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HYDROCARBON POLLUTION MANAGEMENT IN THE VJOSA RIVER (ALBANIA) THROUGH ASSIMILATIVE CAPACITY ANALYSIS

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Abstract— The Vjosa River, shared between Albania and Greece, is the last large wild river in Europe and a protected area. Despite outstanding hydromorphological and ecological values, the lower basin is under pressure from oil exploitation and related activities. This study examines dissolved hydrocarbon (DHC) pollution, quantifying the river's assimilative capacity (AC) and assimilative length (AL) under contrasting hydrological and pollution scenarios, and applying hazard-quotient (HQ) assessment. Results show that hydrogen sulfide (H_2S) and ammonium (NH_4+) are limiting for AC in the warm season, and NH_4^+ also in the cold season; their concentrations exceed standards and the AL required for attenuation is long. Phenols, COD, and dissolved petroleum hydrocarbons (DPHC) generally meet standards. These findings provide a quantitative basis to align control measures for the AC-limiting constituents with the river's capacity and to guide prioritization. Strengthening the monitoring of petroleum- and bitumen-derived compounds (including heavy metals and naphthenic acids) and clarifying the legal framework for rehabilitating legacy hydrocarbon wastes are also essential measures to preserve the ecological integrity of the Vjosa River.
Keywords— Vjosa River, assimilative capacity, hydrocarbon pollution, water quality management, ecological integrity

I. INTRODUCTION

The Vjosa River was recently designated the Vjosa Wild River National Park (IUCN Category II) [1]. It represents an ecosystem of outstanding hydromorphological and ecological value [2]. Endemic fishes—Cobitis ohridana, Pachychilon pictum, Alburnus scoranza, and Oxynoemacheilus pindus—make it a unique natural heritage of Albania and the Balkans [2], [3].

Despite this importance, the lower Vjosa basin faces pressures from economic activities, particularly oil, gas, and bitumen exploitation in Selenica, Gorisht–Kocul, and Karbunara [4]. Additional threats include agriculture, livestock, untreated urban discharges, and soil erosion [5].

Following the National Park proclamation, a Management Plan (2024–2033) was prepared by the National Agency of Protected Areas with international partners, mainly covering the river and its floodplains [6].

Research gap. Despite persistent pressures and protected-area status, no AC/AL/HQ-based assessment exists for the Vjosa to inform discharge permitting and irrigation diversions [7]. Assimilative capacity (AC) is a highly operational management tool compared with risk assessment or environmental impact assessment, because for permitting and planning it translates environmental quality standards (EQS) into allowable loads (kg/day) and minimum discharge spacing (assimilative length, AL) under real hydroclimatic conditions. Understanding AC for key pollutants, the required AL, and hazard-quotient (HQ) categories focuses action on the most hazardous, least-assimilable pollutants and on problematic river reaches, enabling targeted and cost-effective protection.

Objectives. Focusing on dissolved hydrocarbon (DHC) pollutants: H_2S, NH_4+, phenols, chemical oxygen demand (COD), and dissolved petroleum hydrocarbons (DPHC), this study provides a quantitative basis to identify limiting DHC pollutants, to estimate AC and AL under warm (low-flow) and cold (high-flow) scenarios, to classify risks via HQ, and to guide management measures [8], [9].

II. MATERIALS AND METHODS

A. Study Area The Vjosa River is the second largest in Albania, draining 6,800 km² (4,540 km² in Albania). It flows 272 km (190 km in Albania) from the Pindus Mountains (Greece) to the Adriatic Sea. The study area extends from Poçemi to the delta, near major oil exploitation sites:

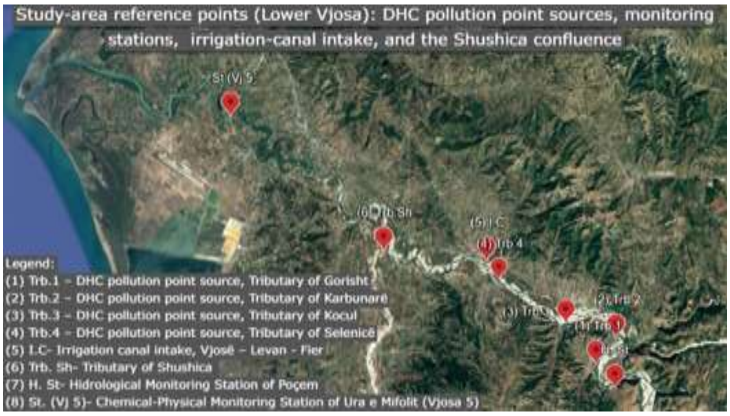

Fig. 1 Geographical Location of Vjosa River Basin

B. Geology and Hydrology

In its lower basin, the Vjosa crosses the Ionian tectonic zone and Quaternary deposits of the pre-Adriatic plain, dominated by gravels, sands, clays, and silts, producing braided and meandering channels. The average basin slope is 28%, while the riverbed slope is ~4%. The climate is Mediterranean, with 950–1,600 mm annual precipitation (66% in autumn–winter) and mean temperatures of 10.7–17.5 °C. Maximums reach 41.6 °C in Fier and 43.5 °C in Selenica [10]. Mean discharges vary from ~60 m^3/s upstream to ~200 m^3/s downstream; floods often exceed 900 m^3/s, while 100-year events surpass 5,000 m^3/s. Karstic springs such as the "Blue Eye" and Viroi (25–30 m^3/s) sustain baseflow during dry periods. [11].

C. Mining and Oil Exploitation

The basin hosts clays, limestones, gravels, and energy resources (oil, gas, bitumen) [12]. Gravel extraction has declined in recent decades [13]. Oil exploitation in the Gorisht–Kocul and Karbunara fields began in the 1960s, producing >11.5 Mt. [14]. Bitumen mines are near Selenica. In the area exploited by the current operator, there are also oil residues, "ecological pits," and other wastes that constitute significant pollution, for which—under Albanian legislation—the current operator bears no legal responsibility. Hydrocarbon pollution still reaches the river through tributaries.

The coordinates of the discharge points are:
40°30'02"N 19°42'50"E – Tributary of Gorisht (Trb 1)
40°30'54"N 19°43'39"E – Tributary of Karbunarë (Trb 2)
40°31'24"N 19°41'34"E – Tributary of Kocul (Trb 3)
40°32'47"N 19°38'48"E – Tributary of Selenicë (Trb 4).

Fig. 2 Study-area reference points (Lower Vjosa): DHC pollution point sources, monitoring stations, Vjosë–Levan–Fier irrigation-canal intake, and the Shushica confluence.

D. Numerical Data

Hydrological data were obtained from the Poçemi hydrological station on the Vjosa River. The discharge point of tributary Trb 1 is located next to this station. The hydrological variables—discharge Q (m^3/s) and flow velocity V (m/s)—represent monthly means for the years 2010–2022. The low-flow period includes May–October (warm season) with a mean river-water temperature T_v = 27 °C; the remaining months represent the high-flow period with T_v = 10.5 °C [15].
Dissolved Hydrocarbon (DHC) pollution is represented by hydrogen sulfide (H_2S), phenols, chemical oxygen demand (COD), ammonium (NH_4+), and dissolved petroleum hydrocarbons (DPHC), measured during 2023, in Trb 1 prior to its confluence with the Vjosa.

Analyses followed standard protocols: H_2S (APHA 4500-S^{2-} E), phenols (APHA 5530 D / ISO 6439), COD (APHA 5220 B / ISO 6060), NH_4^+ (APHA 4500-NH_3 F / ISO 7150-1), and dissolved oil & grease (APHA 5520 B / EPA 1664A) [16].
Based on field surveys, quantitative measurements were collected only at Trb 1; the relative ranking of (DHC) pollutions among tributaries is: Trb 1 > Trb 2 > Trb 3 > Trb 4.
DHC pollution in Trb 1–Trb 3 is of the same type (oilfield waters), whereas Trb 4 drains the bitumen mine and, in addition to the indicators above, contributes naphthenic acids (data unavailable), which have properties distinct from dissolved oil [17]. Heavy metals and non-dissolved oil—present in large amounts along the banks and bed of the Vjosa, especially near discharge points—as well as fractions that may dissolve under certain conditions were not considered. DHC- pollutions indicators were compared against EU water policy/quality standards [18], [19].

TABLE I HYDROLOGICAL DATA AND DHC – POLLUTANTS FOR WARM-COLD SEASON

Pollutants	T_{water} (°C)	Q(m^3/s)	V (m/s)	H_2S mg/l	Phenols mg/l	COD mg/l	NH_4 mg/l	DPHC mg/l
Trb (1)	27	0.12		118	0.75	1235	17	28
River (p1)	27	62.7	0.61	0	0	65	0.059	0
Trb (1)	10.5	0.13		97	0.35	905	12	19
River (p1)	10.5	292.11	1.39	0	0	40	0.048	0
Standard				0.1	1	100	0.05	20

E. Data Sufficiency and Limitation

Number This study uses 2010–2022 hydrological data (Poçemi), 2023 chemical data for Trb 1, and field visits. This coverage is sufficient to assess AC and AL under two seasonal scenarios. However, having concurrent chemical measurements for Trb 2–Trb 4 would allow us to capture and verify any overlap of assimilative zones.

F. Equations applied and analytical techniques

The analysis begins with Trb.1 (Tributary of Gorisht).
The assimilative capacity, AC, expressed in kg/day (and also in g/s), is calculated according to [20] using Equation (1).

$$AC = (C_{std} - C_x) \cdot Q \cdot 86.4 \tag{1}$$

Where:
- Q (m^3/s) — discharge of the river/tributary at the confluence point;
- C_{std} — the standard value of the pollutant concentration;
- C_x (mg/L) — the pollutant concentration after some time since entering the river.

According to [21], the concentration after a given time t is:

$$C_X = C_0 \cdot e^{(-k \cdot t)} \tag{2}$$

C_0 (mg/l), Initial concentration of the pollutant after mixing of the river with a tributary, is calculated [22] using Equation (3).

$$C_0 = (C_{riv} \cdot Q_{riv} + C_{tri}b \cdot Q_{tri}b)/(Q_{riv} + Q_{tri}b) \tag{3}$$

k - Temperature-dependent reaction coefficient (k)

The decomposition coefficient, according to [23] depending on water temperature is given by the Arrhenius-type Equation:

$$kT = k_{20} \cdot 0^{(T - 20)} \tag{4}$$

Where:
- kT is the reaction coefficient at water temperature T,
- k_{20} is the reaction coefficient at 20 °C,
- θ is the temperature correction factor (usually between 1.02 and 1.12),
- T is the water temperature in °C

Assimilation length (AL), [24]: The Equation (5) for the AL is:

$$AL = -(V/K) \cdot (C_x / C_0) \tag{5}$$

Hazard-quotients (HQ) scoring. Hazard quotients (HQ) are then calculated as the ratio of concentration to the corresponding standard [25].

$$HQ = C_{meas} / C_{std} \tag{6}$$

Hazard categorization. An HQ value > 1 signals potential risk for aquatic organisms, whereas HQ ≤ 1 indicates acceptable conditions (I). For clearer distinctions in the degree of exceedance, some authors have used additional HQ categories [26], [27].
– < HQ ≤ 1.5 — Slight exceedance (II);
– 1.5 < HQ ≤ 3.0 — Moderate exceedance (III);
– < HQ ≤ 10 — High exceedance (IV);
– HQ > 10 — Extreme exceedance (V);

III.RESULTS AND DISCUSSION

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A. Approach 1

The Assessment of AC and AL for the warm and cold seasons for DHC pollutants from Trb.1 only, without considering the other tributaries.

By applying Equations (1) – (5) to the chemical, hydrological data (Table 1), and adopting the following values for the decay coefficient k, [28] - [32],

- for H_2S, k_{20}=0.50/d-1, θ=1.08;
- for NH_4+, k_{20}=0.20/d-1, θ=1.07;
- for Phenols, $k_{20} \approx 0.08\ d^{-1}$, $\theta \approx 1.06$;
- for COD, $k_{20} \approx 0.25\ d^{-1}$, $\theta \approx 1.06$;
- for DPHC, $k_{20} \approx 0.03\ d^{-1}$, $\theta \approx 1.07$.

We obtain the following results, as presented in

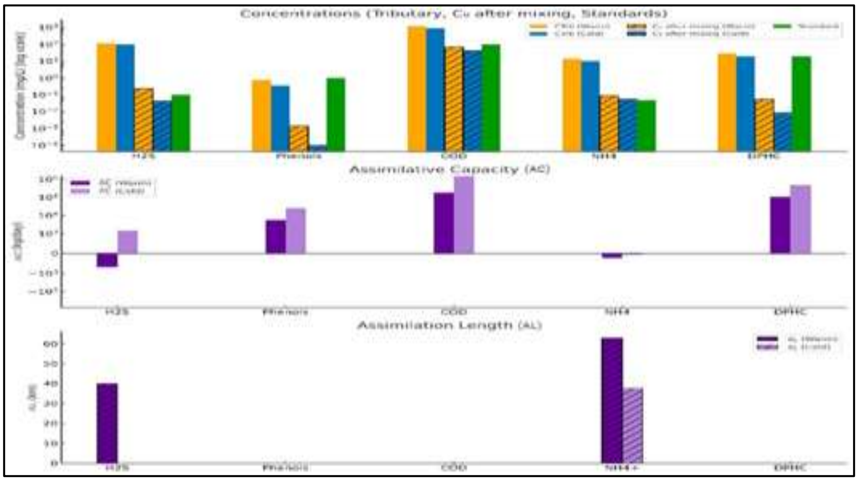

Table 2.

TABLE IIAC AND AL VALUES FOR TRB 1 (WARM-COLD SEASON)

Pollutants	C_{Trb1} (mg/l) warm	C_o (mg/l) warm	C_{Trb1} (mg/l) cold	C_o (mg/l) cold	C_{std} (mg/l)	AC (kg/day) warm	AL (km) warm	AC (kg/day) cold	AL (km) cold
H_2S	118	0.23	97	0.04	0.1	-680.65	39.9	1435	0
Phenols	0.75	≈0	0.35	10.4	1	5419.8	0	25245	0
COD	1235	67.2	905	40.4	100	177837	0	1505256	0
NH_4	14	0.09	9.8	0.05	0.05	-224.49	62.9	-83.746	37.6
DPHC	28	0.05	19	0.01	20	108262	0	504777	0

The indicators of H_2S and NH_4^+ exceed the standard after mixing; accordingly, AC is negative and a minimum AL is required, ≈ 40 km for H_2S and ≈ 63 km for NH_4^+.

For phenols, COD, and DPHC, post-mixing concentrations are below the standard, so AL = 0 km.

Overall, the computed results indicate that, in the warm season, the limiting pollutants for the river's AC are H_2S and NH_4^+, in the cold season, is NH_4^+.

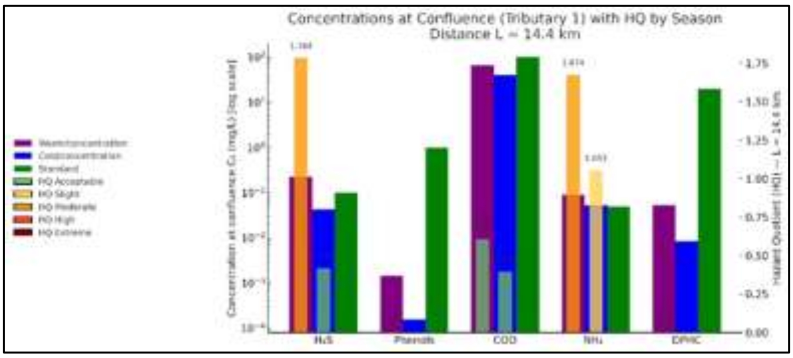

Fig. 3 Concentrations (log scale) and their standards, ACs, Als, for warm and cold Season. (only Trb.1)

These results indicate that, assuming Trb.1 is the sole source of pollution, exceedances of the standards would occur for H_2S and NH_4^+ during the warm season, and for NH_4^+ during the cold season, at the water-diversion point to the Vjosa–Levan–Fier irrigation canal. Impairment of irrigation water quality amplifies the impacts of DHC pollutants in the Vjosa. The canal diverts about 2.3 million m³/year of water from the Vjosa.

B. Approach 2. HQ scoring and categorization of DHC pollutants at the irrigation water-diversion point. (only trb1)

Step 1: Compute pollutant concentrations at the irrigation diversion point. This is done using Equation (5) over a distance of 14.4 km from Trb 1 to the water-diversion point, for warm-cold seasons

Step 2: Based on the computed concentrations, according to formulas (6), hazard quotients (HQ) were evaluated for each pollutant for both; the warm and cold seasons.

Step 3: HQ categorization for each pollutant, for warm and cold seasons, following [26], [27]. After these three steps, the results are presented in Table 3.

TABLE III SEASONAL POLLUTANT CONCENTRATIONS AND HQ CATEGORIZATION IN THE RIVER, 14.4 KM FROM POINT 1 (TRB.1–VJOSA CONFLUENCE)—THAT IS, AT POINT 5 (IRRIGATION WATER DIVERSION

Pollutants	Co1 (mg/l) warm	$C_{14.4Km}$ (mg/l) warm	C_o1 mg/l cold	$C_{14.4Km}$ cold	C_{Std} (mg/l)	HQ warm	HQ Category	HQ cold	HQ category
H_2S	0.225	0.178	0.043	0.041	0.1	1.784	III	0.419	I
Phenols	0.002	0.001	0.00	≈0	1.0	0.001	I	0	I
COD	67.23	60.67	40.38	39.69	100	0.607	I	0.397	I
NH_4	0.091	0.083	0.05	0.05	0.05	1.674	III	1.053	III
DPHC	0.053	0.052	0.008	0.008	20	0.002	I	0	I

C. Approach 3. Comparative analysis of AC, AL, HQ and their categories, also considering Trb.2–Trb.4.
In the absence of numerical data for DHC pollution in Trb.2–Trb.4, we conduct a comparative, qualitative/semi-quantitative analysis.
For Trb.1–Trb.3, the hazard ranking is as follows, based on [33] – [35]:

$$H_2S > \text{phenols} > \text{DPHC} > NH_4^+ > \text{COD} \quad \text{(a)}$$

Trb.4—in addition to the DHC pollutants listed above—conveys pollution from bitumen mining, i.e., it also discharges naphthenic acids (NAs). Downstream of the Trb.4 discharge, the hazard ranking is therefore adjusted as follows, based on [36]: [to be completed with the specific order].

$$H_2S > \text{Fenole} > \text{NAs} > \text{DPHC} > NH_4^+ > \text{COD} \quad \text{(b)}$$

If ranked by the HQ indicator, for Tributary 1 we obtain:

$$\text{HQ } H_2S = \text{HQ } NH_4^+ > \text{HQ COD} > \text{HQ DPHC} > \text{HQ Phenols} \quad \text{(c)}$$

These comparisons show that H_2S ranks first both in the hazard ordering and in the HQ-based ordering, whereas phenols, although second in the hazard ranking, fall to the bottom when ranked by HQ. Tributaries Trb.2 and Trb.3 do not change this HQ ordering; they exhibit similar DHC pollution but at lower magnitudes than Trb.1.
Final ranking, considering both hazard and HQ orderings:

$$H_2S > NH_4^+ > \text{NAs} > \text{COD} > \text{DPHC} > \text{phenols} \quad \text{(d)}$$

By river reach:

- Point 1 → Point 2:
  - HQ (H_2S): Category III (moderate)
  - HQ (NH_4^+): Category III
  - HQ (COD, DPHC, Phenols): Category I

- Points 2 → Point 4: Due to inputs from Trb.2–Trb.3, HQ categories are likely to increase (e.g., III→IV; I→II) and AC to decrease.
- Point 4 → to the irrigation-canal intake: NAs must be considered; AC decreases.
- Reach from the canal intake→ to the Shushica confluence: No major changes in HQ or AC are expected.
- After the inflow of the Shushica tributary, substantial hydrological changes occur that enhance assimilation. The mean discharges of the Shushica at its confluence with the Vjosa are Q = 9.78 m³/s in the warm season and Q = 37.2 m³/s in the cold season [8].

D. Verification of results.
The study finding, $C_o(NH^4) = 0.08$ (mg/L) at L=14.4 km, correlates with the National Monitoring Program (NMP) results [37]: for the indicator Std (0.05) < $NH_4^+ \leq 0.3$ mg/L, the Vjosa basin waters are rated Good quality (Class II). The NMP has no monitoring station near/just downstream of the hydrocarbon discharge points; the closest station is Mifol Bridge. In addition, independent monitoring [38], [39] at several stations—including Mifol Bridge—has shown that the Vjosa River waters are heavily contaminated with heavy metals; a major source within the basin is hydrocarbons (among others). Groundwater in the Vjosa aquifer exhibits similar contamination patterns.

IV.CONCLUSIONS

This study shows that the assimilative capacity (AC) and assimilation length (AL) of the Vjosa River vary markedly with pollutant type, tributary inflows, and seasonal conditions. The warm season is the most problematic, with lower AC and higher AL for H_2S and NH_4^+, identified as the limiting pollutants. The reach with the highest HQ category (oscillating between Category III–IV for the limiting pollutants) extends from Point 1 →Point 6—i.e., from the entry of Trb.1→ irrigation canal, in practice up to the confluence of the river Shushica.
This reach constitutes a highly threatening environment for aquatic species due to the high toxicity of H_2S and NH_4+. The situation is further aggravated by the large amounts of undissolved oil. Consequently, immediate protective measures are required to safeguard the Vjosa.

Recommendations for operators and authorities:

– Seasonal discharge control. Reduce or suspend discharges of oil-contaminated waters during the warm season, when the river's AC for H_2S and NH_4+ is lowest and exceedances of water-quality standards are most likely.
– Effluent pre-treatment. Subject industrial wastewater to advanced treatment (e.g., aeration, biological oxidation, adsorption on activated carbon) prior to discharge into tributaries, to reduce concentrations of hydrogen sulfide, ammonium, and phenols.
– Emergency oxygenation. During low-flow periods, implement artificial aeration (e.g., diffusers or cascades) in critical tributaries to prevent oxygen depletion and acute H_2S toxicity.
– Continuous hotspot monitoring. Install automatic sensors for dissolved oxygen, H_2S, and NH_4+ in sensitive reaches to enable real-time detection of threshold exceedances.
– Progressive remediation of legacy pollution. Gradually rehabilitate oil-contaminated sites along tributaries through soil washing, bioremediation, or other appropriate methods to prevent chronic leakage into the river.

Recommendations for National Decision-Makers:

– Improve the regulatory framework for legacy pollution. The national legal framework should explicitly require current operators to rehabilitate hydrocarbon wastes inherited from past exploitation activities. This would close existing legal gaps, ensure accountability, and accelerate the remediation of polluted hotspots that continue to threaten the ecological integrity of the Vjosa basin.
– Strengthen the National Monitoring Program. Increase the number of monitoring stations along the Vjosa and expand the set of indicators—specifically hydrogen sulfide (H_2S) and naphthenic acids (NAs)—for which data are currently lacking.

Recommendations for Researchers:

– Integrate field measurements with modeling. In future studies, combine in-situ observations with modeling approaches to better predict pollutant behavior under varying hydrological and seasonal conditions.
– Include sediment compartments. Extend analyses to sediments to capture the cumulative effects of oil-related pollution across the basin.
– Assess chronic ecological impacts. Address the long-term ecological effects of petroleum-related compounds.

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