Journal of International Environmental Application and Science *ISSN-2636-7661*

Publishing Office: *Department of Industrial Engineering, Engineering Faculty, King Abdulaziz University, P.O. Box: 80204 Jeddah 21589 Saudi Arabia*; Tel: +966 533 107628; Fax: +966 2 2486695.

Frequency: Journal of International Environmental Application and Science (ISSN 2636-7661) is published 4 times per year.

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Ergas SJ, Schroeder E, Chang D, Scow K, (1994) Spatial distributions of microbial populations in biofilters. In: Proceedings of the *78th Annual Meeting and Exhibition of the Air and Waste Management Association*, pp. 19-24, Cincinnati, OH.

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J. Int. Environ. Appl. and Sci., Vol. 20 No. 3 pp: 158-192 September 2025

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J. Int. Environmental Application and Science, Vol. 20(3): 158-169 (2025)
Research Paper

Analysis of the Physico-Chemical and Microbiological Water Quality in the Protected Area of the Buna River, Shkoder Albania

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Received June 17, 2025; Accepted July 26, 2025

Abstract: Protected freshwater areas can be extremely important for preserving their biodiversity, as well as providing ecosystem services around them. Globally, there is an increasing need to reduce threats to freshwater resources in protected areas, as well as to recognise the associated issues and manage them to safeguard these resources. This study aimed to evaluate the physico-chemical and microbiological quality along the Buna River in the Shkodra region of Albania. The Buna River flows through both urban and rural areas of great interest in northern Albania. The surrounding area includes a mosaic of natural habitats with rich biodiversity and serves as an important destination for nature-based tourism. The assessment of Buna River's quality was carried out through a detailed analysis of the previously missing correlation between physico-chemical and microbiological parameters. This study aimed to take a new approach by analysing the correlation between these two aspects of water quality in this ecologically and touristically important protected area. Sampling in the Buna River was conducted monthly from June 2023 to September 2024 at six stations, resulting in a total of 600 analyses. For the evaluation of the correlation between the data obtained from the study areas, the statistical program SPSS was used, specifically the Pearson correlation. The study results provide a detailed overview of the state of the water and the impacts stemming from human activities such as pollution, agriculture, and tourism. The findings confirm that the majority of the stations were highly polluted in terms of microbiological and physico-chemical parameters. These data provide important recommendations for taking necessary measures and maintaining the ecological balance of this protected area of national and international importance.

Keywords: *Buna river, microbiological quality, physico-chemical analysis, protected areas*

Introduction

Shkodra region is the main destination for visitors to protected areas in Albania, accounting for 26% of total visitors during the first 8 months of 2024, with an increase of 2% compared to the same period in 2023, according to statistics from the Ministry of Tourism and Environment. The Blue Eye and Lake Shkodra are the most visited attractions, while the Buna River - Velipojë is the most frequented landscape among protected landscapes. Data on visitor numbers in natural reserves and parks show that during August 2023, the Blue Eye (34%) had the highest number of visitors, followed by Lake Shkodra (21%). The number of visitors to Albania's protected landscapes shows that the Buna river -Velipojë (56%) has been the destination of greatest interest, followed by Lake Pogradec (24%). In natural tourism, Shkodra leads the national ranking. (Ministry of Tourism and Environment 2024)

The Shkodra region is known for its biodiversity and unique natural landscapes, where the Buna River and Lake Shkodra are protected areas of international interest. The Buna River is a Category V protected landscape (IUCN), along with the Franz Josef Delta and Island, the

Velipoja Reserve, the Viluni Lagoon, the Baks-Rrjoll Beach, the Domni and the surrounding territories (Republic of Albania 2005). The Buna River is a short 44 km river with a natural delta, part of the EMERALD and IBA networks, and a habitat for many species of migratory fish and birds. Lake Shkodra represents the largest aquatic ecosystem and is the only area in Albania included in the RAMSAR Convention for habitats of ecological importance. It carries rare, endemic and threatened

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species, enriching the natural and environmental values of the region National (Environmental Agency. Protected Areas 2020)

Lake Shkodra, due to its high biodiversity and its ecological function as an important habitat for waterfowl and several other species of flora and fauna, was included on February 2, 2006, in the list of areas of international importance protected by the RAMSAR Convention (Regional Environmental Center Albania/RAMSAR. 2010)

Surface waters are an important part of the natural ecosystem. However, human activities are increasingly threatening these waters with pollution, which mainly comes from human activities themselves. These impacts jeopardise the ecological quality and natural function of water bodies (UNEP 2021). The impact of human activities, challenges and threats to protected areas are numerous, starting from pollution; the discharge of untreated wastewater, the use of chemical fertilizers such as pesticides in rural areas and their discharge into rivers, land use by cutting down trees without criteria, climate change and indiscriminate hunting and fishing during the breeding season in fauna. Sustainable management of water resources requires regular monitoring to identify anthropogenic impacts and protect aquatic biodiversity (EEA 2022)

The importance of physicochemical and microbiological analyses is essential for identifying sources of pollution and assessing the ecological status and sustainable conservation of water resources. Through physicochemical analyses of the Buna River, it is possible to identify sources of pollution mainly resulting from human activities. Parameters such as pH, nitrites, nitrates and phosphates play an important role in identifying urban discharges and agricultural activities such as the use of fertilisers and pesticides, as well as the discharge of untreated wastewater (WHO 2016; Małgorzata et al.,2024)

These indicators serve as indicators for assessing the risks of the aquatic ecosystem in protected areas. At the same time, the analysis of microbiological parameters such as faecal coliforms and fecal streptococcus constitutes a direct indicator of the risk of the occurrence and spread of infectious diseases. These indicators are important in recreational areas. The presence of these bacteria is also linked to the impact on biodiversity and aquatic ecosystems (EPA 2021; WHO 2023)

The purpose of the study of the Buna River is essential and important for assessing the ecological status of the most important waterway in Albania, as it directly affects the conservation of biodiversity and the ecological balance of protected areas. The detailed analysis of the Buna River through the assessment of microbiological, physical and chemical parameters provides important data that can contribute to improving water management. The data obtained are of particular importance for maintaining the quality of the aquatic ecosystem and the environment, ensuring optimal conditions for the survival and well-being of biodiversity in protected areas. The relationship between physical, chemical and microbiological indicators is a key factor for assessing the self-purification capacity of water bodies and their impact on aquatic life.

Research Hypothesis

Starting from the objectives of this study and based on the analysis of the theoretical and practical context, the research hypothesis has been formulated as follows: Considering the anthropogenic impacts on the aquatic ecosystem of the Buna river, we assume that there is a significant correlation between the physicochemical parameters and microbiological indicators of water, which varies according to the intensity of pollution and human activity at the monitoring stations, reflecting the ecological state of the river.

Materials and Methods

Location and study period

The study was conducted in the Shkodra region, Albania, during the period June 2023- September 2024. A total of six stations were included along the Buna River watershed, where microbiological, physical and chemical parameters were analysed for each of them. Samples were taken once a month for one year, covering all four seasons. Sample selection was carried out along the entire. Buna river, focusing mainly on protected areas with ecological and socio-economic importance that are frequented by the public for recreational water activities such as beaching, bathing, fishing, nature walks and animal observation. These areas also represent key areas for rural development and for the conservation of flora and fauna. At station S1-the plant is located near the area where the Buna river originates from Lake Shkodra and also near the water treatment plant. The study of this station can provide us with valuable information regarding the efficiency of the operation of the wastewater treatment plant. At station S2- the bridge Buna is an overpopulated area with numerous buildings and various functions, such as local businesses around, and above all, we have the discharge of wastewater from the city of Shkodra. At station S3-the confluence of the Buna River with the Drin River, where the interaction between the waters of the two rivers and their impact on water quality parameters will be studied. At station S4- Darragjat is characterized as a rural area inhabited by the population, where they are mainly engaged in agricultural activities and carry out various activities near the sources of the Buna River. At station S5- Reç i Ri is like that observed at station S4. At station S6- Pulaj was selected due to its position near the Buna delta as the last point before flowing into the sea, which serves as a spatial summary of the entire Buna River line from the beginning to the end. During the monitoring at six stations, 144 microbiological parameters, 288 physical parameters and 168 chemical parameters were assessed for each station. A complete analysis was performed for each station, including all these parameters, resulting in a total of 600 analyses.

Table 1. Geographic coordinates of the Buna River sampling stations

Code of stations	Sampling stations	Geographical coordinates
S1	Buna River-Plant	42°03'21.2"N 19°28'18.2"E
S2	Buna River-Buna Bridge	42°02'55.8"N 19°29'29.2"E
S3	The confluence of the Drin and Buna rivers	42°01'37.5"N 19°28'19.4"E
S4	Buna River-Darragjat	42°00'06.1"N 19°27'23.6"E
S5	Buna River-Reç i Ri	41°54'55.3"N 19°21'27.9"E
S6	Buna River-Pulaj	41°52'27.8"N 19°22'33.7"E

Water Sampling

Two samples were collected simultaneously—one for microbiological analysis and the other for physico-chemical analysis. The samples for microbiological analysis were placed in sterile glass bottles, and each bottle was labelled with the sampling date, sample number, location, and geographic coordinates. (ISO 19458: 2006). Samples intended for physico-chemical parameter analysis were placed in plastic bottles labelled with the sampling date, sample number, location, and geographic coordinates (ISO 5667–3:2024)

Sample Transport

The water samples were preserved and transported under controlled temperature conditions using a thermobox and were analysed on the same day (within 24 hours) from the time of collection from the Buna River (ISO 5667–3:2024)

Methods used for Physical Parameters

The analysis of the Buna River for physical parameters included a total of 288 analyses. Temperature as a physical parameter was studied according to the APHA 2550 A method, using the Aqualytic Al 15 (APHA 1998).

Turbidity was measured using the TURB 430 IR-WTW turbidimeter, following the ISO procedure. (ISO 7027-1:2016).

Electrical conductivity was measured using the Aqualytic Al 15 instrument. (EN 27888:2001)

Total dissolved solids were analysed in accordance with the APHA 2540 C method, gravimetric instrument (APHA 2540 C).

Methods used for chemical parameters

The analysis of the Buna River for chemical parameters included a total of 168 analyses. The chemical parameters evaluated were pH, ammonium, nitrites, nitrates, and phosphates.

The pH value was measured directly in the field through "in situ" measurement using the AQUALYTIC AL 15 device (ISO 10523- 2008)

Ammonium levels were measured using the spectrophotometer DR 1900 following the ISO procedure (ISO 7150-1:1984). Nitrites levels were measured spectrophotometer DR 1900 (EPA- NERL :354.1 method 8507)

Nitrates were measured using the spectrophotometer DR 1900 following the ISO procedure. (ISO 7890-1:1986) and phosphates were determined using the DR 1900 Spectrophotometer (APHA 4500-P-E method 8048).

Methods used for microbiological parameters

The microbiological analysis of the Buna River included a total of 144 analyses. The microbiological parameters assessed were *Faecal coliforms* and *Faecal streptococci*. Identification and enumeration of these parameters were performed using the Most Probable Number (MPN) method. The MPN method was applied in three stages: presumptive test, confirmatory test, and completed test (APHA 1998)

For the analysis of *Faecal coliforms*: In the presumptive test, LB medium was use. (Bakare *et al.,* 2003). In the confirmatory test, ECB medium was applied (APHA 1998). For the completed test, EMB agar was used. (BAM Chapter 4., 2010). For the analysis of *Faecal streptococci*: In the presumptive test, Azide Dextrose Broth was used. (Mallmann *et al.,* 1950). In the confirmatory test, Ethyl Violet Azide Broth (EVA) was used. (Litsky et al., 1955). The enumeration of faecal coliforms and faecal streptococci was done using the statistical MPN index table (CNR-IRSA 2003)

Results and Discussions

By statistical processing with SPSS, Pearson correlation, we have analysed the correlation of physical, chemical and microbiological parameters as they influence the pollution of the Buna river in the six analysed stations, also using Excel, the graphic models for the parameters studied in detail have been presented.

In Figure 1, station S1 resulted of excellent quality, while the other five stations along the entire length of the Buna River are outside the norms, based on the new Directive 2006/7EC, classified as poor quality for the presence of *Fecal coliforms*, while for *Fecal streptococci* all analysed stations are within the norms and are classified as excellent quality. The ratio between the two microbiological parameters shows that the source of pollution is mainly from human activity such as the discharge of untreated wastewater from the city of Shkodra that flows directly into the river and waste deposited near the river.

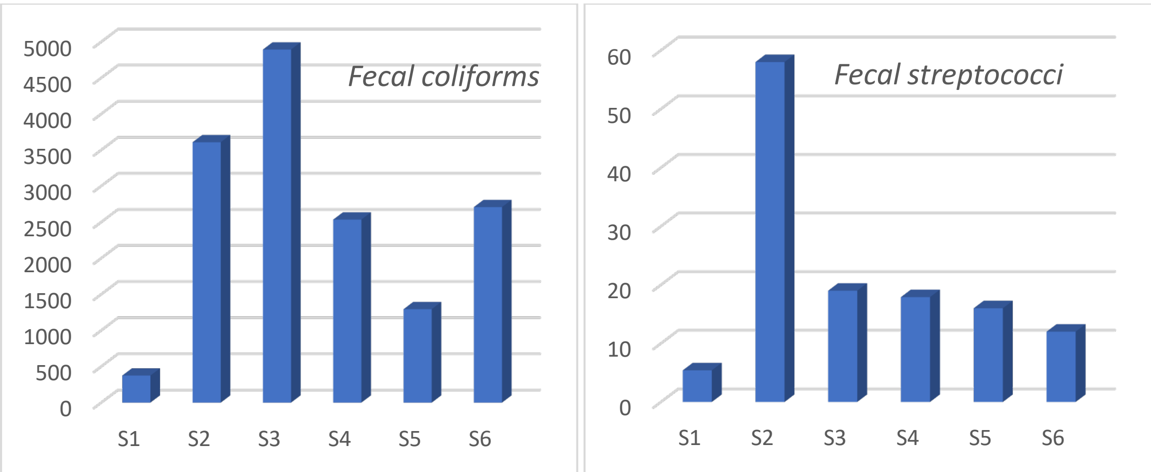

Figure 1. Distribution of *Faecal coliforms* and *Faecal streptococci* values according to stations

Figure 2 illustrates the classification of waters according to the criteria set by NIVA for water quality for phosphates, station S1 is classified in class III average quality, while station S2 and S4 are classified in class V very bad, while other stations such as S3 and S5 are classified in class I very good, while station S6 is classified in class II good. The high value of phosphate in S2 comes because of the discharge of untreated wastewater from the city of Shkodra, while in S5 it is an area where agriculture is developed, and the indiscriminate use of chemical fertilizers influences pollution. From the above, the differences in the classification of chemical parameters between stations highlight the crucial role of local pollution sources, as well as the importance of wastewater treatment for maintaining surface water quality. According to NIVA for chemical parameters for NO_3, station S1 is classified in class I very good, while the other five stations are classified in class II good quality.

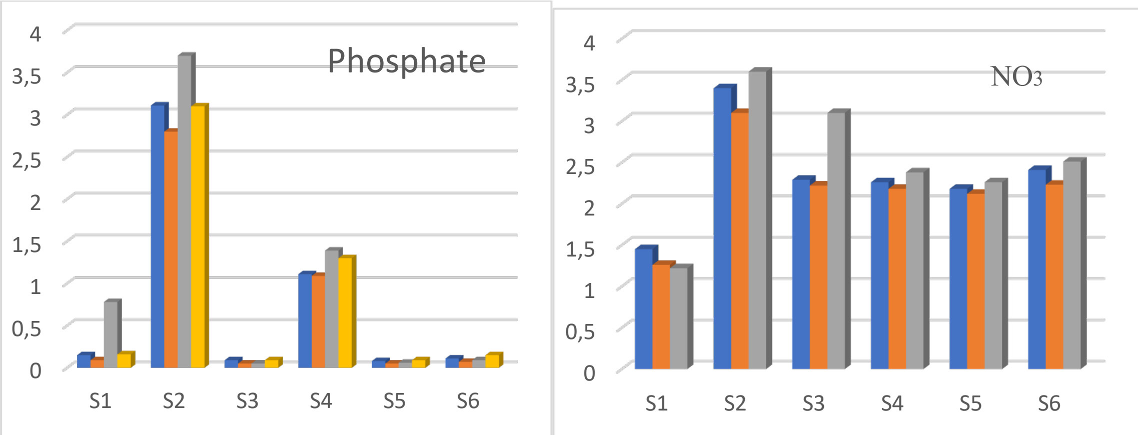

Figure 2. Distribution of phosphate and nitrate values according to stations

Figure 3 illustrates the classification of waters according to the criteria set by NIVA for ammonium, where S2 is classified as class III average, while the other stations are classified as class I very good. Around station S2, untreated city wastewater is mainly discharged, which influences the classification of ammonium. According to NIVA, for the chemical parameter NO2, all stations are classified as class I very good.

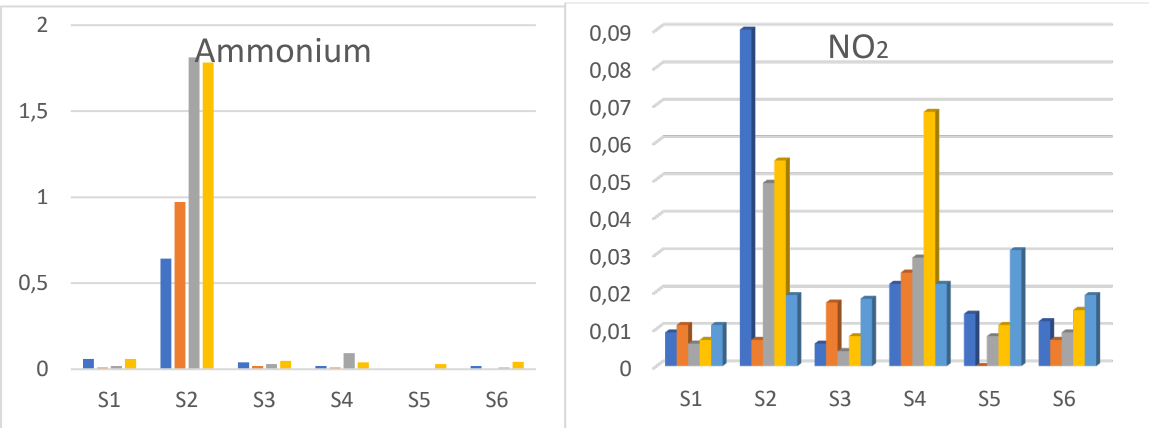

Figure 3. Distribution of ammonium and nitrite values according to stations

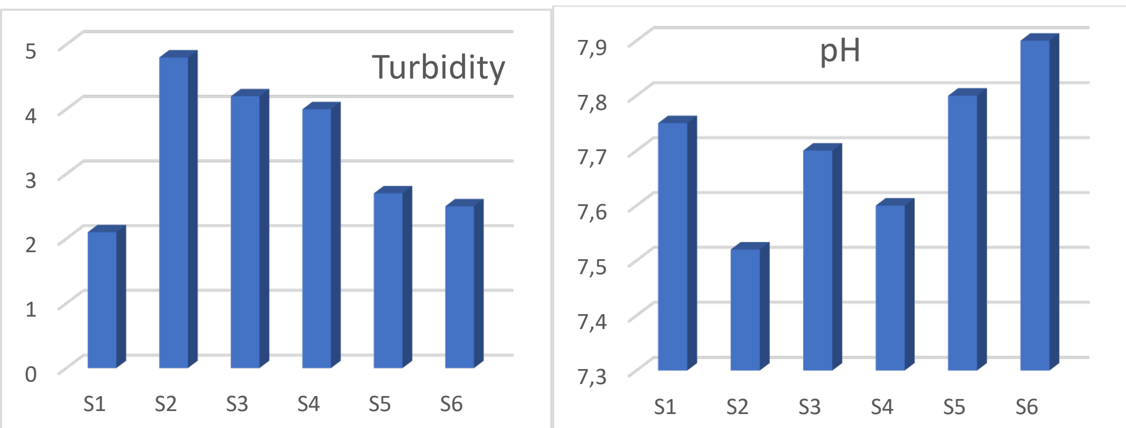

Figure 4. Distribution of turbidity and pH values according to stations

Figure 4 illustrates the classification of waters according to the criteria set by NIVA for turbidity; all stations are classified in class V very bad. High turbidity is an indicator that shows that in these studied stations there is pollution or degradation of water quality. At station S6, a slightly higher increase in pH value is observed than in other stations, but it is within the established norms. High turbidity values highlight an urgent need for protective measures and rehabilitation interventions, while pH values indicate a relative stability of chemical parameters, despite small local deviations.

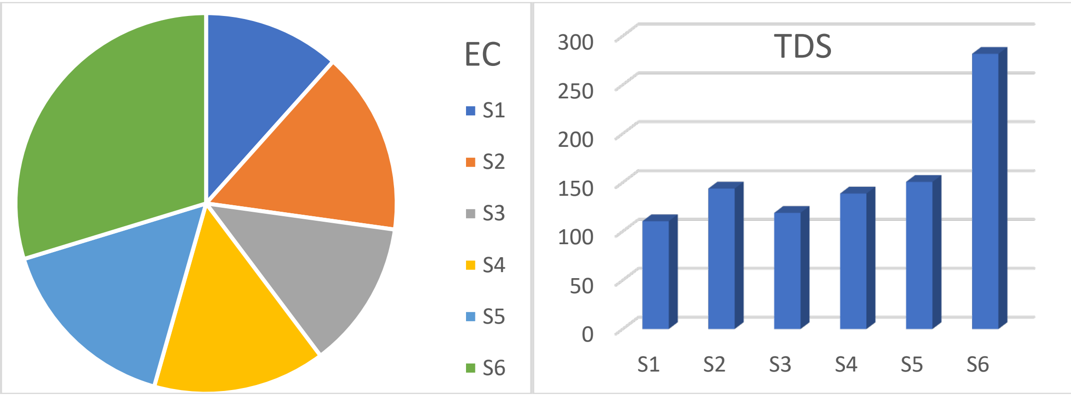

Figure 5. Distribution of electrical conductivity and TDS values according to stations

In Figure 5 we have illustrated the electrical conductivity and TDS where both stations S4 and S6 have higher values than the other stations as a result of the position where S1 we have pollution as a result of the discharge of untreated wastewater, while at S6 we have pollution mainly from agriculture where waste is discharged directly into rivers.

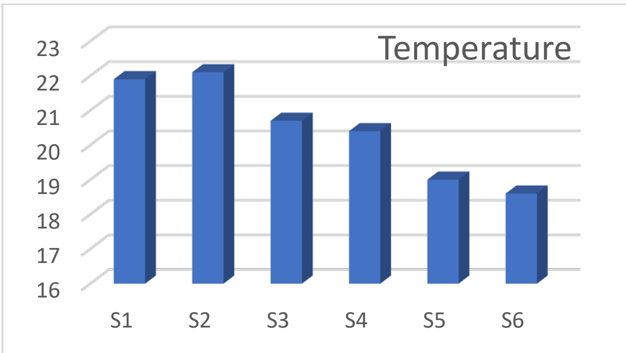

Figure 6. Distribution of temperature values according to stations

The lowest temperature of the studied stations is station S6. Using SPSS, we used Pearson's correlation to observe how the pollution of the Buna River along its line influences the parameters with each other. The results of the correlation analysis show that there is a perfect positive and significant correlation between EC and TDS a very strong relationship between each other. (r=1).

Table 2. Table of correlation of Buna River – Plant of electrical conductivity with TDS

Correlations		Buna River-Plant EC	Buna River-Plant TDS
Buna River-Plant EC	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		0.000
	N	15	15
Buna River-Plant TDS	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	0.000	
	N	15	15
**. Correlation is significant at the 0.01 level (2-tailed).			

At the Bune Bridge station, a negative correlation is observed between temperature and EC (r= -0.794) and temperature with TDS (r= -0.510). EC with TDS positive correlation, a very high relationship between each other (r= -0.8). The pH parameter with NO_2 has a very high positive correlation with each other (r= -0.884), while the pH parameter with fecal coliforms has a negative correlation (r= -0.625)

Table 3. Table of correlation of Buna bridge

Correlations		Buna Bridge Temp	Buna Bridge pH	Buna Bridge EC	Buna Bridge TDS	Buna Bridge NO2	Buna Bridge FC
Buna Bridge Temp	Pearson Correlation	1	0.098	-0.794**	-0.510	0.318	0.017
	Sig. (2-tailed)		0.729	0.000	0.052	0.603	0.953
	N	15	15	15	15	5	15
Buna Bridge pH	Pearson Correlation	0.098	1	-0.239	0.049	0.884*	-0.625*
	Sig. (2-tailed)	0.729		0.391	0.862	0.046	0.013
	N	15	15	15	15	5	15
Buna Bridge EC	Pearson Correlation	-0.794**	-0.239	1	0.800**	-0.158	0.158
	Sig. (2-tailed)	.000	.391		0.000	0.800	0.574
	N	15	15	15	15	5	15
Buna Bridge TDS	Pearson Correlation	-0.510	0.049	0.800**	1	-0.158	0.188
	Sig. (2-tailed)	0.052	0.862	0.000		0.800	0.503
	N	15	15	15	15	5	15
Buna Bridge NO2	Pearson Correlation	0.318	0.884*	-0.158	-0.158	1	0.825
	Sig. (2-tailed)	0.603	0.046	0.800	0.800		0.086
	N	5	5	5	5	5	5
Buna Bridge FC	Pearson Correlation	0.017	-0.625*	0.158	0.188	0.825	1
	Sig. (2-tailed)	0.953	0.013	0.574	0.503	0.086	
	N	15	15	15	15	5	15

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

At the station of the studied point where the Buna river joins the Drini river, we have a negative correlation between temperature values and NO_3 (r= - -1) but for the TDS and EC parameters, we have a very high positive correlation (r= -0.998), EC with streptococcus has a significant real positive correlation (r= 0.5), PO_4 and coliforms have a very high positive correlation (r= 0.984), TDS and streptococcus have a significant real positive correlation (r= 0.563)

Table 4. Table of correlation of Drin and Buna river

Correlations		The confluence of the Drin and Buna rivers. TDS	The confluence of the Drin and Buna rivers. PO4	The confluence of the Drin and Buna river. FC	The confluence of the Drin and Buna rivers. FS	The confluence of the Drin and Buna rivers. NO3
The confluence of the Drin and Buna rivers. Temp	Pearson Correlation	-0.455	-0.456	0.237	-0.365	-1.000*
	Sig. (2-tailed)	0.088	0.544	0.395	0.180	0.012
	N	15	4	15	15	3
The confluence of the Drin and Buna rivers.EC	Pearson Correlation	0.998**	0.421	-0.126	0.533*	0.938
	Sig. (2-tailed)	0.000	0.579	0.654	0.041	0.225
	N	15	4	15	15	3
The confluence of the Drin and Buna rivers.TDS	Pearson Correlation	1	0.421	-0.115	0.563*	0.938
	Sig. (2-tailed)		0.579	0.682	0.029	0.225
	N	15	4	15	15	3
The confluence of the Drin and Buna rivers.PO4	Pearson Correlation	0.421	1	0.984*	0.311	-0.437
	Sig. (2-tailed)	0.579		0.016	0.689	0.712
	N	4	4	4	4	3

The confluence of the Drin and Buna rivers. FC	Pearson Correlation	-0.115	0.984*	1	-0.014	-0.475
	Sig. (2-tailed)	0.682	0.016		0.960	0.685
	N	15	4	15	15	3
The confluence of the Drin and Buna rivers. FS	Pearson Correlation	0.563*	0.311	-0.014	1	0.726
	Sig. (2-tailed)	0.029	0.689	0.960		0.483
	N	15	4	15	15	3
The confluence of the Drin and Buna rivers. NO_3	Pearson Correlation	0.938	-0.437	-0.475	0.726	1
	Sig. (2-tailed)	0.225	0.712	0.685	0.483	
	N	3	3	3	3	3

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2- tailed)

At the Darragjat station, temperature along with TDS and EC, pH with coliforms and EC with coliforms have a negative correlation, while EC with TDS has a positive perfect correlation with each other (r= 1). EC with fecal streptococcus (r= 0.551) and TDS with fecal streptococcus (r=0.551) have a real positive correlation, while TDS with coliforms have a negative correlation (r= - 0.522).

Table 5. Table of correlation of Darragjat station

Correlations		DarragjatTemp	Darragjat pH	Darragjat EC	Darragjat TDS	Darragjat FC	Darragjat FS
Darragjat. Temp	Pearson Correlation	1	0.155	-0.743**	-0.743**	0.405	-0.417
	Sig. (2-tailed)		0.582	0.002	0.002	0.135	0.122
	N	15	15	15	15	15	15
Darragjat pH	Pearson Correlation	0.155	1	-0.008	-0.008	-0.576*	0.065
	Sig. (2-tailed)	0.582		0.976	0.976	0.025	0.817
	N	15	15	15	15	15	15
Darragjat EC	Pearson Correlation	-0.743**	-0.008	1	1.000**	-0.522*	0.551*
	Sig. (2-tailed)	0.002	0.976		0.000	0.046	0.033
	N	15	15	15	15	15	15
Darragjat TDS	Pearson Correlation	-0.743**	-0.008	1.000**	1	-0.522*	0.551*
	Sig. (2-tailed)	0.002	0.976	0.000		0.046	0.033
	N	15	15	15	15	15	15
Darragjat FC	Pearson Correlation	0.405	-0.576*	-0.522*	-0.522*	1	-0.251
	Sig. (2-tailed)	0.135	0.025	0.046	0.046		0.367
	N	15	15	15	15	15	15
Darragjat FS	Pearson Correlation	-0.417	0.065	0.551*	0.551*	-0.251	1
	Sig. (2-tailed)	0.122	0.817	0.033	0.033	0.367	
	N	15	15	15	15	15	15

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

At the Reç i Ri station, temperature along with TDS, EC, NO2, coliforms, ammonium and coliforms have a negative correlation with each other. While the EC parameter in relation to TDS has a perfect positive correlation (r= 1), EC with coliforms has a real positive correlation (r= 0.662) and EC with streptococcus has a real positive correlation with each other (r= 0.568). TDS with coliforms and streptococcus has a real positive correlation (r= 0.568).

Table 6. Table of correlation of Reç i Ri station.

Correlations		Reç Temp	Reç EC	Reç TDS	Reç NH4	Reç FC	Reç FS	Reç NO2
Reç Temp	Pearson Correlation	1	-0.535*	-0.535*	-0.960*	-0.569*	0.055	-0.912*
	Sig. (2-tailed)		0.040	0.040	0.040	0.027	0.847	0.031
	N	15	15	15	4	15	15	5
Reç EC	Pearson Correlation	-0.535*	1	1.000**	0.641	0.662**	0.568*	0.276
	Sig. (2-tailed)	0.040		0.000	0.359	0.007	0.027	0.653
	N	15	15	15	4	15	15	5
Reç TDS	Pearson Correlation	-0.535*	1.000**	1	0.641	0.662**	0.568*	0.276
	Sig. (2-tailed)	0.040	0.000		0.359	0.007	0.027	0.653
	N	15	15	15	4	15	15	5
Reç NH4	Pearson Correlation	-0.960*	0.641	0.641	1	.c	0.333	0.305
	Sig. (2-tailed)	0.040	0.359	0.359		0.000	0.667	0.695
	N	4	4	4	4	4	4	4
Reç FC	Pearson Correlation	-0.569*	0.662**	0.662**	.c	1	0.278	.c
	Sig. (2-tailed)	0.027	0.007	0.007	0.000		0.315	0.000
	N	15	15	15	4	15	15	5
Reç FS	Pearson Correlation	0.055	0.568*	0.568*	0.333	0.278	1	-0.265
	Sig. (2-tailed)	0.847	0.027	0.027	0.667	0.315		0.667
	N	15	15	15	4	15	15	5
Reç NO2	Pearson Correlation	-0.912*	0.276	0.276	0.305	.c	-0.265	1
	Sig. (2-tailed)	0.031	0.653	0.653	0.695	0.000	0.667	
	N	5	5	5	4	5	5	5

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

At the Pulaj station, the temperature parameter with turbidity has a negative correlation (r= -0.547) as well as temperature with NO2 (r= -0.947). The pH values with NH4 and pH with PO4 have a negative correlation. EC with coliforms and TDS with coliforms have a significant positive correlation (r= 0.537). NO_2 with NH4 (r= 0.982) and NO_2 with PO_4 (r= 0.990) and NH4 with PO4 (r= 0.999) have a very high positive correlation. Faecal coliforms and faecal streptococci have a significant positive correlation (r= 0.520).

Correlation data at the Pulaj station indicate significant pollution from nutrients and pathogenic microorganisms, closely linked to anthropogenic impact. Very strong positive correlations between ammonia, nitrites and phosphates suggest a unified source of pollution, while positive correlations between microbiological and chemical parameters highlight the complex interaction that affects the deterioration of water quality. These results indicate the need for protective measures and continuous monitoring, as well as for more effective treatment of polluted waters to protect the coastal area from further pollution.

Table 7. Table of correlation of Pulaj station.

		Pulaj Turb	Pulaj NO_2^-	Pulaj NH_4	Pulaj NO_3^-	Pulaj PO_4^-	Pulaj FC	Pulaj FS
Pulaj Temp	Pearson Correlation	-.547*	-0.947*	-0.864	0.091	-0.870	0.188	-0.434
	Sig. (2-tailed)	0.035	0.015	0.136	0.942	0.130	0.503	0.106
	N	15	5	4	3	4	15	15
Pulaj pH	Pearson Correlation	-0.271	-0.792	-0.973*	-0.705	-0.960*	0.352	-0.027
	Sig. (2-tailed	0.329	0.110	0.027	0.502	0.040	0.198	0.924
	N	15	5	4	3	4	15	15
Pulaj Turbidity	Pearson Correlation	1	0.644	0.612	0.419	0.582	-0.462	-0.148
	Sig. (2-tailed		0.241	0.388	0.725	0.418	0.083	0.599
	N	15	5	4	3	4	15	15
Pulaj EC	Pearson Correlation	-0.310	-0.854	-0.877	0.994	-0.852	0.537*	0.101
	Sig. (2-tailed	0.261	0.065	0.123	0.067	0.148	0.039	0.720
	N	15	5	4	3	4	15	15
	Pearson Correlation	-0.310	-0.854	-0.877	0.994	-0.852	0.537*	0.101

Pulaj TDS	Sig. (2-tailed	0.261	0.065	0.123	0.067	0.148	0.039	0.720
	N	15	5	4	3	4	15	15
Pulaj NO2	Pearson Correlation	0.644	1	0.982*	0.541	0.990*	-0.075	-0.113
	Sig. (2-tailed	0.241		0.018	0.636	0.010	0.905	0.857
	N	5	5	4	3	4	5	5
Pulaj NH4	Pearson Correlation	0.612	0.982*	1	0.634	0.999**	-0.036	-0.155
	Sig. (2-tailed	0.388	0.018		0.563	0.001	0.964	0.845
	N	4	4	4	3	4	4	4
Pulaj NO3	Pearson Correlation	0.419	0.541	0.634	1	0.634	0.163	0.163
	Sig. (2-tailed	0.725	0.636	0.563		0.563	0.896	0.896
	N	3	3	3	3	3	3	3
Pulaj PO4	Pearson Correlation	0.582	0.990*	0.999**	0.634	1	0.009	-0.110
	Sig. (2-tailed	0.418	0.010	0.001	0.563		0.991	0.890
	N	4	4	4	3	4	4	4
Pulaj FC	Pearson Correlation	-0.462	-0.075	-0.036	0.163	0.009	1	0.520*
	Sig. (2-tailed	0.083	0.905	0.964	0.896	0.991		0.047
	N	15	5	4	3	4	15	15
Pulaj FS	Pearson Correlation	-0.148	-0.113	-0.155	0.163	-0.110	0.520*	1
	Sig. (2-tailed	0.599	0.857	0.845	0.896	0.890	0.047	
	N	15	5	4	3	4	15	15

Conclusion

Due to human activities and lack of adequate attention from responsible institutions, protected areas are at risk of being destroyed, putting mass tourism at risk. Based on the results, fecal coliforms and faecal streptococci, the ratio between them indicates that the pollution is mainly human.

The poor quality of surface waters used for recreation, bathing, beach making and land irrigation brings problems to public health, and consequently, the treatment of diseases has a higher cost than the removal of pollution from pathogens of water origin. A strong positive correlation was found between TDS and electrical conductivity reflecting a high content of dissolved ions in water. At the Buna river station near the bridge, the correlation of pH with fecal coliforms is negative, this indicates that pH is a limiting factor for the growth of fecal bacteria in unsuitable conditions. At the station where the Buna river joins the Drini River, we have a significant positive correlation between EC with fecal streptococcus and with PO4 parameters with fecal coliforms which indicates a common source of pollution. Also, at the Darragjat station, EC with streptococcus have a positive correlation At the Pulaj station many parameters such as: EC with coliforms and TDS with coliforms, NO2 with NH4, NO2 with PO4 and NH4 with PO4 have a positive correlation because of a common source of pollution. Being a station where agriculture prevails, we have agricultural runoff, organic pollution and untreated wastewater discharges which influence these ratios.

The comparison of the results of this study with the data published by the European Environment Agency (EEA 2024) for Albania shows a clear alignment regarding the poor quality of bathing waters. According to the EEA report, Albania ranks last in Europe for bathing water quality, with only 16% of monitored sites classified as having excellent quality and 22.7% as having poor quality. The monitoring results conducted as part of this study in the Buna river support this assessment out of six monitored stations, only one was classified as having excellent quality, while the other five stations were assessed as having poor quality due to exceeding the limits for microbiological pollutants. This comparison indicates that microbiological contamination remains a serious issue in the surface waters of the studied area and reflects the national situation reported by the EEA.

The construction of a wastewater treatment plant for the city of Shkodra, aiming to create a modern infrastructure that meets environmental and sanitary standards, not dumping wastewater into rivers, would influence the quality of the Buna River. The Buna River Nature Reserve in Velipojë must be preserved and protected, as well as reforested, as these forests protect the soil from erosion, limit the flow into the lake and play a role in increasing the quality of the rich air. Also, forests act as a natural barrier that stops excess water.

Acknowledgment: *We thank the Faculty of Natural Sciences for the important contributions to this study.*
Compliance with Ethical Standards Ethical responsibilities of Authors: *The author has read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors".*
Conflict of Interest: *The authors declare that they do not have any conflict of interest.*
Change of Authorship: *The author has read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and is aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.*

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J. Int. Environmental Application and Science, Vol. 20(3): 170-182 (2025)
Research Paper

Evaluating The Ecological Value of the Fushë Kuqe - Patok Lagoon Complex

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Received September 17, 2025; Accepted October 26, 2025

Abstract: Although wetlands occupy less than 9% of the Earth's surface, they contribute up to 40% of global annual ecosystem services. Wetlands, despite being among the most biodiverse ecosystems on Earth, face persistent pressures and threats, and remain inadequately researched. Our study will focus on a Managed Nature Reserve, part of which is the Patok - Fushe Kuqe Lagoon. From an ecological point of view, we have analysed the physical, chemical, nutritional and organic pollutant parameters relating to the lagoon waters. We measured the pH, DO, TSS, NH_4-N, NO_2-N, NO_3-N, PO_4-P, total phosphor, COD and BOD_5. These parameters resuleted within the standards, except for BOD and COD, which have shown values approximately 10 and 3 times higher than their respective concentration threshold limits, resulting in poor status of the lagoon's water quality. According to the results, high concentrations of phosphorus and nitrogen can lead to eutrophication, resulting in rapid growth of algae and phytoplankton, which decreases oxygen in surface waters and damages aquatic communities. This research aims to highlight the importance of sustainable management of the coastal lagoon, to preserve the ecosystem services, it provides and to promote actions that improve wetland resilience.

Keywords: *coastal wetlands, ecological assessment, eutrophication, Patok - Fushe Kuqe Lagoon.*

Introduction

Wetlands are considered the most important ecosystems worldwide and occupy a considerable area, which, according to some studies (Matthews et al. 1987; Finlayson et al., 1999), ranges from 5.3 million km^2 to 12 million km^2 of the Earth's surface. They are essential ecosystems because they provide ecological services such as biogeochemical cycles, cimate, erozion and flood regulations, as well as groundwater control, coastal protection, climate change mitigation, biodiversity and habitat conservation and recreational opportunities (Millennium Ecosystem Assessment, 2005; Gardner et al., 2015; Newman et al., 2020; Ten Brink et al., 2011). Although wetlands occupy less than 9% of the Earth's surface, they contribute up to 40% of global annual ecosystem services (Zedler and Kercher 2005).

Wetlands in Albania occupy about 90,000 ha or 3.2% of the territory. While the total surface area of coastal lagoons is over 130 km^2, they are saltwater as a result of communication with the sea and extend along the coastline from north to south parallel to the sea. Our study will focus on the Managed Nature Reserve "Kune -Vaın - Tale - Patok - Fushëkuqe - Ishëm", part of which is the Patok - Fushkuqe Lagoon.

Regardless of their importance, coastal wetland ecosystems are among the most threatened in the world (Millennium Ecosystem Assessment, 2005). They are seriously threatened by eutrophication, pollution, land-use changes, deforestation, overexploitation of groundwater resources, the introduction of invasive alien species, urbanization and increased economic development, caused by human activity in coastal areas of all continents (Millennium Ecosystem Assessment, 2005; European Commission 2007; Esteves et al., 2008; van Asselen et al. 2013; Davidson 2014; Wittmann et al., 2015). The greatest pressures on wetlands come from soluble substances such as nitrates and pesticides used in agricultural activities, heavy metals from industry, and phosphates from domestic wastewater (European Commission, 2007; Abazi & Balliu, 2012; Abazi et al., 2012; Abazi et al., 2013).

The Patok lagoon complex, from an ecological perspective, has problems related to discharges from rivers that carry potentially polluting substances and sediments (specifically from the Mat River) as well

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as discharges from drainage canals and agricultural areas of the villages surrounding the lagoon territory, which carry polluting elements of agricultural activity.

This scientific research is focused on the ecological assessment of the Patok - Fushe Kuqe lagoon complex, with the aim of understanding the current ecological state of the lagoon. The research goals are intended to be achieved through the knowledge and evaluation of the physico-chemical parameters of the lagoon waters. At the same time, it is aimed at the economic assessment, which is being carried out for the first time in a lagoon area, identifying the main goods and services of the lagoon (Millennium Ecosystem Assessment, 2005). The scientific objectives are:

- Assessing the ecological status of the lagoon complex through the analysis of several key environmental indicators such as physical-chemical parameters, the level of pollution from river discharges and the level of nutrients in the water.
- The evaluation of the relationships between the concentrations of nutrients and organic pollutants (nitrogen, phosphorus, COD, BOD) with the quality status of lagoon waters, in order to identify the risk of eutrophication.
- Identification and analysis of issues related to the management of the lagoon complex for its sustainable development.

This study aims to identify the ecological problems of this lagoon complex, with the aim of raising awareness for sustainable management of the lagoon.

Materials and Method

Study Area

Patok Lagoon is part of Rodoni Bay and is about 4.5 km long and 1.3 km wide and is located between the two rivers Mat to its north and Ishem to its south. The Patok Lagoon is connected to the Adriatic Sea through a channel in the southern part which is directly connected to the sea (Fig. 1). The Patok lagoon complex was designated in 1962 (Decision, 2010) it has the status “Managed Nature Reserve”, in category IV according to the IUCN, amended in 2022 (Decision, 2022).

The Patok - Fushe Kuqe wetland complex had an area of about 4,200 ha but has undergone major changes under the action of natural factors (sedimentary deposits and erosion) and human activities which have reduced the surface area of the lagoon. Nowadays, the Patok wetland complex consists of an inner and outer lagoon with an area of about 480 ha, a forest area of about 200 ha and agricultural land of about 600 ha. The area encloses only fresh sediments brought by the Mat River from mountain catchments and is characterized by river alluvium and ophiolitic sand and pebbles.

From a climatic point of view, the Patok - Fushe Kuqe wetland complex is characterized by a mild winter and cool summer, an average annual temperature of about 15.5 °C and an average annual rainfall of about 1,463 mm and with about 2479 hours of sunshine per year, which indicates that it is a typical Mediterranean plain area with high climatic potential that favors the development of the lagoon's biodiversity.

The environmental impacts of the lagoon water are related to the sediment flows of the Mat River, along with which come polluting elements, which reduce the normal functioning of the lagoon, affecting its productivity. In the eastern part, the lagoon is bordered by agricultural land, the activity of which affects the water quality in the lagoon through inflows.

Sampling and Processing

To determine the ecological status of the lagoon, based on several key physico-chemical indicators in this wetland complex, water sampling was conducted at 6 sampling stations. Sampling stations have been strategically selected, at the estuaries and channels connecting the lagoon to the surrounding villages, to monitor the impact of all potential sources of pollution. Specifically, in the estuaries and channels connecting the lagoon with the villages around it to see the impact of potential pollution sources.

“Ruttner” samplers were used for the sampling process. For each station, 1.5 liters of water were collected in plastic bottles, which were then placed in a refrigerated box (4 °C). Further, the samples taken were sent and analyzed at the Laboratory of the Department of Environment and Natural Resources at the Agricultural University of Tirana. The sampling stations in the Patok Lagoon are shown on the Fig. 2 and Table 1 . Water sampling sites and geographic coordinates

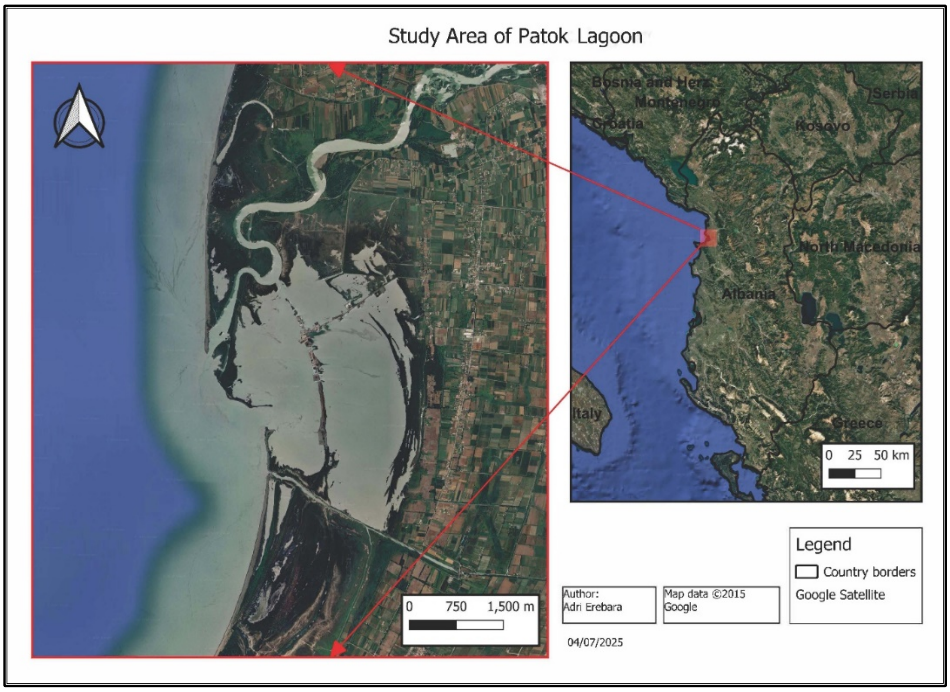

Figure 1. Study area of Patok Lagoon (map data: Google Earth, QGIS, 3.34.7-Prizren)

Table 1. Water sampling sites and geographic coordinates

Sample no.	**Sample ID**	**Lagoon**	**UTM_WGS84_Zone 34T**	
			East	**North**
1	Mat 1	Patok	382156	4610928
2	Mat 2	Patok	382154	4610805
3	Bar 1	Patok	382822	4610640
4	Bar 2	Patok	383126	4610789
5	Village 1	Patok	384125	4611050
6	Village 2	Patok	384154	4611420

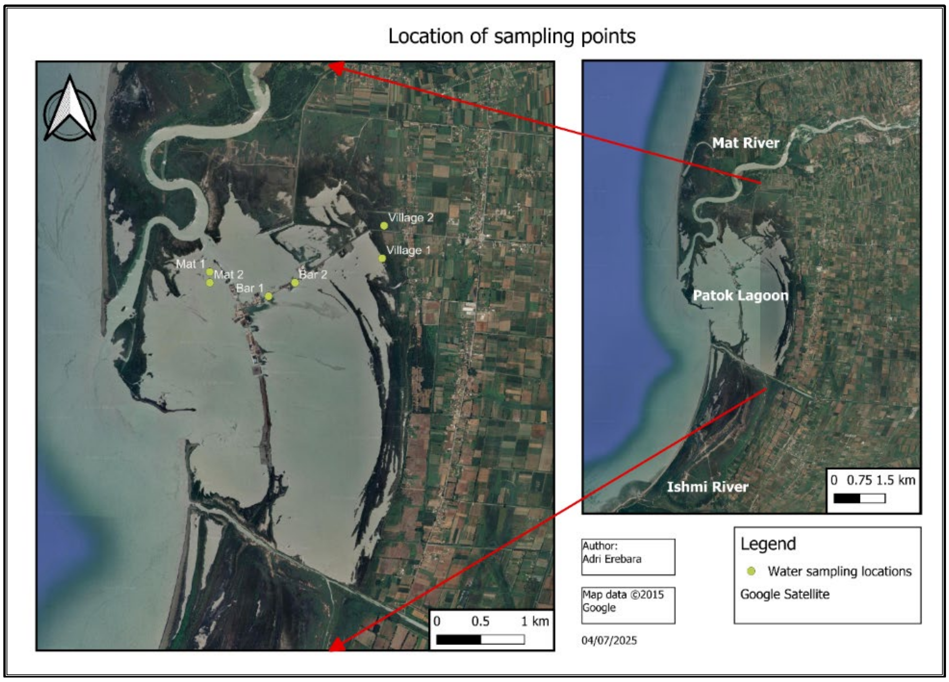

Figure 2. Geographical position of the Patok Lagoon and sampling sites (map data: Google Earth, QGIS, 3.34.7-Prizren)

<u>Methods used for water physical-chemical analysis</u>

The physico-chemical pollution indicators that were analyzed and the standard procedure followed are:

- **pH and Dissolved Oxygen** (DO) – measurements were carried out in the field using the multiparametric probe WTW 340i
- **Total Suspended Solids** (TSS) – the quantity of solid particles is measured by the difference in weight of a filter, which has collected the suspended particles in the water column, by drying at 105 °C.
- **Ammonium** (NH_4-N) – the method ISO 7150;1984 was applied, where the water sample was measured in a strong alkaline solution, which reacted with a chlorinating agent to form monochloramine. The spectrometric measurement was made at a wavelength of about 655 nm of the blue compound formed by the reaction of ammonium with salicylate and hypochlorite ions in the presence of sodium nitroso pentacyano-ferrate (III) (sodium nitroprusside).
- **Nitrites** (NO_2-N) – are determined by their reaction with the reagent amino-4 benzene sulfonamide in the presence of orthophosphoric acid and measurement of absorbance at 540 nm (S SH EN 26777: 1993).
- **Nitrates** (NO_3-N) – the measurement was performed in a 10 mm optical cuvette, with spectrometric measurements of absorbance at 324 nm according to the ISO 7890-1:1986 method.
- **Phosphorus Forms** (PO_4-P) – to measure phosphates, as PO_4^{3-}, organic phosphorus and hydrolyzed polyphosphates were oxidized with potassium peroxodisulphate to orthophosphates. The absorbance was measured and the concentration of orthophosphates present was determined at 880 nm, using the ISO 6878:2004 method (ISO, 2004).
- While for **total phosphorus**, measurements were carried out in a spectrophotometer with a wavelength of 880 nm, using the U.S. Environmental Protection Agency, 1978 method.
- **Chemical Oxygen Demand** (COD) – the oxidation of organic materials in the presence of H_2SO_4 and $KMnO_4$ at the boiling point was used to calculate COD. Unconsumed $KMnO_4$ reacts with oxalic acid at the end of the oxidation phase, and $KMnO_4$ also defines the residues of this reaction (ISO 15705:2002).
- **Biological Oxygen Demand** (BOD5) – was measured using the OXI-top system over a 5-day incubation period (APHA, AWWA, & WEF, 2017).

The control of the degree of pollution of lagoon waters is carried out through the measurement and evaluation of the most important parameters such as: organic matter content, usually expressed as Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD5), nutrients, mainly the various forms of nitrogen and phosphorus content, as well as temperature, pH, salinity, dissolved oxygen, and suspended solids. Important indicators in determining water quality and its use are organic load indicators (U.S. Environmental Protection Agency, 1999). Sources of organic matter include wastewater discharges, industrial effluents, and agricultural land drainage waters. This organic pollution leads to increased metabolic processes that require oxygen. The content of nutrients, such as phosphorus and nitrogen, causes the phenomenon of eutrophication, i.e. the excessive production of algae, phytoplankton, etc., causing a decrease in oxygen in surface waters and damage to biotic communities that are of great importance to humans.

Flora and fauna of the lagoon

Flora

In the Fushe Kuqe - Patok lagoon complex 166 plant species are recorded (Dhora and Beqiraj, 2001). The main types belong to: 29 *Graminaceae* family, 7 *Cyperaceae*, 7 *Chenopodiaceae*, 8 *Rosaceae*, 10 *Leguminosae,* 11 *Compositae*, as well as *Equisetum, Pteridium* etc.

In its western part the most common are the underwater meadows of *Fucus virsoides* and *Posidonia oceanica*. *Fucus virsoides*. Fanerogamous meadows cover about 40% of the lagoon bottom layer and are mainly composed of *Zostera noltii*, but in the most shallow and quiet water of the lagoon there is also *Ruppia spiralis* and *Ruppia cirrhosa.* In the meadows of *Posidonia oceanica* a population of *Penaeus keraturus* is identified. In the peripheral area the lagoon is covered by hygro and hydrophilic vegetation which are dominated by 3 main plant associations of *Phragmites*, *Thypha* and in some places *Scirpus* species. While halofile vegetation is located in the north and southern part of the lagoon and consists of some plant associations where the most important are *Arthrocnemum* and *Juncus*. Some of the most important associations are gender *Arthrocnemum*, as well as *Salicornia europaea, Limonium vulgare, Inula crithmoides, Halimone portulacoides, Artemisia coerlescens* etc.

The dune vegetation is mainly found in the western part that borders the sea. In the vicinity of water this vegetation is missing, then comes and is gradually added where the types are composed of *Cakile maritime, Xanthium strumarium, Salsola cali, Eryngium maritimum, Medicago marina, Ephedrum Distachia, Cyperus capitus, Echinophora spinosa* etj.

The shrub vegetation consists of a high number of shrubs that are dominated by *Tamarix*, *Vitex* and *Rubus* species. The *Tamarix* species endures salt, grows rapidly and creates environments suitable for housing and reproducing water birds.

Whereas the forest surface that comprises the Fushe Kuqe forest is located in the eastern part of the lagoon. From human activity about half of the forest area is damaged. The wooden floor of this forest is dominated by *Alnus glutinosa*, *Fraxinus angustifolia*, *Ulmus campestre*, *Quercus robur*, *Populus alba*, *Pinus pinea* and *Pinus halepensis*. Instead, the bush floor of the forest is quite dense, consists of *Rubus ulmifolius*, *Crataegus monogyna*, *Oyrocantha coccinea*, *Rosa sempervirens*, *Juniperus oxicedrus*, etc.

Fauna

The diversity of aquatic habitats of the Patok wetland complex, such as freshwaters, canals, marshes, estuaries and the shore around the lagoon, has allowed the development of a variety of groups and species of fauna such as mollusks (mussels and snails), crabs, insects, fish, amphibians, reptiles and especially birds and mammals. The three most interesting groups of animals are: ***1) marine mollusks***, which are numerous. There are species of interest such as several species of *cephalopod* mollusks which are important for sea fishing. ***2) crabs*** are another important group. Particularly important are saltwater crabs, which are numerous and play an important role in nature. Many species of crustaceans are found in the area, such as *Gennadas elegans, Lucifer typus*, *Solenocera membranacea, Penaeus trisulcatus, Sicyonia carinata, Athanas nitescens, Crangon crangon*, *Paguristes eremita*; ***3) insects*** are the largest group that play an important role in the biogenic circulation of substances. This insect fauna of the area belongs mostly to the orders of dragonflies (*Odanata*), locust (*Orthoptera)*, bedbugs (*Hemiptera*), beetles (*Coleoptera*), butterfly (*Lepidoptera*) and flies and mosquitoes (*Diptera*).

Fishes. The lagoon and the marine environment associated with the lagoon have significant quantities of fish. The ichthyofauna consists of many species of fish, such as the three species of mullet (*Mugil cephalus, Liza ramada, Liza saliens*), eel (*Anguilla anguilla*), red mullet (*Mullus barbatus*), common sole (*Solea vulgaris*), gilt-head bream (*Sparus aurata*), European seabass (*Dicentrarchus labrax*) etc.

Amphibians and reptiles. Amphibians and reptiles (Herpetofauna) are found mostly in the forests, swamps, and canals around the lagoon. In the area of the wetland complex, 8 species of amphibians are known, 3 of which are frogs (*Rana*), 2 are toads (*Bufo*), 1 is the European tree frog (*Hyla arborea*) and 2 species are newts (*Triturus*). The loggerhead sea turtle (*Caretta caretta*) often approaches shallow sea waters, but the presence of green sea turtles (*Chelonia mydas*) is also found. The rest of the reptile species are grouped into 10 lizards and 10 snakes.

Birds. The condition of birds in the wetland complex changes during winter, spring, summer and autumn. ***During winter***, out of 70 bird species, 27 species are waterfowl, while another 43 species are found in forests and agricultural lands, of which the largest number are passerine birds. ***During the spring***, 179 bird species were counted, of which 76 species or 42% are waterfowl and 103 species belong to birds of shrubs, forests, pastures, dunes, agricultural lands, etc. The most common birds are little egret (*Egretta garzetta*), northern shoveler (*Anas clypeata*), red-footed falcon (*Falco vespertinus*), curlew sandpiper (*Calidris ferruginea*), caspian gull (*Larus cachinnans*), great reed warbler (*Acrocephalus arundinaceus*), etc. Among the most interesting water birds are the pelican (*Pelecanus crispus*), pygmy cormorant (*Phalacrocorax pygmaeus*), white stork (*Ciconia ciconia*) and eurasian spoonbill (*Platalea leucorodia*). ***During the summer***, most of the nesting birds in the entire area belong to the passerine order (*Passeriformes*). From the order of passerines found in the lagoon and which are the largest group, we can single out the western yellow wagtail (*Motacilla flava*), zitting cisticola (*Cisticola juncidis*), eurasian reed warbler (*Acrocephalus scirpaceus*). ***During autumn***, the first place is again taken by the order of passerine (*Passeriformes*) with 40%, followed by shorebirds (*Charadriiformes*) with 22%, ducks (*Anseriformes*) with 8%, storks (*Ciconiiformes*) with 6% and raptors (*Falconiformes)* 8%.

Mammals. Of the mammals, the largest group are bats with 8 known species, mice with 5 species, and carnivores with 6 known species. The most common species of carnivorous mammals are the jackal (*Canis aureus*), fox (*Vulpes vulpes*), otter (*Lutra lutra*), badger (*Meles meles*), weasel (*Mustela nivalis*) and polecat (*Mustela putorius*).

Results and Discussion

Ecological evaluation of the lagoon

Influence of physico-chemical characteristics on fish growth

pH values obtained from water samples are a good indicator of the lagoon quality, because they constitute one of the main parameters that affect aquatic life and fish growth (Abowei, 2010). In the case of the lagoon studied, the pH ranges from 8.19-7.96, with an average of 8.04 and a highest recorded value of 8.19 (Fig. 3). According to Abowei, 2010, a pH between 7 and 8.5 is ideal for biological productivity and fish life, while a pH lower than 2 is considered harmful to aquatic life. Therefore, it is noted that our values fall within normal pH ranges.

However, the amount of dissolved oxygen required varies from one species to another. Benthic biota requires minimal amounts of oxygen (1-6 mg/L), while shallow water biota require higher oxygen levels (4-15 mg/L) (Osmond et al, 1995). In our case, the average value of dissolved oxygen at the surface of the lagoon water is 3.65 mg/L, with a maximum value of 4.2 mg/L and a minimum value of 3.16 mg/L, as shown in Fig. 4. Therefore, dissolved oxygen is in the range of normal values.

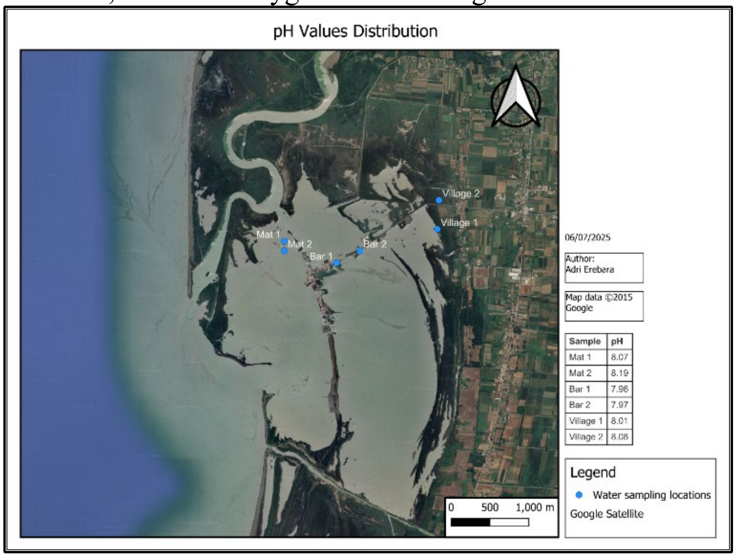

Figure 3. Distribution of pH Values in the Patok Lagoon (map data: Google Earth, QGIS, 3.34.7-Prizren)

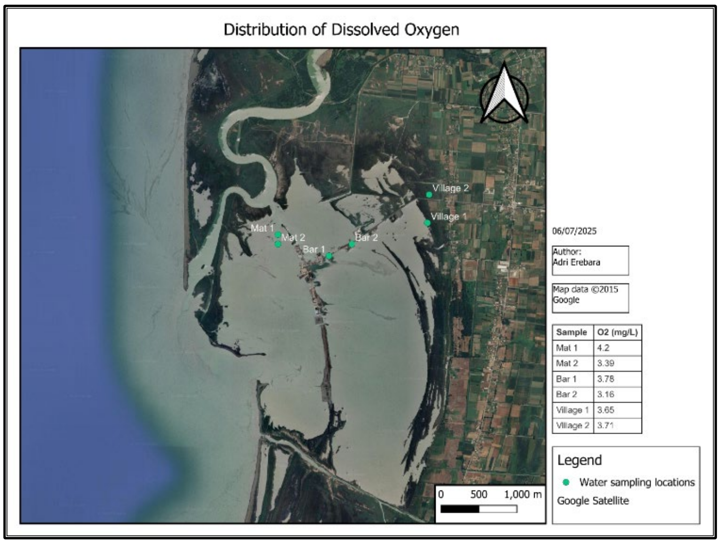

Figure 4. Values of dissolved oxygen in the sampling points (map data: Google Earth, QGIS, 3.34.7-Prizren)

Regarding total suspended solids, which is the mass of suspended particles in the water column, its average value is 84.3 mg/L. With a maximum value of 171 mg/l measured at station Bar 2 and a minimum value of TSS of 11 mg/L, measured at station Village 2 (Fig. 5). Since normal values for suspended solids range from 100 mg/L - 200 mg/L, we are below the value of normal conditions. The values of the results of the physical - chemical parameters are given in Table 2. Table 3. Results of

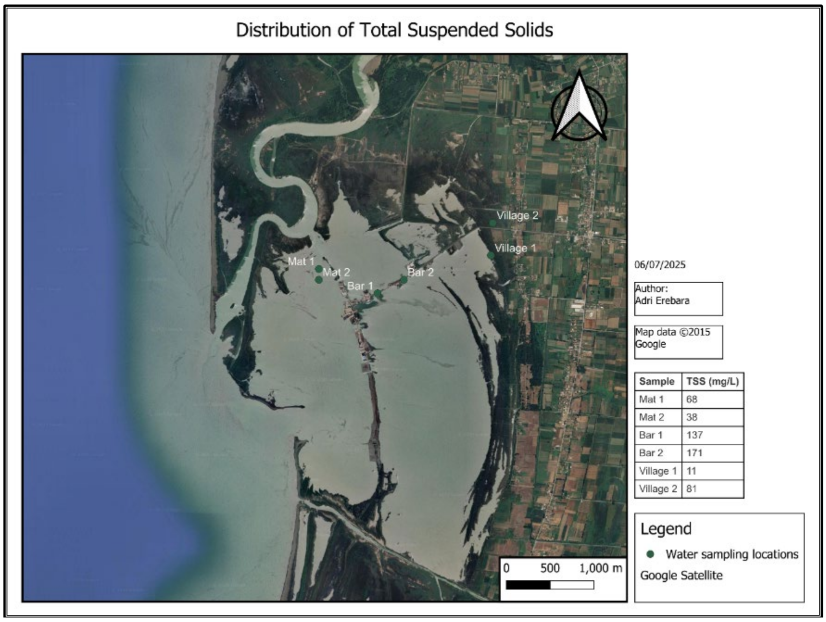

Figure 5. Values of TSS in the water of the lagoon complex (map data: Google Earth, QGIS, 3.34.7-Prizren)

Table 2. The values of the results of the physical - chemical parameters

Sample ID	pH	O_2 mg/L	TSS mg/L	Salinity
Mat 1	8.07	4.20	68.00	26.40
Mat 2	8.19	3.39	38.00	10.36
Bar 1	7.96	3.78	137.00	32.50
Bar 2	7.97	3.16	171.00	32.60
Village 1	8.01	3.65	11.00	33.70
Village 2	8.08	3.71	81.00	21.80
Mean	**8.05**	**3.65**	**84.33**	**26.23**
Median	**8.04**	**3.68**	**74.50**	**29.45**
Min value	**7.96**	**3.16**	**11.00**	**10.36**
Max value	**8.19**	**4.20**	**171.00**	**33.70**
Std. Devi.	**0.09**	**0.36**	**60.15**	**9.02**
Coefficient of Variation (%)	**1.07**	**9.73**	**71.32**	**34.41**

Assessment of nutrient values

Pollution with soluble nitrogen (N) and phosphorus (P) is one of the most important environmental problems related to the deterioration and degradation of water quality as they determine the harmful phenomenon of eutrophication. Ammonium, nitrite and nitrate are reactive, ionic inorganic forms of nitrogen in aquatic systems. These ionic forms are present as a result of surface leaching, dissolution of nitrogen deposits, soil erosion and biological degradation of organic matter, which can enter ecosystems as a result of human activities. Meanwhile, the inorganic forms of phosphorus (P) present in surface waters are orthophosphate (PO_4^{-3}).

The total concentration of inorganic forms in the aquatic environment of NO_3-N > 30-40 mg/L and the total concentration of P > 1-2 mg P / L can cause environmental problems, of which the most detrimental is eutrophication (Camargo & Alonso, 2006). Orthophosphates in the water were not detectable, having values below the limit, while total phosphorus was in minimal values (below 0.1 mg/L), as shown in Fig. 6.

It was also observed that inorganic forms of nitrogen were good, which means that we do not have the eutrophication process in the lagoon. Both nitrites, nitrates, and ammonia showed values below 1 mg/L (Fig. 7, 8 and 9). Nutrient Parameters and COD/BOD

Table 3. Results of Nutrient Parameters and COD/BOD

Sample ID	NO_2-N	NO_3-N	NH_4-N	PO_4-P	P total	COD	BOD
	mg/L	mg/L	mg/L	mg/L	mg/L	mg O_2/L	mg O_2/L
Mat 1	0.007	0.46	0.18	LD	0.021	60	40
Mat 2	0.006	0.275	0.05	LD	0.023	<10	<5
Bar 1	0.017	0.642	0.09	LD	0.032	100	67
Bar 2	0.038	0.638	0.16	LD	0.025	95	64
Village 1	0.01	0.513	0.18	LD	0.018	105	70
Village 2	0.012	0.355	0.11	LD	0.018	45	30
Mean	**0.02**	**0.48**	**0.13**	**LD**	**0.02**	**81.00**	**54.20**
Median	**0.01**	**0.49**	**0.14**	**LD**	**0.02**	**95.00**	**64.00**
Min value	**0.01**	**0.28**	**0.05**	**LD**	**0.02**	**45.00**	**30.00**
Max value	**0.04**	**0.64**	**0.18**	**LD**	**0.03**	**105.00**	**70.00**
Std. Devi.	**0.01**	**0.15**	**0.05**	**LD**	**0.01**	**26.79**	**18.01**
Coefficient of Variation (%)	**79.55**	**30.92**	**41.65**	**LD**	**23.08**	**33.07**	**33.22**

*LD - Limit of Detection

COD and BOD content

BOD determines the amount of oxygen consumption (mg O_2 L^{-1}) by aerobic biological organisms to oxidize organic compounds. While COD is an indicative measure of the amount of oxygen that can be consumed by reactions in a given solution, the standard amount is 120 mg/L. Based on EU standards, BOD standard value for coastal surface waters is ≤ 4-5 mg/L and the COD standard amount is ≤ 5 times higher than BOD, which is giving ≤ 20-25 mg/L as standard value of the European Water Framework Directive (European Parliament & Council, 2000).

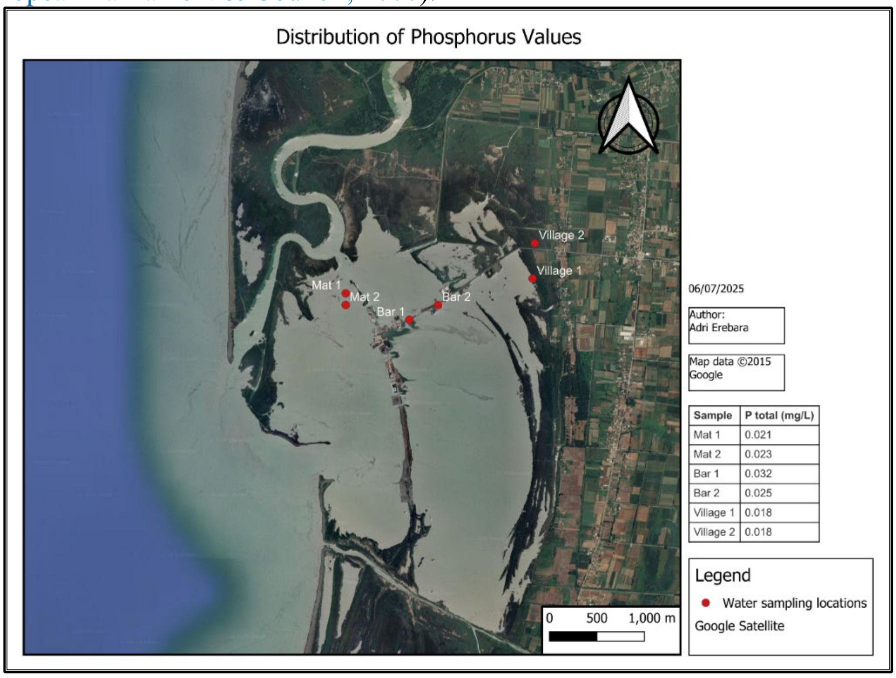

Figure 6. Water phosphorus levels (map data: Google Earth, QGIS, 3.34.7-Prizren)

For the BOD parameter, except for the sampling point at station Mat 2 which had normal values, all other samples showed very high values, with the average value being 54.2 mgO_2/L and the maximum value recorded being 70 mgO_2/L, at sample Village 1 (Fig. 10). Such high values, higher than 10 times the threshold concentration, can be correlated with urban and also agricultural wastewater discharges, typical for the land uses in the area.

The same situation also occurs for the COD values, where values are more than 3 times the contamination threshold concentration according to the Water Frmework Directive, with an average of 81 mgO_2/L and maximum value of 105 mgO_2/L at the sampling point Village 2 (Fig. 11).
These values of BOD and COD, organic pollutant parameters, determine the water quality status of the lagoon, as according to the Water Framework Directive, the parameter with the lowest values determines the status of the water body.

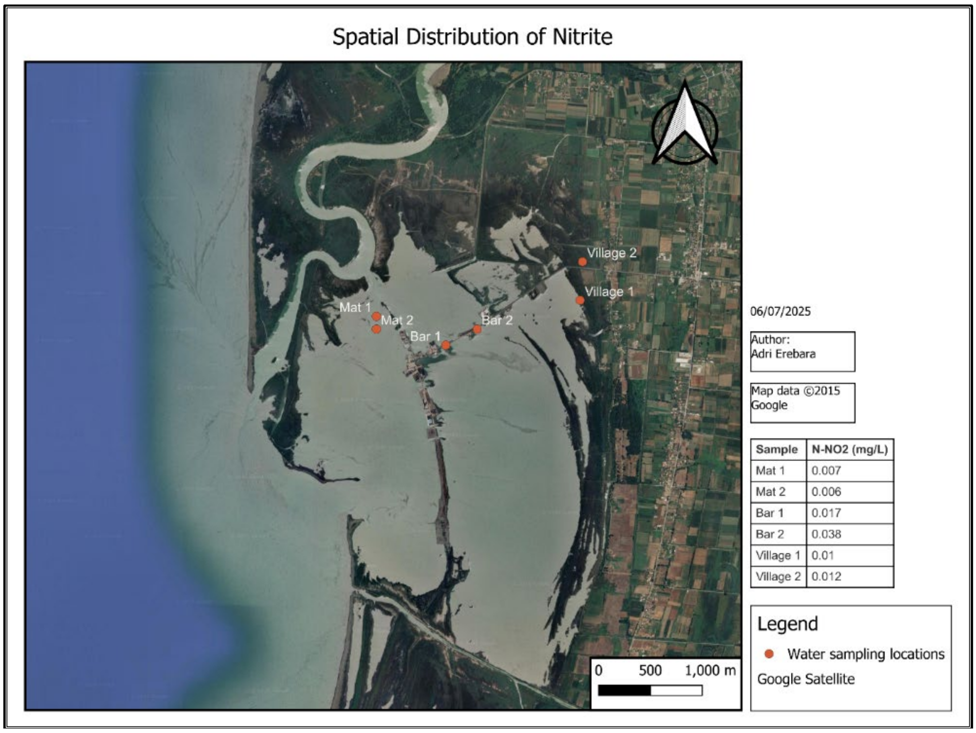

Figure 7. Nitrite variation in the waters of Patok Lagoon (map data: Google Earth, QGIS, 3.34.7-Prizren)

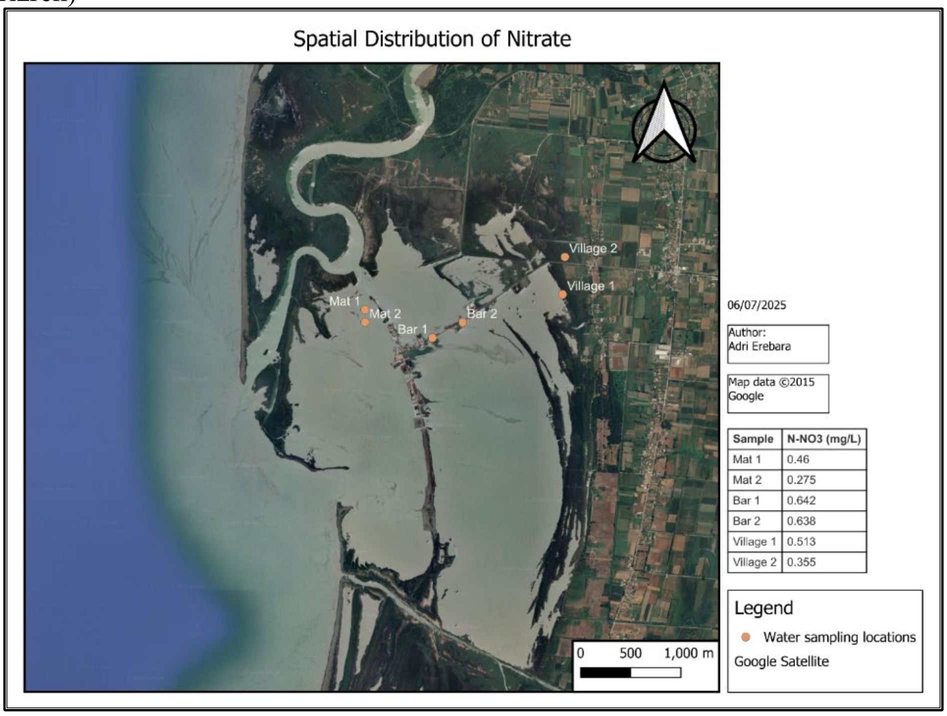

Figure 8. Distribution of Nitrate values in the sampling points (map data: Google Earth, QGIS, 3.34.7-Prizren)

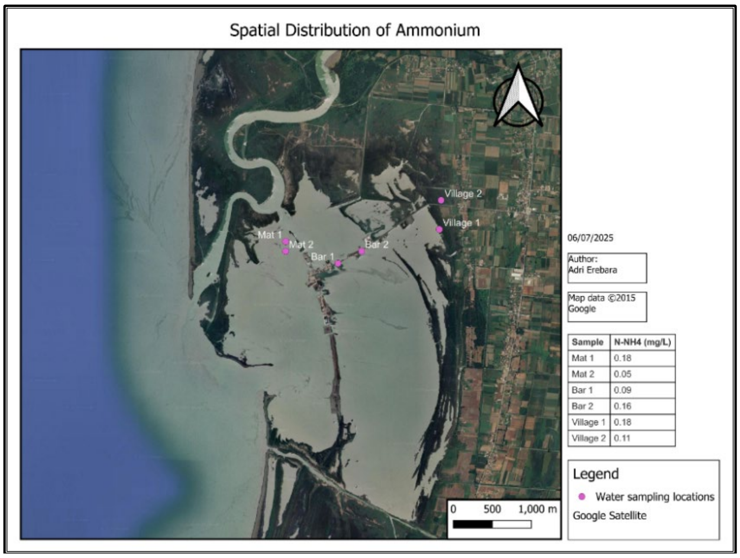

Figure 9. Distribution of Ammonium values in the sampling points (map data: Google Earth, QGIS, 3.34.7-Prizren)

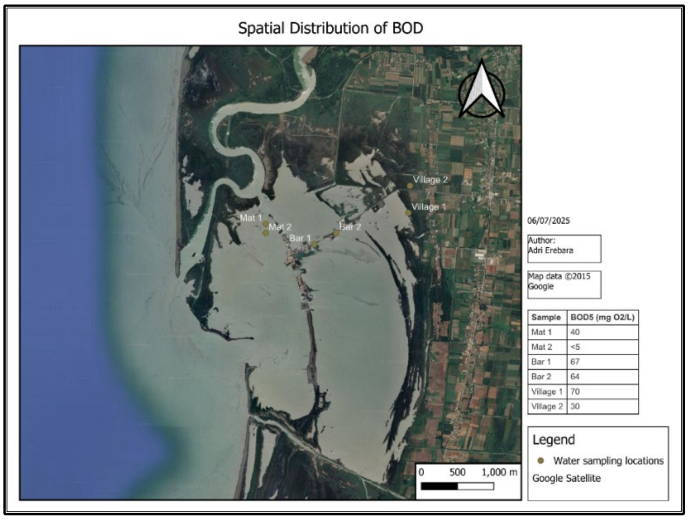

Figure 10. Distribution of BOD values in the Lagoon of Patok (map data: Google Earth, QGIS, 3.34.7-Prizren)

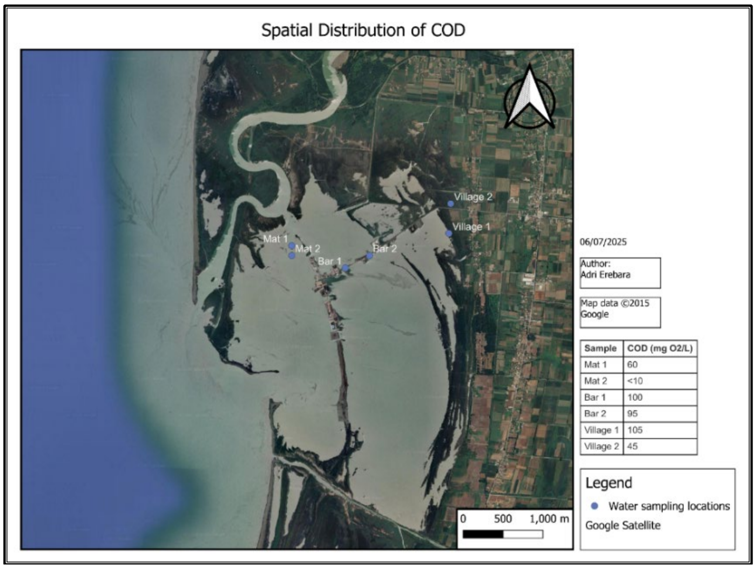

Figure 11. Lagoon water COD level (map data: Google Earth, QGIS, 3.34.7-Prizren)

Conclusions

From the study conducted for the ecological evaluation and analysis of the Patok − Fushe Kuqe Lagoon complex, for sustainable management of the lagoon, it results that:

- By analyzing and evaluating several key environmental indicators such as physical-chemical parameters, the level of pollution from river discharges and the level of nutrients in the water, it turns out that the condition of the lagoon is poor. The physical-chemical parameters are around normal values, with the exception of BOD and COD, which was in avarage 10 and 3 times higher than the threshold concentration, respectively. These values of the organic pollutant parameters (BOD and COD) determine the overall state of the lagoon's water quality, since according to the Water Framework Directive, the status of the water body is determined by the status of the parameter with the lowest values in the assessment.

From the identification and analysis of the problems related to the management of the lagoon complex for sustainable development, it results that:

- The current management of the Patok − Fushe Kuqe Lagoon complex is not in accordance with the required level (according to Millennium Ecosystem Assessment, 2005) and this requires the intervention of local and central institutions and awareness of the local community for the conservation and sustainable management of the lagoon.

Given the state of wetlands and the ongoing pressure on them from multiple factors, local and regional authorities as well as other local stakeholders need to make transformative changes towards more sustainable management of wetlands to increase their resilience through the interaction and integration of natural ecosystems linked to human-modified terrestrial and aquatic ecosystems. (Dudley et al., 2021).

Acknowledgment: *We gratefully acknowledge our colleagues from the Agro-Environment and Ecology Laboratory at the Agricultural University of Tirana for their valuable assistance and support with laboratory analyses.*

Compliance with Ethical Standards Ethical responsibilities of Authors: *The author has read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors". This research was based on field observations, environmental sampling, and laboratory analyses conducted within the Fushë Kuqe–Patok Lagoon Complex. No human participants or experimental animals were involved, and no protected species were harmed. All procedures complied with relevant national legislation and institutional guidelines for environmental research.*

Conflict of Interest: *The authors declare that they do not have any conflict of interest.*

Change of Authorship: *The author has read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and is aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.*

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J. Int. Environmental Application and Science, Vol. 2025(3): 183-192 (2025)
Research Paper

Waste Management Policy Evolution in the United Kingdom and Its Implications for the United States

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Received September 25, 2025; Accepted October; 2025

Abstract: Waste management presents urgent environmental, economic, and public health challenges, with the United Kingdom (UK) emerging as a leader through policy development, circular economy integration, and technological innovation (OECD, 2022; Department for Environment, Food and Rural Affairs [DEFRA], 2023a). Over the past 30 years, the UK has transitioned from a landfill-dependent system to one driven by financial incentives, extended producer responsibility (EPR), and knowledge-based waste processing. However, unresolved issues such as stagnation in recycling, plastic pollution, contamination, and post-Brexit regulatory uncertainty continue to impact its future. These developments are of high transatlantic significance and are important as the country seeks effective waste governance solutions. This study critically analyses how the UK waste management policies' focus has changed since the 1990s to 2023 and whether they are effective, considering technological advances and the ability to adjust strategy. Through benchmarking the UK, in comparison with the well-established and emerging economies, the paper draws on the lessons that are actionable and policy transfer opportunities the United States can use in pursuing its sustainable waste systems. The UK has sharply reduced landfill use and advanced policy tools like EPR and plastic taxes, though recycling rates have stagnated and closed-loop performance remains limited. Moreover, several UK strategies such as fiscal incentives, standardized labelling, and expanded EPR offer practical guidance for improving U.S. waste policy.
Keywords: *Policy; United Kingdom; United States; Waste Management.*

Introduction
Global Context

Waste production has turned out to be one of the crucial governance and environmental issues of the 21st century. It is estimated that global municipal solid waste will increase to 3.88 billion tons by 2050, up by 2.24 billion tons in 2020, based on the data in What a Waste 2.0 published by the World Bank, which has significant implications regarding climate change, biodiversity loss, and health (Kaza et al., 2018). Waste management is thus the key element to meeting several international commitments, the United Nations Sustainable Development Goals (SDGs), the Paris Climate Agreement, and national-level net-zero commitments (OECD, 2022).

The UK Context

The United Kingdom (UK) withstood the immense changes in waste management over the last 30 years, as the country managed to transition the landfill-based waste governance model (in which more than 80 percent of municipal waste was landfilled in the early 1990s) to a diversified system that focuses more on recycling, energy recovery, and the principles of the circular economy (DEFRA, 2023a; Eurostat, 2023). This has been facilitated by such landmark policies as:

- Environmental Protection Act (1990) - brought about the contemporary waste management regulation.
- Landfill Tax (1996) taxed landfill disposal by providing financial incentives to reduce it.

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- Waste Strategy for England (2007) - established national targets of recycling and diversion.
- Resources and Waste Strategy (2018) - proposed to adopt some measures to integrate the circular economy.
- Plastic Packaging Tax (2022) -encouraged recycled content to be used in packaging.

Such will limit dependence on landfills to under a quarter by 2023 and make the UK one of the global leaders of Extended Producer Responsibility (EPR) and market-based policies of waste reduction (DEFRA, 2023b). Nevertheless, since 2015, the rates of recycling have stagnated at about 44% due to the presence of contamination, differences in local authorities, and infrastructural capacity (WRAP, 2023). Brexit has also confused the conditions of alignment with EU waste directives and the trade of secondary materials.

The U.S. Context

America has similar issues, but it works within a very decentralized system of waste governance and rules that change in each state and each municipality. Landfilling almost 53% of municipal solid waste also means the U.S. performs poorly in recycling behind even the UK and EU leaders, with the national average at just 32% across the country (EPA, 2022). Although some states like California and Oregon have introduced EPR legislation and ambitious recycling goals, there is no national landfill tax, and the national coordination on recycling standards has been low (NCSL, 2023).

Market susceptibility experienced in the U.S. is also comparable to that of the UK (after all, the National Sword policy implemented by China in 2018 led to a halt in the import of recyclables), although these two countries may not be as vulnerable now as the UK is. This has caused the revelation of the necessity of domestic reprocessing capacity and higher harmonization of policies. The UK case study has great transatlantic policy transfer potential in terms of its fiscal tools, its EPR systems, and their public engagement campaigns.

Purpose of the Study

This study aims to:

1. The historical development of UK waste management policies from the year 1990 to 2023 is critically discussed.
2. Make a comparison of performance in the UK with both developed (the United States, Germany) and developing (India, Nigeria) economies.
3. Determine the best policy interventions that may provide knowledge in restructuring the governance of waste in the U.S.
4. Offer specific, evidence-based proposals complying with international frameworks of sustainability.

Hypotheses

H1: The combination of fiscal incentives, regulatory regimes, and technological innovation has meant the UK has seen a considerable reduction in its reliance on landfills and a corresponding rise in waste recovery rates.

H2: U.S. countries can find a quantifiable increase in the levels of waste diversion and recycling by implementing similar-adapted UK-style policies, such as landfill taxes, expansion of EPR, and universally uniform recycling practices.

Method Overview

The research design used in this study is qualitative-descriptive, which incorporates policy analysis in comparative benchmarking. The sources of data consist of 72 policy papers, government reports, DEFRA, Eurostat, UNEP, OECD, U.S. EPA, and NCSL datasets. Policies are analyzed both chronologically and thematically in an attempt to determine the effectiveness of the legislation, the use of technology, and positioning to meet the targets of sustainability.

Research Design, Sample, Instruments, and Procedure

- **Research Design:** Qualitative-descriptive, combining historical policy analysis with cross-national benchmarking.
- **Sample:** Policies, regulations, and performance data from the UK (1990–2023) and comparator nations.

- **Instruments:** Document analysis protocols, comparative policy matrices, and thematic coding frameworks.
- **Procedure:** Sequential analysis starting with UK historical review, followed by comparative benchmarking against international best practices, and culminating in recommendations for U.S. application.

Contribution to Knowledge

The present paper adds to the body of literature on comparative environmental policy by offering a comprehensive, longitudinal approach towards the evolution of UK waste management and its transatlantic policy application. The synthesis of lessons learned in the UK experience elucidates a theoretical study based on details provided in the study that can assist U.S. policymakers to implement fast progress in achieving circular economy goals despite the lingering institutional constraints.

Background

Global Waste Management Trends

Waste management has turned out to be a global governance issue driven by environmental, economic, and social requirements. World Bank estimates that the quantity of municipal solid waste produced globally will have grown by 73 percent by the year 2050, due to population growth, urbanization, and changes in consumption behavior (Kaza et al., 2018). Developed countries are characterized by a higher waste rate per capita and access to more developed systems of waste treatment, whereas the developing countries may face extant problems with poor infrastructure and waste collection systems (OECD, 2022). The convergence of international policy frameworks (United Nations Sustainable Development Goals (SDGs), Paris Climate Agreement, and Basel Convention on the Control of Transboundary Movements of Hazardous Wastes) is increasingly demanding a greater role of waste governance in the climate and sustainability policies of countries.

The UK Policy Evolution

The United Kingdom's waste management policy trajectory can be broadly divided into three phases:

1. **Regulatory Modernization (1990–2000):** The Environmental Protection Act (1990) defined a contemporary system of waste regulation, licensing, and enforcement. Landfill disposal is such a task, and a significant economic disincentive was introduced in 1996 with the first Landfill Tax to be introduced anywhere in the world (DEFRA, 2023b).
2. **Target-Driven Policy Expansion (2001–2010):** During this time, we witnessed the Waste Strategy for England (2007) adding statutory targets in recycling and recovering as it was accompanied by compliance requirements with the EU Landfill Directive (Eurostat, 2023). They gave local government a set of incentives that focused on enhancing kerbside collection programs and investing in sortation.
3. **Circular Economy Integration (2011–2023):** Lately, the years concerned with matching circular economy principles have been observed, as the Resources and Waste Strategy (2018) defines. Both waste prevention and material recovery aim at reducing the volume of waste products and increasing their recovery. Examples of such initiatives include an increase in Extended Producer Responsibility (EPR) frameworks and the proposed Plastic Packaging Tax (2022). Nevertheless, in terms of recycling rates, despite these developments, the figures have plateaued at 44% since 2015 (WRAP, 2023), implying that whatever has been done will have diminishing returns unless accompanied by the restructuring of the system.

The U.S. Waste Governance Framework

The U.S. waste management system displays such characteristics as its federalist nature, with the policy-making power in the states and local decision-making. Such decentralization results in a huge lack of uniformity in the waste collection, recycling infrastructure, and performance by state (EPA, 2022). No single federal tax on landfill use or consistency in EPR policy like the one in the UK exists, but the features of recycling and producer responsibility liberalization created by state laws have been delivered in states such as California, Oregon, and Maine (NCSL, 2023).

At the national level, the U.S. recycles about 32 percent of municipal waste, and landfill is still the most used disposal mode (EPA, 2022). Risks in the markets, especially the National Sword policy in China, have shown the significance of how the country relies on other process markets, which justify the need to develop domestic reprocessing capabilities (OECD, 2022).

Comparative Insights: UK vs. U.S.

This comparative outlook (Table 01) shows that, on one hand, the UK has also been successful in primarily reducing landfill, although it has used coordinated fiscal and regulatory actions, whereas the U.S. has been slow in adopting a national policy as a coordinated effort. On the other hand, the experimentation approach at the state level of the U.S. can provide an example of regional innovation, which can prove useful for the UK and its regional inequalities.

Table 1: A cross-national comparison between the United Kingdom and the United States

Dimension	United Kingdom	United States
Governance	Centralized national policy frameworks with local authority delivery	Decentralized state-by-state regulation
Landfill Reliance	<25% of municipal waste (2023)	>50% of municipal waste (2022)
Recycling Rate	Plateaued at ~44%	~32%
Fiscal Tools	Landfill tax, EPR, plastic tax	Limited landfill surcharges, patchwork EPR
Technology Adoption	AI sorting, anaerobic digestion, waste-to-energy	Advanced sorting in select states, composting growth
Policy Challenges	Post-Brexit alignment, recycling contamination	Infrastructure disparity, market dependency

Research Gap

Notwithstanding that government reports and analyses exist concerning waste policy development in the sector, there is little peer-reviewed scholarly synthesis with direct implications of the U.S. waste governance that also highlight the evolution of the waste policy in the UK. Most of the research is divided by waste stream or type of policy, but little longitudinal work is found that goes beyond the respective legislative history into economic instrument and technology changes all into one framework (OECD, 2022). Besides, little comparative research has been conducted on the transatlantic policy transfer possibilities between the UK and the U.S, especially regarding post-Brexit trade, climate objectives, and the shift to the circular economy.

Conceptual Framework

This work will be based on a combination of comparative environmental policy analysis and policy transfer framework that depicts how one jurisdiction innovations can be transferred to another jurisdiction (Dolowitz & Marsh, 2000). This is because analyzing the UK policy interventions against policies that can be applied in the U.S., the research notes the best practices, limitations, and the need to adapt to such policies so that effective bursts in waste governance can be achieved.

Methodology

Research Design

This research followed a qualitative-descriptive research design, which was used to critically analyze the development of waste management policies in the United Kingdom (UK) and isolate the policy-relevant lessons for the United States (U.S.). This design was chosen due to the possibility of examining thoroughly the legislative evolution and fiscal interventions in its historical and comparative aspects as well as technological interventions (Creswell & Poth, 2018). The methodology combines chronological policy analysis, thematic coding, and comparative benchmarking and can be both profound in terms of longitudinal policymaking and cross-nationally applicable.

Data Sources

Several sources of data were also employed to secure triangulation of research and the soundness of the results

Policy and Legislative Documents:
- UK: Environmental Protection Act (1990), Landfill Tax (1996), Waste Strategy for England (2007), Resources and Waste Strategy (2018), Plastic Packaging Tax (2022).
- U.S.: EPA National Recycling Strategy (2022), Connecticut, Minnesota, New York, Pennsylvania waste generator summary report, EPR summary legislation report (California, Maine, Oregon).

Statistical Databases:
- DEFRA waste statistics database (UK)
- Eurostat mun. waste stats. (EU & UK).
- E.P.A. waste characterization reports
- OECD circular economy indicators.

International Reports and Frameworks:
- What a Waste 2.0 (World Bank, 2018).
- UN Sustainable Development Goals (SDGs) database
- Basel Convention Distributes

Peer-Reviewed Academic Literature:

Journal articles of Waste Management, Resources, Conservation and Recycling, and Journal of Environmental Policy & Planning.

Sampling Strategy

The 72-document sample (42 UK-focused and 20 U.S.-focused, and 10 international/comparative studies) was selected through a purposive sampling strategy to publish between 1990 and 2023. The criteria of selection were:
1. Applicability directly to waste policy, financial instruments, or technological change.
2. Access to quantitative measures of performance, or qualitative policy assessments.
3. Presence in authoritative government, academic or international sources.

Data collection instruments

The study has developed two major instruments:

i. Document Analysis Protocol:

The main points of each document, such as the objectives of the policy, their implementation strategy, observable changes, and challenges were extracted based on a structured template.

ii. Comparative Policy Matrix:

This was a tool that was used to compare the UK with the U.S. in a systematic manner such that it covered aspects of governance structures, fiscal tools, technology adoption, and its engagement with the population as well as its performance measures.

Analytical Procedure

The analysis was borne out through three steps:

1. Chronological Mapping:

The UK waste policy expanse was divided into three such phases (19902000, 20012010, 20112023) to encapsulate the identified stages of modernization of regulation, growth focused on the development of the targets, and integration of the circular economy aspects.

2. Thematic Coding:

With the NVivo software, the policies were coded within thematic categories, which included the following: legislative drivers, economic instruments, technological innovations, institutional capacity, and mechanisms of behavioral change.

3. Comparative Benchmarking:

The performance of the UK (e.g., landfill diversion rates, recycling rates, EPR coverage) was benchmarked against the U.S national and leading state performance, against EU leaders (e.g., Germany), and emerging economy case studies (e.g., India, Nigeria).

Validity and Reliability Measures

As a measure of validity, several sources of data were cross-validated, and the government statistics, being official, were given their preference over the secondary interpretation of data. Reliability was ensured using a detailed audit trace of coding decisions and data transformations, as well as policy classifications. Based on the sample of 15% of the documents, the inter-coder reliability has been achieved with a 0.87 rate of agreement, which testifies to high consistency.

3.7 Ethical Considerations

Since the study made use of publicly available secondary data only, there were no human subjects involved in the research, and no official ethical permission was necessary. However, the sources are all acknowledged and information analysis is performed with a pledge to loyalty and clarity.

Results

UK, Policy Outcome Trends (1990 2023)

To examine the evolution of the UK's performance in waste management in the last three decades, it can be noted that the UK has already shown significant improvement in the diversion of landfills, modest progress in recycling rates, and continuous investment in waste-to-energy (WtE) and circular economy technologies.

Some of the key achievements could be considered as follows:

- **Landfill diversion:** More than 80 per cent of municipal waste went to landfill in 1990; this fell to less than 25 per cent in 2023(DEFRA, 2023b).
- **Recycling:** Between 2000 and 2015, recycling grew (until the number stabilized by 44 percent, starting at an insignificant percentage point above 10 percent (WRAP, 2023).
- **EPR and taxation:** The establishment of EPR systems, the introduction of the Plastic Packaging Tax (2022) has encouraged manufacturers to use recycled content.
- **Technological adoption:** Implementation of AI-based sorting mechanisms and practices, anaerobic digestion of food waste, and blockchain-based leg checks of the waste.

Comparative UK–U.S. Performance

Benchmarking indicates that the UK is ahead in some of the policy instruments and landfill disposal, but the U.S. still experiences more variability since some of the instruments are left to the states, and there are no appropriate federal instruments at the fiscal level, as shown in Figure 02.

Table 2. UK–U.S. Comparative Waste Management Indicators (2022–2023)

Indicator	United Kingdom	United States	Leading EU Comparator (Germany)
Landfill Reliance	24%	50%+	0.5%
Recycling Rate	44%	32%	67%
Waste-to-Energy Share	~20%	~12%	~31%
EPR Coverage	Comprehensive (packaging, WEEE, batteries)	Limited (few states)	Comprehensive
Plastic Packaging Tax	Yes (from 2022)	No (state initiatives only)	No EU-wide tax, but strong producer obligations
Circular Economy Strategy	Nationally integrated	Fragmented (state-led)	Nationally integrated

Trends in Fiscal and Regulatory Tools

The Landfill Tax in the UK (now 102.10 (2023) per tonne of active waste) has been highly successful in inducing dependence on landfill, as well as in statutory recycling and producer requirements. In comparison, the U.S. does not have a national landfill levy, and the most common interface is given on a state or local level that has resulted in a somewhat haphazard development (EPA, 2022).

Technological Innovations

Efficiency has been at an important level because of technological interventions:

- **UK:** AI-enabled optical sorting (Biffa, Viridor), anaerobic digestion on >700 new facilities, and blockchain-enabled recycling credit trading pilots.
- **U.S.:** AMP Robotics has gone fully robotics-assisted sorting, Californian composting infrastructure expansion, and chemical recycling pilot-scale factories.

There are, however, limits to the scalability of the two countries in terms of cost of capital, acceptability among the populace and market fluctuations of secondary materials.

Comparative Barriers to Progress

Analysis indicates that despite progress, both countries face persistent barriers, as shown in Table 3.

Table 3: Comparative Barriers to Progress in the United Kingdom and the United States

Barrier	UK	U.S.
Recycling Contamination	High, particularly in mixed-stream systems	High in single-stream systems
Infrastructure Disparity	Between rural and urban authorities	Between states and regions
Policy Uncertainty	Post-Brexit regulatory divergence	Lack of federal coordination
Market Dependence	Reliance on export markets for certain recyclables	Reliance on international markets pre-*National Sword*

Summary of Key Findings

The UK has shown that centralized policy frameworks coupled with fiscal disincentives can provide massive reductions in landfills.

Recycling has stagnated in both countries, which suggests that a structural change is required in terms of contamination management systems, investments in infrastructure, and awareness of the general population.

There can be a two-way learning course between the US waste governance with the UK style of fiscal instruments, and the UK government can learn with the localized innovation models of the states in the US.

Discussion

Overview

The findings of this analysis indicate that although the United Kingdom has achieved significant success in the governance of waste, especially concerning landfill diversion, EPR implementation, and integration of the fiscal policies, the country experiences continued issues concerning recycling performance, control of waste contaminants, and post-Brexit regulatory coherence. In the United States, localized innovation in some states is present, yet it lacks a coherent national strategy and, in turn, brings about vast performance disparities.

The results substantiate the main idea of the research:

H1: The UK has been able to divert volumes more onto landfill than the U. S. through its incorporated policy framework and fiscal measures, but both countries have not been able to maximize recycling results provided by systemic and behavioral obstacles.

Interpretation of Key Comparative Insights

Governance Structures

The UK has had a centralized policy-making system, which has enabled a national approach to be taken on the determination of its national targets and fiscal instruments, including the Landfill Tax. It has worked well in decreasing the amount of landfill put into landfills but has not been as successful in achieving high recycling rates because of downstream behavioral and infrastructure insufficiency. States such as California and Oregon in the U.S. have embraced decentralized governance, which fosters innovation and development of waste diversion policy. Other states are not so lucky to have such high policy levels and adopt or emulate California and Oregon, and hence, there is a divided success rate among the countries.

Fiscal and Regulatory Tools

The Landfill Tax has become one of the most renowned practices globally since it has achieved a high degree of disposal to landfill through the establishment of solid financial counterincentives (DEFRA, 2023b; OECD, 2022). In the U.S., the lack of a federal landfill tax undermines the motivation to divert, but the result has been success at the state level with deposit returns and EPR measures (NCSL, 2023).

Technological Innovation

These two countries are also adopting sophisticated waste sorting and treatment systems, although it would only take time since UK is integrating AI sorting, anaerobic digestion, and blockchain tracking, which indicates better coordination at a national level than the U.S. system that is carried out mainly by the private sector. Nevertheless, American chemical recycling pilots and increased composting give evidence of where the UK needs to learn lessons of the American innovation ecosystems.

Policy Transfer Opportunities

From UK to U.S.:

1. **National Fiscal Instruments:** Introduce a federal landfill levy to bring about similarities in diversion incentives.
2. **EPR Frameworks:** Implement new broad producer responsibility laws on packaging, WEEE and batteries.
3. **Plastic Packaging Tax:** Place a recycled content tax to encourage demand of recycled materials.

From U.S. to UK:

1. **Locality-Daxtic Model of Innovation**: Adopt locality-sensitive experiments to deal with local differences in waste streams.
2. **Public-Private Partnerships (PPPs):** PPPs should be expanded as a channel to finance infrastructure based on U.S. municipal-corporate approaches.
3. **Community:** Level Composting The scale up of localized organic waste efforts, such as those developed in California or Vermont.

Implications for the Circular Economy

The stagnation of recycling rates in both nations will indicate that optimization of the collection systems, minimizing contamination, and engaging the population need to become the main policy priorities. Unless both countries invest more heavily in domestic reprocessing and secondary material markets, both will fail to realize the full potential of the UN SDGs, the targets of the Paris Climate Agreement, and the Net Zero 2050 promises.

Limitations

Although such research is built upon policy and performance overview, the basis of such research is secondary data that can differ in their measurement understanding and presentation, and under-reporting. Additionally, there are no primary stakeholder interviews, which might bring more light into the aspects of political feasibility, reaction of the industry, and attitudes of the people. Studies in the future need to incorporate mixed methods to capture the above dimensions.

Conclusion & Policy Recommendations

Conclusion

This paper has demonstrated that the development of the waste management policy in the United Kingdom has been done through attempts to turn its formerly landfill-based system into a diversified model that involves recycling, waste-to-energy, and the circular economy approaches represents a source of ideas that the United States should pay attention to. Centralized policy regime, fiscal inducements, such as the Landfill Tax and good Extended Producer Responsibility (EPR) coverage, have seen the UK significantly decrease its dependence on landfill to below a quarter of the municipal solid waste.

Yet, systemic issues such as stagnating recycling rates, very high contamination rates, and relatively low investment across the board in infrastructure can hamper the progress toward the Net Zero 2050 and the UN SDG goals in both countries. U.S. decentralized governance allows creating local innovation, but there is a lack of unity in the national approach, compared to a centralization providing the UK with strategic clarity, but the danger of regional discrepancy in performance.

In summary, the above-presented policy exchange model between the two transatlantic nations shows that to achieve success in waste governance, it is important to embrace a hybrid model: a mixture of the UK policy, where a national strategy is used, and the U.S. approach, where community-based initiatives are adopted in the governance of issues.

Policy Recommendations

For the United Kingdom

1. **Consolidate Recycling Infrastructure and Contamination Exclusion**
    - Invest in national, uniform collection and sorting.
    - Broaden the civic consciousness activities geared towards contamination prevention.
2. **Increase the scope of EPR to Emerging Waste Streams**
    - Add some textiles, construction waste, and emerging electronic waste.
3. **Step up Low-Carbon Waste Technologies**
    - Offer subsidies to scaled innovation projects, including enhanced anaerobic digestion, chemical recycling, and AI-material recovery.
4. **Capitalize on Regional Models of Innovation**
    - Pilots developed and implemented in a locally contextualized manner, which were inspired by experimentation within U.S. states.

For the United States

1. **Embrace a Federal Landfill Levy**
    - An equal financial penalty against landfilling of waste is to be implemented after the Landfill Tax of the UK.
2. **Introducing the Nationwide EPR law**
    - Uniform the producer responsibility on packaging, electronics, and hazardous waste to mitigate disparities among the states.
3. **Imposing a Plastic Packaging Tax**
    - Foster the use of recycled material and spur home secondary material markets.
4. **Massive Community Composting Programs**
    - Train up, build out small-scale organic waste management systems like in successful California/Vermont models.

For Both Nations

1. **Build Secondary Material Markets**
    - Foster recycling by retailing materials to markets through government procurement and other incentives to the private sector.
2. **Bring Waste Management into Climate Policy**
    - Consider waste policy a direct means by which carbon reduction targets can be met, as such, climate action plans.
3. **Improve the Transatlantic Policy Collaboration**
    - Institute a working group on waste governance between the U.K. and the U.S. to exchange innovations, review together pilot projects, and align research on resource-revolution changes.

The findings of the study are evidence that waste management is not a simple technical issue but an adjustment and administrative change process. With the rate of waste generation increasing rapidly all around the world, the UK and the U.S. now have a big choice in front of them: By taking the gradual progress path or adopting a paradigm shift that integrates fiscal legislation, technological advancements, and community involvement. Sharing failures and successes, the two countries can become examples to the other nations to provide sustainable waste governance.

Acknowledgment: *We gratefully acknowledge Prof. Dr. Khaled Hussainey (Bangor University, UK) and Prof. Dr. Shahzad Hussain (Rawalpindi Women University, Pakistan) and our other colleagues for their valuable assistance and support throughout the study.*

Compliance with Ethical Standards Ethical responsibilities of Authors: *The author has read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors". This research was based on literature data analysis.*

Conflict of Interest: *The authors declare that they do not have any conflict of interest.*

Change of Authorship: *The author has read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and is aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.*

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