treatment in organized towns across the country in the past ten years

years	Annual domestic water consumption/ 3 m	Proportion of incorporated towns that can handle domestic sewage	Treatment capacity of sewage treatment equipment/ (m3 ·d-1)	Number of sewage treatment devices/piece	Treatment capacity of sewage treatment plant/ (m3 ·d-1)	Number of sewage treatment plants/unit
2011	498 547. 650,000	/	710. 100,000	8 125	1 1.1243 million	1 651
2012	512 288.47 million	/	867.08 million	10 652	1 475.88 million	2 158
2013	536 832. 84 million	18.87%	1 3.0966 million	6 371	1 114.80 million	2 060
2014	558 444. 340,000	21.65%	1 006.34 million	8 667	1 338.71 million	2 961
2015	577 768. 310,000	25.28%	1 131. 100,000	11 573	1 423.65 million	3 076
2016	589 756.06 million	28.02%	1 041.38 million	12 421	1 422.77 million	3 409
2017	590 166.86 million	47.06%	1 3.8369 million	/	1 714.15 million	4 810
2018	589 238. 200,000	53.17%	1 613.43 million	/	2 238.84 million	7 687
2019	616 804. 89 million	59.67%	1 874.88 million	/	2 477.34 million	10 650
2020	641 351.94 million	65.35%	2 1.5736 million	/	2740.05 million	11 374
2021	649 082. 200,000	67.96%	2 361.84 million	/	2 932.71 million	13 462

In recent years, although urban and rural areas have paid more and more attention to the treatment of domestic sewage, as of 2021, the number of incorporated towns with sewage treatment plants or domestic sewage treatment equipment only accounts for about 68%. The reason for this is that there may be the following problems that limit its use develop.

3.3.1 Government financial pressure is too great

Funds for agricultural pollution construction mainly come from national and local finances. The economic level in rural areas is low, and the local area cannot purchase enough equipment or perform routine maintenance, resulting in idle waste of resources. Local governments can use the PPP (public-private-partnership) model to support and encourage the investment of social funds, which can not only help local enterprises develop but also reduce financial pressure.

3.3.2 Lack of reasonable technology and unified emission standards

The quality and quantity of domestic sewage in rural areas fluctuate greatly, and the drainage volume in each region is different. Sufficient research should be conducted in the early stage to use classified treatment methods for domestic sewage in different regions and select appropriate treatment technologies. In addition, urban and rural areas should also adopt unified emission standards, which will also be conducive to the promotion of integrated domestic sewage treatment devices.

3.3.3 Lack of professionals

The operation and maintenance of integrated domestic sewage treatment equipment requires professionals. Most of the staff in rural areas work part-time and do not have a deep understanding of rural domestic sewage treatment, which may cause problems in the operation of the entire system. In view of this situation, we should vigorously develop the intelligent operation of integrated processing equipment, and use cloud operation to detect problems in the operation of the device in time and improve the processing efficiency of the entire device.

3.4 Development Trend of Mobile Integrated Processing Equipment

With the improvement of my country's sewage treatment system, the domestic sewage treatment structure has become more reasonable. For the treatment of domestic sewage in remote areas, when users live together (move into buildings), sewage plants can be built locally, but concentrated living is difficult to achieve in the short term. Therefore, during the transition period, mobile sewage treatment devices can be used to treat the current domestic sewage. At present, mobile integrated treatment equipment is mainly used in the treatment of domestic sewage in construction camps and rural domestic sewage [47-48]. Mobile sewage treatment units can play an important role in the field of emergency rescue. For camping sites after disasters, the drainage pipe network system may be damaged. Mobile sewage treatment devices can temporarily treat domestic sewage in the camp to provide guarantee for the production and life of residents. Li Weixing et al. [49] used mobile integrated sewage treatment facilities to treat contaminated water sources. After flocculation, sedimentation, ultrafiltration, and disinfection, they reached drinking water standards to ensure healthy water use after disasters. For domestic sewage generated from temporary construction camps or large-scale activities in the countryside, mobile sewage treatment devices have irreplaceable advantages. With the development of sewage treatment technology, the performance of mobile sewage treatment equipment will also be optimized to a great extent. Membrane separation technology has the advantages of good separation effect and small space required, and is widely used in the design of mobile sewage treatment equipment. However, as the processing time of the membrane unit reaction device goes by, the membrane pores will become clogged, and the membrane pores need to be cleaned regularly. The membrane components are also easily damaged, making maintenance costs higher. With the continuous deepening of research on membrane pollution removal and membrane modification technology, the anti-pollution and impact resistance of membrane modules have gradually increased, and the application prospects of mobile sewage treatment devices will become wider.

In addition, the article selects two cases that use AO series technology as the core process and meet the Class A emission standard of the "Pollutant Discharge Standard for Urban Sewage Treatment Plants" (GB 18918-2002), and analyze their economic benefits. Their sewage treatment The cost is 1. 5 ~ 2. 0 yuan/m3[50-51], while the treatment cost of urban sewage treatment plants is about 1 yuan/m3[52]. Therefore, rural domestic sewage treatment policies should be flexible and changeable, measuring water quality and quantity and sewage treatment costs. For densely populated areas, sewage treatment plants can be built for unified collection and treatment. For areas with small flow, mobile integrated domestic sewage treatment equipment can be used for "online appointment" treatment.

4 CONCLUSION

Mobile integrated treatment equipment is a key link in my country's sewage treatment system. It makes my country's sewage treatment system more complete and is worthy of discussion and research. The mobile integrated sewage treatment device combines and simplifies the existing complex processes, making the unit structure combination more reasonable, forming an integrated treatment process, and improving the efficiency of sewage treatment. Compared with underground domestic sewage treatment equipment, mobile sewage treatment equipment has more advantages in domestic sewage treatment in remote areas and during construction periods, and will not cause a waste of resources. Most of the existing mobile integrated domestic sewage treatment equipment uses AO as the core process. This is because this technology has low cost and convenient operation and management. However, its hydraulic retention time is long and an additional sedimentation tank is required. In order to improve the water output Water quality still needs to be used in conjunction with other processes, etc. On the premise of ensuring mobility, the treatment efficiency of the device is limited.

The upgrading of mobile integrated domestic sewage treatment equipment is closely related to the research and development of efficient domestic sewage treatment technology. With the rapid development of the environmental field, the types of domestic sewage treatment technologies are gradually increasing, and a variety of high-performance processes are gradually applied in the field of domestic sewage treatment. This provides more possibilities for the development of mobile sewage treatment devices, among which advanced catalytic oxidation and membrane separation processes deserve attention. Advanced catalytic oxidation technology relies on the hydroxyl radicals generated by the reaction to efficiently remove CODCr and ammonia nitrogen in sewage. The device with this process as the core occupies a small area, and when combined with other phosphorus removal processes, the effluent can reach "Urban sewage treatment plant pollutants Class A emission standards of the "Emission Standards" (GB 18918-2002). However, the initial investment in this process is relatively large, and future research can focus on reducing costs, such as developing low-cost electrocatalytic anode coatings and optimizing electro-Fenton and photocatalytic reaction conditions. Membrane separation is a simple and efficient sewage treatment technology. Through the combined use of multiple membrane separation processes, the effluent quality can reach drinking water standards. However, due to the high production cost and easy pollution of membranes, their application in mobile integrated domestic sewage treatment devices is limited. Future research can be based on reducing membrane pollution, such as the research on self-cleaning membrane materials, to achieve "one machine, one membrane" "To reduce operation and maintenance costs. Due to the high cost performance of biological methods (low price and high efficiency), the treatment method of future mobile integrated sewage treatment equipment will still be a joint treatment model with biological methods as the core process and physical and chemical methods as the advanced treatment process. In addition to technological breakthroughs, rural domestic sewage treatment models and operating mechanisms should also be optimized. Different treatment methods should be adopted according to the water quality and quantity of different regions, and cooperation between local governments and enterprises should be strengthened to drive economic development and reduce local financial pressure.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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EVALUATION OF AVIFAUNA DIVERSITY IN HYGAM WETLAND (RAMSAR SITE)

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Abstract: Jammu and Kashmir are rich in natural resources, especially in Wetlands. These Wetlands provide wintering, feeding and breeding grounds for millions of resident (local), and non-resident summer migrants and Migratory birds especially waterfowl (ducks, geese and swans) visiting from different countries. The research studies the status & diversity of various avifauna populations of (Resident, Summer Migrants & Migratory) in Hygam Wetland Reserve a Ramsar Site in Jammu & Kashmir. The study was conducted in 4 seasons (Spring, Summer, Autumn and winter) from January 2022 to December 2023. Visual basis and strip-transit methods were used for the counting of avifaunal populations in the study site. With the help of a expert field guide, monographs and Standard books identification of birds was done. In the study area the Species diversity of the identified birds showed variation between the sites. The highest number & density of avifauna was observed at **1 – site** (emergent & dense vegetation) followed by **2-site** (Radhiam/Akhnoonpora). Out of the total identified avifauna population in winters (winter miratory birds), Mallards were counted highest followed by Northern Pintail and Gadwall. The other species (Residents/Summer mirants) observed were Pond heron, little egret, common coot, Purple swamphen, common teal, Northern Shoveller and goose were also observed in te study area. Out of 42 species of birds recorded from the study area, 19 species were the residents, 11 species found were summer migrants and 12 species represented the winter migrant community. From residential birds, the grey pigeons makes up 70% of the bird diversity followed by the golden finch, blue billed magpie, Streaked laughing thrush, blue whistling thrush & Purple Moorhen. From summer migrants Starlings, dominate the area followed by Tickle's thrush, Indian ring dove, Indian Whiskered tern, European hoopoe etc. The total number of Winter migratory birds that make up 75 to 80% of bird diversity in winter are Mallards, Northern Shoveller, Common Teal, Pin Tail, Geese and common coots.
Keywords: Present status of water birds; Bird diversity; Hygam wetland; Ramsar Site; Migratory birds; Resident and non-resident birds; Threats; Conservatio; Kashmir

1 INTRODUCTION

Wetlands are are the most productive and important habitats as they perform a variety of functions and are found throughout the biosphere. Wetlands act as a transition zone between terrestrial and aquatic ecosystems and are highly diverse and productive habitats [1]. Wetlands provide a home for a large diversity of wildlife including birds, mammals, fish, amphibians, insects and plants [2].

Wetlands in India cover an area of 58.2 million hectares [3]. Approximately 23% (310 of 1340) of the bird species found in India [4] are known to be dependent on wetlands [5]. Birds are forestanding species of global biodiversity found in every habitat [6] and key indicators of ecosystem health and stress [7]. Knowledge of the composition of bird communities is crucial to determining the ecology and health of the local ecosystem or regional landscapes[8]. Understanding bird community structure and diversity is therefore essential to recognize the importance of landscapes for avian conservation [9].

Jammu and Kashmir is an avian-rich state [10] with about 28 vital bird areas [11] and is home to 12 threatened bird species and six near-threatened species globally. A high degree of eco-climatic variability and distinctive, varied bio-geographical and ecological features are responsible for this spectacular bird diversity [12].

A network of wetlands covering an area of more than 7,000 hectares is located in the Valley of Kashmir. The Valley of Kashmir is renowned for its fully blossomed wetland ecosystems and wide variety of avifauna diversity.

Over 3 lakh migratory waterfowl, including graylag geese, mallards, pochards, Eurasian coot, and gadwall & goose travel to Kashmir's wetlands in the winter seasons for feeding and spawning. All of these birds depend on the wetlands for their survival. It is known that 37 species of waterfowl breed in western Siberia. Ten of these species were seen in Haigam Wetland, while fifteen have been reported from Hokersar Wetland.

In Jammu and Kashmir, eleven out of twenty-one Important Bird Areas meet Ramsar requirements and five wetlands are designated as Ramsar sites two in 2022 like Shalbug & Hygam [13]. Ramsar sites have already been designated for Wular and Hokersar because of their significance for biodiversity. Also, Haigam, and Shallabug, were declared as Ramsar Sites in 2022, and these above wetlands have been documented in the network of Important Bird Areas [13] and [14].

Numerous aquatic and semi-aquatic vegetation may be found in the Hygam wetland, which serves as a suitable home for a range of resident, summer and migratory birds. Since Hygam Wetland supports a larger number of Mallards than other waterbodies in Kashmir, it has earned the nickname "Queen of the Mallards".

Many investigators have studied the diversity, distribution, seasonal migration etc. of birds in various wetlands and lakes of Kashmir [15], [16], [17], [18] but little is known about the birds of Hygam wetland in the recent past. This study aims to determine the current status of avifauna populations (Resident, Summer & Migratory birds in the wetland.
Anthropogenic activities have led to growing environmental deterioration in the Kashmir-Himalayan valley, which is well-known for its diversity of wetlands. Overexploitation of resources (e.g., harvesting, fishing, and hunting) of several Kashmir wetlands has caused the decline or the near disappearance of many plant and animal species [19].
Increased siltation, eutrophication (run-off from catchment areas), agricultural conversion, receding open water areas, expanding reed beds, construction of canals, weirs, and over-grazing are the major threats to wetlands of Jammu and Kashmir [20].
During the present study, only a few thousand bird populations (residential, summer migrants and Migratory) were observed & recorded in the study area, due to low water levels as most of the wetland area is walkable by foot and barren due to high siltation and low open water in winters for birds. In near future, we may lose many important avifauna populations and some important winter migratory guests visiting this site if important measures are not taken immediately.

2 STUDY AREA

Haigam wetland or Rakh or Jhil (Ramsar Site) is named after a village Haigam Tehsil Sopore district Baramulla of Jammu & Kashmir. The wetland is ovoid. From Baramulla district in the north, It is located 22 km away and from Srinagar, it is 45 km away. It has an area of about 14 km (1400 hectares) with about 4 km of reed beds but the total area of the wetland has shrunk to 7.25 km due to encroachment, siltation & reed beds. In 1945. The area was notified as a game reserve for duck shooting. The Department of Wildlife Jammu & Kashmir is maintaining the wetland. The wetland is dominated by extensive reed beds [21].

3 GEOGRAPHICAL LOCATION

With a maximum depth of 1.2 meters, the wetland is situated on the flood plains of the Jhelum River. At a height of 1585 meters above sea level, the site's coordinates are 34°13′30″…34°16′4″N latitudes and 74°30′27″ - 74°32′33″E longitudes. The average temperature is between 25 and 30 degrees Celsius. This area receives between 900 and 1000 mm of rain annually. This wetland gets its water from several smaller streams, including Balkul and the flood spill stream of Ningli Nallah. As shown in Figure 1.

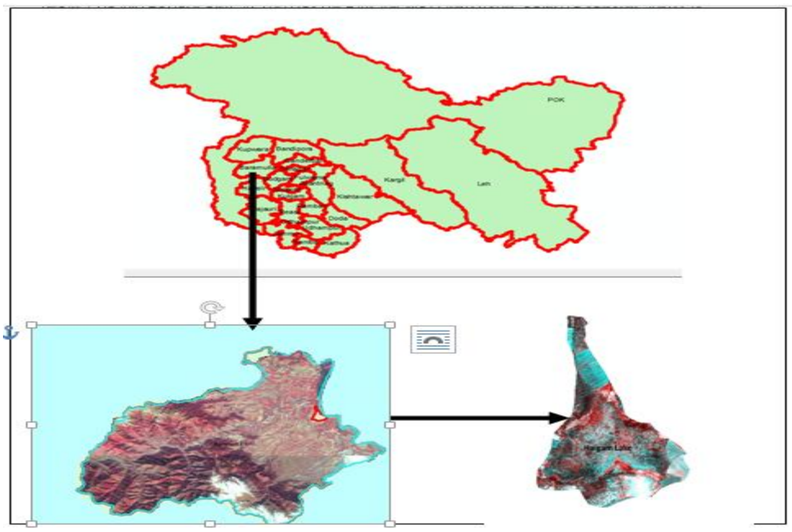

Figure 1 Study Area

4 MATERIAL AND METHODS

A sampling technique was used to examine the current state of birds in the wetland season (January 2022 to December 2023) while considering the size of the study region. The study area has been divided into four sampling sites. Site –I (Scattered Salix trees with dense and emergent vegetation), II- site (Wandakpora/ Aakhanpora & Raidagam side), III-site (Village Hygam side with Salix plantations) and site barren with scattered and dense Salix plantation (Andergam & Lolipora).
Six distinct observation locations were set up in the wetland plantation zones, spaced 50–100 meters apart. Six observation locations were set up in the wetland's interior. The study region was divided into three categories: vegetation type, water depth, and habitat type. Out of the Six study sites, four were aquatic and 2 were terrestrial sites. For the estimation of the avifauna population in in wetland following scientific methods were employed for research:

4.1 Strip Transect Method

The strip transect method was employed for bird counting while travelling in a boat through the narrow water channels. With each transect, a distance of 100 meters was covered to count the number of birds on the left and right sides of the boat.

4.2 Visual Counting Method

For estimation of avian fauna population the visual counting method with the help of Binoculars (10×50X) was employed.

4.3 Point Count Method

Since the majority of the wetland is dried out and most of it was easily accessible on foot, The point count method was employed for counting birds.
By keeping track of the birds that flew into and out of the study plots throughout the research, double counting was avoided. Transect monitoring was done in the early morning and late evening, Since birds are visible and at its peak as done by [22] and [23]. Using a Canon 1300d camera with a 250mm to 400mm zoom lens, photographs of birds were also taken. An expert field guide was also employed for bird identification in order to obtain accurate visuals. Observations were made from 6:00 a.m., when the birds were feeding, to 7:00 p.m., when they leave for their resting places.

5 RESULT AND DISCUSSION

From January 2022 to December 2023 the avifauna populations were observed. The Spring summer, autumn and winter seasons were used to measure variations in the avifauna population. Of the 41 bird species (both Residential, summer migrants and Winter migrants) that were identified from the site—representing residential, summer, and winter migrants —19 species were found to be residents, 11 species were discovered to represent summer migrants, and 11 species represented winter migrants (Table & Figure 2-4). The identified avifauna varied throughout the sites in the study area in terms of species richness and diversity. In site I (which has dense, emergent vegetation and open water surrounding it) has the highest density of migratory birds. Because it has been less affected by human activity, this site serves as a favorable habitat for migratory and other birds to nest, breed, and rest. Site II (Wadakpora/ Akhnoonpora & Radigam side) is where residential and summer migrants are found in large numbers in summer and autumn seasons due to availability of food and space for nesting in the trees and residential houses. The site is towards the residential side of the wetland. In Autumn season the number of summer miratory birds decrases as summer migrants go for migration and no of residential birds incrases as they move towards these residential areas and nearby paddy fields for food and resting.
In this study site it was observed that several bird species (ducks, geese and cormorants) were attracted by the fish species like carp and seeds produced by various aquatic vegetation [24], reported that there is a positive correlation between the avian species diversity and richness with the vegetation cover. Mallards prefer Areas having dense vegetation of emergent macrophytes. Whereas open water was preferred by pochards, coot, gadwall and geese.
From the total number of identified birds, Mallards were the most counted at I-site (200), Northern pintail at (150 species) at II - site. Within the wetland, other species observed included Common Teal (90) at site I and (60) at site II (Graph 2). Graylag geese (100), Gadwall, Eurasian Wigeon, Northern Shoveller, purple moorhen and Swamphen were also observed from the study sites. Of all the aquatic bird species found in the area , over 55% were migratory.

Table 1 Residential Birds Diversity Found in the study area (Jan. 2022 to Dec. 2023)

	English Name	Scientific name	Total No of species Found
	Number of Residential Birds		
1	House crow	Corvus splendns	150
2	Common Myna	Acridotheres tristis	60
3	Sparrow Halk	Accipiter nisus	07
4	White Cheeked Bulbul	Holpestes leucogenys	40
5	Kashmir house sparrow	Passer domestics	100
6	Common pariah kite	Milvus migrans	17
7	Little grebe (Dabchick)	Tachybatus ruficollis	40
8	Grey Heron	Ardea cinerea	40
9	Pond Heron/Paddy bird	Ardeola grayii	80
10	Little Egret	Casmerodius albus	20
11	Green Sandpiper	Tringa ochropus	10
12	Night Heron	Nycticorax nycticorax	15

13	Blue kingfisher	Alcedinidae	30
14	Purple swamphen	Porphyrio phorphyiro	150
15	White-breasted Kingfisher	Halcyon smyrnensis	50
16	Grey Wagtail	Motacilla cinerea	20
17	Northern Lapwing	Vanellus vanellus	20
18	common kingfisher	Alecdo atthis	20
19	Common Moorhen	Gallininula chloropus	15
20	Fantail snipe	Gallinago gallinago	120
21	Common Sandpiper	Actitis hypoleucos	100
22	Pied Kingfisher	Ceryle rudis	40
23	Kashmiri grey tit	Parus major	40
24	European little ringed plover	Charadrius dubius	30
25	Common eagle	Accipitridae	40
26	Common Pigeon	Columba livia	150
27	Red-Waltted Lapwing	Vanellus indicus	50
28	European goldfinch	Carduelis carduelis	200
29	Streaked laughing thrush	Trochalopteron lineatum	400
30	Red-billed blue magpie	Urocissa erythoryncha	150
31	Blue whistling thrush	Myophonus caeruleus	150
32	Woodpecker	--	50
Total			2404

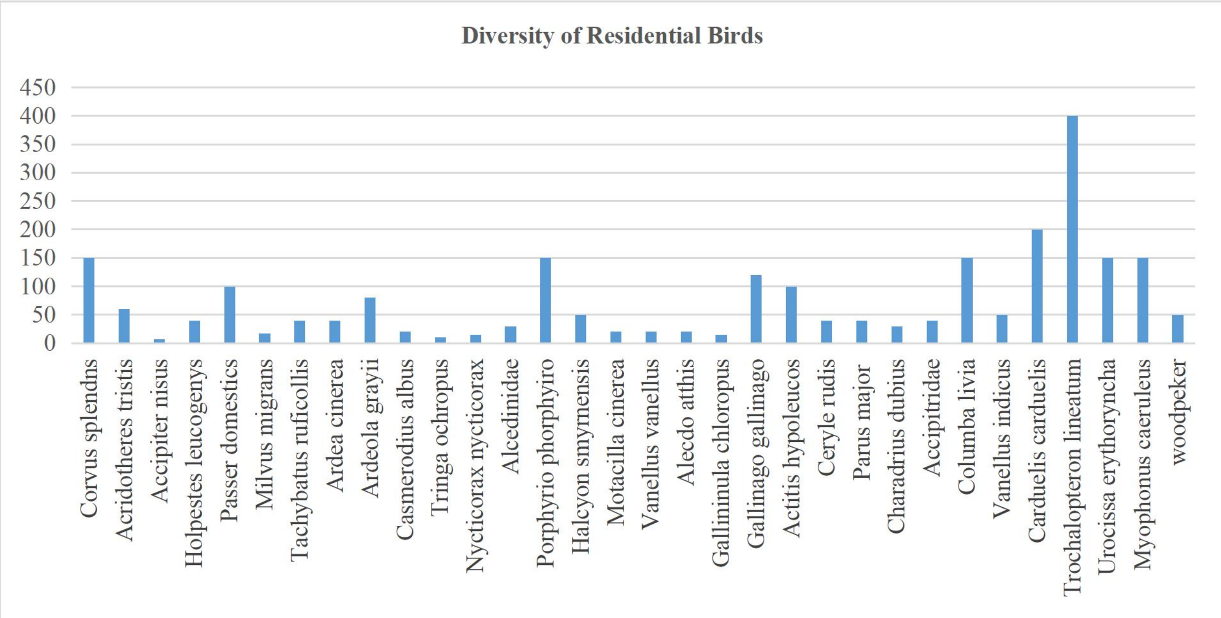

Figure 2 Diversity of Residential Birds (Jan. 2022- Dec. 2023)

Table 2 Summer Migratory Birds Diversity in the study area (Jan. 2022 to Dec. 2023)

S.NO	English Name	Scientific name	Total No of Species Found
Summer Migrants in Hygam			
1	Pheasent tailed jacana	Hydrophasianus chirurgus	2
2	Gold franted finch	Metoponia pusilia	5
3	Slaty headed parakeet	Psittacula himalayana	20
4	Indian Oriole	Oriolus oriolus kundoo	0
5	Owl	Strigiformes	6
6	Rufous backed shrike	Lainius schach erythonotus	10
7	Little bittern	Ixobrychus minutus	0
8	Starlings	sturnidae	100
9	Common swallow	Hirundo rustica	70
10	European hoopoe	Upupa epops	50
11	Indian ring dove	Streptopelia decaota	70
12	Paradise Flycatcher	Terpsiphone paradisi	5
13	Golden blacked woodpecker	Dinopium benghalense	12
14	White-breasted Kingfisher	Halcyon smyrnensis	40
15	Whistling thrush	Myophonus	50

16	Yellow Wagtail	Motacilla flava	30
17	Common swallow	Hirundinidae	40
18	Eurasian lapwing	Upupa epops	20
19	Reed Warbler	Acrocephalus scirpaceus	60
20	Rufous backed Shrik	Lanius schach	50
21	Eastern grey wagtail	Motacilla cinerea	30
22	Tickle's thrush	Turdus unicolor	60
23	Indian Whiskred tern	Chlidonias hybrida	40
24	Gloden oriole	Oriolus oriolus	20
24	Red shank	Tringa totanus	30
26	Blue tailed bee eater	Merops philippinus	20
Total			1063

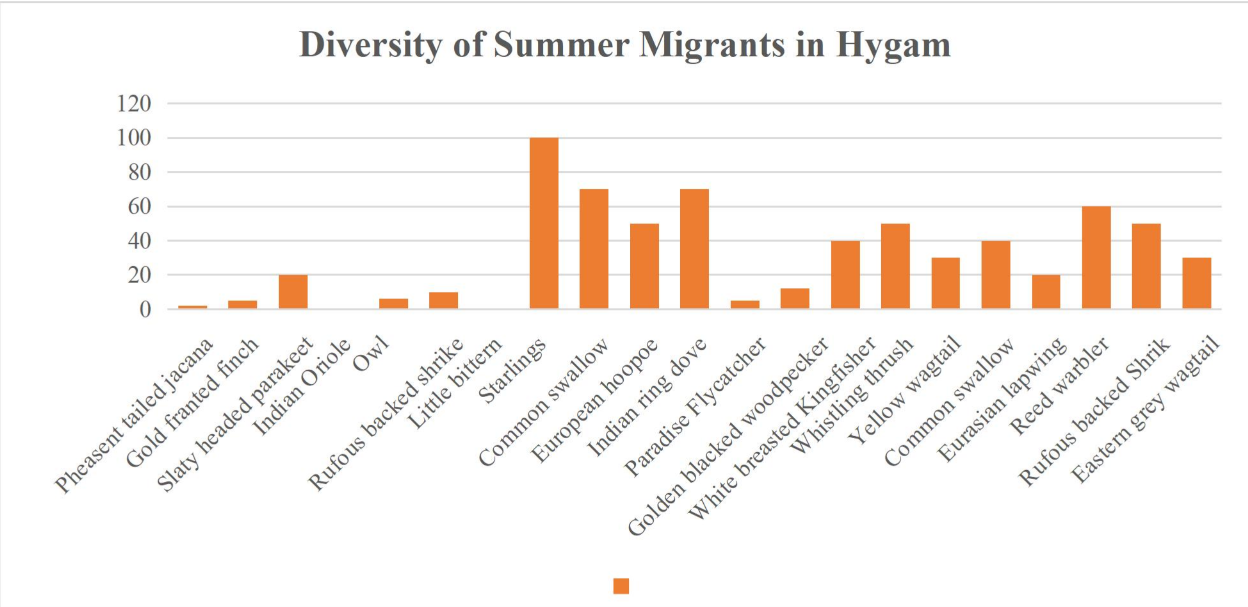

Figure 3 Diversity of summer Migrant Birds Species-wise (Jan. 2022- Dec. 2023)

Table 3 Number of Migratory Birds found in in the study area (Jan. 2022 to Dec. 2023)

S.NO	English Name	Scientific Name	IUCN Conservational Status	Total No of Species Found
Winter migratory Birds visiting Hygam				
1.	Northern Pintail	Anas acuta	Least Concern	5000
2.	Common Teal	Anas crecca	Least Concern	8000
3.	Mallard	Anas platyrhynchos	Least Concern	9500
4.	Gadwall	Anas strepera	Least Concern	6000
5.	Northern Shoveller	Anas clypeata	Least Concern	1500
6.	Common Coot	Fulica arta	Least Concern	2500
7.	Grey leg Goose	Anser anser	Least Concern	10
8.	Red crested Pochard	Rodonnessa rufina (Pallas)	Least Concern	10
9.	Pallas Fish eagle	Haliaeetus leucoryphus	Endangered	0
10.	Geese	Anser domesticus	Least Concern ---	100
11.	Weigon	Mareca	Least Concern	900
12.	Garganey Teal	Spatula querquedula	Least Concern	150
Total				33670

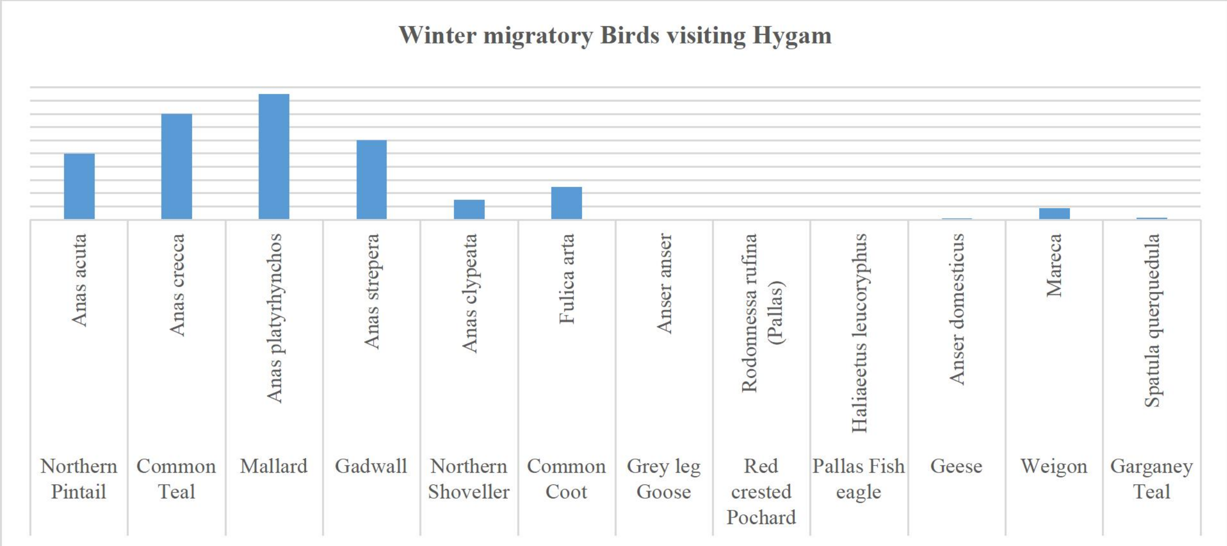

Figure 4 Species-wise number of Migratory Birds (Jan. 2022- Dec. 2023)

6 CONCLUSION AND RECOMMENDATIONS

The research aimed to find out the current status of the avifaunal population in the wetland. There is seasonal variation in the bird population as well as variation among the study sites.

The government have paid less attention to the wetland Reserve, despite its socio-economic and ecological significance. Dense growth of reeds and other emergent vegetation are dominant in the study area. The area of the wetland was about 1400 hectares (14 km) earlier but now the total area of the wetland has shrunk to 725 hectares (7.25 km) [25]. This decline in wetland areas led to the loss of waterbird populations due to habitat destruction and loss of food.

The migratory bird species that were not observed in the current study but were previously discovered in the wetland included the ferruginous duck, red-crested pochard, Palla's fish eagle, and garganey. During the current investigation, no sightings of the Little-bitten, Gold-finned Finch, or Indian Oriole were observed among the summer migrants.

The little grebe, green sandpiper, grey and night Heron & white-breasted kingfisher were found in fewer numbers from residential birds, due to less open water surface and drying of the wetland in the summer season which leads to less food available for these species. Shrinking areas, siltation, eutrophication, pollution, encroachment and people using this wetland as a shooting site in winter are other reasons for dwindling avifauna populations from this wetland.

Another main cause for the decline of the avifauna populations from the study area is the cutting and burning of the reed beds in the summer and autumn seasons by the local people for fodder which destroys the nests of the residential and summer migrants. Due to these reasons, the birds migrate to other areas are their number may remain very low which may be the reason that these birds may not be seen from this reserve.

From past research, it was found that lakhs of water birds were visited in this wetland, but now only a few thousand avifauna diversity visited the site due to the above reasons.

For the maintenance of species diversity and abundance regulation of water levels and creation of open water, areas are important to cater to the requirements of many avifauna species, for feeding to diving ducks and for resting to many other species. Many species that are crucial to the wetland will lost soon if immediate measures are not taken to protect the dying Wetland.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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EFFECTS OF GROUNDWATER LEVEL CHANGES ON VERTICAL TRANSPORT OF NITROGEN AND PHOSPHORUS

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Abstract: With the intensification of global climate change and human activities, the fluctuation of groundwater level is becoming more and more significant, which has an important impact on the transport and distribution of nitrogen and phosphorus in soil. In this paper, the effects of water table rise and fall on the vertical transport of nitrogen and phosphorus were investigated, and the joint mechanism of hydrogeological conditions, soil type, vegetation cover and human activities on the migration pattern of nitrogen and phosphorus was analysed. Through a combination of field investigation and indoor simulation experiments, this study monitored the changes of nitrogen and phosphorus concentrations in soil profiles under different water table conditions. The results showed that the rise and fall of the water table directly affected the distribution of dissolved oxygen in the soil pore water, which in turn affected the nitrification and denitrification of nitrogen, as well as the adsorption and release process of phosphorus. The research in this paper not only reveals the control mechanism of groundwater level change on nitrogen and phosphorus transport, but also provides a scientific basis for the rational use and management of land resources.
Keywords: Water table; Nitrogen and phosphorus transport; Vertical distribution; Hydrogeological conditions; Soil environment

1 INTRODUCTION

Nitrogen and phosphorus are two key nutrient elements in ecosystems, and their cycling and transport are directly related to eutrophication of water bodies and changes in soil fertility [1]. The cyclic change of groundwater level is an important hydrological phenomenon in the natural environment, especially under the dual influence of climate change and human intervention, the trend of its change and its impact on the environment are more and more unnoticeable. In recent years, scientists have shown great interest in how changes in the water table affect the vertical transport and transformation of nitrogen and phosphorus by influencing soil physicochemical properties. This study focuses on the effect of water table change on the vertical transport of nitrogen and phosphorus, aiming to understand its inner mechanism and its environmental effect through empirical research.

2 THE CONCEPT OF GROUNDWATER LEVEL CHANGE AND ITS ENVIRONMENTAL EFFECTS

Groundwater level refers to the position of the water surface in the lower part of the groundwater surface where the water pressure at any point is equal to the atmospheric pressure [2]. It is a crucial concept in the groundwater system, which directly affects groundwater recharge, discharge and the direction and rate of groundwater flow. The change of groundwater level is a complex process, which is affected by a combination of factors.

Firstly, rainfall is one of the important drivers of groundwater level changes. Climate change leads to unstable rainfall patterns and changes in the spatial and temporal distribution of rainfall, which directly affects the groundwater recharge process. The amount, intensity and distribution of precipitation affects the amount and quality of groundwater recharge, which in turn affects the rise and fall of groundwater levels. Secondly, surface water bodies also play a key role in changes in groundwater levels. There is a hydrological connection between groundwater and surface water, and changes in surface water can directly affect the level of groundwater through seepage or recharge. For example, changes in the water level of rivers, lakes, wetlands and other water bodies can directly affect the trend of groundwater level changes. Besides, groundwater exploitation is one of the important factors of groundwater level change. With the acceleration of urbanisation and the increase of industrial water use, over-exploitation of groundwater has become a common problem. Large-scale groundwater exploitation will lead to the continuous decline of groundwater level, and even form a situation of groundwater resource depletion, which will have a serious impact on the groundwater system. In addition, the hardening of the ground surface during urbanisation can exacerbate changes in groundwater levels. The increase in the horizontal area of the urban surface and the decrease in soil cover result in rainwater not being able to penetrate the soil but flowing directly into the drainage system, reducing groundwater recharge [3]. This surface hardening also increases surface runoff and groundwater loss, negatively affecting the balance of the groundwater system.

3 DYNAMICS OF NITROGEN AND PHOSPHORUS IN THE SOIL-WATER-PLANT SYSTEM

In the soil-water-plant system, nitrogen and phosphorus are critical nutrient elements in the ecosystem, and their form and availability are regulated by a variety of biogeochemical processes [4]. Soil is an important reservoir and exchange site for these elements, while changes in the water table directly affect their distribution and transport in the soil.

Nitrogen exists in various forms in soil, including organic nitrogen, ammonium nitrogen (NH_4^+) and nitrate nitrogen (NO_3-). Organic nitrogen is mainly derived from organic matter in the soil, whereas ammonium nitrogen and nitrate nitrogen are caused by microbial activity. Ammonium nitrogen is converted from the organic form mainly through microbial mineralisation, whereas nitrate nitrogen is produced through nitrification. The distribution and transport of these two forms of nitrogen in the soil are affected by changes in the water table.

Shifts in the water table affect the transport and transformation processes of nitrogen in the soil. Nitrate nitrogen, in particular, because it is more soluble in water, is more likely to migrate with groundwater flow. When the water table rises, the amount of soil pore water increases, resulting in nitrate nitrogen being more easily dissolved and transported with groundwater flow. And when the water table decreases, the oxygen content in the soil increases, which is favourable to nitrification and increases the generation of nitrate nitrogen, thus affecting the content and distribution of nitrate nitrogen in the soil.

Compared with nitrogen, phosphorus exists mainly in the adsorbed state in soil particles. Minerals such as iron, aluminium and calcium in the soil play an important role, and they form complexes with phosphorus, making the migration and cycling of phosphorus in the soil restricted. Changes in the water table affect the water content in the soil and the movement of soil particles, which in turn affects the process of phosphorus adsorption and release [5]. When the water table rises, the water content in the soil increases, which may dilute the phosphorus concentration in the soil and reduce the adsorption of phosphorus to soil particles, making it easier for phosphorus to be released into the pore water. On the contrary, when the water table decreases, the water content in the soil decreases, which may increase the opportunity for phosphorus to come into contact with soil particles and increase the adsorption of phosphorus, thus decreasing the dissolution and transport of phosphorus in the soil.

4 EXPLORATION OF THE MECHANISM OF THE EFFECT OF GROUNDWATER LEVEL ON THE MIGRATION OF NITROGEN AND PHOSPHORUS

The mechanism of groundwater level rise and fall on nitrogen and phosphorus transport is a systematic problem involving complex biogeochemical processes. Firstly, the rise and fall of the water table will cause changes in the chemical properties of soil pore water and affect the concentration and activity of dissolved substances in the soil. When the water table rises, the amount of pore water in the soil increases. This increased water leads to a decrease in the oxygen content of the soil, especially when the soil pore space is filled with water, which may result in a low-oxygen or even anaerobic environment [6]. Under these conditions, denitrification takes place and nitrate nitrogen is reduced to nitrogen gas, thus reducing the amount of nitrate nitrogen in the soil. The reduction of nitrate nitrogen, which is a form that readily permeates downward, reduces the migration of nitrate nitrogen to groundwater bodies.

Also, a rising water table leads to dilution of phosphorus concentrations in the soil. The relative decrease in the concentration of phosphorus in the soil with increased moisture reduces the adsorption of phosphorus to soil particles and therefore reduces the amount of phosphorus fixed. This makes it easier for phosphorus to dissolve in soil water and migrate downward with water movement, increasing the potential for phosphorus to migrate to groundwater bodies.

Conversely, when the water table falls, the amount of air in the soil pores increases and the amount of oxygen in the soil increases. This provides favourable conditions for nitrification and promotes the production of nitrate nitrogen. Nitrification is the process of oxidising ammonia nitrogen or organic nitrogen to nitrate, so the nitrate nitrogen content in the soil increases. This increases the amount of nitrate nitrogen migrating downward, increasing the likelihood of nitrate nitrogen entering groundwater bodies.

5 INFLUENCE OF HYDROGEOLOGICAL CONDITIONS AND SOIL TYPE ON NITROGEN AND PHOSPHORUS TRANSPORT

Hydrogeological conditions and soil type are important factors affecting nitrogen and phosphorus transport, and they have a significant effect on the vertical migration of nitrogen and phosphorus in soil. Firstly, different hydrogeological conditions can directly affect the transport and distribution of water in the soil, which in turn affects the transport of nitrogen and phosphorus [7]. For example, sandy soils have larger porosity and lower adsorption capacity, which makes it easier for water and the dissolved nitrogen and phosphorus therein to penetrate downward and migrate vertically. The loose structure of sandy soils allows water and the dissolved N and P therein to move rapidly through the soil, and thus sandy areas are usually more prone to N and P leaching, leading to nutrient loss and environmental pollution.

On the contrary, in clayey soils, the high adsorption of clay particles makes the soil more capable of adsorbing nitrogen and phosphorus, and the migration rate is slower. This leads to the phenomenon of nitrogen and phosphorus accumulation in the soil profile. Due to the dense structure and smaller porosity of clayey soils, water and the dissolved nitrogen and phosphorus therein move slower through the soil and are more readily adsorbed and immobilised by the soil particles, which slows down the rate of vertical migration of nitrogen and phosphorus. As a result, clayey soil areas typically exhibit a lower risk of nitrogen and phosphorus loss, but may also result in the accumulation of nutrients in the soil, with consequences for soil fertility and ecosystem health.

In addition to hydrogeological conditions, the amount of organic matter in the soil is an important factor influencing nitrogen and phosphorus transport. Organic matter-rich soils can reduce the loss of nitrogen and phosphorus through their good adsorption and fixation effects. Organic matter has a high surface area and negative electronegativity, which can form complexes with nitrogen and phosphorus plasma nutrients and fix them in soil aggregates, preventing their downward infiltration and loss [8]. Therefore, organic matter-rich soils usually exhibit a higher nitrogen and phosphorus retention capacity, which helps to reduce nutrient loss and environmental pollution.

6 CONCLUSION

Through the study of the effect of groundwater level changes on the vertical transport of nitrogen and phosphorus, we can conclude that the dynamic change of groundwater level is an important factor affecting the cycling and transport of nitrogen and phosphorus in the groundwater environment. This effect is realised by altering the physical and chemical properties of the soil, microbial activity and the level of dissolved oxygen in the soil solution. In order to effectively manage and protect water resources, an understanding of these mechanisms is essential for the development of scientific groundwater protection policies and the implementation of soil management practices.

COMPETING INTERESTS

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FLOOD SUSCEPTIBILITY MAPPING USING GIS – BASED MULTI – CRITERIA DECISION – MAKING "MCDM" METHOD: A CASE STUDY OF KANDAHAR PROVINCE, AFGHANISTAN

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Abstract: Floods, which are common than other natural disasters like earthquakes, heavy precipitations, and droughts, are one the primary effects of global climate change and have major effects on human safety, sustainable development, and economic growth. As climate warming and intensifying hydrologic cycle worsen, global flooding risks may increase, potentially impacting Afghanistan as well. Severe flooding being caused by rising temperatures, erratic rainfall patterns, and extreme weather in Afghanistan, especially in the region of Kandahar. Despite the significance of identifying and mapping flood – prone areas, this province has not participated in any previous studies done on the topic at hand. Therefore, the aim of this research was to develop a flood susceptibility map for Kandahar province and identified flood – prone areas with high levels of occurrence by integrating Geographic Information System (GIS) and Multi – Criteria Decision – Making (MCDM) method, with Analytic Hierarchy Process (AHP). To achieve the study's goal, 11 Flood Causative Factors (FCFs), such as runoff potential, slope, rainfall, flow accumulation, distance from rivers, topographic wetness index (TWI), drainage density, lithology, Digital elevation model (DEM), sediment transport index (STI), and curvature, were weighted and overlayed. The resulting map depicted five different levels of susceptibility to flooding: least, low, moderate, high, and very high. The model's final map of flood susceptibility was found to be in line with past flood occurrences in the study area, demonstrating the successful outcome of the methodology utilized to locate and map flood – prone areas.
Keywords: Flood susceptibility map; GIS; MCDM; AHP; Kandahar Province; Afghanistan

1 INTRODUCTION

Relatively significant flows that surpass the natural pathways created for the runoff are referred to as floods. The river is at a high stage during a flood, and the river water typically overflows its banks [1]. Floods are serious natural calamities that have an impact on economic growth, sustainable development, and human safety, as a result of global climate change, floods are global problems that affect most of the world [2]. According to studies, floods have happened more frequently recently than other natural disasters, including earthquakes, heavy precipitations, and droughts [3]. In fact, the risk of worldwide flooding may rise in the future [4], due to warming climate and the resulting intensification of the hydrologic cycle [5]. For instance, studies indicate that even in most optimistic climate change scenario, sea levels are predicted to rise by 0.55 meters by 2100, endangering coastal cities, especially the larger one at risk [6]. Moreover, flood events are expected to occur more frequently in the southeast Asian region, east and central Africa, and a large portion of Latin America [7]. People in the world experience flood hazards every day. Many major floods have occurred worldwide in recent decades. For example, China in 1931 "which is thought to be the world's deadliest natural disaster and resulted in over 2 million deaths, is among the most deadly floods ever recorded" [8], floods in southeast Spain in 1997 [9], floods in south France in 2003 [10], flood events in the northwest Iberian Peninsula in 2000 [11], etc. Increased temperature, unpredictable rainfall patterns, and more extreme weather events are all causing higher level of severe flooding in Afghanistan. Such as, in 2019, with 97mm rain falling in 30 hours, Kandahar city and its surrounding districts experienced severe floods, and the event resulted in 20 fatalities and roughly 2000 homes being damaged [12]. Floods in Charikar, north of Kabul, in August 2020 killed over 100 people and collapsed hundreds of buildings [13]. Heavy flooding in the Spin Buldak district of Kandahar province, in August 2022 destroyed a large number of homes, farms, gardens, and other landscapes [14]. In April 2024, there were floods in 23 provinces of Afghanistan, then caused over 100 deaths and 54 injuries from heavy rains and flooding, at least 2134 houses were destroyed, 10789 animals perished, 800ha of farmland and 85Km of roads were damaged. The most affected areas were Kandahar, Herat, Western Farah, and Southern Zabul [15]. In July 2024, there were 40 fatalities, 25 injuries, and extensive infrastructure damage in several districts of the provinces of Badakhshan, Kunar, Laghman, Nangarhar, and Nuristan in eastern and northeastern Afghanistan due to strong windstorm, intense rains, and flash floods [16]. Furthermore, one of the afghan provinces that is particularly vulnerable to flooding during periods of high rainfall is Kandahar province. Therefore, the aim of the study was to create a flood susceptibility map for Kandahar province and identify flood – prone areas that are at high levels of flood occurrence. There are 3 types of methods for flood susceptibility mapping, 1st are Statistical methods, 2nd Soft computing methods, 3rd are MCDM methods [17]. Based on mathematical formulas, statistical methods are indirect ways to evaluate the connections between flood triggers and floods [18]. Soft computing is a numerical intelligence approach [19], that combine methods like Fuzzy Logic, Neural Networks (NNs), and Genetic Algorithms [20]. To improve results and solve specific problems [21], enhancing the analysis environment and decision

– making process and equating to human expertise [19]. A wide range of technical techniques for organizing decision issues and creating, assessing, and ranking potential decisions are offered by the Multi – Criteria Decision – Making (MCDM) methods [22]. This study used the Multi – Criteria Decision – Making MCDM method to identify flood – prone areas in Kandahar province, Afghanistan.

2 MATERIALS AND METHODS

2.1 Description of Study Area

This study is conducted on Kandahar province, which is one of the southern provinces of Afghanistan, sharing a border with Pakistan, to the south. It is surrounded by Helmand in the west, Uruzgan in the north and Zabul province in the east. The greater region surrounding the province is called LOY Kandahar. According to National Statistic and Information Authority (NSIA), the population of Kandahar province is approximately 1.5 million in 2021. The latitudinal extension of the province is from 29° 31' 32" N to 32° 29' 01" N, and the longitudinal extension of the province is from 64° 26' 46" E to 67° 48' 34" E. The province covers an area of 54022 km^2. location of the study area is shown below in Figure 1.

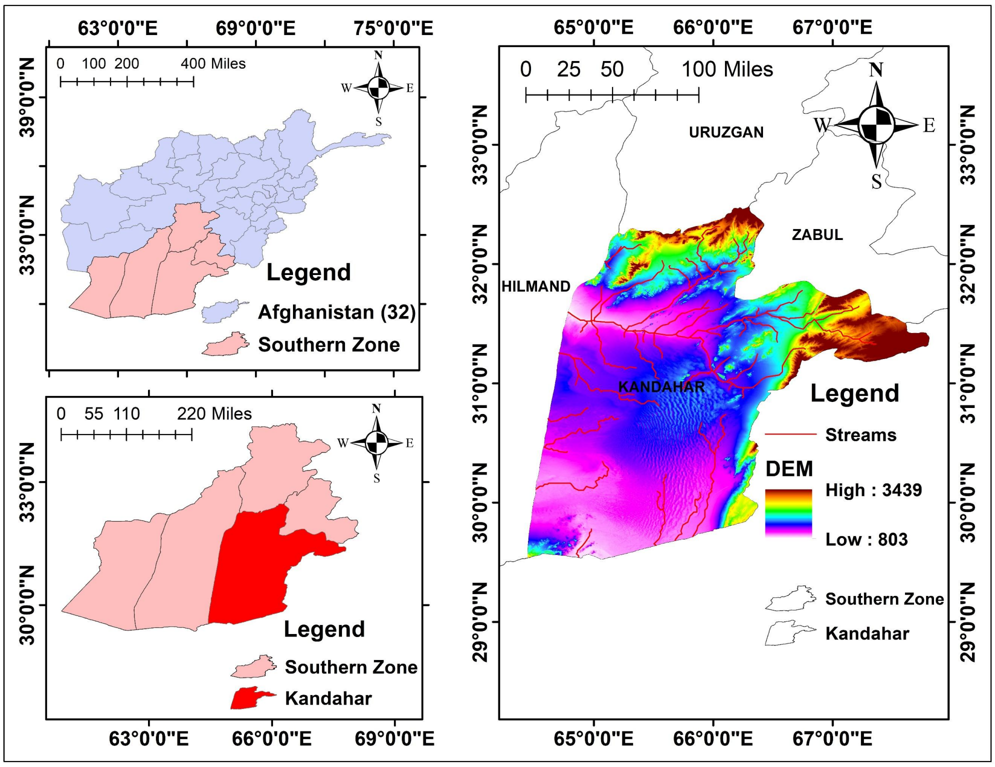

Figure 1 Study Area

2.2 Data and Sources

This study used open – access data (internet resources) to collect Remote Sensing (RS) data such as, land use/cover, soil, geology/lithology, rainfall, and Digital Elevation Model (DEM). Table 1 discusses all the sources from which the necessary data for this study was collected.

Table 1 Data and Sources

S. No	Data type	Original Format	Source
1	Soil	Vector	https://www.fao.org/soil-portal/data-hub/soil-mapsanddatabases/
2	Lithology	Vector	Afghan Geological Survey Department
3	Land use/cover	Raster	https://livingatlas.arcgis.com/landcover/
4	Rainfall	//	https://power.larc.nasa.gov/data-access-viewer/
5	DEM	Raster	USGS
6	River network	Vector	https://mapcruzin.com/free-Afghanistan-arcgis-mapsshapefiles.htm
7	Provincial boundary	Vector	https://mapcruzin.com/free-Afghanistan-arcgis-mapsshapefiles.htm

2.3 Methodological Flow Chart

The study area flood susceptibility map was developed by a process. The flood susceptibility map was created in four "4" stages utilizing the Geographic Information System GIS – based Multi – Criteria Decision – Making (MCDM) technique. The 1st stage involves the generation of all considered Flood Causative Factors (FCFs). The 2nd stage involves reclassifying all the considered FCFs. In 3rd stage, used the Analytic Hierarchy Process (AHP) to determine the weight of each FCF. The 4th stage is overlay analysis, which creates a flood susceptibility map. Figure 2 shows all 4 stages.

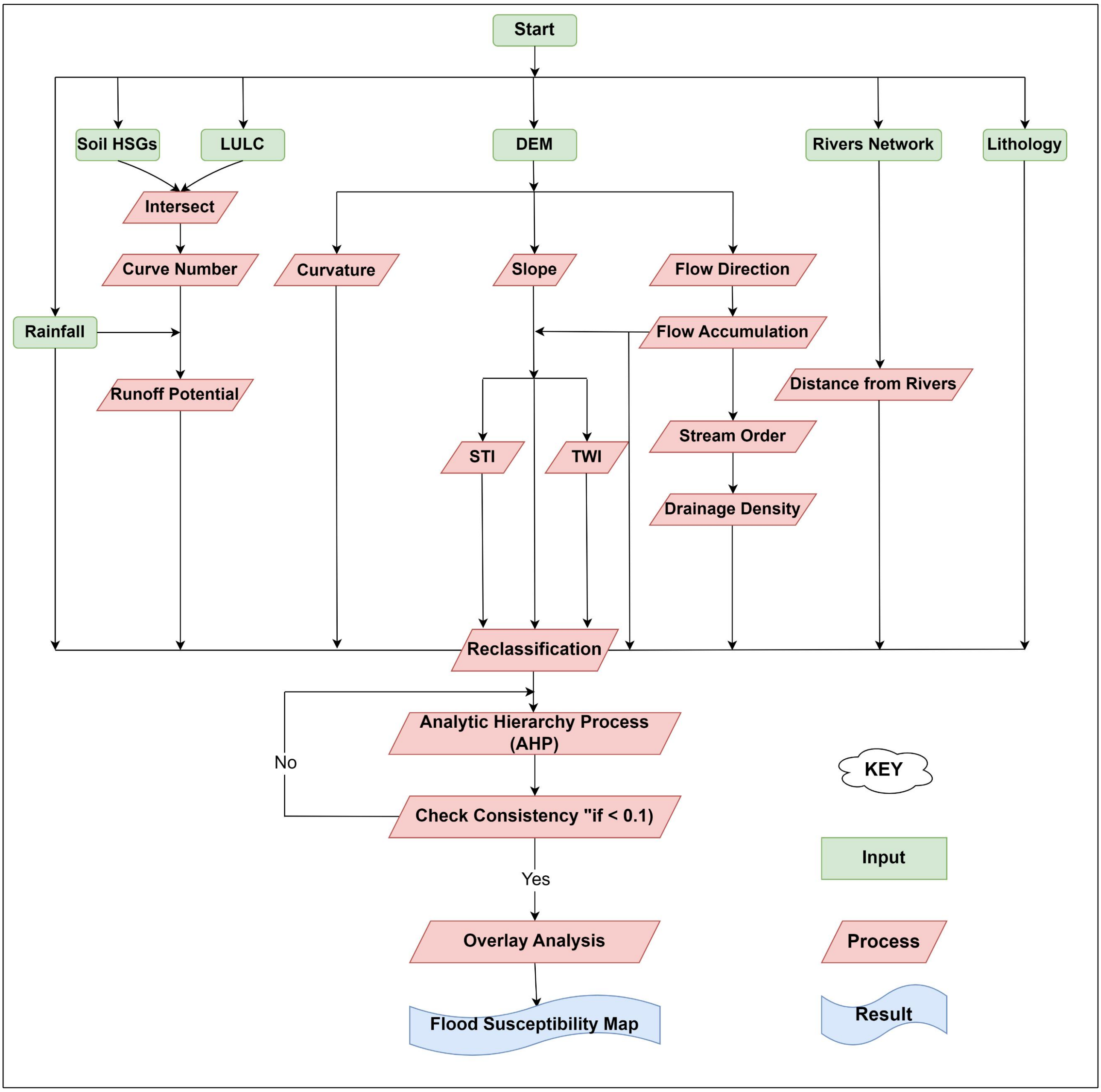

Figure 2 Flowchart of the Study

2.4 Generation of Flood Causative Factors "FCFs"

2.4.1 Digital elevation model (DEM)
Elevation is a factor considered when assessing flood danger. In general, Lower – Elevated regions are more likely to experience flooding than Higher – Elevated regions because they experience a greater proportion of river outflow and flood more quickly during high water flows [23].A 30m resolution Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM) is obtained for this study, and the study area DEM is then extracted using ARCGIS 10.7.1 platform. The DEM of the study area is shown in Figure 1(Study Area).

2.4.2 Flow accumulation

The flow direction is calculated to construct the flow accumulation throughout the runoff simulation procedure. The number of cells that flow through a certain cell determines the flow accumulation in that cell [24]. Greater flow accumulation values make a place more susceptible to flooding and simpler for runoff to form. To make flow accumulation map. Utilizing the DEM of the study area, the flow accumulation map is created. First, the flow direction map is created using the DEM, and then the flow accumulation map is created directly from the flow direction using Hydrology Tools in Arc toolbox. The flow accumulation map of the study area is shown below in Figure 3.

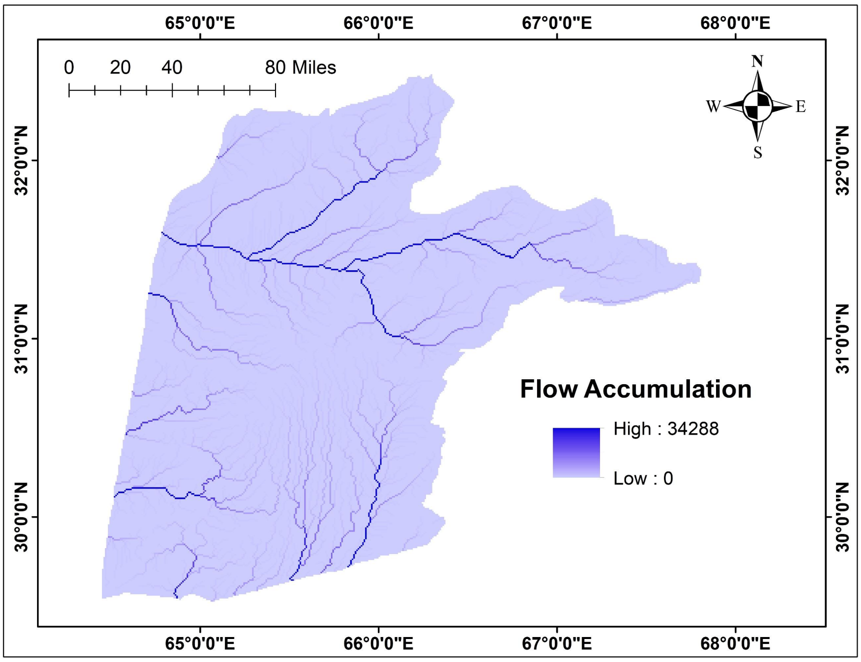

Figure 3 Flow Accumulation

2.4.3 Stream order and drainage density

Cells with accumulating flow above the threshold set by the user are referred to as stream orders. Many scholars have researched many methods for numerical definitions of stream orders; the most popular ones are the Shreve method [25], and Strahler method [26]. In each of these two methods, stream order is imagined as a tree with strong roots and slender branches in each of these two methods. However, these two approaches differ in how they identify the many branches at different levels. The stream that results from the merger of the rivers with different stream orders is assigned the higher of the two numbers [26]. The Shreve approach also assigns the outermost streams to the number 1 order. In contrast to the Strahler technique, which adds the two numbers at a connection [25]. The stream order is quantified in this study using the Strahler method, shown in Figure 4. Drainage density is defined as, the ratio of the total length of stream segments to total area of a drainage basin [27]. And calculated by the Equation 1. Flooding is more likely to occur in places with high drainage density than in areas with low drainage density. The drainage density map is created from stream order map using line density tool under density in spatial analyst tool. The study area's drainage density map is shown below in Figure 5.

$$D_d = \frac{\sum_{i=1}^{n} L}{A} \quad (1)$$

Where, D_d is the drainage density, n is the number of streams, L is the stream length (km), and A is the drainage basin (km).

2.4.4 Slope

The formation and dispersion of floods are significantly influenced by slope. The spread at which surface waterflows is determined by the land's slope. It is a signal that indicates how vulnerable the area is to flooding [28]. The amount of water covering the ground and the chance of a flood rise as the slope decreases and the velocity of surface waterflow decreases [29]. The higher slope found in mountainous areas regularly stop water from collecting and make the areas less susceptible to flooding [30]. The study area slope map is shown below in Figure 6.

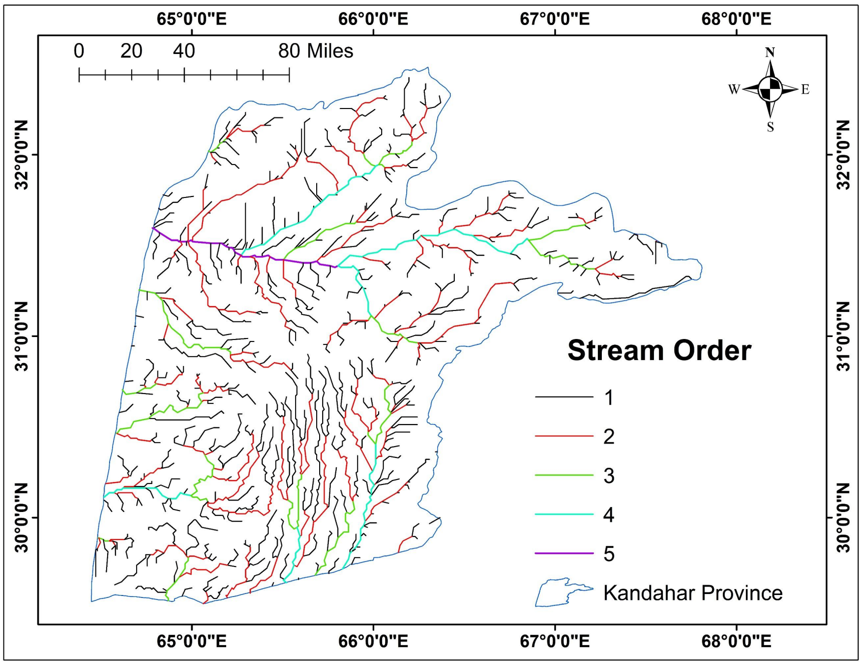

Figure 4 Stream Order (Strahler Classification)

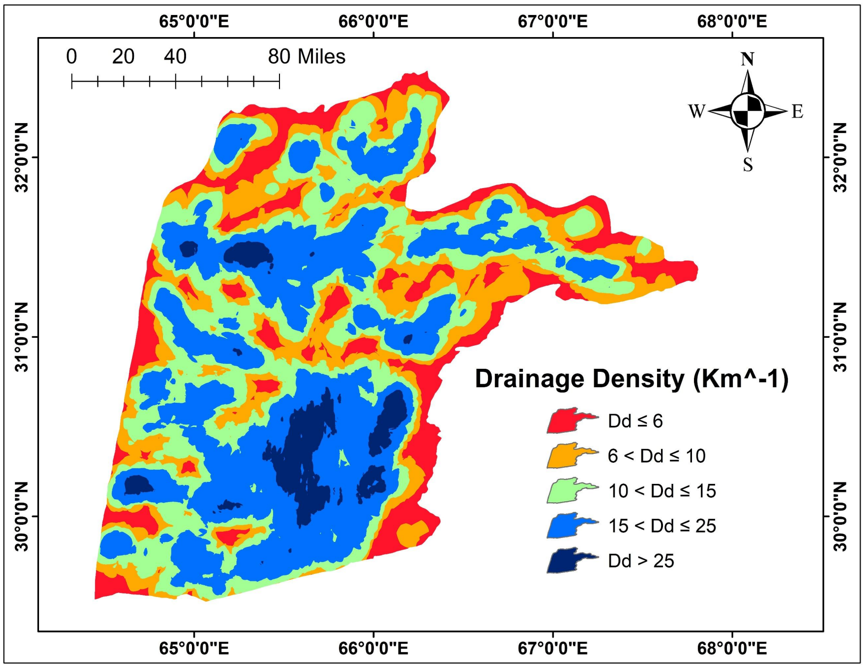

Figure 5 Drainage Density

2.4.5 Soil

Another factor that is frequently included in flood susceptibility mapping is soil type [17]. The type of soil has a major influence on the infiltration process [31]. The soil's fine texture composition increases surface runoff and decreases infiltration rate [31]. Therefor places with finer soil texture have a higher chance of flooding than areas with coarser soil texture [32]. The FAO/UNESCO soil map of the world is downloaded, and then the study area soil map is clipped from the world soil map using the geoprocessing tools in ARCGIS 10.7.1 platform, which is shown in Figure 7. Table 2 describes the 4 hydrological Soil Groups (HSGs) classification system based on runoff potential and infiltration rate, which is developed by the USDA – Soil Conservation Service [33]. Generally, there are 4 types of HSGs in the world, but the study area has two types, HSG – A and HSG – D. the brief explanation of the study area soil is discussed below in Table 3, and the study area HSG soil map is shown in Figure 8a.

2.4.6 Land use and land cover (LULC)

Land use and land cover are two of the most significant elements influencing the likelihood of floods. Despite their frequent interchange in literature, the terms "Land cover" and "Land use" are distinct. Land cover describes the physical and biological characteristics of the basin, such as its forests, arid regions, and wetlands, etc. that make up the nature of the basin. On the other hand, land use describes how the basin is used, including for farming, manufacturing, and settlements, and it is influenced by socioeconomic activities. Area with high densities of vegetation are frequently less susceptible to flooding, because vegetation causes significant infiltrations and slow down the rapid flow of water [31]. Areas such as permanent wetlands, built up regions, settlements, barren land (Excluding Sand Dunes and Sand Cover), etc. are more susceptible to flooding. The study area landcover map is shown in Figure 8b.

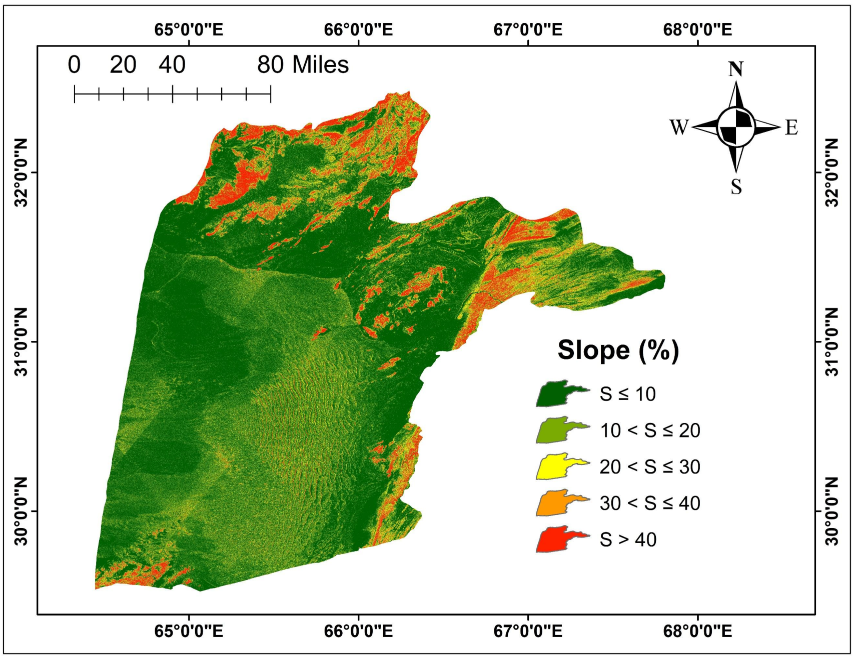

Figure 6 Slope Map of the Study Area

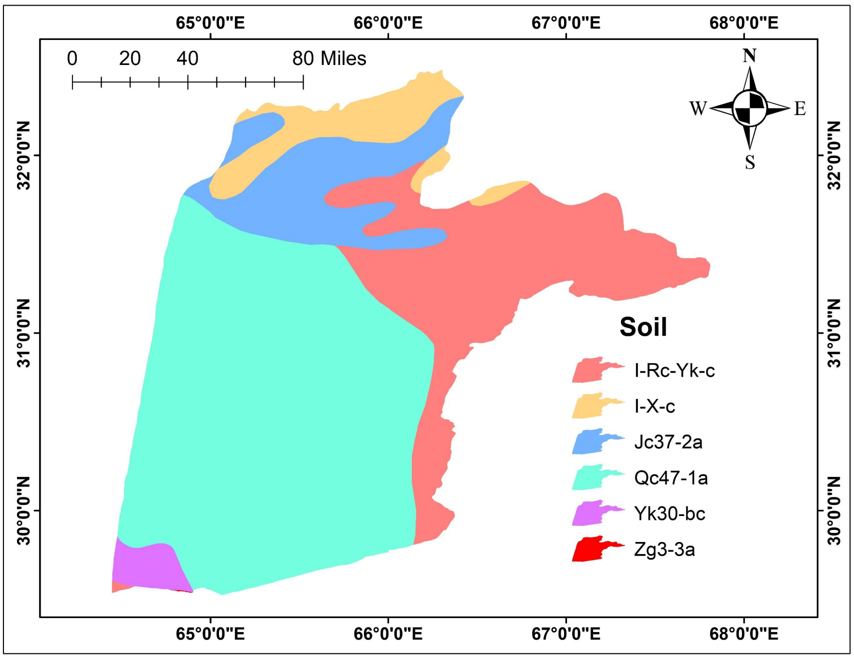

Figure 7 Soil Map of the Study Area

Table 2 Description of 4 HSGs

HSGs	Textures	Properties
A	Sand, loamy sand, or sandy loam	High infiltration rate, Low runoff potential
B	Silt loam or loam	Moderate infiltration rate, Moderately low runoff potential
C	Sandy clay loam	Low infiltration rate, Moderately high runoff potential
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	Very low infiltration rate, High runoff potential

Table 3 Description of Study Area Soils

SNUM	Map Symbol	FAO – Soil	Textural property			Texture	HSGs
			Sand (%)	Clay (%)	Silt (%)		
3508	I–Rc–Yk–c	Lithosols	35	26	39	Loam	D
3512	I–X–C	Lithosols	45	22	33	Loam	D
3525	Jc37–2a	Calcaric Fluvisols	47	18	35	Loam	D
3542	Qc47–1a	Cambic Arenosols	62	16	22	Sandy–Loam	A
3598	Yk30–bc	Calcic Yermosols	36	27	37	Loam	D
3621	Zg3–3a	Glayic Solonchaks	29	52	19	Clay	D

2.4.7 Curve number (CN)

The CN, a dimensionless number that depends on the Hydrologic Soil Groups (HSGs) and land cover of the particular area, ranges from 30 for permeable soils that has high rate of infiltration to 100 for waterbodies, snow, and ice [34]. Areas with higher number of CN are more vulnerable to flooding than areas with lower numbers of CN. The study area CN map is shown below in Figure 8c.

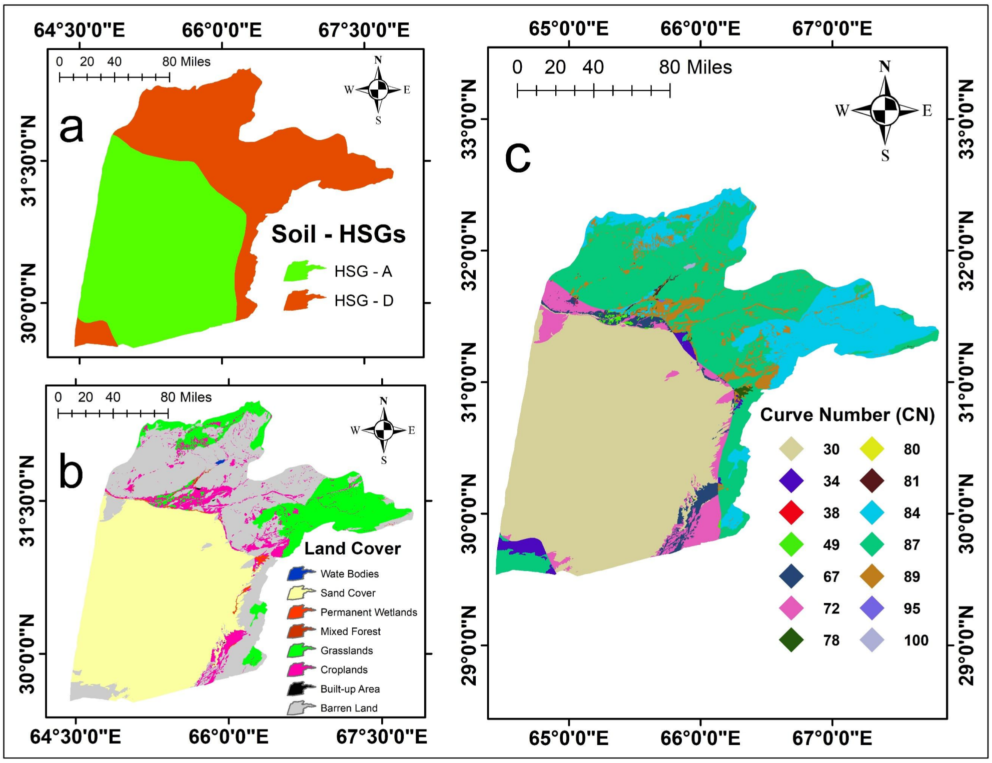

Figure 8 a, Soil HSGs. **b,** Land Cover. **c,** Curve Number

2.4.8 Rainfall

Rainfall is the most significant parameter that determine the likelihood of floods [35]. Rainfall needs to be taken into account in any estimate of flood susceptibility since without it, floods are unthinkable [31]. The spread of the flood, it's duration, it's range of influence, and potential damages to the area are all influenced by intensity, duration, and amount of the precipitation [17]. The study area rainfall data of 23 years "from 2000 to 2022" is downloaded from NASA power access site, then based on that data the rainfall map is created. Which is shown in Figure 9.

2.4.9 Runoff potential

Soil runoff potential is defined as the chances of surface runoff happening during rain falling and snow melting. When water moves through soil at a slow enough rate for water to flow across the surface of the land into waterbodies, this is known as surface runoff [36]. Higher runoff potential areas are typically more susceptible to flooding than lower runoff potential areas. To create the runoff potential map for the study area, use the Equation 2 through the "Map Algebra" tool in ARCGIS 10.7.1 platform.

$$Q = \frac{(P - I_a)^2}{P - I_a - S} \tag{2}$$

Where Q is runoff potential (mm), P is rainfall (mm), $I_a = 0.2S$ is initial abstraction, and S is potential maximum retention (mm) which is calculated using Equation 3. the study area runoff potential map is shown below in Figure 10.

$$S = \frac{25400}{CN} - 254 \quad (3)$$

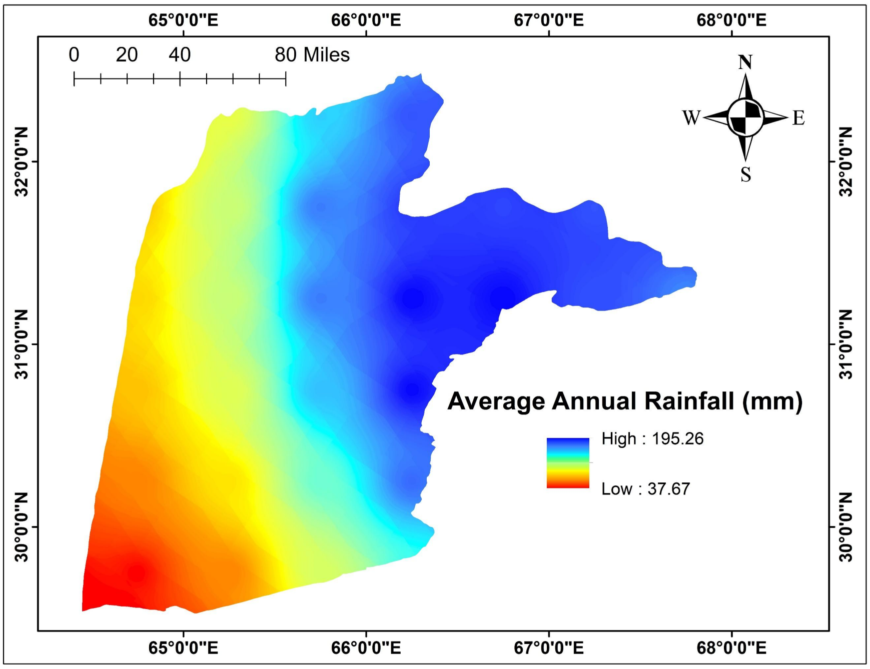

Figure 9 Rainfall Map of the Study Area

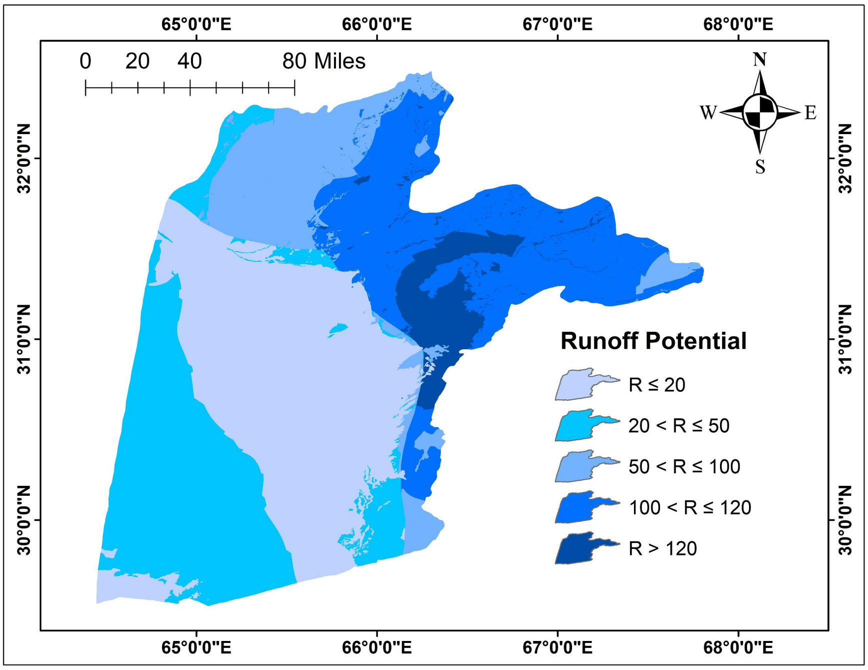

Figure 10 Runoff Potential Map of the Study Area

2.4.10 Topographic wetness index "TWI"

TWI is a key idea in the field of hydrology and geomorphology. It is used to evaluate and model the spatial distribution of potential wetness and water accumulation on a surface. It is a useful tool for land use planning, environmental management, and the conservation of natural resources since it helps to comprehend how water moves over different surfaces. The topographical influence on runoff generation and flow accumulation volume at a specific region is measured using TWI [31]. It describes the propensity of water under the influence of gravity to gather at a certain location or flow downward [37]. Flood danger is directly correlated with TWI; the higher the TWI score indicates a higher chance of flooding [38]. The TWI is calculated using Equation 4.

$$TWI = \ln\left(\frac{A_s}{\tan(\beta)}\right) \quad (4)$$

Where β indicates the slope gradient (in degrees) and A_s indicates catchment area. The TWI map of the study region is shown in Figure 11.

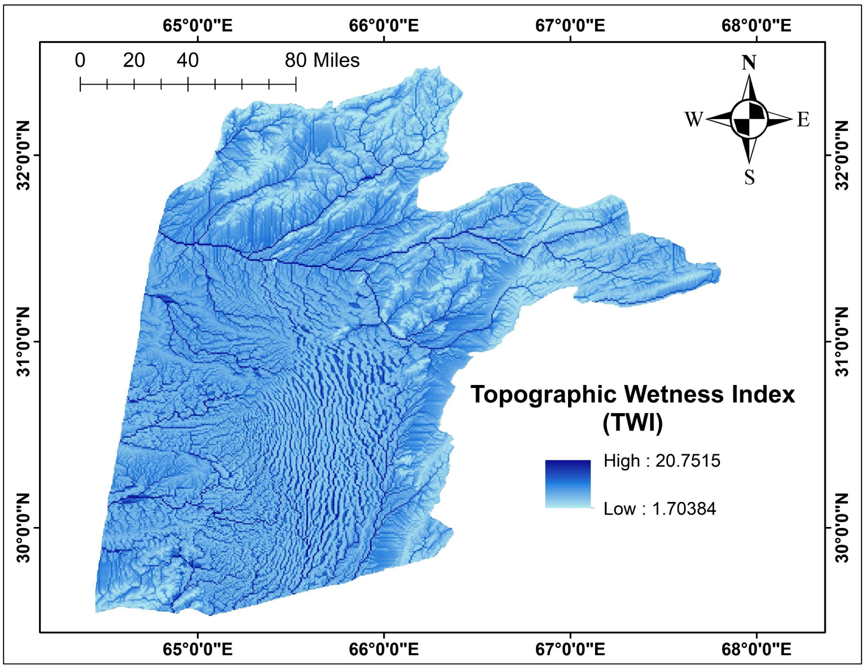

Figure 11 Topographic Wetness Index (TWI) of Study Area

2.4.11 Sediment transport index "STI"

STI has a strong connection with any region's runoff features. Flood events are more likely to occur in areas with low STI values, and vice versa [39]. The Equation 5 is used to get STI from DEM [40].

$$STI = \left(\frac{A_s}{22.13}\right)^{0.6} \times \left(\frac{Sin\beta}{0.0896}\right)^{1.3} \tag{5}$$

Where β indicates the slope gradient (in degrees) and A_s indicates catchment area. The STI map of the study region is shown in Figure 12.

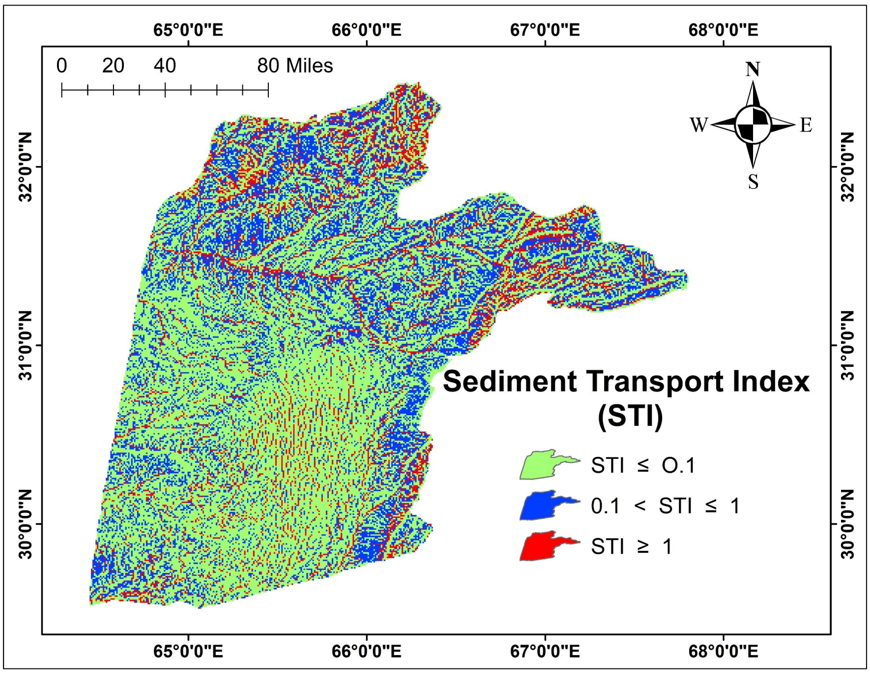

Figure 12 Sediment Transport Index (STI) of Study Area

2.4.12 Distance from river

The distance between a site and the river network affects, how far the flood spreads throughout the basin [41]. Due to the fact that excess water from rivers first reaches adjacent lowland areas and the side river banks, places near to rivers are more likely to experience flooding than areas farther from rivers [42]. The river network map of all country is downloaded, then the study area distance from river map is created through Euclidian distance tool under distance in spatial analyst tools in ARCGIS10.7.1 platform. The study area distance from rivers map is shown in Figure 13.

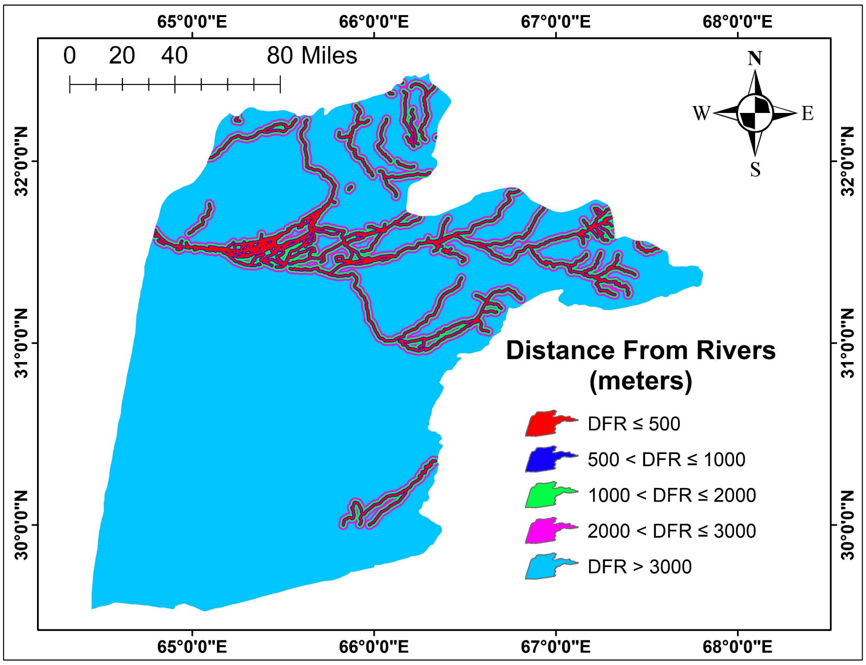

Figure 13 Distance from Rivers Map of Study Area

2.4.13 Geology/Lithology

Studies have demonstrated that formations with geologically impermeable surfaces are more vulnerable to flooding [43]. Simultaneously, geology plays a major role in the drainage pattern development process, which is linked to water accumulation processes and factors influencing the overflow capacity [44]. The lithology map of Afghanistan is obtained from "Afghan Geological Survey Department", then the study area lithology map is clipped from the gathered lithology map, which is shown in Figure 14. Then the study area lithology map is reclassified according to permeability which is shown below in Figure 15.

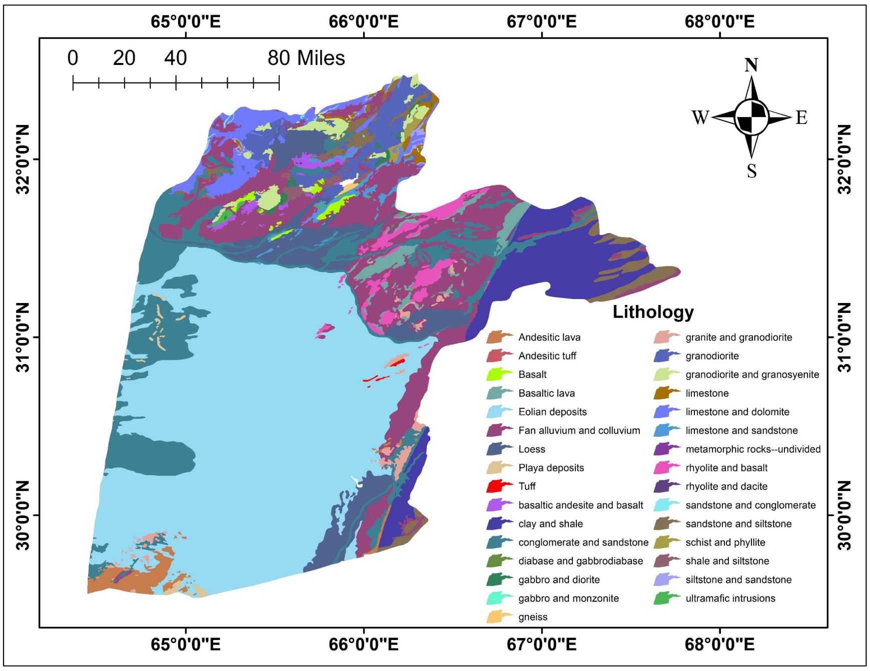

Figure 14 Lithology Map

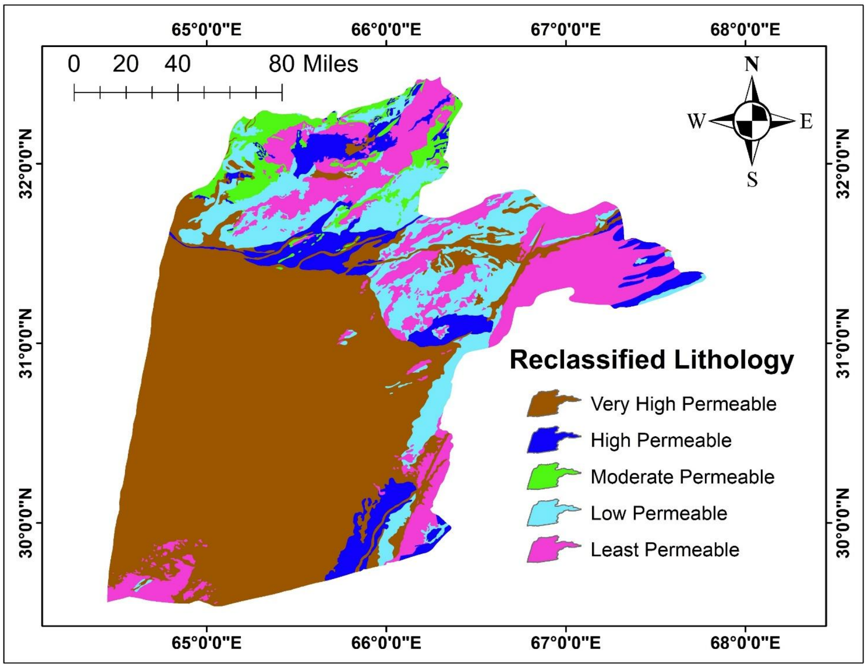

Figure 15 Reclassified Lithology Map

2.4.14 Curvature

This parameter represents processes connected to erosion, flow velocity, and accumulation [45]. Both flow and possibility of floods are impacted by curvature [46]. Floods also tend to happen in places where the curvature is flat [47, 48]. According to some studies the most accurate predictors of flood occurrences are elevation and curvature [49]. The study area curvature map is shown below in Figure 16.

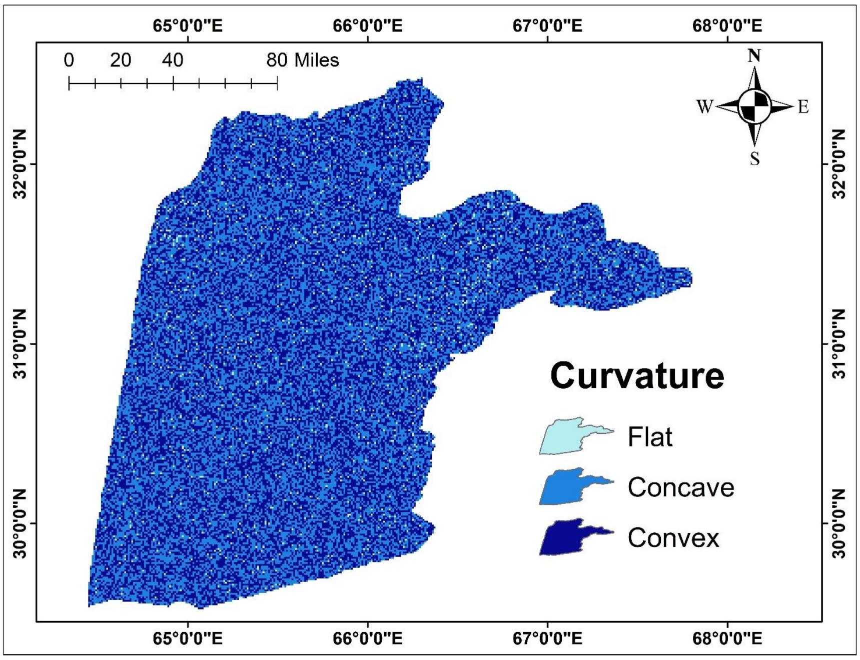

Figure 16 Curvature Map of the Study Area

2.5 Multi – Criteria Decision – Making "MCDM"

Selecting from a range of options is a part of the process of decision – making. MCDM is a procedure that allows values to be assigned to alternatives and several criteria to be evaluated simultaneously in complicated problems like disasters, and MCDM method, are those that enable the best option to be chosen from multiple criteria applied simultaneously [22]. Put another way, it is a technique that enables decision – makers to consider the effectiveness of numerous independent variables while reaching the best conclusion possible given the situation and relevant elements [50].

2.6 Reclassification of the Flood – Causative Factors (FCFs)

The 11 flood – causative factors were all reclassified based on their vulnerability to flooding using ArcGIS's reclassification tool, with using a 1 – 5 scale, where 1 denotes the least susceptibility to flooding, and 5 denotes the very high susceptibility to flooding, raster layers are reclassified into 5 classes. The only criteria that are reclassified into their respective 3 classes are Sediment transport index (STI) and curvature, each of which has three variants. Reclassification of the selected raster layers is described in Table 4.

Table 4 Reclassification of flood causative factors

Flood Causative factors	Classes	Flood Susceptibility	Ratings	Average Weight (%)
Runoff Potential (mm)	$R \leq 20$	Least	1	24
	$20 < R \leq 50$	Low	2	
	$50 < R \leq 100$	Moderate	3	
	$100 < R \leq 120$	High	4	
	$R > 120$	Very High	5	
Slope (%)	$S \leq 10$	Very High	5	16
	$10 < S \leq 20$	High	4	
	$20 < S \leq 30$	Moderate	3	
	$30 < S \leq 40$	Low	2	
	$S > 40$	Least	1	
Rainfall (mm)	$Rf \leq 60$	Least	1	16
	$60 < Rf \leq 80$	Low	2	
	$80 < Rf \leq 100$	Moderate	3	
	$100 < Rf \leq 150$	High	4	
	$Rf > 150$	Very High	5	
Flow Accumulation	$Fa \leq 500$	Least	1	11
	$500 < Fa \leq 2000$	Low	2	
	$2000 < Fa \leq 5000$	Moderate	3	
	$5000 < Fa \leq 15000$	High	4	
	$Fa > 15000$	Very High	5	
Distance from rivers (m)	$D \leq 500$	Very High	5	11
	$500 < D \leq 1000$	High	4	
	$1000 < D \leq 2000$	Moderate	3	
	$2000 < D \leq 3000$	Low	2	
	$D > 3000$	Least	1	
TWI	$T \leq 5$	Least	1	7
	$5 < T \leq 9$	Low	2	
	$9 < T \leq 13$	Moderate	3	
	$13 < T \leq 16$	High	4	
	$T > 16$	Very High	5	
Drainage Density	$Dd \leq 6$	Least	1	5
	$6 < Dd \leq 10$	Low	2	
	$10 < Dd \leq 15$	Moderate	3	
	$15\ Dd \leq 25$	High	4	
	$Dd > 25$	Very High	5	
Lithology	Very high permeable	Least	1	4
	High permeable	Low	2	
	Moderate permeable	Moderate	3	
	Low permeable	High	4	
	Least permeable	Very High	5	
DEM (m)	803 – 1200	Very High	5	3
	1200 – 1500	High	4	
	1500 – 1900	Moderate	3	
	1900 – 2400	Low	2	
	2400 – 3439	Least	1	
STI	$St \leq 0.1$	Very High	5	2
	$0.1 < St \leq 1$	Moderate	3	
	$St > 1$	Least	1	
Curvature	Flat	Very High	5	1

Concave	Moderate	3
Convex	Least	1

2.7 Analytic Hierarchy Process (AHP)

Table 5, lists several main MCDM methods, with AHP being the most widely used. The AHP method, created by Thomas L. Saaty [51], is a more straightforward and effective approach for making decisions on complicated issues with multiple criteria. Since the early 21st century it has been widely used with GIS [52], providing a user – friendly solution by combining sophisticated tools for huge – data computing, visualization, and mapping with decision – making support approaches [53]. In this study, the AHP technique is carried out through the following 3 steps.

1st Step, create pairwise comparison decimal matrix Table 7: where weights were assigned to each factor to express the importance of each factor relative to other factors. This was done utilizing related review literature and professional opinion to fill a pairwise comparison decimal matrix. The Flood Causative Factors (FCFs) are graded on a scale of 1 to 9, with 1 stating equal significance and 9 stating one factor is extremely more significant than other. Saaty's pairwise comparison scale [54] is discussed below in Table 6.

2nd Step, calculated normalized pairwise matrix Table 8: after summing up all of the numbers in each column of the pairwise comparison decimal matrix Table 7, divide each column's entry by its column – wise sum to obtain the matrix's normalized score. The sum of each column in normalized pairwise matrix Table 8 should be 1. And the weight of each factor is calculated from a normalized pairwise matrix using the arithmetic mean of each factor's row in the normalized pairwise matrix.

3rd Step, Consistency ratio (CR): calculate the consistency ratio in order to assess the judgement's validity. And use CR < 0.1 "Acceptable" to verify the value. The CR value is calculated using Equation 6.

$$CR = \frac{CI}{RI} \tag{6}$$

Where: RI is the random inconsistency index and CI is the consistency index. Table 9, discusses the value of RI for the number of criteria (n), while Equation 7, is used to calculate CI.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{7}$$

Where: n is the number of flood causative factors in AHP analysis, and λ_{max} is the total of the products of the column wise sum in pairwise comparison decimal matrix Table 10, and the average weights from normalized pairwise matrix.

Table 5 Main MCDM Techniques

Name	Full Name	Primary Author	Time
VIKOR	Vesekriterijunska Optimizacija I Kopromisno Resenje	Opricovic S.	1998
ANP	Analytic Network Process	Saaty T.L.	1996
PROMETHEE	Preference Ranking Organization method for Enrichment Evaluation	Brans J.P.	1984
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution	Hawang C.	1981
DEMATEL	Decision Making Trial and Evaluation Laboratory	Gabus A.	1972
AHP	Analytic Hierarchy Process	Saaty T.L.	1970
ELECTRE	Elimination and Choice Translating Reality	Benayoun R.	1966

Table 6 Saaty's Pairwise Comparison Scales

Numerical Values	Intensity of Importance
1	Activity is equally Important to another
3	Activity is moderately important to another
5	Activity is strongly important to another
7	Activity is very strongly important to another
9	Activity is extremely important to another
2,4,6,8	Intermediate values between the two adjacent judgments
Reciprocals	Values for inversion comparison of importance

Table 7 Pairwise Comparison Decimal Matrix

FCF	R	S	Rf	Fa	DFR	TWI	Dd	Litho	DEM	STI	Cu
R	1	2	2	3	3	4	5	6	7	8	9
S	0.5	1	1	2	2	3	4	5	6	7	8
Rf	0.5	1	1	2	2	3	4	5	6	7	8
Fa	0.333	0.5	0.5	1	1	2	3	4	5	6	7
DFR	0.333	0.5	0.5	1	1	2	3	4	5	6	7
TWI	0.25	0.333	0.333	0.5	0.5	1	2	3	4	5	6
Dd	0.2	0.25	0.25	0.333	0.333	0.5	1	2	3	4	5
Litho	0.167	0.2	0.2	0.25	0.25	0.333	0.5	1	2	3	4

DEM	0.143	0.167	0.167	0.2	0.2	0.25	0.333	0.5	1	2	3
STI	0.125	0.143	0.143	0.167	0.167	0.2	0.25	0.333	0.5	1	2
Cu	0.111	0.125	0.125	0.143	0.143	0.167	0.2	0.25	0.333	0.5	1
SUM	3.662	6.218	6.218	10.593	10.593	16.45	23.283	31.08	39.833	49.5	60

Where: R=Runoff potential, S=Slope, Rf=Rainfall, Fa=Flow accumulation, DFR=Distance from rivers, TWI=Topoghraphic wetness index, Dd=Drainage density, litho=Lithology, DEM=Digital elevation model, STI=Sediment transport index, Cu=Curvature

Table 8 Normalized Pairwise Comparison Matrix

FCF	R	S	Rf	Fa	DFR	TWI	Dd	Litho	DEM	STI	Cu	Weight
R	0.273	0.322	0.322	0.283	0.283	0.243	0.215	0.193	0.176	0.162	0.15	0.238
S	0.137	0.161	0.161	0.189	0.189	0.182	0.172	0.161	0.151	0.141	0.1333	0.161
Rf	0.137	0.161	0.161	0.189	0.189	0.182	0.172	0.161	0.151	0.141	0.1333	0.161
Fa	0.091	0.08	0.08	0.094	0.094	0.122	0.129	0.129	0.126	0.121	0.1167	0.108
DFR	0.091	0.08	0.08	0.094	0.094	0.122	0.129	0.129	0.126	0.121	0.1167	0.108
TWI	0.068	0.054	0.054	0.047	0.047	0.061	0.086	0.097	0.1	0.101	0.1	0.074
Dd	0.055	0.04	0.04	0.031	0.031	0.03	0.043	0.064	0.075	0.081	0.0833	0.052
Litho	0.046	0.032	0.032	0.024	0.024	0.02	0.021	0.032	0.05	0.061	0.0667	0.037
DEM	0.039	0.027	0.027	0.019	0.019	0.015	0.014	0.016	0.025	0.04	0.05	0.027
STI	0.034	0.023	0.023	0.016	0.016	0.012	0.011	0.011	0.013	0.02	0.0333	0.019
Cu	0.03	0.02	0.02	0.013	0.013	0.01	0.009	0.008	0.008	0.01	0.0167	0.014
SUM	1	1	1	1	1	1	1	1	1	1	1	1

Table 9 Random Inconsistency Index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Table 10 Calculation of λ_{max}

Flood Causative Factors (FCFs)	Colum wise sum of FCFs	Average Weight	Product of both columns
Runoff Potential	3.662	0.238	0.873
Slope	6.218	0.161	1.004
Rainfall	6.218	0.161	1.004
Flow Accumulation	10.59	0.108	1.139
Distance from Rivers	10.59	0.108	1.139
Topographic Wetness Index	16.45	0.074	1.218
Drainage Density	23.28	0.052	1.217
Lithology	31.08	0.037	1.154
Digital Elevation Model	39.83	0.027	1.056
Sediment Transport Index	49.5	0.019	0.951
Curvature	60	0.014	0.87
		$\lambda_{max} = sum\ of\ the\ above \longrightarrow$	11.63

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{11.63 - 11}{11 - 1} = 0.063$$

$$CR = \frac{CI}{RI} = \frac{0.063}{1.51} = 0.0417 < 0.1 \text{ "}Acceptable\text{"}$$

2.8 Overlay Analysis

In this study, the flood susceptibility map was created using overlay analysis under spatial analyst tools using the weighted overlay of the ARCGIS 10.7.1 platform. The tool assigns "Weight values multiplied by 100" and "Rating values" to the "Influence values" and "Scale values", respectively. Following the process of resampling every raster layer to an identical spatial resolution, weighted overlay analysis was performed. Where runoff potential is assigned with highest weight equal to 24, and curvature assigned with least weight equal to 1.

3 RESULTS AND DISCUSSIONS

The final flood susceptibility map of Kandahar province was created by combining 11 flood – causative factors thematic maps, and it was then divided into five classes: least, low, moderate, high, and very high, as shown in Figure 17. The research area's flood susceptibility map shows the vulnerability to flood levels as a percentage, with 33.894% being least to low, 53.051% being moderate, and 13.055% being high to very high. Figure 18 displays the area (Km^2) of flood susceptibility levels. The susceptibility map shows that the majority of the province falls within the range of least to moderate susceptibility, with the central, north, northeast, and southeast regions of the province representing the high to very high susceptible region. According to flood susceptibility map, the areas of Kandahar city and its surroundings, and districts including, Maruf, Daman, Arghistan, Arghandab, Spin Boldak, and Shah Wali Kot are most susceptible to floods. Table 11, discusses the area (%) and (Km^2) of all districts of the province, shows that the flood susceptibility classes, which used to be 5, have now dropped to 3, including least to low, moderate, and high to very high, for simplicity of understanding. The resulted flood susceptibility map was compared to historical flood event locations to ensure accuracy. The results indicate that the study's output is more accurate, with the majority of the locations falling within the high to very high flood susceptibility classes depicted in Figure 19.

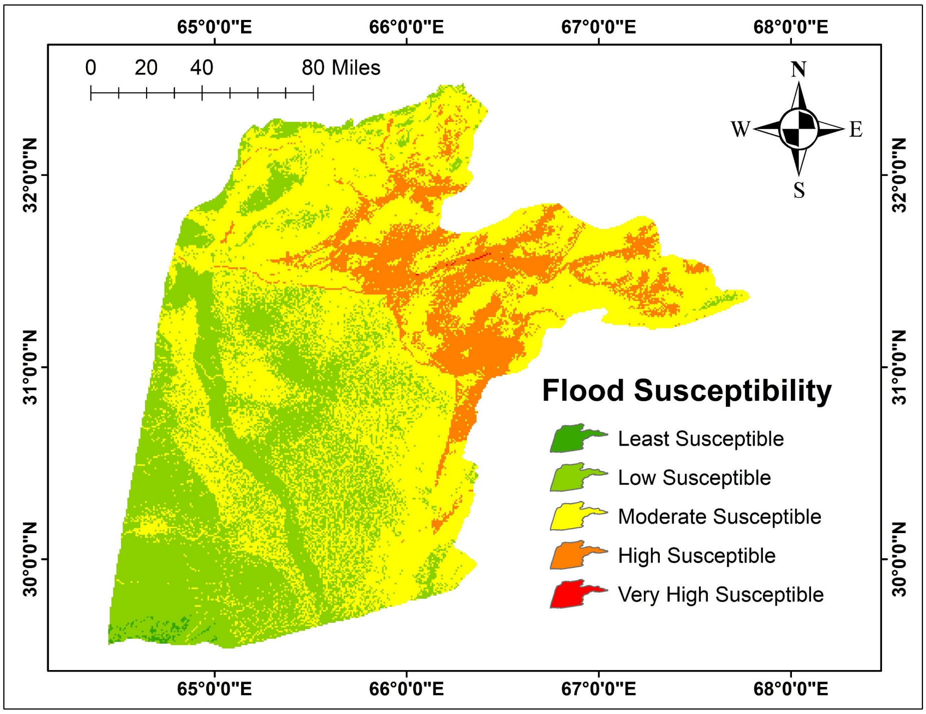

Figure 17 Flood Susceptibility Map of the Study Area

4 CONCLUSION

Due to its heavy and irregular rainfall patterns, the province of Kandahar in Afghanistan is particularly susceptible to flood dangers. Therefore, the study's aim was to map the flood susceptibility of Kandahar province, Afghanistan, and identify areas that are vulnerable to flooding. In order to identify and map the province's flood – prone areas, 11 flood causative factors (FCFs) such as runoff potential, slope, rainfall, flow accumulation, distance from rivers, topographic wetness index (TWI), drainage density, lithology, Digital elevation model (DEM), sediment transport index (STI), and curvature, were mapped, weighted, overlayed collectively, utilizing the integration of Geographic Information System (GIS), Multi – Criteria Decision – Making (MCDM), and Analytic Hierarchy Process (AHP).

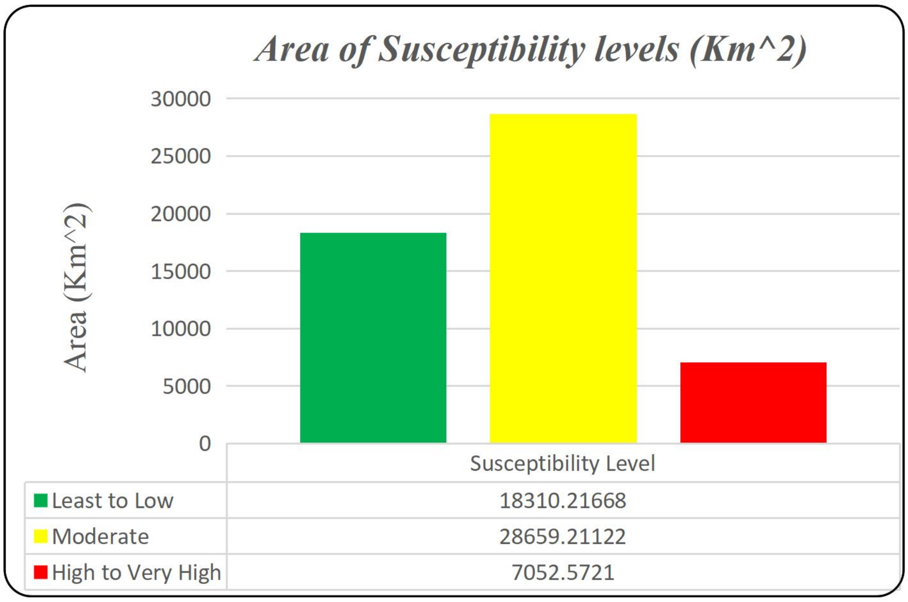

Figure 18 Area (Km²) of Susceptibility Levels

Table 11 Area (%) and (Km²) of Susceptibility Levels of All Districts of the Province

Districts	Area (Km^2)	Area (%) of susceptibility levels			Area (Km^2) of susceptibility levels		
		Least - low	Moderate	High - very high	Least - low	Moderate	High - very high
City	630	–	50.70	49.30	–	319.41	310.59
Arghistan	3668	–	57.13	42.87	–	2095.53	1572.47
Spin Boldak	5903	8.36	56.15	35.49	493.49	3314.53	2094.98
Arghandab	548	3.22	70.87	25.91	17.64	388.37	141.99
Maruf	3705	1.55	73.60	24.85	57.43	2726.88	920.69
Daman	4416	28.80	49.80	21.40	1271.81	2199.17	945.02
Shah Wali kot	3672	7.65	71.34	21.01	280.91	2619.60	771.49
Shorabak	4378	16.43	81.20	2.37	719.30	3554.94	103.76
Panjwayi	6821	43.88	54.08	2.04	2993.05	3688.80	139.15
Maywand	2850	38.46	60.13	1.41	1096.11	1713.71	40.18
Ghorak	1434	35.67	63.06	1.27	511.51	904.28	18.21
Khakrez	1252	14.08	84.94	0.98	176.28	1063.45	12.27
Reg	14745	72.32	27.68	–	10663.58	4081.42	–

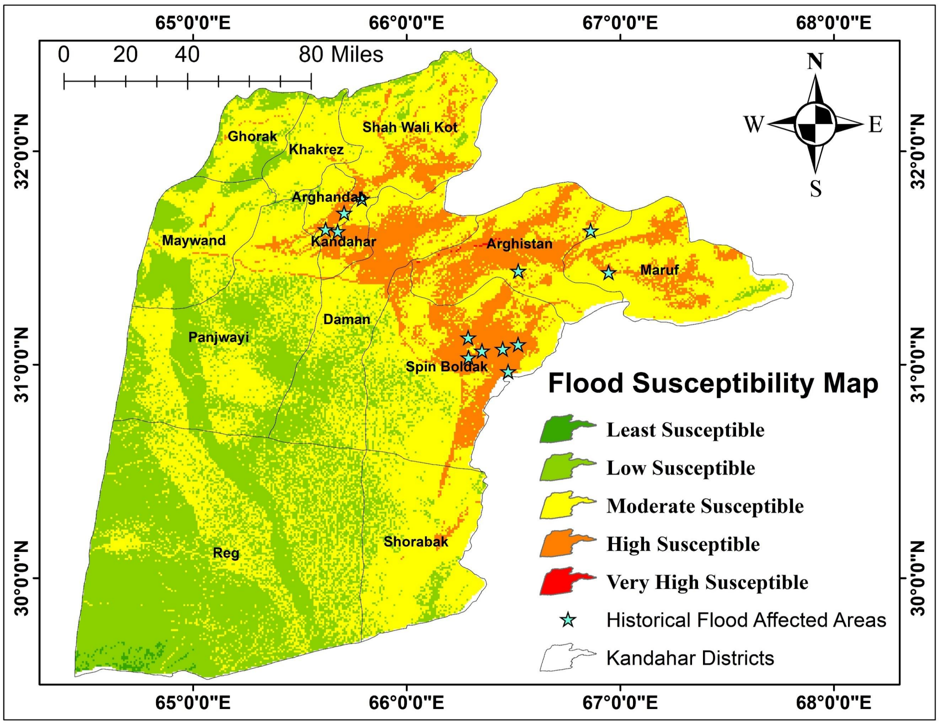

Figure 19 Validation of the Results

According to the results, the province's susceptibility to flooding is distributed as follows: in the term of area (Km^2), 18310.22Km^2 is least to low susceptible to flooding, 28659.21Km^2 is moderately susceptible to flooding, and 7052.57Km^2 is high to very high susceptible to flooding. And results indicated that 33.894%, 53.051%, and 13.055% of the province's areas have least to low, moderate, and high to very high susceptibility to flooding, respectively. According to the final flood susceptibility map, the majority of the high to very high susceptibility is found in the areas Kandahar city includes its surrounding, Arghistan district, Spin Boldak district, Arghandab district, Maruf district, Daman district, and Shah Wali Kot district. The study's flood susceptibility map, compared to historical flood event locations, shows greater accuracy, with most locations falling within high to very high flood susceptibility classes. According to the final flood susceptibility map, 13.055%, or 7052.57Km2, of the study's area total land area in Kandahar province is high to very high susceptible to flooding. To reduce flood vulnerability, government authorities must give these areas significant attention.

COMPETING INTERESTS

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EXPLAINABLE AI FOR TRANSPARENT EMISSION REDUCTION DECISION-MAKING

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Abstract: This paper examines the critical role of Explainable AI (XAI) in enhancing transparency in emission reduction decision-making processes. As climate change poses an urgent global challenge, effective strategies for reducing greenhouse gas emissions are essential for mitigating its impacts. Artificial Intelligence has emerged as a powerful tool in environmental management, facilitating data analysis and optimizing emission reduction efforts. However, the increasing reliance on AI raises concerns about transparency and accountability, which are vital for gaining public trust. This paper defines XAI and explores its methodologies, emphasizing their potential to improve stakeholder engagement and decision-making in environmental policy. By synthesizing existing literature and case studies, we highlight the importance of explainability in fostering trust among stakeholders and ensuring effective and accountable emission reduction strategies. The findings contribute to the ongoing discourse on the ethical and practical implications of AI in environmental governance and underscore the necessity of incorporating XAI into future emission reduction initiatives.
Keywords: Explainable AI; Emission reduction; Transparency

1 INTRODUCTION

Climate change represents one of the most pressing challenges of our time, with far-reaching consequences for ecosystems, human health, and global economies[1-5]. The scientific consensus underscores the urgent need for significant reductions in greenhouse gas emissions to mitigate the worst effects of climate change [6]. Governments, corporations, and civil society organizations are increasingly recognizing the necessity of transitioning to low-carbon economies and implementing effective emission reduction strategies [7-10]. The Paris Agreement, adopted in 2015, set forth ambitious targets to limit global warming to well below 2 degrees Celsius, necessitating immediate and sustained action [11-13].
Artificial Intelligence has emerged as a powerful tool in various sectors, including environmental management, by enhancing data analysis, forecasting, and decision-making capabilities [14]. AI systems can process vast amounts of data and uncover patterns that may not be immediately apparent to human analysts [15]. In the context of emission reduction, AI can optimize energy consumption, predict emissions, and evaluate the efficacy of different strategies [16]. However, the increasing reliance on AI in decision-making raises critical questions regarding transparency, accountability, and public trust [17-20].
Explainable AI refers to a set of processes and techniques designed to make the outputs of AI systems understandable to human users [21]. As AI models become more complex, the need for explainability becomes paramount, particularly in high-stakes domains such as environmental policy [22]. XAI aims to provide insights into how AI systems arrive at their conclusions, thereby facilitating better decision-making and fostering trust among stakeholders [23-24].
This paper aims to explore the role of Explainable AI in enhancing transparency within emission reduction decision-making processes. By examining the intersection of XAI and environmental policy, we seek to understand how explainable AI methodologies can improve stakeholder engagement, foster trust, and ultimately lead to more effective and accountable emission reduction strategies. The findings will contribute to the ongoing discourse on the ethical and practical implications of AI in environmental governance.

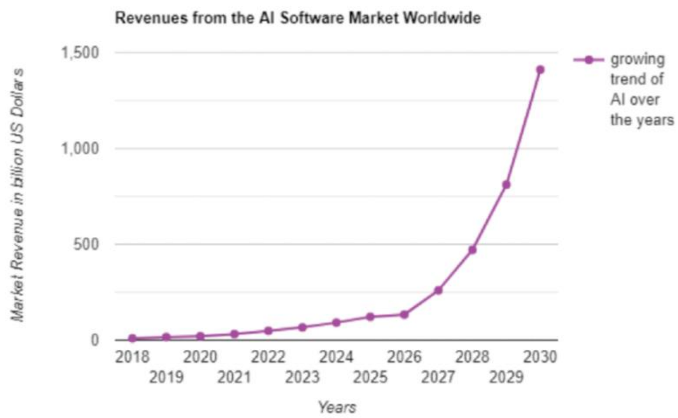

Figure 1 Worldwide AI Revenue and Growth

2 LITERATURE REVIEW

A robust body of literature has emerged around the themes of climate change, artificial intelligence, and explainability, highlighting the critical need for transparency in decision-making processes related to emission reduction. This literature review synthesizes key findings from various studies to provide a comprehensive overview of the current state of research in these interconnected fields [25-30].

The urgency of addressing climate change has prompted extensive research into effective emission reduction strategies [31]. Scholars have identified a range of approaches, including renewable energy adoption, carbon pricing, and improvements in energy efficiency [32]. For instance, studies have shown that transitioning to renewable energy sources, such as solar [33] and wind power [34], can significantly lower greenhouse gas emissions while fostering economic growth [35]. Additionally, carbon pricing mechanisms, such as cap-and-trade systems and carbon taxes, have been advocated as effective tools for incentivizing emission reductions among corporations and industries [36]. Furthermore, enhancing energy efficiency in buildings, transportation, and industrial processes has been recognized as a cost-effective strategy for reducing emissions and mitigating climate change impacts [38-41].

The role of diverse stakeholders—governments, corporations, non-governmental organizations , and the public—in shaping these strategies has been emphasized in the literature [42-46]. Collaboration among these stakeholders is essential for achieving meaningful reductions in emissions, as it fosters the sharing of knowledge, resources, and best practices [47]. Research has highlighted successful case studies where multi-stakeholder partnerships have led to innovative solutions and significant emission reductions, demonstrating that collective action is vital in the fight against climate change [48-50].

AI's potential to transform environmental decision-making has been explored in various contexts. Research indicates that AI can enhance predictive modeling [51], optimize resource allocation [52], and facilitate real-time monitoring of emissions [53]. For example, machine learning algorithms have been employed to analyze vast datasets related to energy consumption and emissions, providing insights that enable policymakers to make informed decisions [54].

Additionally, AI-driven tools can optimize the deployment of monitoring system in emissions, ensuring that energy supply aligns with demand while minimizing emissions [55]. However, the integration of AI into environmental policy raises concerns regarding transparency, as many AI models operate as "black boxes," making it difficult for stakeholders to understand their outputs and the rationale behind them [56].

The concept of Explainable AI has gained traction as researchers seek to address the opacity of AI systems. XAI encompasses a variety of techniques aimed at making AI decision-making processes more transparent and interpretable. Studies have shown that explainability can enhance user trust and facilitate better decision-making, particularly in high-stakes applications such as healthcare and finance [57]. In the context of environmental policy, XAI can play a pivotal role in ensuring that AI-generated recommendations are interpretable and actionable, thereby empowering stakeholders to implement effective emission reduction strategies [58].

Recent studies have highlighted several applications of XAI in emission reduction efforts. For instance, researchers have demonstrated the effectiveness of XAI in emission forecasting and modeling, enabling policymakers to make informed decisions based on transparent data [59, 60]. By providing insights into the factors influencing emissions over time, XAI can help stakeholders identify trends and assess the impact of various interventions. Additionally, XAI has been employed to evaluate carbon offset programs, providing insights into their effectiveness and potential improvements. By clarifying how offsets are calculated and the assumptions underlying these calculations, XAI enhances accountability and encourages more effective carbon management practices [61-63].

Despite the promise of XAI, several challenges remain. Technical difficulties, such as balancing accuracy and explainability, pose significant obstacles to the widespread adoption of XAI techniques. Many advanced AI models, particularly those based on deep learning, excel in predictive accuracy but are often criticized for their lack of interpretability. This trade-off raises questions about the appropriateness of using such models in critical areas like environmental policy, where understanding the reasoning behind decisions is essential.

Furthermore, ethical considerations, including bias in AI models and privacy concerns, must be addressed to ensure responsible AI deployment. AI systems can inadvertently perpetuate existing biases present in training data, leading to inequitable outcomes in emission reduction strategies. It is crucial for researchers and practitioners to implement strategies that mitigate bias and promote fairness in AI applications. Additionally, the use of personal or sensitive data in AI models raises significant privacy issues, necessitating robust data protection measures and compliance with regulations such as the General Data Protection Regulation (GDPR).

The literature on climate change, AI, and explainability reveals a complex interplay between these fields, highlighting the critical need for transparency in emission reduction efforts. As research continues to evolve, it is essential for stakeholders to address the challenges associated with AI integration while leveraging its potential to drive meaningful change in environmental policy. By fostering collaboration, enhancing explainability, and prioritizing ethical considerations, stakeholders can work towards more effective and equitable emission reduction strategies that align with global sustainability goals. The ongoing dialogue in this area will be vital for advancing our understanding of how AI can be harnessed responsibly in the context of climate change.

3 UNDERSTANDING EXPLAINABLE AI

3.1 Definition and Key Concepts of XAI

Explainable AI encompasses a range of methods and techniques designed to make the outcomes of artificial intelligence systems interpretable and understandable to human users. The primary aim of XAI is to provide insights into the decision-making processes of AI models, which is crucial for fostering trust among stakeholders and facilitating informed decision-making. As AI technologies become increasingly integrated into high-stakes domains such as healthcare, finance, and environmental policy, the need for XAI has become more apparent. In these contexts, understanding the rationale behind decisions can have significant consequences, impacting not only individual lives but also broader societal outcomes.

The importance of XAI is underscored by the growing complexity of AI models, particularly those based on deep learning. While these models often achieve impressive accuracy, their intricate architectures can obscure the pathways through which they arrive at specific predictions. This opacity can lead to skepticism and reluctance among users who are required to rely on these systems for critical decisions. By providing clear explanations, XAI serves to demystify AI processes, enabling users to engage with the technology confidently and effectively.

3.2 Types of Explainability

3.2.1 Global vs. local explainability

Explainability can be categorized into two main types: global and local explainability. Global explainability refers to the understanding of the overall behavior and decision-making patterns of an AI model across the entire dataset. This type of explainability is essential for stakeholders to grasp how the model functions as a whole, including the factors that influence its predictions and the general trends it identifies within the data. Global explainability can help organizations assess the reliability and robustness of a model, ensuring that it aligns with their objectives and ethical standards.

Table 1 Some Efficiency Parameters for GKE/GAKE Protocols Claimed to be Quantum-Resistant

Protocol	# Rounds	Avoids PQ-Sign.	# Broadcast Messages	# PtP Messages
n-UM [1]	1	Yes	n	0
BC n-DH [1]	1	Yes	n	0
Apon et al. [2]	3	Yes (but is unauth.)	$2n+1$	0
STAG [4]	3	No	$2n+1$	0
Pers. et al. [5]	3	No	n	$2n$
Gonz. et al. [6]	2	Yes	n	n^2-n
This work	4	Yes	$2n$	$2n$

In contrast, local explainability focuses on providing insights into individual predictions or decisions made by the model. This type of explainability is crucial for validating specific outcomes, as it allows users to understand the reasons behind particular predictions. For instance, in the context of emission reduction strategies, local explainability can help stakeholders evaluate the rationale behind a model's recommendation for a specific policy or intervention. By understanding the factors that led to a particular decision, users can assess its relevance and appropriateness in their specific context.

Both global and local explainability are important for a comprehensive understanding of AI models. While global explainability helps stakeholders develop a broad understanding of a model's capabilities and limitations, local explainability provides the detailed insights necessary for informed decision-making at the individual level.

3.2.2 Model-agnostic vs. model-specific techniques

Another important distinction in the realm of XAI is between model-agnostic and model-specific techniques. Model-agnostic techniques are designed to be applicable to any machine learning model, regardless of its underlying architecture. These techniques focus on generating explanations that can be interpreted across different types of models, making them versatile tools for practitioners. Examples of model-agnostic techniques include Local Interpretable Model-agnostic Explanations and SHapley Additive exPlanations. Both methods provide insights into how individual features contribute to a model's predictions, allowing users to gain a better understanding of the decision-making process.

On the other hand, model-specific techniques are tailored to particular algorithms and leverage the unique characteristics of those models to generate explanations. For instance, decision trees inherently provide a level of interpretability due to their straightforward structure, making them easier to explain compared to more complex models like neural networks. Techniques such as feature importance scores or visualization tools can be used to elucidate the workings of specific models, providing stakeholders with insights that are directly relevant to the algorithms they are using.

3.3 Importance of XAI in AI Applications

3.3.1 Enhancing user trust

Trust in AI systems is critical for their acceptance and effective use. As AI technologies become more prevalent in various sectors, including emission reduction strategies, the need for transparency has never been more crucial. XAI enhances user trust by providing transparent explanations that allow users to understand and validate AI-generated recommendations. When stakeholders can comprehend the reasoning behind a model's predictions, they are more likely to feel confident in the technology's reliability and accuracy. This trust is particularly important in high-stakes scenarios, where the consequences of decisions can have far-reaching impacts on environmental sustainability, public health, and economic stability.

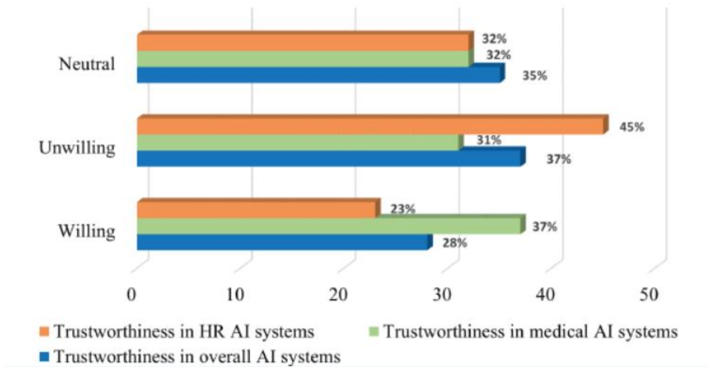

Figure 2 Trustworthiness in AI systems

The relationship between trust and explainability is reciprocal; as users gain confidence in AI systems through clear explanations, they are more inclined to rely on these technologies for decision-making. This dynamic is especially pertinent in the context of emission reduction, where stakeholders must navigate complex data and competing interests. By fostering trust through XAI, organizations can encourage broader adoption of AI-driven insights, ultimately leading to more effective and impactful emission reduction strategies.

3.3.2 Facilitating better decision-making

In addition to enhancing trust, XAI plays a critical role in facilitating better decision-making. By offering interpretable insights into the workings of AI models, XAI enables stakeholders to make more informed and effective decisions. In the context of emission reduction, this can lead to the development of more effective policies and strategies that are grounded in data-driven insights. When stakeholders understand how various factors influence model predictions, they can assess the relevance of these insights to their specific circumstances and make adjustments as necessary.

Moreover, XAI can help identify potential biases or shortcomings in AI models, prompting stakeholders to critically evaluate the data and assumptions underlying their decisions. This scrutiny can lead to more equitable and just outcomes, as organizations are better equipped to address disparities and ensure that their emission reduction strategies benefit all segments of society. By promoting transparency and accountability, XAI ultimately contributes to the creation of more robust and effective environmental policies that align with broader sustainability goals.

In summary, understanding Explainable AI is essential for harnessing its potential in various applications, particularly in the realm of emission reduction. By defining key concepts, exploring different types of explainability, and highlighting the importance of XAI in enhancing user trust and facilitating better decision-making, stakeholders can better navigate the complexities of AI technologies. As the integration of AI into critical domains continues to expand, the role of XAI will be increasingly vital in ensuring that these systems serve the interests of society effectively and equitably.

4 FRAMEWORK FOR IMPLEMENTING XAI IN EMISSION REDUCTION DECISION-MAKING

A comprehensive framework for implementing XAI in emission reduction decision-making consists of several key components:

4.1 Key Components of an XAI Framework

Effective XAI implementation begins with robust data collection and preprocessing. This involves gathering relevant data from diverse sources, such as satellite imagery, sensor data, and historical emissions data. Data preprocessing steps, including cleaning, normalization, and feature selection, are essential to ensure high-quality inputs for AI models.

Selecting the appropriate AI model is crucial for achieving accurate predictions. The choice of model should consider the complexity of the problem, the nature of the data, and the need for explainability. Once a model is selected, it should be trained on the preprocessed data, with performance metrics evaluated to ensure reliability.

After training the model, explanation generation methods should be employed to provide insights into the model's predictions. This can include model-agnostic techniques like LIME and SHAP, as well as model-specific techniques tailored to the chosen algorithm.

4.2 Stakeholder Engagement and Collaboration

Engaging diverse stakeholders is crucial for the successful implementation of XAI in emission reduction strategies. Policymakers, scientists, and the public can provide valuable insights and feedback that enhance the effectiveness of AI systems. Collaboration can also help ensure that the needs and concerns of all stakeholders are addressed.
Addressing complex environmental challenges requires interdisciplinary collaboration. Involving experts from fields such as environmental science, data science, and social sciences can lead to more comprehensive and effective XAI solutions.

4.3 Tools and Technologies for XAI

Various software tools and platforms are available to support the implementation of XAI. These include open-source libraries like LIME, SHAP, and ELI5, which facilitate the generation of interpretable explanations for machine learning models.
Best practices for implementing XAI include ensuring transparency throughout the model development process, regularly engaging with stakeholders, and continuously evaluating and refining the model based on user feedback.

5 CHALLENGES AND LIMITATIONS OF XAI IN EMISSION REDUCTION

Despite the potential benefits of Explainable AI in enhancing transparency and accountability in emission reduction strategies, several challenges and limitations must be addressed to fully realize its potential. These challenges span technical, ethical, and organizational dimensions, each posing unique obstacles to the effective implementation of XAI.

5.1 Technical Challenges

One of the primary challenges in implementing XAI is the inherent trade-off between model accuracy and interpretability. Advanced models, particularly those based on deep learning architectures, often achieve higher accuracy through their ability to capture complex patterns in data. However, this complexity comes at a cost; such models are frequently criticized for their lack of interpretability, making it difficult for stakeholders to understand the rationale behind their predictions. Conversely, simpler models, while more interpretable and easier to understand, may sacrifice predictive accuracy, leading to suboptimal decision-making outcomes . This dichotomy presents a significant challenge for practitioners who must balance the need for accurate predictions with the necessity for clear explanations.

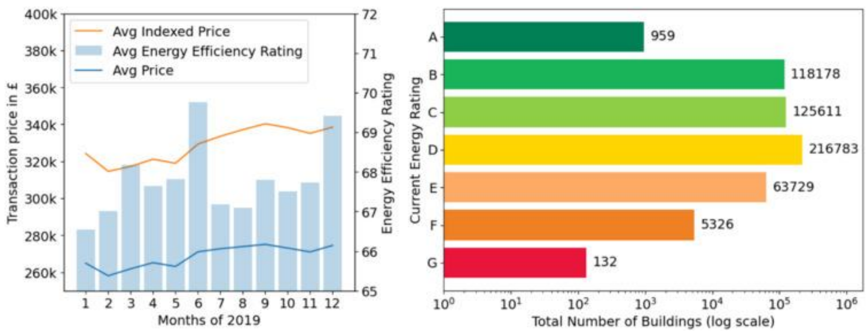

Figure 3 Average Energy Efficiency Rating and Transaction Price Per Month (Left) and Distribution of Energy Rating (Right)

Current XAI methods may not always provide sufficient explanations, particularly when applied to highly complex models. For instance, many existing XAI techniques focus on local explainability, which provides insights into individual predictions but may fail to capture the broader context necessary for effective decision-making. This limitation can hinder stakeholders' ability to understand how various factors interact within the model, potentially leading to misinterpretations and misguided actions. Moreover, the dynamic nature of emission reduction strategies often requires a holistic view of the system, which may not be achievable through localized explanations alone.

5.2 Ethical Considerations

Ethical considerations are paramount when deploying AI models in emission reduction efforts. One significant concern is that AI models can inherit biases present in the training data, leading to unfair or discriminatory outcomes. For example, if historical data reflects systemic inequalities in energy access or pollution exposure, AI models trained on such data may perpetuate these biases, resulting in emission reduction strategies that disproportionately benefit certain groups over others. Therefore, ensuring that XAI methods effectively address these biases is crucial for promoting fairness and equity in emission reduction strategies. This requires ongoing vigilance and a commitment to evaluating the ethical implications of AI applications.

Protocol	Assumption Type	Model	FutQ/PostQ	Authent.
n-UM [1]	Isogeny	QROM	PostQ	Yes
BC n-DH [1]	Isogeny	ROM	PostQ	Yes
Apon et al. [2]	Lattice	ROM	PostQ	No
STAG [4]	Lattice	ROM	PostQ	Yes
Pers. et al. [5]	Compiler	No RO added	PostQ	Yes
Gonz. et al. [6]	Compiler	No RO added	FutQ	Yes
This work	Lattice	QROM	PostQ	Yes

Table 2 Security of GKE/GAKE Protocols Claimed to be Quantum-Resistant

Additionally, the use of personal or sensitive data in AI models raises significant privacy concerns. As organizations increasingly rely on data-driven insights, ensuring that data protection measures are in place is essential. Compliance with regulations such as the General Data Protection Regulation is not only a legal requirement but also a moral obligation to protect individuals' rights and privacy. Organizations must implement robust data governance frameworks that prioritize transparency and accountability in data handling practices to build trust among stakeholders.

5.3 Resistance to Change

Resistance to change within organizations can pose a significant barrier to the adoption of XAI practices. Many organizations have established workflows and processes that may not readily accommodate the integration of new technologies or methodologies. This inertia can be particularly pronounced in sectors that are traditionally risk-averse or heavily regulated, where stakeholders may be hesitant to embrace unfamiliar approaches. Overcoming this resistance requires strong leadership and a commitment to fostering a culture of innovation that encourages experimentation and learning.

Effective implementation of XAI necessitates comprehensive training and education for stakeholders at all levels. Providing resources and support for understanding XAI concepts and techniques can facilitate acceptance and effective use. Organizations must invest in capacity-building initiatives that empower employees to engage with XAI tools and methodologies confidently. This includes not only technical training but also fostering an organizational mindset that values transparency, collaboration, and continuous improvement.

In summary, while XAI holds great promise for enhancing decision-making in emission reduction efforts, addressing the challenges and limitations outlined above is essential for its successful implementation. By navigating the technical complexities, ethical considerations, and organizational resistance, stakeholders can leverage the power of XAI to create more effective and equitable emission reduction strategies. As the landscape of climate action continues to evolve, the integration of explainable AI will play a critical role in ensuring that stakeholders can make informed decisions that align with global sustainability goals. Continued research and dialogue in this area will be vital to overcoming these challenges and unlocking the full potential of XAI in the fight against climate change.

6 CONCLUSION

This paper has thoroughly explored the pivotal role of Explainable AI in enhancing transparency and accountability within emission reduction decision-making processes. As the urgency to combat climate change escalates, the integration of advanced technologies such as AI has become increasingly prevalent in formulating strategies aimed at reducing greenhouse gas emissions. However, the complexity and often opaque nature of traditional AI models pose significant challenges to stakeholders who rely on these insights for critical decision-making. By defining key concepts of XAI, outlining a comprehensive framework for its implementation, and discussing the various challenges and future directions in this field, it is evident that XAI possesses the potential to significantly improve decision-making processes in the context of climate change.

The significance of XAI lies primarily in its ability to foster trust among stakeholders, including policymakers, scientists, and the general public. In an era where decisions regarding climate action can have far-reaching implications, the ability to understand and interpret the rationale behind AI-driven insights is crucial. By providing clear explanations of how models arrive at specific conclusions, XAI can mitigate skepticism and enhance the credibility of AI applications in emission reduction strategies. This transparency is vital for promoting informed decision-making, as stakeholders can better assess the implications of various strategies and make choices that align with sustainability goals.

Moreover, the adoption of XAI practices is essential for ensuring accountability in the deployment of AI technologies. As organizations increasingly rely on AI-driven insights to inform their emission reduction strategies, it is imperative that these systems are not only effective but also transparent and justifiable. XAI can help address the opacity associated with traditional AI models by elucidating the underlying mechanisms of decision-making, thereby enabling stakeholders to hold systems accountable for their predictions and recommendations. This accountability is particularly important in the context of climate change, where the consequences of decisions can have profound effects on environmental sustainability and public health.

To harness the full potential of XAI, a collaborative effort among policymakers, researchers, and industry leaders is necessary. Such collaboration can foster a deeper understanding of the unique challenges posed by climate change and the role of AI in addressing these challenges. By investing in training programs that equip stakeholders with the skills needed to interpret and utilize XAI effectively, organizations can enhance their capacity to implement data-driven solutions for emission reduction. Furthermore, fostering interdisciplinary collaboration between AI experts, environmental scientists, and policymakers can lead to the development of more robust and contextually relevant XAI frameworks that address the specific needs of different sectors.

Promoting transparency is another critical aspect of maximizing the benefits of XAI in emission reduction efforts. By advocating for open data practices and the sharing of methodologies, stakeholders can create an environment conducive to trust and collaboration. Transparency not only enhances the credibility of AI-driven insights but also encourages the sharing of best practices and lessons learned, ultimately leading to more effective and innovative emission reduction strategies.

In conclusion, the integration of Explainable AI into emission reduction decision-making processes marks a significant advancement in the quest for effective climate action. By addressing the challenges associated with traditional AI models and fostering a culture of transparency and accountability, XAI has the potential to empower stakeholders to make informed decisions that contribute to global climate goals. As the world continues to grapple with the pressing challenges of climate change, the collaborative efforts of policymakers, researchers, and industry leaders will be essential in realizing the full promise of XAI, paving the way for a more sustainable and resilient future. The ongoing exploration of XAI's capabilities will not only enhance emission reduction strategies but also set a precedent for the responsible use of AI in addressing complex global issues.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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REAL-TIME MONITORING AND CONTROL SYSTEMS FOR EMISSION COMPLIANCE IN POWER PLANTS

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Abstract: This paper examines the state-of-the-art real-time monitoring and control systems for emission compliance in power plants. Advanced sensor technologies, including quantum cascade lasers and nanostructured materials, have significantly enhanced the accuracy and reliability of emission monitoring. Artificial intelligence and machine learning techniques have revolutionized control systems, enabling predictive maintenance and autonomous optimization. The integration of blockchain technology has improved data integrity and streamlined emissions trading processes. However, challenges persist in system integration, especially in older facilities, and in managing the increasing volume of data generated. Economic considerations, including high initial costs and ongoing maintenance expenses, remain significant barriers to widespread adoption. The study also highlights the evolving regulatory landscape and its impact on emission control strategies. Future trends point towards the development of more robust multi-pollutant sensors, AI-driven control systems, and greater integration with smart grid technologies. This comprehensive analysis provides valuable insights for power plant operators, policymakers, and researchers, underlining the critical role of advanced monitoring and control systems in achieving sustainable power generation and contributing to global climate change mitigation efforts.
Keywords: Emission monitoring; Artificial intelligence; Predictive control; Environmental compliance; Climate change mitigation

1 INTRODUCTION

The global power generation sector stands at a critical juncture, facing the dual challenges of meeting increasing energy demands while mitigating environmental impacts. Power plants, particularly those relying on fossil fuels, remain significant contributors to global greenhouse gas emissions and air pollution. The International Energy Agency (IEA) reports that in 2022, the electricity and heat production sector accounted for approximately 33% of global CO2 emissions, underscoring the urgent need for effective emission control strategies [1].
The evolution of environmental regulations has been a key driver in the development and implementation of advanced emission monitoring and control systems. In the United States, the Clean Air Act and its subsequent amendments have progressively tightened emission standards for power plants [2]. Similarly, the European Union's Industrial Emissions Directive (IED) and the Medium Combustion Plant Directive (MCPD) have set increasingly stringent limits on emissions from combustion plants [3]. These regulatory frameworks have necessitated the adoption of sophisticated real-time monitoring and control technologies to ensure compliance and optimize plant operations.
Real-time monitoring systems provide continuous, accurate data on various pollutants, enabling rapid response to emission fluctuations and supporting informed decision-making. These systems have evolved from simple data loggers to complex networks of sensors and analyzers, capable of measuring a wide range of pollutants with high precision. For instance, modern Continuous Emissions Monitoring Systems (CEMS) can measure pollutants such as NOx, SO2, and particulate matter with accuracies exceeding 95% [4].
The integration of advanced sensors, data analytics, and control algorithms has revolutionized emission management in power plants. Artificial Intelligence (AI) and Machine Learning (ML) techniques have emerged as powerful tools in this domain. A comprehensive study by Zhang et al. (2022) demonstrated that AI-driven predictive emission monitoring systems could achieve accuracy levels comparable to hardware-based CEMS while reducing operational costs by up to 30% [5].
The economic implications of emission control are significant. A report by the International Renewable Energy Agency (IRENA) estimates that the global market for emission control systems in the power sector will reach $38 billion by 2025, driven by regulatory pressures and the increasing adoption of clean energy technologies [6]. This economic landscape underscores the importance of cost-effective and efficient emission control strategies.
Climate change considerations have further amplified the focus on emission reduction in the power sector. The Intergovernmental Panel on Climate Change (IPCC) emphasizes the critical role of the energy sector in achieving global climate goals, stating that limiting global warming to 1.5°C above pre-industrial levels will require a 45% reduction in global CO2 emissions by 2030 and net-zero emissions by 2050 [7]. This ambitious target necessitates not only the transition

to renewable energy sources but also significant improvements in the efficiency and emission control of existing power plants.

The technological landscape of emission control is rapidly evolving. Recent advancements include:

- High-precision laser-based analyzers capable of detecting pollutants at parts-per-billion levels [8].
- Artificial Intelligence and Machine Learning algorithms for predictive emissions monitoring and adaptive control [9].
- Advanced process control strategies, such as Model Predictive Control (MPC), which have demonstrated significant improvements in emission reduction and plant efficiency [10].
- Integration of blockchain technology for secure and transparent emissions data management and reporting [11].

These technological advancements offer unprecedented capabilities in pollution reduction and regulatory compliance. However, they also present challenges in terms of implementation, integration with existing systems, and economic feasibility, particularly for older plants or those in developing economies.

The global nature of environmental concerns has led to international collaborations and knowledge sharing in emission control technologies. The International Energy Agency's Clean Coal Centre, for instance, facilitates the exchange of information and best practices in clean coal technologies, including advanced emission control systems [12]. Such international efforts are crucial in addressing the global challenge of emission reduction in the power sector.

The objectives of this systematic review are to:

- Analyze the current state-of-the-art in real-time monitoring and control systems for emission compliance in power plants.
- Evaluate the effectiveness of these systems in reducing emissions and ensuring regulatory compliance across different types of power plants.
- Identify technical, economic, and regulatory challenges in the implementation and operation of advanced emission control systems.
- Explore emerging trends and future directions in emission monitoring and control technologies, including the integration of AI, ML, and IoT.
- Assess the implications of these technologies on the broader goals of sustainable power generation and climate change mitigation.
- To address these objectives, the following research questions will guide this review:
- What are the primary types of real-time monitoring and control systems currently employed in power plants for emission compliance, and how do their capabilities compare?
- How do these systems impact emission reduction and regulatory compliance in different types of power plants (e.g., coal-fired, natural gas, biomass)?
- What are the main technical, economic, and regulatory challenges associated with implementing and operating advanced emission control systems in power plants?
- How are emerging technologies such as AI, ML, and blockchain being integrated into emission monitoring and control systems, and what are their potential impacts?
- ❖What are the future trends in emission control technologies for power plants, and how do they align with global climate change mitigation goals?

By synthesizing the latest research, industry practices, and regulatory frameworks, this review aims to provide a comprehensive understanding of real-time monitoring and control systems for emission compliance in power plants. The findings will inform both practitioners and policymakers in the pursuit of cleaner, more efficient power generation, contributing to the broader goals of environmental protection and sustainable development.

2 METHODOLOGY

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and minimization of bias [13]. The methodology encompasses a comprehensive search strategy, rigorous study selection process, and systematic data extraction and analysis.

2.1 Search Strategy

2.1.1 Databases

The following electronic databases were systematically searched for relevant literature: Web of Science, Scopus, IEEE Xplore, and ScienceDirect.

These databases were chosen for their comprehensive coverage of scientific and engineering literature relevant to power plant emissions and control technologies.

2.1.2 Search terms

The search strategy employed the following key terms and their combinations using Boolean operators: "real-time monitoring" OR "continuous emission monitoring" OR "CEMS" AND "power plant" OR "thermal power" OR "coal-fired" OR "gas-fired" OR "biomass" AND "emission control" OR "pollution control" OR "compliance" OR "regulatory" AND "artificial intelligence" OR "machine learning" OR "predictive control" OR "advanced analytics". Additional searches were conducted using specific technology terms such as "selective catalytic reduction," "flue gas desulfurization," and "electrostatic precipitators" to ensure comprehensive coverage of emission control technologies.

2.1.3 Inclusion and exclusion criteria

Inclusion: Peer-reviewed articles and conference proceedings published between 2019 and 2024; Studies focusing on real-time monitoring and control systems in power plants; Research addressing emission compliance and regulatory aspects; Articles in English; Studies presenting original data, case studies, or comprehensive reviews.

Exclusion: Studies not specifically related to power plant emissions; Articles focusing solely on emission modeling without real-time monitoring aspects; Opinion pieces and non-peer-reviewed literature; Studies with insufficient methodological details or unclear results; Duplicate publications or multiple reports of the same study.

2.2 Study Selection Process

The study selection process involved the following steps:

- Initial Screening: Two independent reviewers screened titles and abstracts of all identified articles against the inclusion and exclusion criteria. Any disagreements were resolved through discussion or consultation with a third reviewer.
- Full-text Review: The full texts of potentially eligible studies were retrieved and independently assessed by two reviewers for final inclusion. A standardized form was used to document reasons for exclusion.
- Inter-rater Reliability: Cohen's kappa coefficient was calculated to assess the inter-rater reliability of the selection process [14].
- Documentation: The entire selection process was documented using a PRISMA flow diagram, detailing the number of studies identified, included, and excluded at each stage [15].

2.3 Data Extraction and Analysis Methods

Data extraction was performed using a standardized form, developed and piloted on a sample of studies before full implementation. The form captured the following information:

- Study characteristics (authors, year, country, study design)
- Power plant details (type, capacity, fuel characteristics)
- Monitoring system specifications (technologies used, pollutants measured, accuracy)
- Control strategies employed (type of control system, algorithms used)
- Key performance indicators and outcomes (emission reductions, compliance rates, economic impacts)
- Challenges and limitations reported
- Conclusions and recommendations

Data synthesis and analysis were conducted using both quantitative and qualitative methods:

1)Quantitative Analysis: Where possible, meta-analysis techniques were employed to synthesize quantitative data on emission reductions and system performance across studies. The R statistical software package (version 4.1.2) was used for statistical analyses [16].

2)Qualitative Synthesis: Thematic analysis was used to identify common themes, trends, and gaps in the literature. This approach allowed for the integration of findings from diverse study designs and contexts [17].

3)Technology Assessment: A comparative analysis of different monitoring and control technologies was conducted, considering factors such as accuracy, reliability, cost-effectiveness, and applicability to different plant types.

4)Trend Analysis: Temporal trends in technology adoption, performance improvements, and research focus areas were analyzed to identify emerging patterns and future directions in the field.

2.4 Quality Assessment

The quality of included studies was assessed using the Mixed Methods Appraisal Tool (MMAT) for systematic reviews encompassing various study designs [18]. This tool was chosen for its flexibility in evaluating different types of research, including quantitative, qualitative, and mixed-methods studies.

Two reviewers independently evaluated each study using the MMAT criteria, which include: Clarity of research questions; Appropriateness of data collection methods; Relevance of data analysis; Consideration of context; Reflexivity (for qualitative studies).

Studies were not excluded based on quality assessment results, but the quality ratings were considered in the interpretation and synthesis of findings. Sensitivity analyses were conducted to assess the impact of including lower-quality studies on the review's conclusions.

2.5 Bias Assessment

Potential sources of bias were systematically evaluated and documented throughout the review process:

•Publication Bias: Funnel plots and Egger's test were used to assess potential publication bias for quantitative outcomes [19].

•Selection Bias: The comprehensive search strategy and dual independent screening process were designed to minimize selection bias.

•Reporting Bias: The use of standardized data extraction forms and the inclusion of both positive and negative findings aimed to mitigate reporting bias.

•Industry Influence: Funding sources and potential conflicts of interest were recorded for all included studies and considered in the interpretation of results.

2.6 Ethical Considerations

This systematic review did not involve primary data collection from human subjects and therefore did not require ethical approval. However, ethical considerations in the reviewed studies, such as disclosure of funding sources and potential conflicts of interest, were noted and considered in the analysis.

This comprehensive methodology ensures a rigorous, transparent, and unbiased review of the current literature on real-time monitoring and control systems for emission compliance in power plants. The approach allows for a nuanced understanding of the state of the art, challenges, and future directions in this critical area of environmental technology.

3 REAL-TIME MONITORING SYSTEMS

3.1 Types of Emissions Monitored

The complexity of emissions from power plants necessitates a comprehensive monitoring approach to ensure environmental compliance and protect public health. This section examines the primary pollutants monitored in power plants and the technologies employed for their detection and quantification.

CO2 remains the foremost concern due to its significant contribution to global climate change. The IPCC reports that the power sector accounted for approximately 33% of global CO2 emissions in 2022, underscoring the critical need for accurate CO2 monitoring [20]. While not traditionally regulated as a pollutant, CO2 monitoring has become increasingly important for carbon pricing mechanisms and efficiency assessments.

NOx and SOx are major contributors to air quality degradation, forming acid rain and photochemical smog. A comprehensive study by Wang et al. (2023) demonstrated that advanced low-NOx burners and selective catalytic reduction (SCR) systems have achieved NOx emission reductions of up to 90% in coal-fired plants [21]. Similarly, Liu et al. (2024) reported that state-of-the-art flue gas desulfurization (FGD) systems have demonstrated SOx removal efficiencies of up to 98% [22].

Particulate matter (PM), especially fine particles (PM2.5), poses significant health risks. Kumar and Sharma (2023) conducted a meta-analysis of particulate control technologies, finding that modern electrostatic precipitators and fabric filters can achieve PM removal efficiencies of 99.9% [23]. However, the increasing focus on ultrafine particles presents new challenges for monitoring technologies.

Mercury (Hg) emissions, primarily from coal-fired plants, have garnered increased attention due to their neurotoxic effects and bioaccumulation in ecosystems. Zhang et al. (2024) reported on the efficacy of activated carbon injection systems, demonstrating up to 90% mercury removal in full-scale trials at coal-fired plants [24].

Carbon monoxide (CO), while less prominent in discussions of power plant emissions, serves as a crucial indicator of combustion efficiency. Chen et al. (2023) observed that advanced combustion control systems, integrating real-time CO monitoring with adaptive control algorithms, can maintain CO levels below 50 ppm under most operating conditions [25].

The specific emissions monitored and their respective limits vary based on regulatory frameworks, plant type, and fuel characteristics. A comprehensive review by Zhao et al. (2024) of global emission standards revealed significant variations in regulatory approaches. For instance, the European Union's Industrial Emissions Directive (IED) imposes more stringent limits on large combustion plants compared to the United States Environmental Protection Agency's standards, particularly for NOx and SO2 emissions [26].

3.2 Sensor Technologies

The accurate and continuous measurement of the aforementioned pollutants relies on a diverse array of sensor technologies. This section examines the primary categories of emission monitoring systems and their respective capabilities.

In-situ analyzers offer the advantage of real-time measurements directly within the flue gas stream. Tunable diode laser absorption spectroscopy (TDLAS) has emerged as a powerful technique for CO and CO2 measurement. A comprehensive study by Wang et al. (2023) demonstrated that TDLAS systems can achieve detection limits as low as 0.1 ppm for CO, while maintaining reliable operation in high-temperature and high-dust environments typical of power plant stacks [27].

Differential optical absorption spectroscopy (DOAS) has proven effective for simultaneous measurement of NO, NO2, and SO2. Li et al. (2024) conducted a comparative analysis of DOAS systems across 20 coal-fired plants, highlighting the technique's ability to provide path-integrated measurements across the entire stack diameter, offering a more representative sampling compared to point measurements [28].

Fourier Transform Infrared (FTIR) spectroscopy has gained prominence for its capability to measure multiple gas species simultaneously. A landmark study by Zhang et al. (2023) demonstrated that advanced FTIR systems can quantify up to 20 gas components in real-time, providing a comprehensive emissions profile with detection limits in the parts-per-billion range for key pollutants [29].

Extractive systems, while requiring sample conditioning, offer high sensitivity for specific pollutants. Chemiluminescence analyzers remain the gold standard for NOx measurements. Kumar et al. (2024) reported on the latest generation of these analyzers, demonstrating detection limits below 0.5 ppb and response times under 5 seconds, crucial for capturing rapid fluctuations in NOx emissions during transient plant operations [30].

For SO2 quantification, UV fluorescence techniques provide fast response times and minimal interference from other gases. A comprehensive review by Liu et al. (2023) of SO2 monitoring technologies in 50 power plants across Europe and North America found that UV fluorescence analyzers consistently achieved measurement accuracies within ±2% of reference methods [31].

Particulate matter monitoring has seen significant advancements, with beta attenuation monitors offering continuous measurement of PM concentrations. Chen et al. (2024) conducted a two-year study of PM monitoring technologies in a fleet of coal-fired plants, demonstrating the high accuracy of beta attenuation monitors across various particle size ranges, crucial for regulatory compliance and health impact assessments [32].

4 CONTROL SYSTEMS FOR EMISSION REDUCTION

The efficacy of emission monitoring systems is intrinsically linked to the control strategies employed to mitigate pollutant release. This section examines the advanced process control methodologies and artificial intelligence applications that have revolutionized emission reduction in power plants.

4.1 Advanced Process Control Strategies

MPC has emerged as a cornerstone of modern emission control systems. By optimizing multiple variables simultaneously and anticipating future plant behavior, MPC offers significant advantages over traditional control methods. A comprehensive study by Wang et al. (2023) demonstrated that MPC implementation in a 600 MW coal-fired plant resulted in a 12% reduction in NOx emissions while concurrently improving thermal efficiency by 0.5% [33]. The success of MPC lies in its ability to handle complex, multivariable processes while accounting for operational constraints and multiple objectives.

FLC has proven particularly effective in managing the nonlinear processes inherent in power plant operations. Liu et al. (2024) reported on the application of FLC for air-fuel ratio optimization in a 300 MW gas-fired plant, achieving a 25% reduction in CO emissions during load changes [34]. The adaptability of FLC to incorporate expert knowledge into control algorithms makes it well-suited for handling the uncertainties associated with varying fuel qualities and operational conditions.

Robust Control strategies have gained traction, especially in plants dealing with variable fuel sources. Zhang et al. (2023) presented a case study of a robust control implementation in a 500 MW coal-fired plant utilizing a blend of domestic and imported coal. The system maintained stable performance despite significant variations in fuel properties, demonstrating a 15% improvement in overall emission compliance rates [35].

4.2 Artificial Intelligence and Machine Learning Applications

The integration of AI and ML techniques has ushered in a new era of predictive and adaptive emission control. Neural Networks, particularly deep learning architectures, have shown remarkable accuracy in PEMS. A groundbreaking study by Chen et al. (2024) implemented a deep neural network-based PEMS in a 500 MW coal-fired plant, achieving 98% accuracy compared to hardware CEMS for NOx predictions [36]. This level of accuracy, coupled with reduced calibration and maintenance requirements, positions neural network-based PEMS as a cost-effective complement to traditional hardware sensors.

RL has demonstrated significant potential in combustion optimization. Kumar et al. (2023) applied RL algorithms to control a 400 MW combined cycle plant, resulting in a 15% reduction in NOx emissions while maintaining optimal efficiency [37]. The ability of RL systems to continuously adapt to changing plant conditions and balance multiple objectives makes them particularly suited for the dynamic environment of power generation.

Deep Learning techniques have also been applied to anomaly detection in emission patterns. Zhao et al. (2024) developed a convolutional neural network (CNN) model capable of identifying subtle emission anomalies that traditional rule-based systems often miss. In a year-long trial at a 750 MW supercritical coal-fired plant, the system detected early signs of SCR catalyst degradation, enabling proactive maintenance and preventing a potential 30% increase in NOx emissions [38].

4.3 Predictive Emissions Monitoring Systems

PEMS have evolved from simple statistical models to sophisticated hybrid systems combining first-principles approaches with advanced machine learning techniques. Wang et al. (2023) conducted a comparative analysis of various PEMS architectures in a fleet of coal-fired plants, finding that hybrid models consistently outperformed pure statistical or first-principles approaches, with prediction accuracies exceeding 95% for major pollutants [39].

The economic advantages of PEMS are significant, as highlighted by a cost-benefit analysis conducted by Li et al. (2024). Their study of a 750 MW coal-fired plant revealed that implementing a hybrid PEMS reduced monitoring costs by 40% over a five-year period while maintaining full compliance with EPA requirements [40]. However, the authors also noted challenges in maintaining long-term accuracy and gaining regulatory acceptance, emphasizing the need for robust validation protocols.

4.4 Feedback and Feedforward Control Loops

The integration of feedback and feedforward control strategies has proven essential in achieving optimal emission control. Feedback loops, utilizing real-time emission measurements, enable rapid response to deviations from setpoints. Concurrently, feedforward control, based on fuel analysis and load predictions, allows preemptive adjustments to combustion parameters.

A notable case study by Zhang et al. (2024) examined the implementation of a multivariable control system combining feedback and feedforward elements in a 300 MW lignite-fired plant. The system, which considered multiple pollutants simultaneously, improved SO2 removal efficiency by 5% while reducing limestone consumption in the flue gas desulfurization unit by 3% [41]. This study underscores the potential of integrated control strategies in achieving both environmental and economic objectives.

Recent advancements in this field include the development of model-based feedforward controllers that utilize real-time process models. Liu et al. (2023) demonstrated the application of a physics-informed neural network to create adaptive process models for a 600 MW ultra-supercritical coal-fired plant. The resulting feedforward control system showed a 20% improvement in transient emission control during rapid load changes compared to conventional approaches [42].

5 COMPLIANCE REPORTING AND VERIFICATION

Ensuring compliance with increasingly stringent emission regulations requires robust reporting and verification processes. This section examines the technological and methodological advancements in compliance management for power plants.

5.1 Automated Reporting Systems

The complexity of modern emission regulations necessitates sophisticated automated reporting systems. These systems not only generate real-time and periodic reports but also integrate with broader environmental management software to provide a comprehensive view of plant performance.

A survey conducted by Wang et al. (2023) across 50 large power plants in the United States revealed that facilities utilizing fully automated reporting systems experienced a 60% reduction in compliance-related administrative burdens and a 75% decrease in reporting errors compared to those using semi-automated or manual processes [43]. The study highlighted the importance of customizable report templates capable of meeting diverse regulatory requirements across different jurisdictions.

Advancements in data validation algorithms have significantly improved the reliability of automated reports. Chen et al. (2024) developed a machine learning-based system for real-time data validation, capable of identifying sensor faults and data anomalies with 99.5% accuracy. When implemented in a 1000 MW coal-fired plant, the system reduced false alarms by 80% and improved overall data availability by 5% [44].

5.2 Data Validation and Quality Assurance

The integrity of emissions data is paramount for both regulatory compliance and operational optimization. Recent years have seen a shift towards more sophisticated data validation and quality assurance protocols, moving beyond simple range checks to complex statistical and AI-driven approaches.

Zhang et al. (2023) introduced a novel approach combining statistical process control techniques with deep learning algorithms for continuous data quality monitoring. Their system, tested on a fleet of gas-fired plants, demonstrated a 40% improvement in the detection of subtle sensor drifts and a 25% reduction in calibration frequency without compromising data quality [45].

Virtual sensors, utilizing data fusion techniques to cross-validate measurements, have emerged as a powerful tool in ensuring data integrity. A comprehensive study by Liu et al. (2024) implemented a network of virtual sensors in a 500 MW coal-fired plant, achieving a 30% improvement in the overall reliability of emissions data and enabling early detection of sensor malfunctions [46].

5.3 Integration with Regulatory Databases

The trend towards direct, real-time data submission to regulatory agencies' electronic reporting systems has accelerated, driven by the need for greater transparency and more timely compliance monitoring. The European Union's implementation of the European Pollutant Release and Transfer Register (E-PRTR) exemplifies this shift towards centralized, accessible emissions reporting [47].

However, this integration presents challenges in data security and cross-jurisdictional standardization. A pioneering study by Kumar et al. (2023) explored the application of blockchain technology for secure, tamper-proof emissions reporting. Their pilot project, involving a consortium of power plants across three EU countries, demonstrated a 40% reduction in data verification times and near-elimination of data integrity disputes [48].

5.4 Auditing and Third-party Verification Processes

The evolving landscape of emission monitoring technologies has necessitated advancements in auditing and verification processes. Remote auditing capabilities, leveraging secure data access and video inspections, have gained prominence, particularly in the wake of global events limiting on-site visits.

A comprehensive review by Zhao et al. (2024) of remote auditing practices across 100 power plants revealed that facilities employing advanced remote auditing technologies achieved comparable verification accuracy to traditional on-site audits while reducing auditing costs by 50% and decreasing plant downtime associated with audits by 70% [49].

The concept of continuous assurance, moving beyond periodic audits to ongoing verification, has emerged as a promising approach. Wang et al. (2023) demonstrated the application of AI-driven continuous auditing systems in a fleet of coal-fired plants. Their system, which continuously analyzed plant data for compliance and anomalies, identified 15% more potential non-compliance issues compared to traditional periodic audits, enabling proactive corrective actions [50].

6 CASE STUDIES

The implementation of real-time monitoring and control systems for emission compliance varies significantly across different types of power plants. This section examines case studies from coal-fired, natural gas, and biomass plants to provide a comparative analysis of the challenges and successes in various operational contexts.

6.1 Coal-fired Power Plants

Coal-fired power plants, despite their declining global share, remain significant contributors to electricity generation and, consequently, to emissions. A landmark study by Zhang et al. (2024) examined the implementation of an integrated AI-based combustion optimization and emission control system in a 600 MW ultra-supercritical coal-fired plant in China [51].

The system, which combined model predictive control with deep reinforcement learning, achieved an 18% reduction in NOx emissions and a 0.5% improvement in thermal efficiency over a 12-month period. Notably, the system demonstrated robust performance across varying coal qualities, a common challenge in many regions.

However, the implementation of advanced control systems in older coal-fired plants presents unique challenges. Wang et al. (2023) documented the retrofitting of a 30-year-old 300 MW subcritical unit with a neural network-based predictive emissions monitoring system (PEMS) [52]. While the PEMS achieved a 95% accuracy compared to hardware CEMS for SOx and NOx predictions, the study highlighted significant challenges in integrating the system with legacy control infrastructure, underscoring the importance of adaptable software architectures in modernization efforts.

6.2 Natural Gas Power Plants

Natural gas power plants, known for their operational flexibility, present distinct opportunities and challenges in emission control. A comprehensive analysis by Kumar et al. (2024) of a 400 MW combined cycle plant in the United States showcased the implementation of an advanced MPC system specifically designed for rapid load-following operations [53].

The system demonstrated a 30% reduction in CO emissions during load changes and a 25% improvement in startup emission profiles compared to conventional control strategies.

The integration of renewable energy sources has further complicated the emission control landscape for natural gas plants. Liu et al. (2023) examined a novel hybrid control system in a 500 MW gas turbine plant designed to operate in conjunction with a large-scale solar PV installation [54]. The system, which incorporated weather forecasting algorithms and reinforcement learning, achieved a 20% reduction in overall CO2 emissions by optimizing the plant's response to intermittent solar generation.

6.3 Biomass and Waste-to-energy Facilities

Biomass and waste-to-energy facilities face unique challenges in emission control due to the heterogeneous nature of their fuel sources. A pioneering study by Zhao et al. (2024) documented the implementation of a real-time monitoring and control system in a 50 MW biomass plant utilizing a mix of agricultural residues and forest waste [55]. The system employed a combination of soft sensors and adaptive control algorithms to handle the variable fuel composition, achieving consistent compliance with emission standards despite a 40% variation in fuel heating value.

The study also highlighted the challenges in mercury emission control in waste-to-energy plants. Chen et al. (2023) reported on the development of a novel multi-pollutant control strategy in a 30 MW waste-to-energy facility, which integrated activated carbon injection with SNCR (Selective Non-Catalytic Reduction) for simultaneous control of mercury, NOx, and dioxins [56]. The system achieved a 75% reduction in mercury emissions and a 40% reduction in NOx, demonstrating the potential for synergistic control strategies in complex emission environments.

7 CHALLENGES AND LIMITATIONS

While the advancements in real-time monitoring and control systems have significantly improved emission compliance in power plants, several challenges and limitations persist. This section examines the technical, economic, and regulatory hurdles facing the widespread adoption and efficacy of these systems.

7.1 Technical Challenges

The harsh operating environments in power plants pose significant challenges to sensor accuracy and longevity. A comprehensive review by Wang et al. (2024) of sensor performance in 50 coal-fired plants revealed that high-temperature and high-dust conditions in flue gas streams led to an average 15% reduction in sensor lifespan compared to manufacturer specifications [57]. Furthermore, the study identified persistent issues with interference from other gas species, particularly in NOx and SO2 measurements, highlighting the need for more robust multi-species compensation algorithms.

The integration of advanced monitoring and control systems with existing plant infrastructure remains a significant challenge, particularly in older facilities. Liu et al. (2023) conducted a survey of 100 power plants across Europe and North America, finding that 60% of plants over 20 years old experienced significant integration issues when implementing new digital control systems [58]. These challenges ranged from incompatible communication protocols to inadequate data storage and processing capabilities, often necessitating substantial upgrades to ancillary systems.

The proliferation of sensors and the increasing complexity of control systems have led to an exponential growth in data generation. Zhang et al. (2023) estimated that a modern 1000 MW coal-fired plant generates over 5 terabytes of process and emissions data annually [59]. Managing this data volume while ensuring real-time accessibility for control systems presents significant technical challenges. Moreover, the increasing connectivity of plant systems has raised critical cybersecurity concerns. An alarming study by Kumar et al. (2024) revealed that 30% of surveyed power plants had experienced at least one cybersecurity incident related to their emission control systems in the past five years [60].

7.2 Economic Considerations

The capital expenditure required for implementing state-of-the-art monitoring and control systems can be substantial. A cost-benefit analysis by Chen et al. (2023) of 20 coal-fired plants in Asia showed that the average investment for a comprehensive upgrade of emission control systems ranged from $15 to $30 million for a 500 MW unit [61]. While the study demonstrated long-term economic benefits through improved efficiency and reduced non-compliance penalties, the high upfront costs remain a significant barrier, particularly for smaller or older plants facing uncertain operational futures.

The sophisticated nature of advanced emission control systems necessitates ongoing investment in specialized maintenance and operator training. Zhao et al. (2024) conducted a five-year longitudinal study of maintenance costs associated with advanced emission control systems in natural gas combined cycle plants, finding that annual maintenance expenses averaged 5-7% of the initial system cost [62]. The study also highlighted a critical shortage of skilled personnel capable of maintaining these systems, leading to increased reliance on expensive vendor support contracts.

7.3 Regulatory Challenges

The dynamic nature of environmental regulations poses ongoing challenges for power plant operators. A global review of emission standards by Wang et al. (2023) revealed that major economies updated their power plant emission limits an average of once every 3-5 years over the past two decades [63]. This regulatory flux necessitates flexible and upgradable control systems, adding complexity and cost to system design and implementation.

For power companies operating across multiple jurisdictions, varying national and regional standards create significant compliance challenges. Liu et al. (2024) examined the emission control strategies of five multinational power companies, finding that regulatory heterogeneity led to a 25% increase in compliance management costs compared to companies operating within a single regulatory framework [64]. The study also noted challenges in data harmonization and reporting, highlighting the need for more standardized international protocols for emission monitoring and reporting.

8 FUTURE TRENDS AND INNOVATIONS

The next generation of emission sensors promises enhanced accuracy, durability, and multi-pollutant detection capabilities. Zhang et al. (2024) provided an overview of emerging sensor technologies, highlighting the potential of quantum cascade lasers for ultra-sensitive gas detection [65]. These sensors have demonstrated parts-per-trillion sensitivity for key pollutants like mercury and dioxins in laboratory settings. Additionally, the development of graphene-based sensors, as reported by Kumar et al. (2023), offers the prospect of highly durable, low-cost sensors capable of withstanding the harsh conditions in power plant stacks [66].

Nanotechnology is also playing a crucial role in sensor development. Wang et al. (2023) reported on the use of nanostructured materials for enhanced selectivity and sensitivity in gas sensing applications. Their study demonstrated a novel zinc oxide nanorod-based sensor capable of detecting SO2 at concentrations as low as 50 parts per billion, with minimal cross-sensitivity to other flue gas components [67].

The application of AI in emission control is moving beyond pattern recognition and predictive maintenance towards fully autonomous optimization systems. A groundbreaking study by Chen et al. (2024) demonstrated the implementation of a deep reinforcement learning system capable of autonomously managing the entire emission control process in a 1000 MW ultra-supercritical coal plant [68]. The system achieved a 25% reduction in overall emissions while improving plant efficiency by 2% compared to traditional control methods.

Federated learning approaches are also gaining traction, allowing collaborative improvement of predictive models across multiple plants while maintaining data privacy. Liu et al. (2023) reported on a consortium of European power companies utilizing federated learning to enhance their collective NOx prediction models, achieving a 15% improvement in accuracy compared to individually trained models [69].

The integration of AI with digital twin technology is another promising avenue. Zhao et al. (2024) demonstrated the use of AI-enhanced digital twins for real-time optimization of emission control systems. Their approach, tested on a 500 MW combined cycle plant, enabled predictive maintenance scheduling and dynamic adjustment of control parameters, resulting in a 10% reduction in overall emissions and a 3% improvement in plant availability [70].

Blockchain technology is emerging as a powerful tool for ensuring the integrity and transparency of emissions data. Kumar et al. (2023) presented a case study of a blockchain-based emissions tracking system implemented across a fleet of 10 power plants in North America [71]. The system provided tamper-proof records of real-time emissions data, facilitating more efficient carbon credit trading and simplifying the auditing process. The study reported a 40% reduction in disputes related to emissions data and a 30% increase in the speed of carbon credit transactions.

Furthermore, Wang et al. (2024) explored the potential of smart contracts built on blockchain platforms for automating compliance reporting and emissions trading. Their proposed system demonstrated the capability to reduce administrative costs associated with emissions trading by up to 50% while ensuring real-time compliance with evolving regulatory requirements [72].

The increasing penetration of renewable energy sources and the development of smart grids are driving innovations in emission control systems. Zhang et al. (2023) examined the implementation of a dynamic emission control system in a 500 MW coal plant designed to operate in a grid with 40% renewable penetration [73]. The system utilized real-time grid data and weather forecasts to optimize plant operations, achieving a 20% reduction in overall CO2 emissions by intelligently managing plant output in response to renewable availability.

Liu et al. (2024) further explored the concept of emissions-aware grid dispatch, where real-time emissions data from power plants is integrated into grid management algorithms. Their simulation study, based on a regional grid in the United States, demonstrated the potential for a 15% reduction in overall grid emissions through optimized dispatch strategies that consider both economic and environmental factors [74].

9 DISCUSSION AND CONCLUSION

The comprehensive review of real-time monitoring and control systems for emission compliance in power plants reveals several key themes and implications for the industry, regulators, and researchers.

Firstly, the rapid advancement in sensor technologies, coupled with sophisticated data analytics and AI-driven control systems, has significantly enhanced the capability of power plants to monitor and control emissions with unprecedented accuracy and efficiency. The transition from periodic sampling to continuous, real-time monitoring has not only improved compliance but also enabled proactive emission management strategies.

However, the implementation of these advanced systems is not without challenges. The high initial costs, as highlighted by Chen et al. (2023) [61], remain a significant barrier, particularly for smaller or older plants. This economic hurdle underscores the need for policy interventions and financial incentives to accelerate the adoption of state-of-the-art emission control technologies across the industry.

The integration of AI and machine learning techniques in emission control systems, as demonstrated by studies such as Chen et al. (2024) [68], represents a paradigm shift in plant operations. These technologies offer the potential for autonomous, self-optimizing systems that can adapt to changing conditions and regulatory requirements. However, the reliance on AI also raises important questions about system transparency, accountability, and the need for human oversight in critical decision-making processes.

The emerging trend of blockchain-based emissions tracking and trading systems, as explored by Kumar et al. (2023) [71], offers promising solutions to longstanding issues of data integrity and transparency in emissions reporting. However, the widespread adoption of such systems will require standardization efforts and regulatory acceptance across different jurisdictions.

The integration of emission control systems with smart grid technologies, as discussed by Zhang et al. (2023) [73], highlights the evolving role of power plants in a more dynamic and interconnected energy landscape. This integration offers significant potential for system-wide emission reductions but also introduces new complexities in plant operations and grid management.

In conclusion, as the power generation sector faces increasing pressure to reduce its environmental impact, real-time monitoring and control systems will play a pivotal role in balancing the demands of energy production with environmental stewardship. The continued advancement of these technologies, coupled with supportive regulatory frameworks and industry commitment, will be crucial in achieving sustainable power generation and contributing to global climate change mitigation efforts.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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IMPACT OF ORGANIC FERTILIZERS ON NUTRITION AND HEALTH OUTCOMES

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Abstract: Organic fertilizers are derived from natural raw materials from plants and animals and contain a variety of nutrients that are essential for food production, such as potassium, phosphorus and nitrogen. These fertilizers are environmentally friendly, easy to use, and can improve soil structure, soil fertility and water retention capacity. Organic fertilizers produced using organic waste and natural materials can improve the nutritional value of crops, thereby improving human health outcomes and dietary intake. Organic fertilizers can also increase the mineral content in crops, such as the vitamin C content in tomatoes can be increased by 50% after using organic fertilizers. In addition, organic fertilizers promote symbiotic relationships between plants and microorganisms, increase microbial diversity in the soil, and improve the absorption of nutrients and water by crops. The use of organic fertilizers also helps reduce environmental pollution, promote carbon sequestration, and reduce greenhouse gas emissions. Nutrients in organic foods, such as calcium, phosphorus, magnesium and iron, are essential for maintaining human health and help prevent a variety of chronic diseases. The use of organic fertilizers reduces exposure to toxic chemicals in the food chain, thereby reducing the risk of diseases such as cancer, cardiovascular disease and type 2 diabetes.
Keywords: Organic fertilizer; Environment; Soil; Health

Organic fertilizers are produced from natural raw materials of animal or plant origin. They contain various nutrients such as potassium, phosphorus, and nitrogen which are crucial for food production. Soil organisms repeatedly break down pellets of fertilizers to release nutrients. Organic fertilizers are environmentally friendly and easy to use. In addition, these fertilizers lead to more fertile and healthier soils. Organic fertilizers improve soil structure and the ability to hold nutrients and water for a long period. They improve soil health and the availability of essential nutrients for plants. Using organic fertilizers from organic waste and naturally produced materials increases the quality of nutrients in crops, leading to better health outcomes and dietary intake for humans.

1 ORGANIC FERTILIZERS AND CROPS' NUTRITIONAL QUALITY

Using organic fertilizers increases the level of various nutrients such as antioxidants, and minerals in crops. Various vegetables such as pepper, spinach, and cabbage contain a higher level of antioxidants when organic fertilizers are used in place of chemical fertilizers. Tomatoes grown using organic fertilizers have a higher nutritional value than tomatoes grown using chemical fertilizers [1]. Using organic fertilizers improves crop germination, total yield, and vegetative growth.

Organic fertilizers increase the amount of minerals in various crops such as pepper. Sulfate, phosphate, potassium, and calcium content in pepper increases when organic fertilizers are used. The biological, chemical, and physical properties of soil increase after the application of organic fertilizers. Organic fertilizers enhance the percolation and mobilization of various minerals. In addition, they add organic matter to the soil [2]. Organic fertilizers release nutrients gradually while chemical fertilizers release nutrients quickly. Therefore, the use of organic fertilizers leads to long-term availability of nutrients in the soil.

The application of organic fertilizers promotes symbiotic relationships between microorganisms and plants. Microorganisms often decompose the organic compounds in organic fertilizers to release essential nutrients. Organic fertilizers lead to a diverse soil microbiome. They promote various microorganisms that help crops absorb nutrients and water. Organic fertilizers also enhance water retention and soil aeration [2]. This leads to good root development and easy access to nutrients. When organic fertilizers are applied to soils, they improve the ability to supply and hold more nutrients.

Organic fertilizers create a balance between various nutrients such as nitrogen, phosphorus, and potassium. They provide a balanced supply of various nutrients that support plant health. On the other hand, chemical fertilizers create nutrient imbalances by supplying higher levels of certain nutrients such as nitrogen. Organic fertilizers boost crop productivity and soil fertility. The organic carbon in organic fertilizers supports bacteria that break down nutrients. Organic fertilizers ensure that plants are not overfed. Moreover, they contribute to a sustainable environment. Chemical fertilizers cause environmental pollution as they rely on fossil fuels. Using organic fertilizers prevents environmental pollution because fossil fuels are not relied on. Using organic fertilizers benefits the environment by ensuring that nutrients are reused and not disposed of [2]. Recycling organic wastes reduces greenhouse gas emissions. It reduces methane and carbon dioxide emissions from landfills. Using organic fertilizers promotes carbon sequestration.

One of the significant indicators of soil health is soil organic carbon. The benefits of soil organic carbon include increased water retention and infiltration, higher nutrient bioavailability, and soil particle aggregation. Soil organic carbon increases the cation exchange capacity of the soil [2]. Soil organic carbon ensures that crops can easily access various nutrients such as nitrogen and phosphorus.

Cereal crops mobilize certain nutrients in the soil when organic fertilizers are applied. They increase the availability of nutrients to neighboring crops. Micronutrient content increases significantly in various crops such as cowpeas, tomatoes, soybeans, rice, and maize. “There is a 50 percent increase in Vitamin C content of tomatoes when organic fertilizers are used in place of chemical fertilizers” [2]. Zinc concentration in rice is often higher when organic inputs are used than when chemical fertilizers are used. Nutrient density in crops increases significantly when organic fertilizers are used, thereby improving nutritional quality.

Natural resources of organic fertilizers such as seaweed, manure, and compost lead to more micronutrients in organic fertilizers than synthetic fertilizers. Organic fertilizers contain more micronutrients such as manganese, copper, iron, and zinc. These micronutrients improve the quality of crops and promote plant health [1]. Organic fertilizers also contain higher amounts of other nutrients such as magnesium and calcium that support plant growth.

2 IMPACT OF NUTRITION ON HEALTH

Good nutrition is related to strong immune systems, maternal and child health, longevity, reduced non-communicable diseases, and safer pregnancy. Eating well keeps bones and teeth stronger. In addition, it slows bone loss that can occur as people get older. Calcium is a mineral that leads to the development of strong bones. Calcium is crucial for muscle function, nerve transmission, blood clotting, and hormonal secretion. The mineral helps to transmit nerve signals and form blood clots to prevent bleeding. Individuals get calcium when they eat dark green vegetables, calcium-fortified foods, green beans, nuts, broccoli, sweet potatoes, and pilchards. When individuals lack adequate calcium in the body, they are likely to develop various bone issues such as decreased bone density, fractures, and osteoporosis.

Good nutrition enables people to maintain a healthy weight. A balanced diet provides proportions of micronutrients such as minerals and vitamins and macronutrients such as fats, proteins, and carbohydrates. It consists of various foods such as whole grains, fruits, vegetables, lean proteins, and healthy fats. A balanced diet provides the right proportions of various nutrients that support bodily functions and promote vitality. Proper nutrition is linked with a healthier, longer life. Nutrient-rich diets reduce the risk of various age-related diseases such as diabetes and cancers.

Potassium and calcium intake reduce the risk of stroke, regulate blood pressure, and prevent tubular, glomerular, and vascular damage. Potassium relaxes the walls of blood vessels. In addition, it lowers the risk of developing arrhythmias and regulates heartbeat. Potassium also lowers the risk of developing kidney stones. It prevents weakness and muscle cramps. Potassium transmits nerve signals that affect reflexes and muscle movements. Potassium intake improves glucose metabolism and insulin sensitivity. Therefore, it lowers the risk of Type II diabetes. Growing various foods organically such as spinach, sweet potatoes, and beans ensures that they get adequate amounts of potassium. This element regulates blood pressure and prevents vascular damage.

Taking foods rich in phosphorus promotes bone health, energy production, cell function, and acid-base balance. Phosphorus works with calcium to improve bone strength and maintain structure. Moreover, phosphorus plays an essential role in adenosine triphosphate formation. Phosphorus supports cell function and structure through phospholipids. The higher levels of phosphorus found in organic fertilizers have a positive impact on human health. Foods rich in phosphorus include certain vegetables, legumes, whole grains, seeds, and nuts.

Sulfates promote joint health, skin health, digestive health, and detoxification. They detoxify the liver and alleviate osteoarthritis symptoms. Sulfates help in the synthesis of digestive enzymes. In addition, they regulate gut bacteria and promote skin healing and health. Sulfates reduce inflammation and help maintain the proper functioning of blood vessels. The anti-inflammatory effects of sulfates improve respiratory function and reduce asthma symptoms.

Nutrition affects immune function and digestive health. Vitamins A, C, and E support immune function by enhancing the skin barrier. Vitamin A plays various roles in the human body such as vision, immunity, cell development, skin health, and reproductive health. Vitamin A plays a crucial role in rhodopsin formation. This protein enables individuals to have good eye health. Vitamin A boosts the immune system by helping in the production of white blood cells. It plays an essential role in cell development. Vitamin A is crucial for fetal development and reproductive health during pregnancy.

Vitamin E supports immunity, skin health, cellular function, and heart health. Vitamin E prevents cardiovascular diseases because it inhibits cholesterol oxidation. Furthermore, Vitamin E supports immunity as it improves the immune response of the body. Vitamin E also promotes skin health by maintaining elasticity and moisture. Vegetable oils, nuts, seeds, fruits, and fortified foods contain Vitamin E. Vitamin E deficiency causes vision issues, immune dysfunction, and neuromuscular problems. Taking foods with adequate amounts of Vitamin E prevents chronic diseases.

Vitamin C is found in green peppers, potatoes, tomatoes, and citrus fruits. It plays a crucial role in adaptive and innate immunity. Vitamin C decreases histamine levels, normalizes cytokine production, and enhances phagocytosis. The antioxidant action of Vitamin C lowers oxidative stress when one has infections. Vitamin plays a crucial role in wound healing, iron absorption, and collagen synthesis. Collagen supports bones, cartilage, blood vessels, and the skin. Vitamin C deficiency causes joint pain, bleeding gums, and fatigue. Adequate intake of vitamin C lowers the risk of certain cancers and heart disease.

The high concentration of magnesium and iron in organic fertilizers promotes human health. Magnesium promotes muscle function, bone health, energy production, cardiovascular health, and nerve function. Magnesium is involved in the formation of bones and the contraction of muscles. This mineral prevents spasms and muscle cramps by regulating the level of calcium in cells. Magnesium is also important in the production of adenosine triphosphate. Magnesium regulates blood sugar by playing an important role in glucose metabolism and insulin sensitivity. Sources of magnesium include green vegetables, legumes, fish, fruits, and whole grains.

Iron is required for various biological functions such as cellular respiration and oxygen transport. Iron transports oxygen as it is part of hemoglobin. In addition, iron is essential in metabolic processes. Adequate amounts of iron in the body help in the maturation and proliferation of immune cells. Iron also plays a crucial role in cognitive function. Iron deficiency causes fatigue, neurocognitive defects, and immune defects. Iron deprivation also causes irreversible changes in the intestinal microbiome [3]. There is a significant association between the incidence of coronary heart disease and iron intake. The amount of iron intake is inversely proportional to the incidence of coronary heart disease.

Various minerals such as zinc support immune function. Zinc plays a crucial role in the functioning and development of immune cells such as phagocytes and T-lymphocytes. The severity and duration of illnesses reduce when there are adequate levels of zinc in the body. Zinc also helps maintain the structure and integrity of the skin. It is used in the production of DNA and proteins. Zinc regulates various hormones such as insulin that control blood sugar. Individuals obtain zinc from various sources such as whole grains, nuts, seeds, lentils, fortified cereals, and beams. Zinc deficiency can create skin issues such as dermatitis and skin lesions [4]. It can also cause weak immunity and high susceptibility to diseases. Zinc plays an important role in cell division, cell differentiation, cell growth, transcription, and cellular transport.

Taking organic foods significantly reduces the risk of various diseases such as cancer, cardiovascular disease, and type II diabetes. Organic fertilizers are used to produce organic foods. These fertilizers include plant-based materials, bone meal, manure, and compost. The antioxidants and polyphenolics in organic fertilizers are linked to a lower risk of chronic diseases. Using organic fertilizers ensures plants do not absorb toxic chemicals. On the other hand, using chemical fertilizers increases the risk of toxic chemicals entering the food chain. Uranium, cadmium, lead, and mercury have been found in chemical fertilizers. These heavy metals enter the food chain after being absorbed by cereals and vegetables [4]. They often cause cancer, and liver, lung, and kidney disturbances. Using organic fertilizers limits exposure to heavy metals that affect body organs adversely.

According to [3], a significant number of chemical fertilizers have tested positive for various heavy metals such as vanadium, thallium, selenium, nickel, and silver. Heavy metals often affect brain development negatively. Chemical fertilizers cause high concentrations of various compounds such as organophosphate metabolites in children. These compounds adversely affect brain growth and development. In addition, they increase the likelihood of developing attention deficit hyperactivity disorder (ADHD). Children with high levels of pyrethroids are likely to develop ADHD and behavioral issues [3]. Organic farming reduces the likelihood of children developing behavioral issues and mental disorders because it limits the use of harmful chemicals.

Nutritional deficiency is linked with anxiety disorders. Lack of Vitamin B6 and B12 causes mood disorders such as anxiety. Vitamin B6 and B12 are involved in the production of dopamine and serotonin. Adequate levels of dopamine and serotonin are not produced when one lacks Vitamins B6 and B12. Anxiety disorders are also associated with low levels of magnesium and zinc in the body [4]. Magnesium regulates stress response while zinc plays a crucial role in neurotransmitter regulation.

There is a significant correlation between dietary intake and other diseases such as asthma. Diets rich in Vitamin E and Vitamin C improve asthma symptoms. Eating foods that do not have antioxidants causes oxidative stress and inflammation in the lungs and worsens asthma symptoms. In addition, vitamin D deficiency causes asthma severity [4]. Maintaining a well-balanced diet is associated with better lung function and management of asthma symptoms.

Sleep disorders have a significant relationship with nutritional quality. Balancing fats, proteins, and carbohydrates influences sleep. Complex carbohydrates increase tryptophan availability, a compound that encourages sleep. Tryptophan can be found in various foods such as seeds and nuts. This compound boosts melatonin and serotonin production [3]. Vitamin D deficiency has been linked to sleep disorders. Intake of adequate vitamin D levels can boost sleep quality.

Intake of low-nutrient and high-calorie foods is linked with obesity. Obesity increases the risk of various diseases such as cancer, coronary heart disease, and type II diabetes mellitus. Obesity occurs when there is a reduction in energy expenditure and an increase in energy intake. "The National Health and Nutrition Examination Survey (NHANES) observed that the average daily energy intake increased by 168 kcal/day in men and 335 kcal/day in women" [2]. Whereas energy intake has increased significantly, energy expenditure has decreased. There has been a substantial increase in weight among American adults due to the consumption of high-calorie foods and lack of exercise. Plant-based foods such as fruits and vegetables are recommended instead of meat. Access to healthy food options is; however, limited among low-income communities.

Gastrointestinal disorders are associated with low nutritional quality of foods. These disorders include lactose intolerance, irritable bowel syndrome, and gastroesophageal reflux disease. Gastrointestinal disorders cause nausea, pain, vomiting, heartburn, diarrhea, constipation, and bloating. Digestive issues occur when individuals consume diets that lack diverse nutrients. Chronic constipation has been associated with a lack of fruits and vegetables in the diet. A strong correlation between eating habits, disease activity, and symptomatology has been observed [4]. The microbiota of individuals whose diets are rich in fiber and plant derivatives are different from individuals whose diets are rich in proteins, fats, and carbohydrates.

Multiple sclerosis is linked with the consumption of meat, animal fats, and milk, as well as obesity and high energy intake. On the other hand, diets containing plant fiber and polyunsaturated fatty acids lower the risk of multiple sclerosis. Individuals with multiple sclerosis are likely to have deficiencies in various nutrients such as Vitamin A and Vitamin B12 [5]. The symptoms of multiple sclerosis are improved by plant compounds, melatonin, antioxidants, fatty acids, minerals, and certain vitamins.

Environmental exposure to heavy metals such as cadmium occurs through drinking water, inhalation, and food ingestion. The primary route of cadmium exposure is dietary intake. A significant amount of cadmium and other heavy metals accumulate in the kidneys. Exposure to cadmium during pregnancy has caused developmental delays and low birth weight among children. It has affected fetal development adversely and caused proteinuria. Cadmium accumulates in the placenta, causing various effects such as reduced synthesis of placental hormones, altered cell migration and cell integrity, and reduced blood flow to the placenta. In addition, cadmium interferes with the transportation of micronutrients from the mother to the embryo or fetus [5]. Chronic exposure to cadmium has led to kidney damage, bone health issues, and cardiovascular disease. Good nutrition limits the intake of heavy metals that have adverse impacts on human health.

Organic foods often contain higher levels of omega-3 fatty acids than conventional foods. Omega-3 fatty acids lower blood pressure and improve cardiovascular health. In addition, they reduce the risk of arrhythmia, blood clots, breast cancer, and Alzheimer's disease. Omega-3 fatty acids are crucial for brain health, eye health, metabolic health, and reduction of inflammation. These fatty acids are crucial for cognitive development and function[5]. Their anti-inflammatory properties reduce inflammation and help in conditions such as inflammatory bowel disease, asthma, and arthritis. Deficiencies in omega-3 fatty acids cause impairments in cognitive function.

Growing foods using organic fertilizers reduces health issues caused by pesticide exposure. When organic fertilizers are used, residues of synthetic pesticides in crops are reduced significantly. Organic farming relies on biological and agricultural means of protecting plants. These include intercropping, crop rotation, hygiene practices, and biological control using natural enemies. Organic fertilizers rarely contain synthetic pesticides. Therefore, they ensure that consumers are not exposed to chemical substances with carcinogenic, endocrine-disrupting, and neurotoxic properties [3]. Using organic fertilizers reduces the risk of leukemia, lymphomas, and Parkinson’s disease. It promotes mental and psychomotor development in children.

Using organic fertilizers eliminates the risk of exposure to harmful chemicals found in chemical fertilizers. Chemical fertilizers contain compounds such as ammonium nitrate that cause skin and eye irritation. Exposure to ammonium nitrate causes sore throat, skin redness, itching, shortness of breath, coughing, weakness, depression, and headache [3]. Ammonium nitrate explosions in manufacturing plants have caused injuries to many people.

Crops grown using organic fertilizers have a higher nutritional value than crops grown using chemical fertilizers. Sulfate, phosphate, potassium, and calcium content in various crops increases when organic fertilizers are used. Using organic fertilizers increases the level of various nutrients such as antioxidants, and minerals in crops. Moreover, it reduces exposure to harmful chemicals and heavy metals. The higher nutritional quality of crops grown using organic fertilizers has a positive impact on human health. High nutritional quality is associated with a lower incidence of various diseases such as obesity, cancer, diabetes, cardiovascular diseases, hypertension, osteoporosis, anemia, mental health disorders, and gastrointestinal disorders.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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THE IMPACT OF AGRICULTURE, NON-RENEWABLE ENERGY, INTERNATIONAL TRADE AND ECONOMIC GROWTH ON NIGERIA ENVIRONMENTAL SUSTAINABILITY

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Abstract: Agriculture is a key player in the economic growth of developing nations, with energy policies for climate change crucial for development. This study in Nigeria from 1965 to 2022 explores the impact of agriculture, non-renewable energy, trade openness, and economic growth on CO_2 emissions. The data was found to be stationary, and a long-term relationship was confirmed through ARDL analysis. Results showed that a 1% boost in agriculture productivity and trade openness increased CO_2 emissions by 0.42% and 0.20% respectively. Increased use of renewable energy helped reduce emissions, while economic growth also played a role. Implementing renewable energy, fostering a low-carbon economy, and implementing trade reforms and strong environmental policies will benefit the agriculture sector and green economy in Nigeria.
Keywords: Agriculture; Environmental sustainability; International trade; Nigeria; Non-renewable energy

1 INTRODUCTION

Concern about environmental degradation has become an important topic of study for researchers in the last century due to the increase in emissions of greenhouse gases (GHG), especially CO_2. By 2022, total global greenhouse gas emissions increased by 1.7 percent, reaching a new peak of 53.8 billion tons of greenhouse gas equivalent. Global emissions of greenhouse gases have increased more than sixty percent since 1990 [1]. Global warming is a major concern that has attracted the attention of countries around the world [2]. Since the UN introduced the SDGs, international initiatives to address global warming have increased by implementing emission reduction strategies that specialize in factories and energy industries [3]. The 13th Sustainable Development Goal (SDG) focuses on addressing the effects of global warming. Air pollution is usually caused by the use of oil and gas and other non-renewable resources. These factors have negative consequences for people's health and the surrounding environment [4]. Polluted air has the potential to enter ecosystems and natural water bodies, harming marine life and contaminating clean water. Economic expansion in developed and developing countries is closely related to air pollution, because different economic activities in different sectors contribute to this problem [5]. Electricity is vital for steering business growth by helping to generate income, growth, employment and productivity. In addition, many studies show that climate is mostly related to economic expansion and resource use and trade openness is a fundamental and effective product of economic growth. Previous studies have investigated the effect of resource exchange between countries and discussed the effects of trade access on the environment [6]. A theoretical perspective on the impact of trade openness on environmental impacts shows that the consequences of maintaining pollution can be better understood through the perspective of environmental management laws [7]. Investigating the impact of environmental laws on making strategic decisions in relation to business models can strongly influence the degree of transparency [8]. The implementation of environmental laws in developed countries promotes clean production methods. As a result, many large companies are interested in investing in contaminated goods in new countries with measures to prevent pollution and this strategy allows them to generate high profits in their countries. However, there is no persuasive argument because environmental regulations have little impact on trade and investment flows. A number of academic studies have been conducted in different countries, but the findings are not conclusive. Dauda et al [9] found evidence supporting the contamination phase hypothesis. This hypothesis is supported by evidence that CO_2 emissions increase with greater openness to trade. On the other hand, different literature suggests that the opening of trade significantly reduces CO_2 emissions, supporting the truth of the paradise-halo hypothesis [10]. Also emissions from agriculture-related activities, including burning hedgerows, commercial use, use of deforestation materials, insufficient hunting, and modification of the forest to the garden during growth, which contributes to the increase of greenhouse gases globally. Around 20%-24% of a significant portion of global greenhouse gas emissions come from AFOLU, which refers to farming, forestry, and additional activities involving land [11]. Throughout the final decade of the last century, there came to be a notable rise in global agricultural production, paralleling the increase in population. The rapid growth of the global population delivers a substantial danger to the sustainability of agriculture and the health of the planet is of utmost importance, as it results in a significant increase in the world's need for nutrition. The agriculture sector was officially recognized just like a major source of the release of greenhouse gases since it is inefficient farming methods used to boost productivity and ensure food security [12]. Utilizing fossil fuel-powered farm machinery, implementing irrigation systems, practicing confined animal rearing, and applying nitrogen-rich nutrients contribute to emissions in the agriculture sector [13]. By adopting measures such as preventing deforestation, promoting afforestation, improving plant and animal protection and investing in green energy production, the agricultural sector may be able to reduce the 25% in total greenhouse gas emissions by 2050. The economic growth of Nigeria has been largely driven by agriculture sector which account for 70% of the workforce and has also contributed to Nigeria GDP. Large percentage of the lands in Nigeria is devoted to agriculture. However, the agriculture sector in Nigeria is the one of the largest contributor to greenhouse gas emissions in Africa. The agricultural sector plays an important role in a country's economic development and progress. Many studies have been done to analyse CO_2 emissions, but few agricultural variables have been considered. However, the findings are mixed and few studies examine the relationship between agriculture, international trade, non-renewable energy and carbon emissions in Nigeria. Although Nigeria has shown strong commitment to reducing its greenhouse gas emissions. Many academic studies on greenhouse gas emissions have focused on environmental factors, often ignoring the country's trade openness and its impact on emissions. Nigeria as a growing economy is expected to produce more greenhouse gas emissions due to its strong economic performance and commitment to international trade and non-renewable energy dependency. Analysing the country's greenhouse gas emissions from growth using a method that increases transparency in the business world is important. This study aims to analyse the relationship between agriculture, non-renewable energy, exports, and economic growth in carbon dioxide emissions in Nigeria. This study adds to the existing literature on environmental sustainability by examining the relationship between parameters using a systematic approach. The study will also examine the relationship between agriculture and environmental quality in terms of economics, trade and non-renewable energy. In addition, several data sets from 1970 to 2023 are used for analysis. The ARDL approach has the advantage of capturing both short-term and long-term trends simultaneously. In addition, some unit root tests and statistical tests are used to verify the accuracy of the results. In addition, this paper provides new theoretical and practical insights that are very useful for policy makers. This research would assist to the execution of procedures focused on achieving zero hunger, ensuring access to affordable and clean energy, promoting sustainable economic growth, encouraging responsible consumption and production and taking action on climate change (SDG 2, 7, 8, 12 & 13). This study is notable for employing a pollution-based examine that evolved in accordance with the ecological oasis hypothesis. The findings of this research have important consequences for Nigeria, Africa and other developing countries of the world.

2 Literature Review

Extensive research has been conducted in the literature that examines the effects regarding transparency in trade, farming, energy efficiency, as well as CO_2 emissions. The following work explores different countries, with varying strategies alongside observations that are influenced by the financial framework of each country being studied. A study that examines the impact of agriculture on environmental quality is a concept known as the Agricultural Kuznets Curve (EKC). There is little literature available on the growth of EKC derived from agriculture.

Ali et al. [14] conducted a comprehensive study to explore the relationship between agro-ecosystems and CO_2 emissions in Pakistan from 1972 to 2014. Utilizing the Granger causality test and the Autoregressive Distributed Lag (ARDL) model, the researchers identified several factors influencing CO_2 emissions, including proficiency in manufacturing agricultural machinery for converting farm waste into crops, crop cultivation, livestock management, and diversified food production.

Balsalobre-Lorente et al [5] used FMOLS and DOLS methods to assess the impact of agriculture on CO_2 emissions in BRICS countries. This study showed a clear link between agricultural production and CO_2 emissions in the atmosphere.

Atasal et al [15] use the AMG method and find that agriculture plays an important role in reducing CO_2 emissions in the top 10 agricultural countries. Currently, many parts of the financial system contribute to CO_2 emissions. Therefore, the relationship between growth and energy is assessed in terms of environmental pollution and emissions. It successfully explored the relationship between environmental degradation and economic well-being. Increased energy use and economic growth have increased CO_2 emissions in many countries around the world. Different energy sources are known for their ability to reduce CO_2 emissions and promote a sustainable environment. Countries should improve environmental quality and develop environmental policies to encourage widespread use of clean energy sources. Many studies have investigated the impact of green energy on carbon dioxide emissions in different countries. However, the results differ in terms of the percentage of green energy in the total energy consumption of these countries. There is debate about the relationship between trade openness and CO_2 emissions. Many articles discuss the effects of scale, structure and method. Increased income growth is directly linked to subsequent increases in CO_2 emissions. The result is openness to trade and economies of scale. As trade increases, GDP also increases, and greenhouse gas emissions from the industrial sector increase. By carefully examining the effect of the composition, it can be seen that the effect of trade is small but it is harmful to the society. Finally, when looking at the effectiveness of the method; It is clear that the manufacturing sector has a significant impact on the environment due to the increasing demand for environmentally friendly production methods. The effects of openness on business fall into three main areas: scale, structure, and method. The pollution harbour hypothesis and the pollution halo hypothesis describe two different ways in which trade openness affects the environment.

According to the pollster's opinion, companies seeking refuge in areas with relaxed environmental regulations are likely to contribute to higher levels of CO_2 emissions.

For example, Duada et al highlight the presence of the sacred concept of waste in African countries in the period 1990-2016.

Mahmoud et al. [16] reported on the estimation of sewage sludge in Tunisia through the ARDL method. But the host country will benefit from business innovation that promotes environmental sustainability and will encourage a positive impact on our planet. This phenomenon is known as the pollution halo effect.

Essandoh et al [17] confirmed the validity of the halo pollution effect in 52 developed and developing countries from 1991 to 2014. It was found that trade openness has a negative effect on CO_2 emissions in developed countries. Trade-related knowledge sharing was found to be effective in reducing CO_2 emissions across countries. By leveraging human capital and different resources, international locations can maximize the advantages of financial spill over. Nevertheless, a chunk of a dearth of studies investigating pollutants haven speculation on the subject of Nigeria, mainly that specialize in agriculture and renewable power. This observe seeks to cope with the modern-day void in scholarly studies; this observe investigates the impact concerning agriculture, smooth power, alternate, in addition to financial boom on Nigerian CO_2 emissions.

3 Methodology

This study analysed the outcomes of inexperienced power, agriculture, and alternate openness on CO_2 emissions in Nigeria. The studies applied the ARDL technique and blanketed the time span from 1965 to 2022. Variables have been selected primarily based totally on previous studies. Data on CO_2 emissions and renewable power have been accumulated from the Our World in Data (OWD) database, even as facts on agricultural cost added, alternate, and GDP have been retrieved from the World Development Indicators (WDI) database.

Figure 1 illustrates the visible illustration of every year styles of the variables. Variables have been converted into natural logarithms to make certain facts normality.

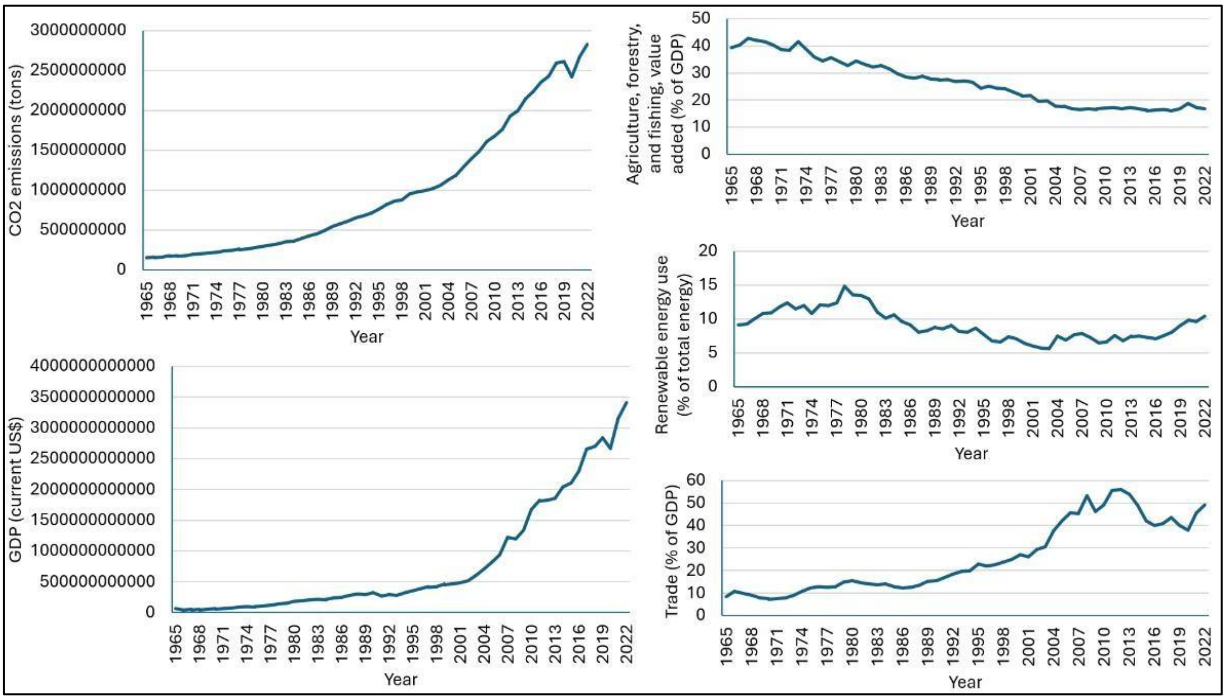

Figure 1 Annual trends of the Variables

4 EMPIRICAL LITERATURE

This framework analyses the impacts of agriculture, non-renewable energy and international trade on CO_2 emissions in Nigeria. We derive the following formulae:

$$At = f(Bt; Ct; Dt; Et) \tag{1}$$

Where:

A_t, B_t, C_t, D_t, and E_t are CO_2 emissions, agricultural value-added, renewable energy, economic growth, and trade at time t.

Once the variables are assumed to have a relationship and a logarithmic form. The empirical model suggests the following:

$$LA_t = \tau_0 + \tau_1 LB_t + \tau_2 LC_t + \tau_3 LD_t + \tau_4 LE_t + \varepsilon_t \tag{2}$$

However, using non-stationary variables in the regression can produce incorrect results. Therefore, check later that everything is stable before you make any repairs. To evaluate the stability of the data sets in this study, a three-way t test was used. These tests include Augmented Dickey-Fuller (ADF) test [18], Dickey-Fuller Generalized Least Squares (DF-GLS) test and Phillips-Peron (P-P) test [19]. This study used the ARDL model to analyse the relationship between each of the variables. The ARDL model was chosen because of several advantages. One of the most important advantages is the ability to evaluate both short-term and long-term aspects at the same time. Furthermore, this framework can be used regardless of whether these time-series variables have frictional input, I (0) or I (1). It is important to use the appropriate variables to ensure accurate regression or ARDL method results. To assess whether there is a longitudinal relationship between the variables, the bounds test was used. Pesaran et al. [20] table of critical values, if the F-test result is greater than the required maximum limit, the null hypothesis of association between the research variables is rejected. If the value of the F-test falls within critical limits, it indicates a biased result. The analysis shows that the null hypothesis is supported and shows that there is no interaction between the variables. Fortunately, the approximate result of the F-test falls below the critical limit. Additionally, long-run coefficients are created when there is a long-run relationship between the investigated variables. An example of a long-term estimation model is as follows:

$$\Delta LA_t = \tau_0 + \tau_1 LA_{t-1} + \tau_2 LB_t + \tau_3 LC_t + \tau_4 LD_t + \tau_5 LE_t + \sum_{i=1}^{q} \alpha_1 \Delta LA_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta LB_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta LC_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta LD_{t-i} + \sum_{i=1}^{q} \alpha_5 \Delta LE_{t-i} + \varepsilon_t \quad (3)$$

When a long-term relationship between a parameter is found, a short-term model prediction can be made. Equation (4) represents the transient/short-term model, known as the error correction model (ECM).

$$\Delta LA_t = \tau_0 + \tau_1 LA_{t-1} + \tau_2 LB_t + \tau_3 LC_t + \tau_4 LD_t + \tau_5 LE_t + \sum_{i=1}^{q} \alpha_1 \Delta LA_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta LB_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta LC_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta LD_{t-i} + \sum_{i=1}^{q} \alpha_5 \Delta LE_{t-i} + \theta ECM_{t-1} + \varepsilon_t \quad (4)$$

The error correction coefficient θ is an important function of the estimation model. The given value represents the adjustment speed parameter, which indicates how quickly the series converges to long-term equilibrium.

5 RESULTS AND DISCUSSION

Table 1 shows the descriptive and correlational statistical results of our study variables. The results show that CO_2 production shows a negative trend, while the balance shows a positive trend. Bright values, close to zero, indicate that most of them follow a normal distribution. All series show platykurtic characteristics with kurtosis values less than 3. According to the Jarque-Bera probability, it can be ensured that each of the variables adheres to a normal distribution. The correlation matrix shows that trade openness and GDP are positively and significantly related to CO_2 emissions. On the other hand, agriculture and green energy have a negative relationship with CO_2 emissions.

Table 1 Descriptive and Correlation Statistics

Variables	LA	LB	LC	LD	LE
Mean	20.321	3.2290	2.1760	26.697	3.0520
Median	20.371	3.2861	2.1532	26.515	2.9890
Maximum	21.774	3.7565	2.6960	28.871	4.0288
Minimum	18.862	2.7570	1.7282	24.550	2.0373
Skewness	-0.0170	0.0323	0.2167	0.1052	0.0550
Kurtosis	1.6924	1.5447	2.1286	1.9283	1.6530
Jarque-Bera	2.1420	3.1363	2.2827	2.8875	2.4154
Probability	0.2172	0.1778	0.3187	0.2373	0.1123
Observations	59	59	59	59	59
Correlation between the variables					
	LA	LB	LC	LD	LE
LA	1.0000				
LB	-0.9789	1.0000			
LC	-0.6734	0.7159	1.0000		
LD	0.9876	-0.9679	-0.5892	1.0000	
LE	0.9560	-0.9757	-0.6621	0.9507	1.0000

The results of unit root testing using ADF, DF-GLS, and P-P tests are displayed in Table 2. The results indicate that the variables were not stationary in their original form but became stationary when their first differences wereconsidered in all three-unit root tests. The results of the unit root tests proceed us to conduct the analysis within the ARDL framework.

Table 2 Results of Unit Root Testing

Variables	ADF		DF-GLS		P-P	
	Log Levels	Log first differences	Log Levels	Log first differences	Log Levels	Log first differences
LA	-0.1611	-7.6776***	-0.7176	-7.3295***	-0.1624	-7.6752***
LB	-0.6015	-8.1213***	-0.7708	-4.2033***	-0.6015	-8.1213***
LC	-1.2927	-7.7088***	-1.3187	-7.6031***	-1.3395	-7.7076***
LD	-0.5072	-8.5875***	-0.8952	-7.1057***	-0.5063	-8.5106***
LE	-0.6676	-6.1753***	-0.6964	-5.2563***	-0.7140	-6.2548***

The study utilized the ARDL-bound testing procedure for a comprehensive and concise long-run cointegration within the variables (Table 3). The result shows the coexistence of accumulation, which indicates the long-term relationship between the variables. This is supported by the F-statistic (26.14) for this sample, which exceeds the critical values.

Table 3 The Outcome of the ARDL Bounds Test

Test statistic	Value	Significance	I(0)	I(1)
F-statistic	26.141	At 10%	1.99	2.94
K	4	At 5%	2.27	3.28
		At 2.0%	2.55	3.61
		At 1%	2.88	3.99

Table 4 displays the estimated findings of the long- and short-run results obtained through the ARDL approach. The outcome suggests that over time, there is a notable increase in CO_2 emissions due to agriculture and trade openness, whereas energy efficiency and GDP have the opposite effect, leading to a decrease in CO_2 emissions. Utilizing renewable energy sources in the immediate future has been shown to lower emissions, while factors such as GDP, agriculture, Trade openness and professional expertise play a crucial role in the rise of CO_2 emissions. The estimated coefficients for agriculture show a clear positive relationship with CO_2 emissions. This implies that a 1% increase in agriculture productivity culminates in a 0.42% rise in CO_2 emissions in the long run, and a 0.15% increase in the short run. One possible reason for this could be the continued dependence on fossil fuel energy in Nigeria's agricultural sector. The agricultural sector heavily relies on fossil fuels for various processes such includes thawing, watering, warmth, wrapping, water delivery, along with conveyance of crop-related merchandise. Unfortunately, the transportation of petroleum and gas leads to the increased emissions of CO_2. It appears that the promotion of the agricultural sector in India does not lead to improvements in the field of energy optimization or the implementation of sources of clean energy. Considering the significant magnitude of the farming industry and the widespread use of fossil fuels in Nigeria, it can reasonably conclude that the expansion of farming processes brings about a rapid increase in CO_2 emissions. Preceding empirical results support the foregoing conclusion Emir et al [21]. It has been stated that farming leads to an upsurge in CO_2 emissions. On the other hand, these findings challenge other scientific evidence that argue farming diminishes CO_2 emissions Raza et al [22].

Table 4 ARDL Long and Short-Run Results

Variables	Long-run			Short-run		
	Coefficient	t-Statistic	p-value	Coefficient	t-Statistic	p-value
LB	0.4192**	3.3519	0.0243	0.1519**	3.6397	0.0342
LC	-1.7624***	-5.1815	0.0001	-1.037***	-5.8351	0.0000
LD	-0.0236*	-1.8467	0.0693	1.9819***	3.6085	0.0002
LE	0.1983**	2.5014	0.0188	0.6061***	4.9516	0.0009
A	15.720	1.8319	0.1047	-	-	-
ECM (-1)	-	-	-	-0.5417***	-3.3119	0.0000 R
Adjusted		0.9883				
R^2		0.9821				

***P<0.01, **p<0.05, *p<0.1

The findings indicate that a 1% increase in non-renewable power consumption increases CO_2 emission by 1.76% in the long run whereas 1.04% in the short-run. In this context, it is imperative to prioritize the embrace of renewable power sources in order to effectively reduce CO_2 emissions in Nigeria. Prior results from experiments further support this outcome Anyanwu et al and Wang et al. The shift from fossil fuels to clean energy uses aids in reducing the negative impact on the Nigeria environment. Non-renewable energy uses will increase environmental degradation through CO_2 emissions.

The estimated coefficient of GDP shows that in the short-run, a 1% rise in GDP boosts CO_2 emissions by 1.98%. However, in the long run, the negative coefficient indicates that a 1% increase in GDP would increase CO_2 emissions by 0.02%. Our research discovered an association among economic growth and CO_2 emissions, following an inverse U shape pattern. This indicates that the association among revenue growth and CO_2 emissions in Nigeria can be reversed as the country's GDP continues to rise. The outcomes support the EKC hypothesis. This result was reinforced by previous empirical findings Uche, Das & Bera [23] that revealed an inverse U shape relationship between economic growth and CO_2 emission. Economic growth is measured by the GDP. Increase in the GDP, or economic growth, assessments in a spike in emissions of CO_2 in Nigeria. As economic growth increases, several demands related to economic growth also increase. To meet the direct and indirect increasing demand of people, waste and garbage are produced more. Fossil fuel burning also increases in the industry, including manufacturing and transportation, to support the increasing economic growth. This suggests that environmental risk should be minimized by adopting environmentally friendly technology Nigerian industry as well as shifting from fossil fuel energy production to renewable energy in Nigeria. Economic growth should be supported through environmentally friendly activities that will reduce CO_2 and lead to sustainable development. Nigeria competitive capacity through sustainable economic development will increase globally.

In terms of trade openness, the positively significant coefficients indicate that a 1% increase in trade openness increases CO_2 emission by 0.20% (long-run) and 0.61% (short run). The results confirmed the pollution haven hypothesis in Nigeria. Prior findings from experiments further supported this outcome Emir, Udemba & Philip [21]. When the degree of trade increases in a nation, it means production as well as consumption increases, which is supported by the higher use of natural resources and enhanced pollution. Industries usually stress their priority on production efficiency over environmental sustainability. When industries prioritize production, it results in environmental degradation through air pollution, water pollution, deforestation, and habitual destruction in India. Moreover, expanded trade resulted in an upsurge in the utilization of transportation that required the use of fossil fuels, thereby increasing CO_2 emissions. Nigeria trade openness may have some economic benefits, but in other to achieve long lasting sustainable development, it required friendly environmentally activities which can be encourage through the use of modern technology.

ECM's estimate of the significance level at the 1% level, with a negative trend, indicates that the deviation from the long-term balance this year will be corrected at a rate of 54% through various channel such as agricultural industry, trade openness, economic development and green power. In addition, the values of R2 and adjusted R2 for the long-term estimation are 0.9883 and 0.9821, respectively, indicating a high level of accuracy for the statistical regression model. It can be seen that the independent factors account for 98% of the variance in the change in the dependent variable. Model reliability was implemented using cumulative sum analysis (CUSUM) and summation of square (CUSUMSQ) based on residual regression (Figure 2). The estimated coefficients of the ARDL model are considered stable because the statistical line falls within the critical limits at the 5% significance level.

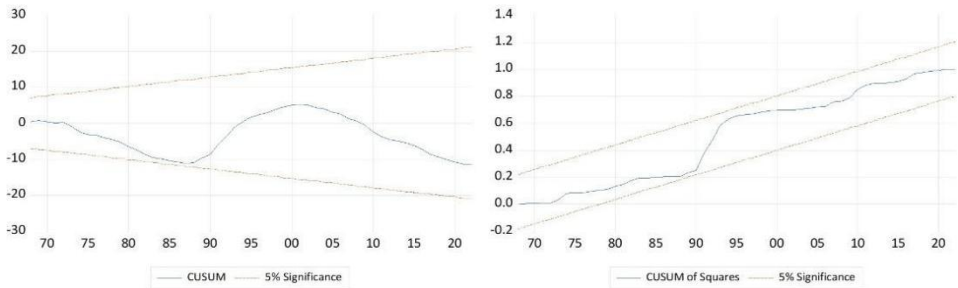

Figure 2 The Results of CUSUM and CUSUMSQ Tests

We went further in conducted additional experimental tests to validate the ARDL model used in this study. The diagnostic tests in Table 5 include the serial correlation test in addition to the univariate test. Analytical analysis shows that the residuals follow a normal distribution and that the model is reasonably well defined. In addition, there is no evidence of serial correlation and heteroskedasticity.

Table 5 The Results of Diagnostic Tests

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	2.2437	0.3282	Normal residual distribution
Ramsey RESET test	0.9843	0.3472	The model is properly specified
Breusch-Godfrey LM test	1.8445	0.1739	No serial correlation exists
Breusch-Pagan-Godfrey test	0.7698	0.2794	No heteroscedasticity exists

6 CONCLUSIONS AND RECOMMENDATION

Nigerian economy is significantly driven by the agriculture and trade sectors, which play a crucial role to encourage the expansion of the marketplace. On the other hand, there is a dearth of scientific and philosophical information about the influence that farming, the utilization of clean energy and trade accessibility has on carbon dioxide emissions. Additionally, the association among independent variables and CO_2 emissions has yielded mixed theoretical and empirical findings. This study addresses to what extent carbon emissions are affected by agricultural practices, economic expansion, and trade liberalization from 1970 to 2022. This research is built on a solid analytical framework provided by the scientific foundation underlying the Kuznets curves of runoff and pollution. We used ARDL as the diagnostic method. Cointegration tests confirm the existence of correlation between the variables in India. Furthermore, when looking at long-term data, it is clear that GDP and the use of renewable energy are associated with lower CO_2 emissions. Conversely, the agricultural sector and global events have increased CO_2 emissions. On the other hand, short-term analyses show that GDP, agriculture and international trade contribute to increasing CO_2 emissions, while renewable energy is effective in reducing them. The negative impact of agriculture, cross-border trade and economic expansion on the environment reflects the lack of environmental justice and the role of enhanced trade to contribute to the decline of the environment. The use of fossil fuels in agriculture leads to a significant increase in CO_2 emissions. Renewable energy is important for the agricultural industry. It is strongly recommended to implement solar energy systems, onshore wind power, efficient irrigation systems, project training and financial support in the agricultural sector to promote environmental sustainability. Government and those in power should celebrate the success of the transition from fossil fuels to clean energy. This can be done by increasing funding for research and development, and strengthening laws and regulations. To reduce the effects of trade opening and the impact of economic growth on the environment, it is necessary to promote the development of environmental industries that can transfer technical knowledge through all sectors of the economy. In order to facilitate an effective and efficient process of knowledge exchange, it is very important for recipient countries to increase their ability to absorb new information.

COMPETING INTERESTS

The author have no relevant financial or non-financial interests to disclose.

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