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Management of Sediments and their Associated Nutrients in the Sanitary Area of Bovilla Lake (Albania) and the Efficiency-Effectiveness of Its Water Making Into Drinking Water

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Abstract: *Access to safe and sufficient drinking water is a fundamental public health and environmental priority. In Albania, Tirana's primary water source, Bovilla Lake, treated at the Babrru water treatment plant, faces recurrent challenges linked to watershed mismanagement. Elevated turbidity, odor, and treatment costs reflect increasing pressures on the raw water quality.*

Applying the DPSIR (Drivers, Pressures, State, Impact, Response) framework, [1], this study investigates the physical and environmental conditions within the critical 320–400 m elevation sanitary area. Results indicate that intensive agriculture, livestock farming, and deforestation are driving soil erosion, sediment deposition, and nutrient enrichment. Concurrently, untreated urban runoff and inadequate waste management practices exacerbate water quality deterioration.

The findings highlight the urgent need for targeted interventions to regulate land use and anthropogenic pressures within the buffer zone. A coordinated, integrated watershed management approach across the broader Bovilla catchment is essential to protect the long-term sustainability and safety of Tirana's drinking water supply.

Index Terms— *Drinking water, sanitary area, management of sediments.*

I. INTRODUCTION

Failure to meet drinking water standards contributes to the spread of numerous infectious diseases [2], [3]. Approximately 90% of waterborne disease incidence is linked to unsafe water supply and inadequate hygiene and sanitation practices. Freshwater accounts for only 2.5% of the planet's water resources, and just 0.5% of that is available as groundwater or surface water [4]. Groundwater sources are insufficient to meet drinking water demands, and increasing population, changes in living standards, and the expansion of agricultural irrigation [5] have led to greater reliance on surface waters. To meet drinking water standards as defined by [6], [7], surface water requires extensive treatment.

Tirana, the capital of Albania, has experienced rapid population growth—from 200,000 residents before 1990 to around 1,000,000 today. This increase in demand has driven the city to diversify its water sources, which now include karstic springs (Selita, Shën Mëri, and Old Bovilla), 29 deep wells, and surface water from the artificial Bovilla Reservoir. Originally built for irrigation in 1992, the reservoir was repurposed in 1994 for drinking water supply with the construction of the Babrru treatment plant. It currently meets 65–75% of the city's water needs.

Socio-economic activities within the lake's catchment, along with changes in its physical-chemical and microbiological characteristics, affect raw water quality, treatment costs, and availability. Two main issues at the treatment plant are high turbidity during heavy rainfall and odor management.

This study applies the DPSIR (Driving Forces–Pressures–State–Impacts–Responses) framework [1] to assess these issues in relation to their causes. Identifying and analyzing anthropogenic pressures, along with physical-chemical monitoring of the lake and its main tributary, enables the evaluation of impacts and the implementation of effective, efficient watershed management measures. Priority is given to the protective buffer zone between 320–400 m above sea level. Improving conditions in this zone can enhance raw water quality, reduce treatment costs, and ensure the availability of drinking water that meets required standards [6], [7].

II. MATERIALS AND METHODS

The catchment area of Bovilla Lake is located in the north-northeastern part of Tirana, at the geographic coordinates N 41° 26' 44", E 19° 52' 9.4", with a maximum elevation of 320 meters above sea level (measured at the dam). The territory falls under the administration of two former municipalities—Zall-Herr and Zall-Bastar—now part of the municipalities of Kruja and Tirana, respectively. Each covers an area of approximately 55.9 km^2.

The municipality of Zall-Bastar, which includes 12 villages, has a population of about 5,800 residents [8], resulting in a population density of 112 inhabitants per km^2.

The surface area and volume of Bovilla Lake are 4.6 km^2 and 80,610,000 m^3, respectively. The maximum designed depth is 45–48 meters, with an average depth of 18–20 meters. The water residence time in the lake is approximately 4.23 years, calculated using the formula $T = V (m^3) / Q (m^3/sec)$. The total surface area of the lake's catchment is about 98 km^2 (9,800 hectares) [9].

Fig. 1 Area of Study (source: Wikipedia)

The climate of the Bovilla Lake catchment falls within the sub-hilly Mediterranean climatic zone, with annual precipitation patterns illustrated in Figure 2. The average annual rainfall ranges from 1,200 to 1,300 mm/year (1 mm of rainfall in a pluviometer is equivalent to one liter of water per square meter). Temperature trends are shown in Figure 3. These data were obtained from source [10].

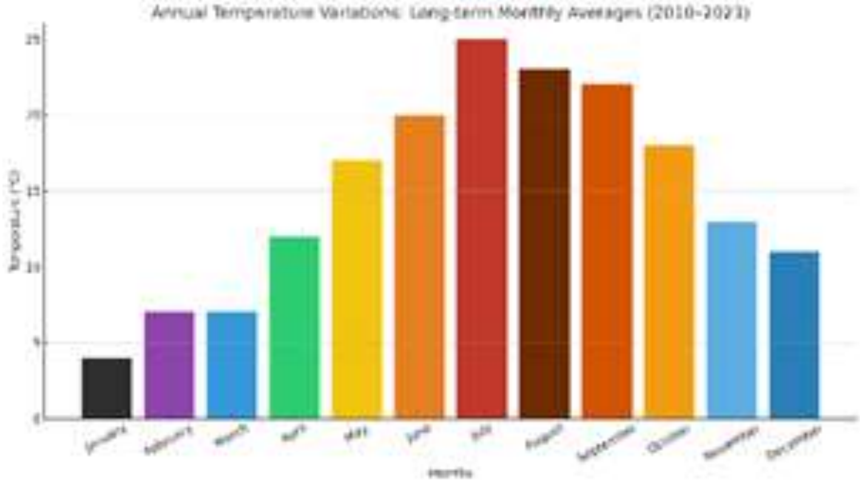

Fig. 2 Annual variations of air temperature

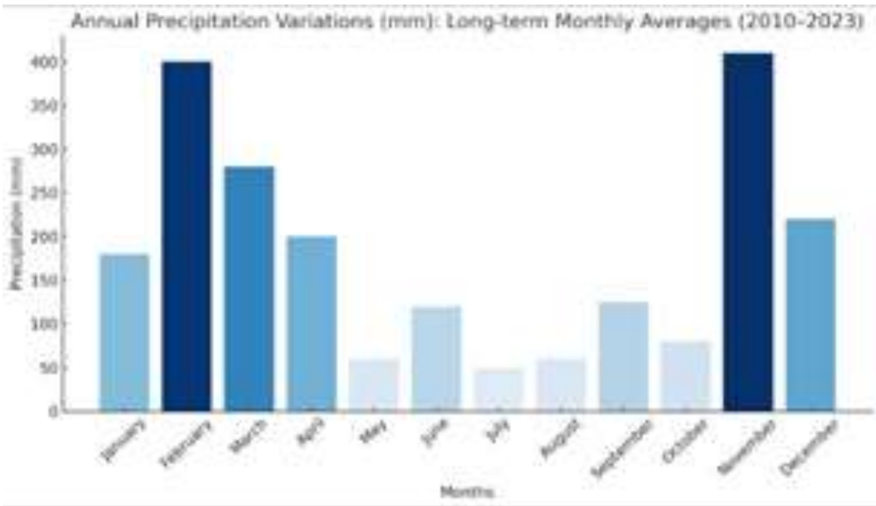

Fig. 3 Annual variations in precipitation

Geological Structure of the Bovilla Region. Spatially, the area corresponds to the carbonate mountain massif of Gami, located within the Krujë-Dajt structural belt. The region is primarily composed of dolomites, interlayered with dolomitic limestones, some of which contain rudists in certain strata. Thin bituminous shales are also found between the dolomites and dolomitic limestones. From a chronological perspective, the carbonate formation dates to the Upper Cretaceous, with a thickness ranging from 1,200 to 1,400 meters. Overlying the Upper Cretaceous carbonate formation are Paleocene deposits, consisting of interbedded dolomites, bioclastic limestones, and biomicritic limestones [11].

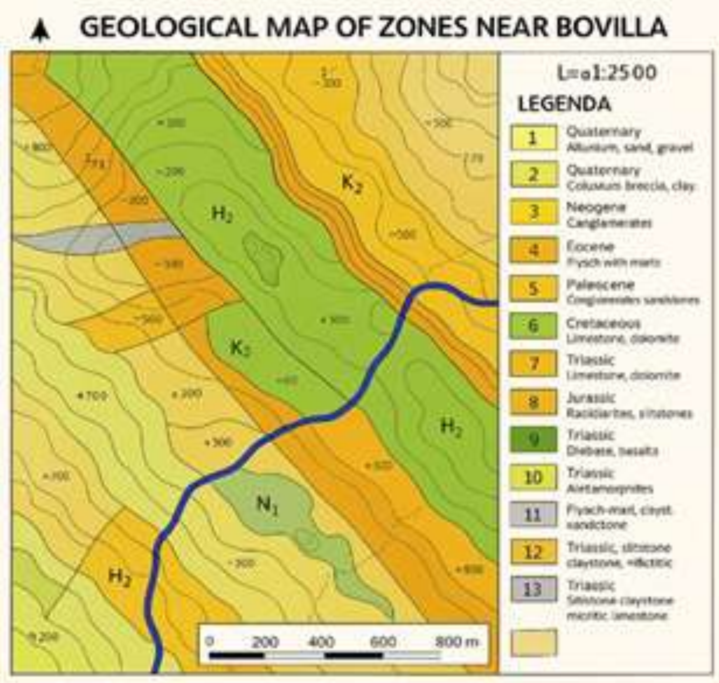

Fig. 4 Geological map of the study region, [12]

Above the carbonate formation lie transitional marls and flysch formations. These consist of a rhythmic interbedding of clay and sandstone, forming a substantial overlying cover characterized by significant thickness. The presence of this layer has made it possible to construct the Bovilla Reservoir, as it prevents the reservoir's waters from diffusing into the underlying carbonate formation [12].

Fig. 5 Marl package and flysch formation (photo by E. Kiri)

Relief and Hydrology: The topography of the catchment area is primarily hilly to mountainous. The area is subject to intense slope processes, landslides, slippages, and erosion. This study focuses on the hilly zone, which consists mainly of flysch, clay, sandstone formations. Various soil types are present: grey, forest dark brown soils, creating microenvironments that support diverse vegetation. The rocky peaks are divided by numerous streams that flow into the Tërkuza River or directly into the Bovilla Reservoir [13].

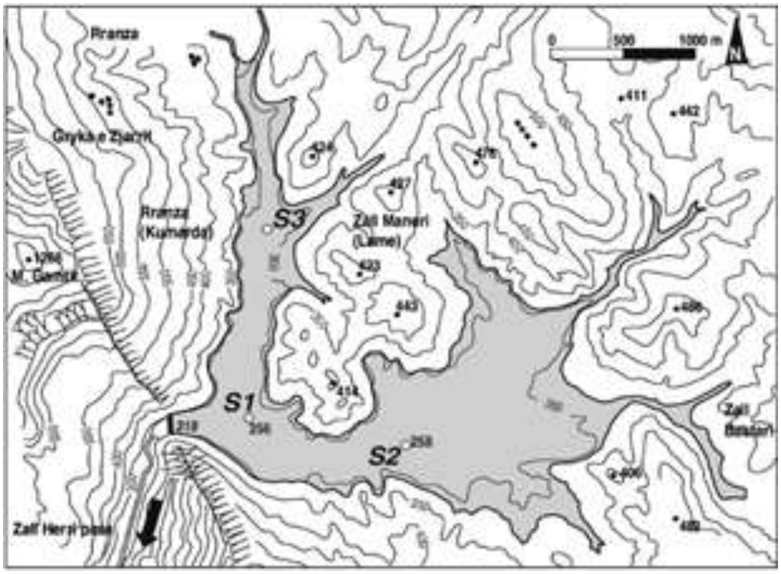

Fig. 6 Topographic map of the Bovilla Reservoir [14]

Tërkuza river lies northwest of Tirana and south of the Kruja district, with a total length of 44.1 km, a catchment area of 182 km², an average elevation of 458 m above sea level, and a slope of 22 m/km. [15].

In addition to surface inflows, Lake Bovilla is also fed by karstic springs—B1, B2, and B3—which emerge from the carbonate complex of the Krujë–Dajt mountain range. Spring B1 originates in the bed of the Tërkuza River, approximately 50 meters upstream of the dam; B2 emerges near the dam on the right bank; and B3 arises from the former riverbed of Tërkuza. Multi-year measurements conducted by the Bovilla Hydrotechnical Node indicate that these springs have a discharge ranging from 130 L/s during dry periods to a maximum of 416 L/s [16]. The Xen River originates near the Skënderbej Mountains, has a multi-year average flow of 1.81 m³/s at the Arrameras Station [17]. These flows are collected in a catchment structure. Hydrologically, the year is divided into two main flow periods.

Vegetation and Human Settlement: The vegetation in the Bovilla area belongs to the beech and shrubland zones Currently, the most populated area within the 320–400 m elevation band is Zall-Bastar, with 1,028 residents. The total population of the catchment is approximately 5,320 [8].

The Bovilla watershed is assessed using the DPSIR framework [1] to understand cause-effect relationships.

Economic Pressures in the Watershed are:

- Livestock farming, with an estimated 115,000 domestic animals—mostly small ruminants (sheep and goats)—grazing freely throughout the basin.
- Agriculture, focused on cereals, fruits, and vegetables, with minimal use of chemical fertilizers and herbicides.
- Trade and transport, although limited, as well as logging and the sale of firewood.
- Collection and sale of medicinal plants.
- Lack of wastewater infrastructure: no centralized sewage treatment system exists; septic tanks are in use.
- Municipal waste is collected in communal bins but not removed daily. These wastes contain: cardboard, plastic, textiles.

Pollution During High-Flow Periods: During high-flow conditions or flood events, the input of waste into the lake increases substantially.

Fig. 7 Plastic waste in the Bovilla Lake (Photo by M. Hoxhaj, 2024)

Other Pressures from Livelihood and Economic Activities: Additional pressures in the watershed stem from logging, carried out not only for household needs but also for commercial purposes. Analysis of satellite imagery reveals that vegetation near inhabited areas is significantly more degraded than in higher, less accessible zones. In the lower beltcomprising Mediterranean shrubland and oak forests closer to settlements, are noticeably more damaged.

The degradation of vegetation increases surface runoff coefficients, which accelerates water flow, as a result, this intensifies processes such as landslides, erosion, sediment transport, leading to sediment accumulation in the lake. To estimate the yield of sediment generated within 320-400 m asl, the sanitary zone, the Universal Soil Loss Equation (USLE) was applied [18], as follows:

$$A = 2.24 \times R \times K \times LS \times C \times P \quad (1)$$

Where:

- A is the erosion intensity (tons/ha/year)
- R is the rainfall-runoff erosivity factor
- K is the soil erodibility factor
- LS is the topographic factor, where L is the slope length and S is the slope steepness
- C is the cover management factor
- P is the conservation practice factor

The following areas have been identified as the most vulnerable to erosion within the sanitary protection zone, such as: surfaces damaged vegetation (SDV), cultivated area (CA). These surfaces were categorized into two groups:

1. Surfaces where sediments flow directly into the lake
2. Surfaces within the sub-basin of the Tërkuza River, where sediments are transported indirectly via the river.

Field observations and satellite images have enabled the determination of these areas.

Table I: Vulnerable Areas to Erosion within the Sanitary Zone

Nr	Lakeside Surfaces	Surface area (ha)	Coordinates
1 L	CA & SDV	44	41°27'13"N 19°53'16"E
2 L	SDV	9	41°26'53"N 19°51'58"E

3 L	CA	6	41°26'11"N 19°54'01"E
4 L	SDV	6	41°26'28"N 19°54'07"E
5 L	SDV	5	41°27'27"N 19°52'12"E
	Total	**70**	
Surfaces in the Terkuza sub-basin			
1 T	Zall Bastar, CA	31	41°25'43"N 19°56'04"E
2 T	Zall Bastar, SDV	30	41°25'41"N 19°55'24"E
3 T	CA (on the right)	17	41°25'53"N 19°55'43"E
4 T	CA (on the left)	10	41°26'07"N 19°55'18"E
5 T	Zall Bastarit, CA	10	41°26'00"N 19°56'06"E
6 T	Shyqyrk,CA	10	41°26'25"N 19°55'26"E
7 T	Shyqyrk, CA	8	41°26'33"N 19°54'59"E
	Total	**127,4**	

Fig. 8 Distribution of surfaces vulnerable to erosion in the sanitary area

Determination of USLE Factors: The (R) erosivity index, which determines the erosive potential based on the 30-minute maximum rainfall intensity, depends on multiple data sources. In our study, this parameter was derived using the map shown in Fig. 8

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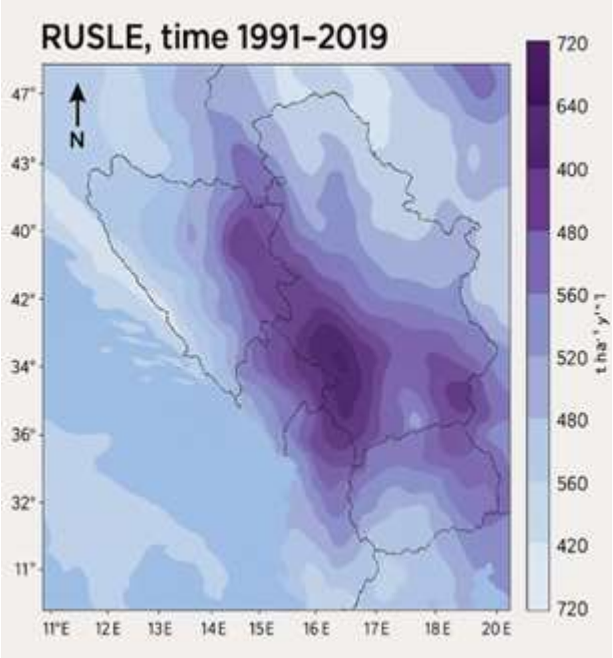

Fig. 9 R-factor obtained for a total 30-year period by RUSLE [19]

(K) Factor – Soil Erodibility: The soil erodibility factor (K) refers to the soil's susceptibility to erosion. Its evaluation takes into account the following parameters:

a) Soil texture

b) Soil depth

c) Rock fragment content in the surface layer

Table III: Reference Values for the Soil Texture Index [20]

Erosion rate		Texture
(1)	low	C(Clay),SC (SandClay), Zc(SiltClay)
(2)	medium	SCL(SandClayLoam), CL(ClayLoam), ZCl(SiltClayLoam), LS(LoamSand),S(Sand)
(3)	high	L(Loam),Zl9SiltLoam), Z(Silt),SL(SiltLoam)

Soil Texture and Depth: Classification Soil texture is classified into three categories based on the proportion of different particle size fractions (ranging from < 0.002 mm to 2.0 mm). Soil depth is also classified into three categories according to the measured depth of the soil pit: < 25 cm, 25–75 cm, >75 cm. The basin is primarily composed of flysch deposits (clay, siltstone, and sandstone) in the lower areas, while the upper slopes are characterized by limestone outcrops. All soil types are present in the basin: grey soils, brown soils, and forest dark brown soils.

Table IIIII: Data on Soil Depth and Profile at the Dajt Station [21]

Monitoring stations	Soil depth profile cm	OM %	Ca %	Mg %
Dajt	0-30	1.132	1.365	0.98
	30-60	1.354	0.987	0.78

(LS) Factor – Topographic Factor: The assessment of this factor was carried out by measuring the slope gradients and lengths. In Fig. 10, is a Landsat–Copernicus satellite image for 1L, in the same manner are assessed for other surfaces, listed in Table I.

Fig. 10 Satellite image of Surface 1L

The (C) and (P) factors were evaluated based on land use and type of vegetation cover. Forests, pastures, and dense shrubland were classified as fully protected against erosion, while cultivated and bare soils were classified as unprotected.

The USLE factors for the study area yielded the values shown in Table 4. Using these values, sediment intensity (in metric tons per hectare per year) and total sediment yield (in tons per year) were calculated according to Equation (1).

Table IVV: Usle Factor Values and Sediment Intensity for Lake-Adjacent Surfaces

R	K	LS	C	P	A(t/ha/y)
110	0.41	1.91	0.25	0.4	19.29

Table V: Usle Factor Values and Sediment Intensity for Surfaces Within the Tërkuza Sub-Basin

R	K	LS	C	P	A(t/ha/y)
110	0.21	1.99	0.27	0.45	12.51

Table VV: Sediment Intensity and Annual Sediment Yield Values for Lake-Adjacent Surfaces (320–400 M.A.S.L.)

	(Lake)Surface area (ha)	A (t/ha/y)	Y(t/yr)
Total	70	19.29	1350.3

Table VII: Calculated Sediment Intensity and Annual Sediment Yield Values for Surfaces in the Tërkuza Sub-Basin (320–400 M.A.S.L.)

	(Tërkuza) Surface area (ha)	A (t/ha/y)	Y(t/yr)
Total	127.4	12.51092	1593.891

Table VIII: Soil Loss Tolerance Rates [18]

Soil Erosion class	Potential soil loss
Moderate	11.2–22.4 tonnes/ha/yr
Severe	>33.6 tonnes/ha/yr

For both surface groups, the Soil Erosion Class falls within the moderate range of 11.2–22.4 tonnes/ha/year. Since this sediment is largely generated from cultivable land, it likely contains nutrients such as nitrogen (N) and phosphorus (P).

According to [22], the total annual amount of nitrogen and phosphorus pollutants entering the reservoir via surface runoff can be estimated using the following empirical formula:

$Wa = 10{-}6 \times Cs \times 0.2 \times A$ (2)

Where:

- Wa is the annual accumulation of adsorbed pollutants in the reservoir basin (kg/year)
- Cs is the concentration of pollutants in the sediment
- A is the area of sediment transport

According to Table 3, organic matter content in the sediments ranges from 1.132% to 1.354%.

This formula illustrates the linear relationship between Wa and erosion levels in the lake basin, emphasizing the importance of erosion control and basin management.

Physico-Chemical Water Analysis

Physico-chemical water analyses were conducted at three points along the Tërkuza tributary:

P1 – 320 m.a.s.l., N 41° 26′ 43″, E 19° 54′ 44″

P2 – 367 m absl, N 41° 25′ 43″, E 19° 55′ 44″

P3 – 400 m.a.s.l, N 41° 26′ 00″, E 19° 57′ 20″

Fig. 11 Sampling points along the Tërkuza River

Water Sampling and Analysis Methodology: Water sampling in the Tërkuza River was conducted in accordance with standard sampling procedures. Samples for chemical analysis were collected in 50 ml plastic bottles. They were transported in a thermal container at a temperature below 10°C, and analysis began within 30 minutes at the laboratory of the Bovilla Water Treatment Plant. Samples were analyzed for several physico-chemical parameters using standard examination methods (APHA, 1998). Parameters such as pH, water temperature, conductivity, turbidity, and multi-parameter probe equipped. (Horiba W-23XD model).

Table VIX: Results of Water Sample Analyses from the Tërkuza River Compared With the Albanian Standard for Drinking Water [23], [24]

Parameter	Point 1	Point 2	Point 3	Al. Standard D.W
Turbidity, NTU	8.3	9.7	15.6	1
Organic substances (KMnO4) mg/L O2	2.08	1.35	1.85	
Chlorides, mg/L Cl-	6.73	7.55	8.79	2.5
Sulfates, mg/L SO42-	21.45	25.15	28.30	15
Ammonia, mg/L NH4+	0.28	0.31	0.5	0.05
Nitrites, mg/L NO2-	0.26	0.28	0.48	0.05
Nitrates mg/L NO3-	2.5	2.8	2.96	25
Total coliforms CFU/100mL	550	392	496	50
Faecal coliforms CFU/100mL	480	989	1235	20

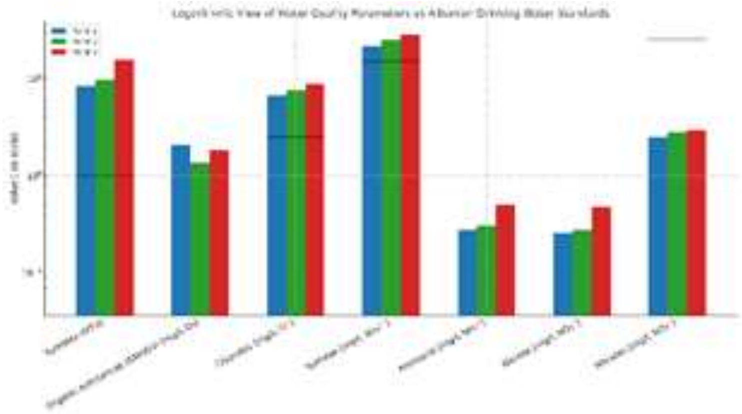

Fig. 12 Graphical presentation of water analysis results from the Tërkuza River (April'2024)

The waters of Bovilla Lake were analysed at three monitoring stations, as shown in the figure below, during the period from May 2023 to March 2024. In the lake, samples were taken from the water layer extracted by the Water Treatment Plant for the production of drinking water. The number and positioning of the monitoring stations in the lake were determined based on the lake's shape and surface area.

- Station 1: 41° 26′ 44″, E 19° 52′ 9.4″, depth 48 m
- Station 2: N 41° 26′ 36.3″, Longitude E 19° 53′ 7.6″
- Station 3: N 41° 27′ 28.3″, Longitude E 19° 52′ 34.0″

Fig. 13 Monitoring stations in Bovilla Lake

Table X: Seasonal Averages Values of Physico-Chemical Parameters in Bovilla Lake (May 2023–May 2024)

Parametri	Summer	Autumn	Winter	Spring
pH	8.01	7.96	8.2	8.06
Conductivity µS/cm	318,6	320.5	322.3	317.6
Turbity, NTU	1.96	6.27	7.81	1.81
Disolved Oxigen mg/l	8.52	8.8	9.6	9.86
Organic substances (KMnO4) mg/L O2	0.89	0.88	0.86	0.9
Sulphates, mg/L SO42-	21.11	21.59	23.29	20.14
Ammonia, mg/L NH4+	0.023	0.029	0.035	0.021
Nitrites, mg/L NO2-	0.005	0.008	0.011	0.007

Nitrates mg/L NO3-	0.82	0.82	0.89	0.83
Phosphates µg/l	47.99	50.3	56.92	50.92

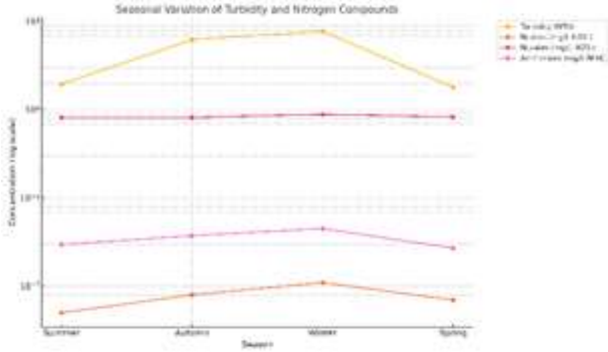

Fig. 14 Seasonal dynamics of nitrogen compounds and turbidity in Lake Bovilla (2023-2024)

In general, it is observed that the average values of chemical indicators reach their maximum during the winter season. This pattern is also evident for turbidity and sediment load, both of which show the highest seasonal averages in winter. Further studies are necessary to clarify these correlations.

III. RESULTS AND DISCUSSION

Based on the calculation of sediment intensity (metric system) for the vulnerable areas within the sanitary buffer zone (320–400 m.a.s.l.) identified along the lakeshore, the result is A = 19.29 tons/ha/year. This is attributed to soil texture (silt, clay, loam, sand) and the LS factor, which reflects the average slope length and a mean gradient of 8%. The total sediment yield for this area is Y = 1,350.69 tons/year. The largest vulnerable area near the lake, Kodra Lame, covers 44 ha, representing 62% of all degraded vegetative surfaces within the buffer zone. Rehabilitating this area alone could reduce sediment generation from degraded vegetation within the buffer zone by approximately 50%. In the Tërkuza sub-basin—also within the 320–400 m elevation band—where cultivated land and bare soil dominate, the calculated sediment intensity is A = 12.51 tons/ha/year, and the total sediment yield is Y = 1,593.89 tons/year.

The two largest vulnerable surfaces are:

- A 31 ha area near the populated center of Zall Bastar, and
- A 30 ha bare area adjacent to the settlement, at a sharp meander of the riverbed.

With the upcoming expansion of the Bovilla Water Treatment Plant in Babrru, which will increase intake capacity from 1,800 L/s to 2,400 L/s, the residence time of water in the lake will decrease. This may lead to a reduction in sediment deposition on the lakebed but an increase in suspended sediment load reaching the treatment plant. Additionally, during low-water seasons, lake levels are expected to drop further. The physical and chemical indicators of water in the Tërkuza tributary exceed the permissible limits for drinking water. In contrast, water in the lake shows fluctuating values for physical and chemical parameters, mainly linked to weather variations. A comparison with measurements from the previous year at the same sampling locations reveals two seasonal extremes:

- Summer extreme: lower lake levels, decreased sediment load, increased organic matter, and deterioration of chemical indicators.
- Winter extreme: higher water levels, peak turbidity due to sediment inflow, and elevated average values for most chemical parameters.

IV. CONCLUSIONS AND RECOMMENDATIONS

Sediments are identified as the primary pollutant source within the 320–400 m.a.s.l. buffer zone. The largest contributor is the 44-hectare area near Lame, which is sparsely cultivated and largely unvegetated. Following this are two additional vulnerable areas of 31 ha and 30 ha, respectively: the first is cultivated land near Zall Bastar, and the second is a bare surface located at the meander downstream of Zall Bastar.

Vegetation rehabilitation using native plant species should begin with the Lame area. Additionally, a stabilizing structure should be installed in the bare meander zone near Zall Bastar, where the risk of deepening erosion and landslides is high. For all other vulnerable areas, soil conservation techniques should be implemented, such as maintaining uncultivated buffer strips to reduce erosion.

State support for organic farming would reduce pesticide and fertilizer use—currently reported to be low—thereby protecting water quality.

Turbidity levels exceed permissible limits at all monitoring stations throughout the year. Turbidity is caused by suspended particles, colloidal materials, both organic and inorganic matter, plankton, and other microscopic organisms.

Wastewater discharge from populated centers, including Zall Bastar and more distant settlements, represents a significant source of pollution. Urban waste management must be improved, as litter often accumulates outside of collection containers. These wastes include cardboard, plastic, batteries, and other materials harmful to water quality.

Livestock grazing, particularly goat herding, contributes to vegetation degradation and introduces waste into the lake. Grazing should be strictly prohibited within the sanitary buffer zone. Good pasture management, including assessment of carrying capacity and aligning livestock numbers accordingly, is essential.

Raising community awareness about the importance of Bovilla Lake—as the primary water supply source for Tirana, the capital and largest city of Albania—is crucial.

Finally, it is recommended to increase the number of monitoring stations for both physical and chemical water indicators in the tributaries and lake, as well as for tracking vegetation cover in the watershed.

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