



Typology and classification of water quality in an intermittent river in a semi-arid Mediterranean climate

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Abstract The typology and classification of rivers are highly relevant concepts in the field of limnology and freshwater ecology. Water body typology systematically categorizes water bodies based on their natural attributes, while water body classification groups them based on specific criteria or purposes for management, regulatory, or administrative reasons. Both concepts play important roles in understanding and managing water resources effectively. This scientific article focuses on the ZAT River in Morocco as a model for studying low-flow and intermittent rivers. The objective is to develop an accurate model for the typology and classification of small, low-flow rivers into homogeneous classes based on natural and anthropogenic factors. The study also investigates the impact of human activities on altering the uniformity and reference nature of the water body. The typology of water bodies is carried out according to

the European methodology specified in The European Commission's Water Framework Directive (WFD) in 2000. The classification of water bodies is conducted by assessing their chemical and biological quality using the weighted index (WI), the Iberian Biological Monitoring Working Group (IBMWP) index, and multivariate statistical methods such as principal component analysis (PCA) for confirming water quality assessment. The results indicate the possibility of dividing the basin into four water bodies. Water bodies show homogeneity in terms of chemical quality when human influence is minimal or during periods of high river flow. However, increased human influence and decreased river flows lead to heterogeneity in chemical quality, indicating an unstable state. This study is the first of its kind in arid and semi-arid intermittent rivers, where such an approach could be suggested to determine their typology and classification.

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Introduction

Due to their ecological and economic interests, surface aquatic resources are among the most investigated ecosystems (Brierley, 2020). Surface water is crucial for both human and animal life as well as the smooth operation of many economic sectors (Julien, 2006). Several decades ago, the typology of

rivers became a highly relevant concept in the field of limnology and freshwater ecology (Wetzel, 2000). Despite rivers being open and continuously changing systems with high temporal and spatial variability, river ecologists proposed the concept of isolated sections that are predictably distributed along the length of a river (Lyche Solheim et al., 2019). Water body typology and water body classification are two distinct concepts in the field of hydrology and water resource management. Water body typology systematically categorizes water bodies based on their natural attributes, while water body classification groups them based on specific criteria or purposes for management, regulatory, or administrative reasons. Both concepts play important roles in understanding and managing water resources effectively (Kagalou & Leonardos, 2009).

Typology for rivers, as mandated by the European Commission's Water Framework Directive (WFD) in 2000, involves the creation of classifications by EU Member States. These classifications incorporate environmental variables or permanent descriptors, with predefined or more loosely defined ranges for each descriptor (as per Annex II of the WFD, system A or B, respectively) (Kagalou & Leonardos, 2009). These descriptors should represent natural conditions, such as altitude, size, basin geology, and supporting abiotic components such as nutrients, transparency, oxygen, flow, and riparian zone structure (Ferreira et al., 2006; Lyche Solheim et al., 2019). These natural conditions are called the reference conditions and are defined as unaltered or minimally altered by human activity (Munné & Prat, 2004; Thorp et al., 2006). A water body type can be defined as a collection of lakes or rivers that share similar natural ecological conditions, encompassing factors such as geo-morphological, hydrological, physicochemical, and biological characteristics. Essentially, a water body type represents a consistent entity with minimal natural environmental variations, which serves as a reference point for detecting human-induced impacts (Dodkins et al., 2005; Heasley et al., 2019; Reyjol et al., 2014). The ecological status of rivers is assessed by comparing deviations from the reference conditions specific to each water body type (Schourup-Kristensen et al., 2021).

The typology employed in Europe for water body delineation primarily relies on natural parameters and has demonstrated effectiveness in rivers characterized

by significant and consistent flows. However, in regions with small, low-flowing, and intermittently present rivers in Mediterranean climates, the European typology incorporates additional criteria, notably considering river discharge. Within this context, three primary categories are established for non-perennial streams based on the annual comparison between observed and expected dry months: "intermittent" (water present for more than 8 months), "ephemeral" (water present for less than 8 months), and "episodic" (water only present following intense precipitation events) (Skoulikidis et al., 2017).

In addition, due to anthropogenic pressure and low river flows, rivers are rapidly undergoing eutrophication processes, which have a considerable negative impact on the quality of water resources, especially for surface waters (Mustapha, 2008). Due to population growth, urbanization, industrial development, and the rise of intensive agriculture in the countries under semi-arid environments, known for their slow-flowing rivers, water resources are coming under increasing pressure (Sehlaoui et al., 2020). Furthermore, in most such countries, wastewater from most urban, rural centers, and industrial units are generally discharged into the receiving ecological systems, with or without prior treatment, resulting in water pollution by organic, nutrients, heavy metals, and pathogens.

Typology of rivers in such arid environment is currently lacking an official framework. However, due to repeated years of drought and the increasing decrease in rivers flow, the need for adapted methodology for river classification remains crucial. Most European countries rely solely on natural parameters to distinguish different water bodies in a river (Lyche Solheim et al., 2019). But in countries with arid and semi-arid climates, the water flow of rivers is intermittent and the questions that could arise is how much this European approach is suitable to be applied in this type of low flux context. The anthropogenic impact could be also considered much structural on watershed basin composition.

Classification techniques, based on the weighted index (WI), is frequently employed by policymakers and researchers and offers a local approach to assess the chemical quality of surface water in Morocco (Ben-Daoud et al., 2011; Mourhir et al., 2014; Qalmoun et al., 2022). In numerous basins in the Mediterranean region, the Iberian Biological Monitoring

Working Group index (IBMWP) is also utilized (Alvarez Troncoso et al., 2022; Arias-Real et al., 2022; Guellaf & Kettani, 2021; Nahli et al., 2022). These indices are a good resource for making wise decisions and evaluating the relative quality of water (Ren et al., 2020; Tripathi & Singal, 2019). Numerous studies also use statistical techniques like principal component analysis (PCA) in addition to chemical and biological indicators (Olsen et al., 2012) to obtain information about the most important chemical parameters that together explain the diversity in the data set (Ustaoglu & Tepe, 2019).

This study is focused on the ZAT River (Morocco) as a model for a low-flow and intermittent river.

The objective is (i) to apply an accurate model for the typology and classification evaluation of small, low-flow rivers into homogeneous classes basing both on the natural and anthropogenic impact factors and (ii) study the anthropogenic impact on the homogeneity of the identified water body basing on their physicochemical and biological water quality. The multivariate statistical methods was used also to confirm water quality assessment.

Materials and methods

Study area

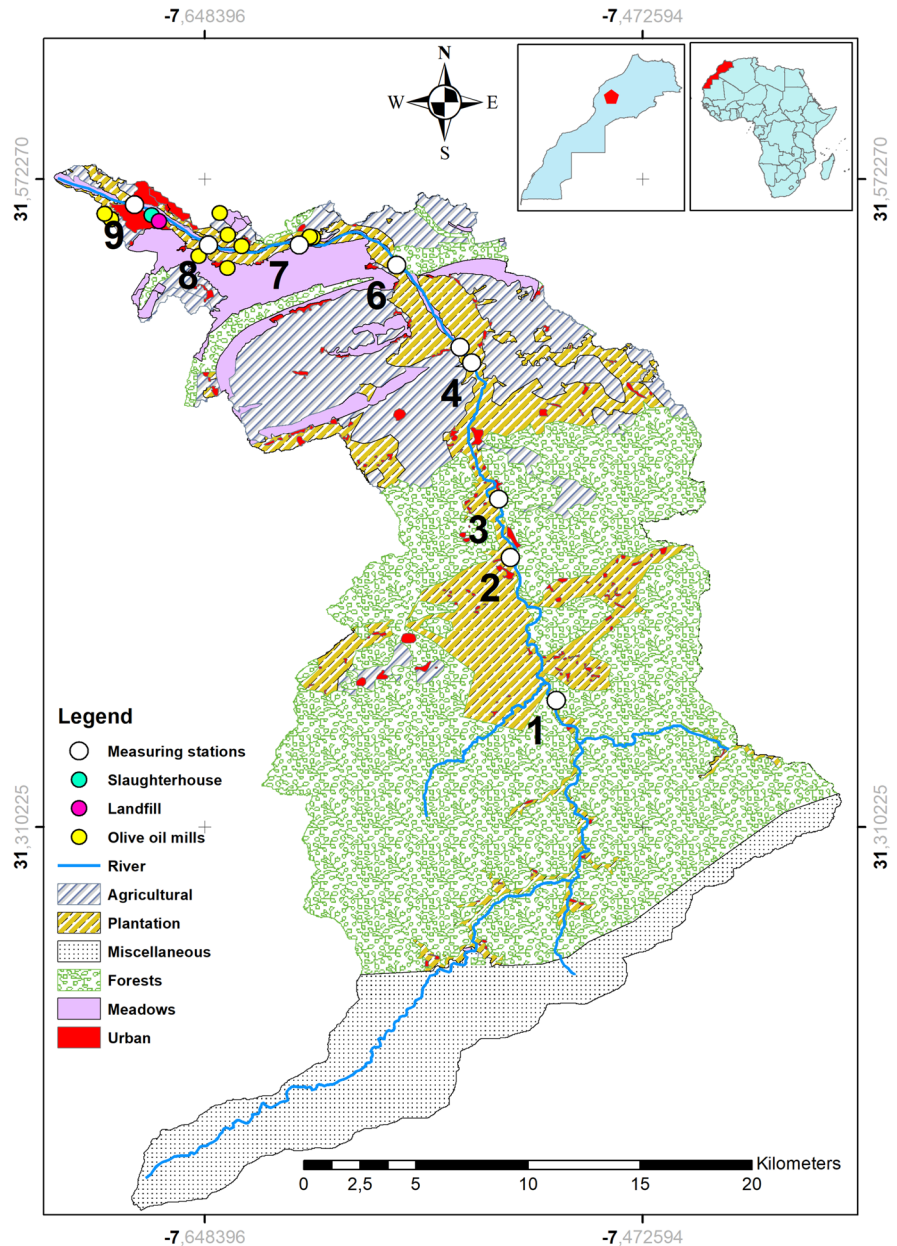
The ZAT basin is one of the sub-basins of the Tensift watershed (Fig. 1). This basin extends from the Atlas Mountains to the Atlantic Ocean in central Morocco, with an area of 20,450 km² (Benkirane et al., 2022). The sub-basin of ZAT is characterized by an area of 921 km² (Boudhar et al., 2010). The dominance of the Mediterranean climate is highly influenced by altitude (Benkirane et al., 2022). It is also characterized by an altitude of 3911 m upstream in the southern part of the basin and an altitude of 430 m downstream in its northern part. With an average slope of 19% in the upper part to 0.88 in the lower part (Chehbouni et al., 2008). The ZAT basin is characterized by the predominance of igneous rocks downstream, Triassic rocks in the middle to the bottom, and the presence of sedimentary rocks downstream (Bouaida et al., 2021). The ZAT sub-basin is drained by an 89-km-long main river (Benkirane et al., 2022). It contains a one flow monitoring station at kilometer 60 on the main

river. This station recorded an average precipitation of 255 mm and an average discharge of 3.33 m³/s (Benkirane et al., 2020). The downstream of the ZAT river is characterized by high water depletion due to irrigation canals and groundwater recharge (Bouimouass et al., 2020), as well as recording an annual average of 1600 mm/year as evaporation rate (Er-Raki et al., 2010). The ZAT River exhibits characteristics of an intermittent river, with water flow ceasing after kilometer 60 during the summer months, particularly in months 7, 8, and 9. In certain years, extended periods of drought may even occur in months 10 and 11, as observed in the year 2020 (Fig. 3). The basin is characterized by the concentration of urban and industrial pollution downstream of the river, with the presence of some agricultural activities (Fig. 1).

Data collection and processing

In order to perform the water bodies in the ZAT River, spatial data has been obtained from the Land Cover website at: <http://earthexplorer.usgs.gov/>, as a DEM. SRTM resolution 30×30 m for the LANDSAT Digital Elevation Model (Shuttle Radar Topography Mission). The DEM was used to define ZAT watershed and evaluate its drainage patterns, elevation, and slope data. The ArcGIS® software's Geographic Information System (GIS) interface was used to perform processing on the DEM data (Benkirane et al., 2020). Using a thematic map of 1/10,000 of Morocco's bedrock geology, a base map of the four geochemical categories was created (siliceous, calcareous, mixed, and organic) (Lyche Solheim et al., 2019; Perez et al., 2019). Thus, 22 lithological units were divided into siliceous or calcareous categories in the ZAT Basin. The study area's ecoregions were divided using the Köppen climate classification (Cui et al., 2021). The ZAT basin bioclimatic stage classification was provided by the local Watershed Agency in Marrakech in addition to valuable information including daily flow, land cover, and sources of pollution (GPS location and quantity of discharges) (Fig. 2). Furthermore, we conducted field surveys, along with monitoring campaigns, throughout the winter, spring, and summer of 2021, in nine sampling points (Fig. 1) with twice a month frequency.

Fig. 1 Geographic location of the study stations (S1 to S9) in ZAT River, Morocco



Water flow data

Water flow was measured at station 7 in 2020/2021 (Fig. 1). Figure 3 describes the evolution of water flow in wet and dry periods. The hydrological conditions in the region throughout the year 2021 can be classified into four distinct hydraulic periods. A medium flow period was observed during January and February (Winter). A high flow period was observed during March and April (Spring). A low flow period

was observed during May and June (Summer). A period characterized by no flow was observed during July and August.

Pollution sources

Different sources of onsite pollution exist in downstream ZAT river area: wastewater from olive oil extraction units (OMW) (Fig. 2), wastewater from the slaughterhouse existing near the part of ZAT

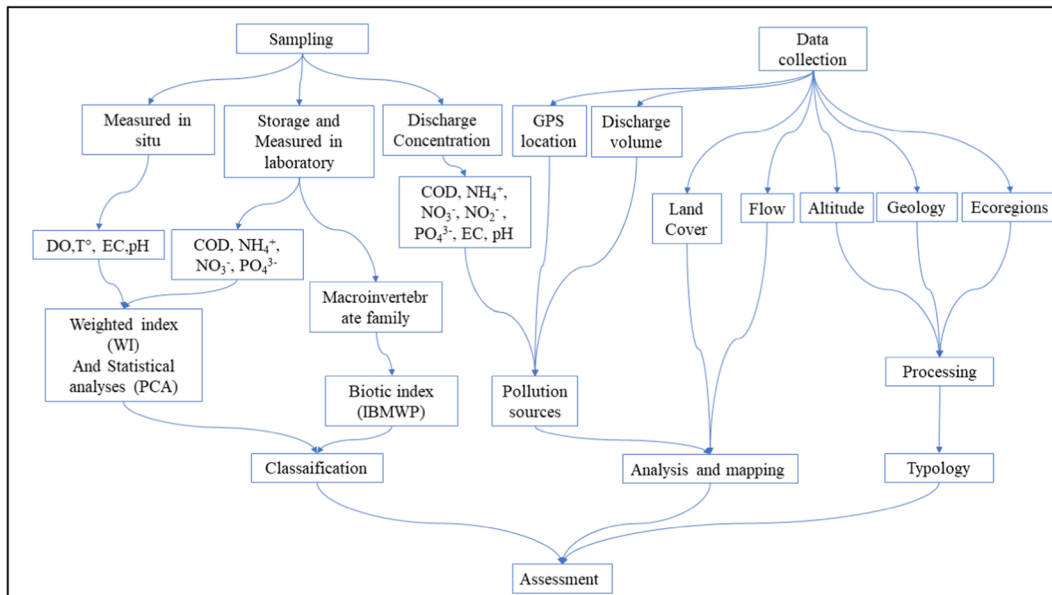
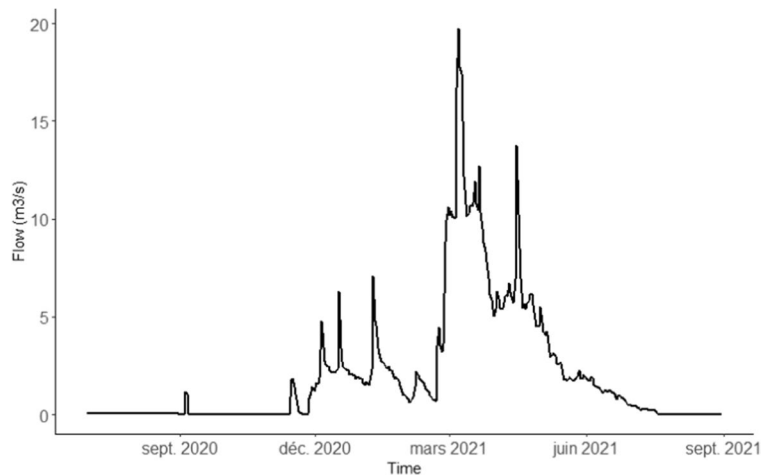


Fig. 2 A workflow scheme of the methodology used in this study

Fig. 3 Flow measured in S7 in ZAT River, Morocco



river called Ait Ourir river (SW), the leachate from the local public landfill (LL), and domestic wastewater discharged from Ait Ourir town (EU). To have a global idea about these different kinds of pollution, three weekly campaigns were undertaken downstream of each source, during May 2021, before their discharge into the river. OMW samples have been taken from a storage reservoir inside the industrial unit that is illegally and anarchically poured from time to time into the river. The mean characteristics of such sources of pollution are described in Table 1.

Typology of river water bodies method

The river ZAT was divided into homogeneous units (water bodies) according to the methodology described in Annex XI, System A of the European Water Framework Directive.

This methodology is based on the use of elevation, geochemical, and climatic data, as morphological, biological, and climatic characteristics of river basins influence river ecosystems and their functioning. The ranges for each type descriptor primarily follow WFD

Table 1 The mean ($n=3$) physicochemical properties of the discharged wastewater into the river surrounding. EU, urban wastewater; SW, slaughter wastewater; OMW, olive mill wastewater; LL, landfill leachate

Parameters	Units	Discharge limit values in river	EU	SW	OMW	LL
Discharge volume	m ³ /day	—	2.503	110	52	50
pH		5.5–9.5	8.01 ± 0.22	7.74 ± 0.12	5.76 ± 0.31	7.52 ± 0.15
CE	μs/cm	2700	1474 ± 144.31	2580 ± 175.11	18,590 ± 250.12	8490 ± 310.04
DCO	mg/l	250	1342 ± 30.91	2509 ± 44.2	193,565 ± 500.32	2576 ± 120.41
NH ₄ ⁺	mg/l	NTK = 40	90 ± 0.87	46.13 ± 1.47	74.01 ± 1.61	73.40 ± 2.01
NO ₃ ⁻	mg/l		3.02 ± 0.16	9.48 ± 0.62	20.01 ± 0.41	12.19 ± 0.86
NO ₂ ⁻	mg/l		6.11 ± 1.01	11.35 ± 0.96	62.20 ± 2.05	12.46 ± 0.51
PO ₄ ³⁻	mg/l	Pt = 15	4.04 ± 0.26	21.22 ± 2.41	34.58 ± 0.11	3.01 ± 0.09
DCO pollutant load	kg/j	—	3.359	276	10.151	129

Annex XI, System A, presented in Table 2. The intersection of the three coverage layers (altitude typology, climatic typology and geological typology) is used for water body identification (Lyche Solheim et al., 2019; Munné & Prat, 2004).

Monitoring of water quality method

During a 6-month period in 2021, the ZAT River was studied to investigate its chemical and biological quality in nine stations situated from upstream to downstream (Fig. 1). Dissolved oxygen, water temperature, electrical conductivity, and pH were measured using a multi-parameter device (HANNA HI 9829, Romania). The other parameters (chemical oxygen demand, ortho-phosphorus, ammonium, nitrates, and polyphenol) were measured in the laboratory according to AFNOR standards. Aquatic macroinvertebrate sampling was conducted between January to June 2021 at the nine sites along the ZAT River. Macroinvertebrates are determined until the family as needed in the calculation of the quality index (Nahli et al., 2022).

Classification of river water body method

Based on the data collected during the monitoring of the chemical and biological quality of the ZAT River over a 6-month period in 2021, the water quality classification of the water bodies is determined based on the application of several multivariate statistical techniques and water quality indicators such as the weighted index (WI) and the biological monitoring working party index (IBMWP). This classification aims to assess the quality of the ZAT River by examining whether the water bodies maintain their reference quality from upstream to downstream or if there is a structural anthropogenic pressure that influences the water bodies to exhibit a higher number of quality classes.

WI (weighted index) determination

The calculation of the weighted index (WI) is integrating different physicochemical (COD, NH₄⁺, NO₃⁻, PO₄³⁻, DO, T°, EC, pH) values by a special

Table 2 Criteria used to establish river types using system A in the two ecoregions of the River Basin District, according to Annex XI of the Water Framework Directive (2000/60/EC)

	Type		
	Altitude	Geology	Ecoregions
Classes	Highlands (> 800 m)	Siliceous	Mountain climate
	Middle altitude (200–800 m)	Calcareous	Mediterranean climate
	Plain (< 200 m)	Organic	

type of mathematical averaging function (1) (Errochdi et al., 2012).

In this study, we will use the system developed by the “Directorate of Water Resources and Planning” in Morocco (Qalmoun et al., 2022). The system is based on the concept of the weighted quality index (Mourhir et al., 2014), calculated using the following formula:

$$WI = li + [(ls - li)/(bs - bi)] \times (bs - pa) \quad (1)$$

- *li*: the lower index · *ls*: the upper index.
- *bi*: the lower bound · *bs*: the upper bound.
- *pa*: the analyzed indicator value.

The ranges of the grid’s water quality assessment ratings are converted into unitless numbers ranging from 0 (very bad quality) to 100 (excellent quality). While evaluating water quality, several forms of pollution are considered. These types of pollution are identified by collections of characteristics that have a similar nature to or an impact on aquatic habitats, such as phosphorus matter (PO_4^{3-}) and organic and oxidizable matters (COD, NH_4^+ , DO). The index of each parameter (WI) was obtained by weighting the concentration of the parameter to classify between very poor and excellent quality by the quality grid (Table 3). Also, the weighted value limit of the parameters defining the selected modification was averaged to provide the index of an adjustment. A set of threshold values that the various parameters of the various modifications must not exceed define each quality class. This index consists of determining the overall quality by the lowest alteration index (Mourhir et al., 2014; Qalmoun et al., 2022).

IBMWP (Iberian Biological Monitoring Working Group) calculation

The biotic index IBMWP is an important method to assess the biological quality of freshwater ecosystems. For the application of the IBMWP index, we considered a family to be present when more than one individual was counted. A score was then assigned to the family, and the scores of the families were added together to determine the IBMWP value for the site. The number of individuals (more than 1) does not affect the score, but the existence or absence of a family affects the score. The sampling was carried out by our hydrobiology team, and the identification

and determination of the samples were based on a key already mentioned in the article and also on the database deposited at the Marrakech Natural History Museum (Nahli et al., 2022).

Statistical analyses

A statistical study was conducted to evaluate the physical and chemical properties of water in the ZAT River Quality Control. The evaluation was carried out by analyzing the data set using the mean, standard deviation, and principal component analysis (PCA). The mean explains the mean value; the standard deviation measures the “dispersion” or “variability” of the samples. Principal component analysis (PCA) explains the correlations between 9 physicochemical parameters and 9 stations over 3 seasons with the analysis of 243 measurements (Olsen et al., 2012). This multivariate statistical analysis was applied to the data using the R system, version 4.1.2.

Results

Identification of ZAT river water bodies

According to the standards of Annex XI of the Water Framework Directive (2000/60/EC), basing on altitude parameter, the ZAT basin is divided into two regions (Fig. 4): the highlands (>800 m) and the middle altitude (200–800 m). A highland zone (altitude > 800 m), with average slope of 6.22%, represents about 90.45% of the area of the whole sub-basin and coincides with the feeding area of ZAT river and its main tributaries. A plain area (altitude < 800 m, average slope 0.88%) which corresponds to the areas of agriculture and development of groundwater pumping. The plain zone occupies about 9.55% of the ZAT sub-basin area.

In terms of the geochemical composition of the lithological units, the ZAT basin contained two zones (Siliceous, Calcareous). The upstream siliceous-dominated zone represents about 34.63% of the surface of the whole sub-basin, and the downstream calcareous-dominated zone represents about 65.37% of the surface of the whole sub-basin (Fig. 4).

The sub-basin is subdivided into two climatic stages, a Mediterranean semi-arid climate, the dominant climate of the basin, which covers 93.49% of

Table 3 Extract from the general grid of physicochemical and microbiological quality used for the classification of surface water in Morocco

Parameters	Unites	Excellent (1) £	Good (2) £	Mediu (3) £	Bad (4) £	Very Bad (5) £
Indices		100-80	80-60	60-40	40-20	20-00
Temperature						
Temperature	C	< 20	20-25	25-30	30-35	>35
pH						
pH		6.5-8.5	6.5-8.5	8.5-9.2	<6.5ou>9.2	<6.5ou>9.2
Organic and Oxidizable Matter						
DO	mg/l	>7	5-7	7-3	3-1	<1
COD	mg/l	<30	30-35	35-40	40-80	>80
NH4-	mg/l	<0.1	0.1-0.5	0.5-2	2-8	>8
Nitrates						
NO3-	mg/l	<10	10-25	25-50	>50	-
Phosphorus Matter						
PO4--	mg/l	<0.2	0.2-0.5	0.5-1	1-5	>5
Mineralization						
CE	µs/cm	<750	750-1300	1300-2700	2700-3000	>3000

the surface area of the ZAT sub-basin, and a mountain climate, which covers the high mountains and represents only 6.51% of the surface area of the ZAT sub-basin (Fig. 4).

The criteria described in Table 1 are used to define the water bodies of the ZAT rivers, according to the WFD. Then, the intersection of the three coverage layers (elevation typology, climatic typology, geological typology) is used to define the river water bodies. The division of the water bodies generates four water bodies in the basin of the ZAT:

WB 1: high plateau, Montagnard, siliceous; WB 2: high plateau, Mediterranean, siliceous; WB 3: high plateau, Mediterranean, calcareous; WB 4: medium altitude, Mediterranean, calcareous (Fig. 5).

Water quality monitoring

Physicochemical monitoring of water quality

In order to verify the homogeneity of the identified water bodies in the ZAT river, the results of the

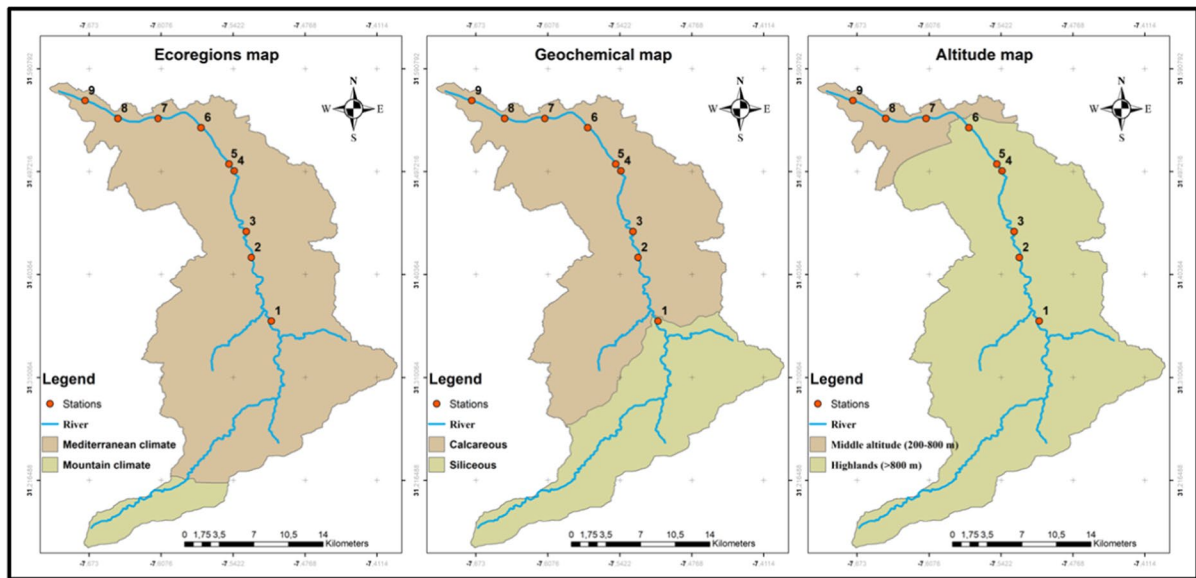


Fig. 4 Results of river type classifications based on altitude, geochemical, ecoregion, in the ZAT watershed district

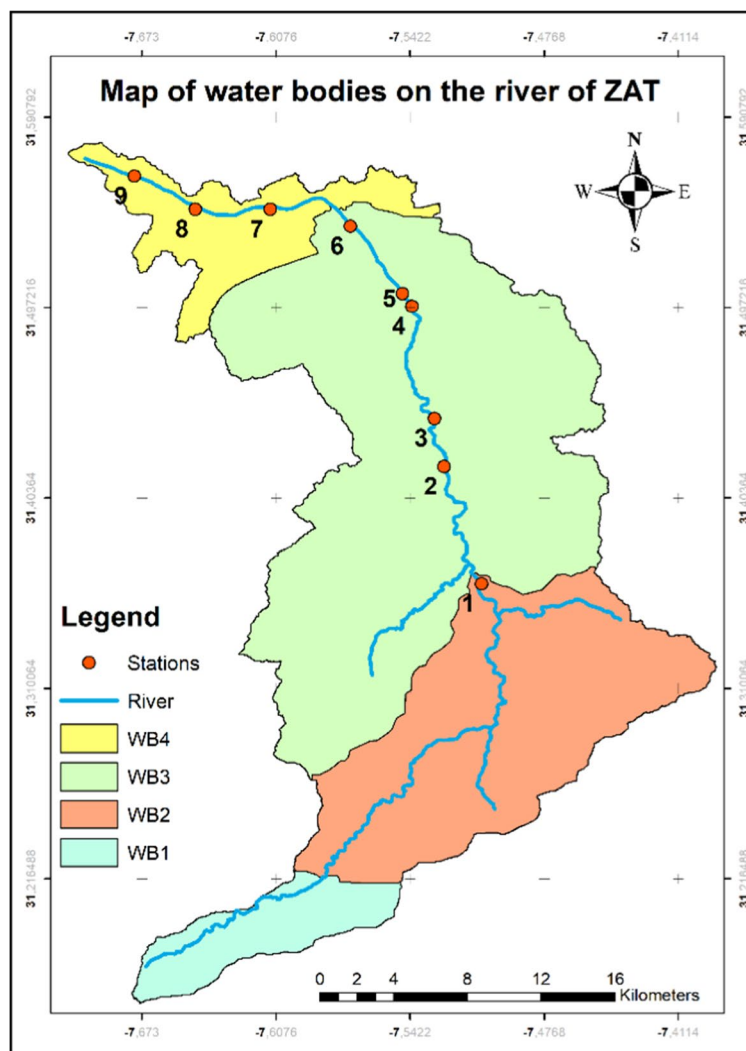
physicochemical quality monitoring in winter, spring, and summer of nine stations in the ZAT river were explored. The WB1 is the most upstream water body. The station 1 represents WB2, WB3 contains stations 2, 3, 4, 5, and 6. WB4 is represented by stations 7, 8, and 9. The degree of pollution of each parameter in each WB has been evaluated according to Moroccan standards and has been shown in Fig. 6.

The temperature recorded very good to good quality, despite its progressive increase from upstream to downstream and its increase in summer, but it did not exceed globally 25°. The pH also recorded very good quality, not exceeding 8.5 in summer, spring, and winter, in all stations. The electric conductivity recorded very good to good quality from station 1 to station 6, and the same quality is recorded at points 7, 8, and 9 only during spring. Stations 7 and 8 recorded an average quality between 1500 and 3000 $\mu\text{S}/\text{cm}$ in winter. On the other hand, in the summer, poor quality is recorded at downstream in station 9 with more than 3000 $\mu\text{S}/\text{cm}$. Dissolved oxygen recorded very good quality in most of the stations and all seasons, except for points 7 and 8 in summer, which recorded a good value, and point 9, which recorded good quality in winter and medium quality in summer. For COD, it recorded very good quality in all stations and seasons, except for point 9, which recorded poor quality in winter and summer. Polyphenol recorded

concentrations below 1 mg/l in all stations, except for points 7 and 8 in winter, which recorded concentrations between 1 and 2 mg/l, and point 9, which recorded 1.26 mg/l in autumn, 2.67 mg/l in summer, and 7.22 mg/l in winter. The ammonium show is good to very good quality in all stations except for station 9, which records medium quality, while nitrates recorded very good quality in all stations. Orthophosphate recorded very good quality from point 1 to point 6, while points 7 and 8 recorded good quality, especially in winter, while only point 9 recorded poor quality.

Figure 7 shows the results of the quality of the ZAT River in winter, spring, and summer according to the Moroccan quality index. Results show that station 1, located in water body 2, is characterized by very good quality in summer, good quality in spring, and medium quality in winter and is directly affected the pH change. For the stations (2, 3, 4, 5, and 6) located in water body 3, they record good quality in all seasons, while points 7 and 8 located in water body 4 record good quality in spring and medium quality in winter and summer under the influence of conductivity. For station 9 located in water body 4, it recorded a good quality in spring, while in winter and summer, it recorded a poor quality due to the effect of the all-following parameters (COD, NH_4 , PO_4 , EC). The results showed that at a high flow rate of about

Fig. 5 Identified river water bodies in the ZAT river, according to the WFD



5.47 m³/s, the river is not strongly affected by the high pollutant load discharged in the spring 3764 kg COD/day at a concentration of 1469.86 mg COD/l, but at a lower river flow rate, the effect of the same pollutant load becomes effective and modify the water quality in water body 4 to make it consist of two classes: a reference class at the upstream and a variable class due to anthropogenic influence at the downstream.

Biological monitoring of water quality

The study found that the biodiversity and specific families of macroinvertebrates can be used to indicate the presence and degree of pollution in the ZAT river. The research was conducted during wet and dry

periods at nine stations along the river, and 13 macroinvertebrate families belonging to 6 orders were identified (Table 4). In winter and summer, station 1 had the most families. Most stations were characterized by the presence of six families, and station 9 had only two families present in both seasons (Simuliidae and Chironomidae). Some families and orders were unique to specific stations and seasons, such as the presence of the family Psychomyiidae at station 2 and the emergence of the orders Gastropoda and Tricladida in summer (Table 5).

The quality obtained by the biotic index IBMWP varies according to the studied stations and the periods of study (winter, summer) (Fig. 8). The station 1 is the only one that present a medium quality in

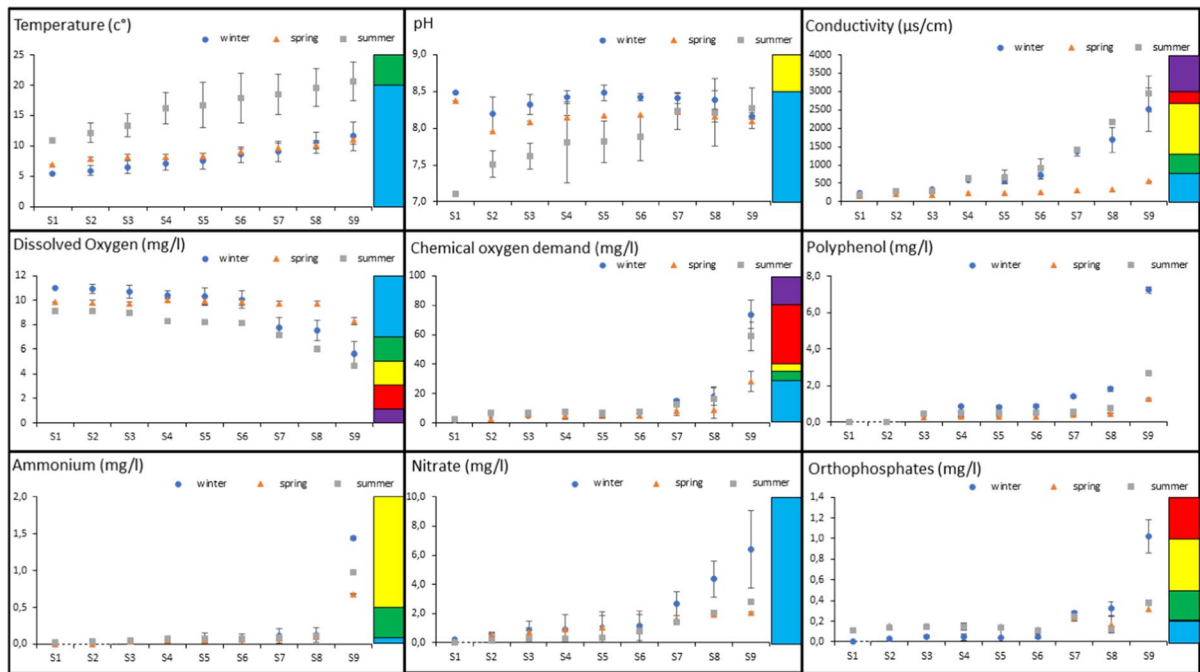


Fig. 6 Spatial and temporal evolutions of the physicochemical quality of the ZAT river in winter, spring, and summer for each parameter (COD, NH_4^+ , NO_3^- , PO_4^{3-} , DO, polyphenol, water temperature, electrical conductivity, pH, and the related water quality)

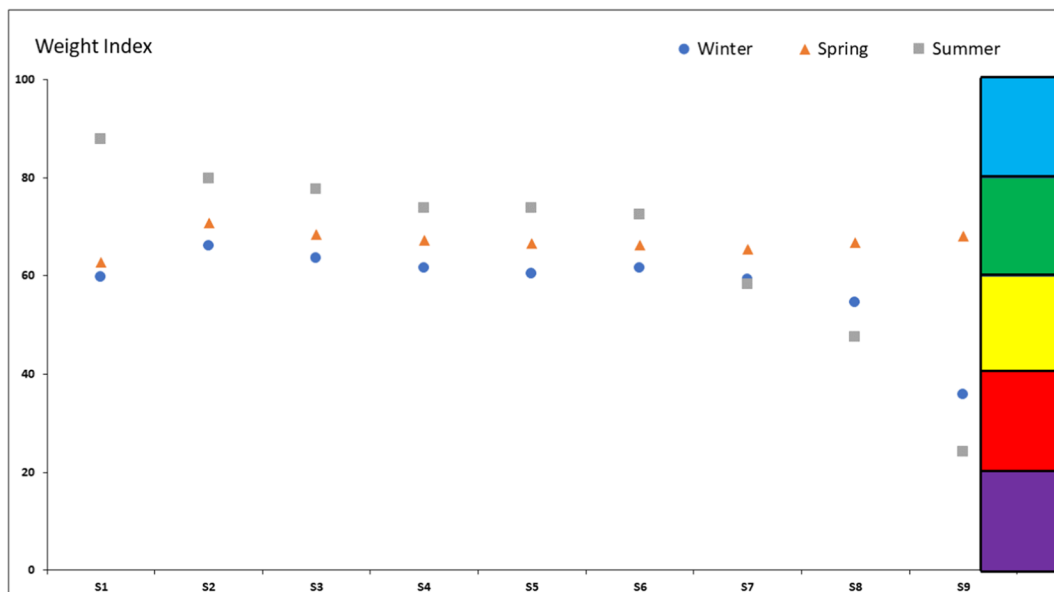


Fig. 7 Values of weighted index recorded at the ZAT sub-basin stations

Table 4 Significance of IBMWP index values

Class	IBMWP value	Water quality
I	>100	Excellent
II	61-100	Good
III	36-60	Medium
IV	16-35	Bad
V	<15	Very Bad

winter and summer. For stations 2, 3, 4, 5, and 6 that were identified in water body 3, medium quality was recorded in summer and poor quality in winter. Stations 7 and 8 have poor quality in both seasons. Station 9 has very poor quality in both seasons (Fig. 8).

Statistical analyses

The PCA results (Fig. 9) show a value of 84% cumulative variance on both axes 1 and 2. The PCA presents the correlation between 9 physicochemical parameters and 9 stations over 3 seasons with the analysis of 243 measurements. The results show a degradation of the chemical quality of water in the different stations along the first axis. The results also show that station 9 is positively correlated with pollutant concentrations, followed by points 7 and 8 with a medium positive correlation, in summer and winter. For the other points (1wi, 2wi, 3wi, 4wi, 5wi, 1sp), they are positively related to the oxygen concentration and negatively to the other pollutants. Concerning the temperature, it appears that it has a positive correlation with all points in summer and a negative correlation with all points in winter.

The PCA is produced by six families: Group 1 (9wi) has high concentrations of pollutants and low concentrations of oxygen and low temperature. Group 2 (9su) has high concentrations of pollutants, high temperatures and low concentrations of oxygen. Group 3 (7wi, 8wi, 9sp) has medium pollutant concentration, low temperature, and low oxygen concentration. Group 4 (7su, 8su), presents a medium concentration of pollutants, a high temperature, and a low concentration of oxygen. Group 5 (1wi, 2wi, 3wi, 4wi, 5wi, 1sp) has high oxygen concentration and low temperature and pollutant concentration. Group 6 (1su, 2su, 3su, 4su, 5su, 1su) has a high positive concentration for temperature. The drop shows no significant results.

Discussion

River water body identification

The typology of the basin reveals four distinct water bodies based on their characteristics and spatial distribution. The first water body, covering 6.51% of the basin area, exhibits a mountainous climate with snow accumulation. The second water body encompasses 28.12% of the basin area and is predominantly a forested region, with a small portion utilized for agricultural purposes. The third water body, constituting the largest portion at 59.82% of the basin area, is characterized by traditional agricultural lands, pastures, and olive cultivation, while lacking any significant industrial or urban activities. Lastly, the fourth water body, accounting for 9.55% of the basin area, is located at the river mouth. It is notable for its high concentration of olive oil factories and the presence of a sizable city with approximately 40,000 inhabitants. This area is characterized by permeable soil and the presence of a water bed, which influences water volume dynamics, resulting in a gradual decrease until the water eventually disappears at the river's end.

For the purpose of examining the impact of human activities on the uniformity of water bodies, we have collected samples from two distinct water bodies, namely WB3 and WB4. This comparative analysis aims to investigate the changes induced by human influence on the homogeneity of these water bodies, with specific emphasis on the unique characteristics exhibited by WB3 and WB4.

According to the hypothesis of the creation of water bodies (Ferreira et al., 2006; Lyche Solheim et al., 2019; Schourup-Kristensen et al., 2021), a water body type is characterized by a collection of lakes or rivers that share similar natural ecological conditions, encompassing factors such as

Table 5 Taxonomic richness of the study stations (S1 to S9) in Oued ZAT, during wet (January 2021) and dry (June 2021) periods

Sampling period																					
Macroinvertebrate			January (winter)									June (summer)									
Class	Order	Family	S1	S2	S3	S4	S5	S6	S7	S8	S9	S1	S2	S3	S4	S5	S6	S7	S8	S9	
Insecta	Ephemeroptera	Baetidae	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+		
		Caenidae	+	+	+	+	+	+	+	+										+	
	Diptera	Heptageniidae	+		+	+	+	+	+	+			+	+	+	+	+	+	+		+
		Simuliidae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		Chironomidae	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		Limoniidae												+	+	+	+				
Mollusca	Trichoptera	Tabanidae	+			+						+									
		Hydropsychidae	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	
		Psychomyiidae		+										+							
Tubertaria	Gasteropodes	Planorbidae										+									
		Lymnaeidae												+			+				
		Planariidae												+							
Arachnida	Hydracarina	Hydracarinae	+	+	+							+		+	+					+	

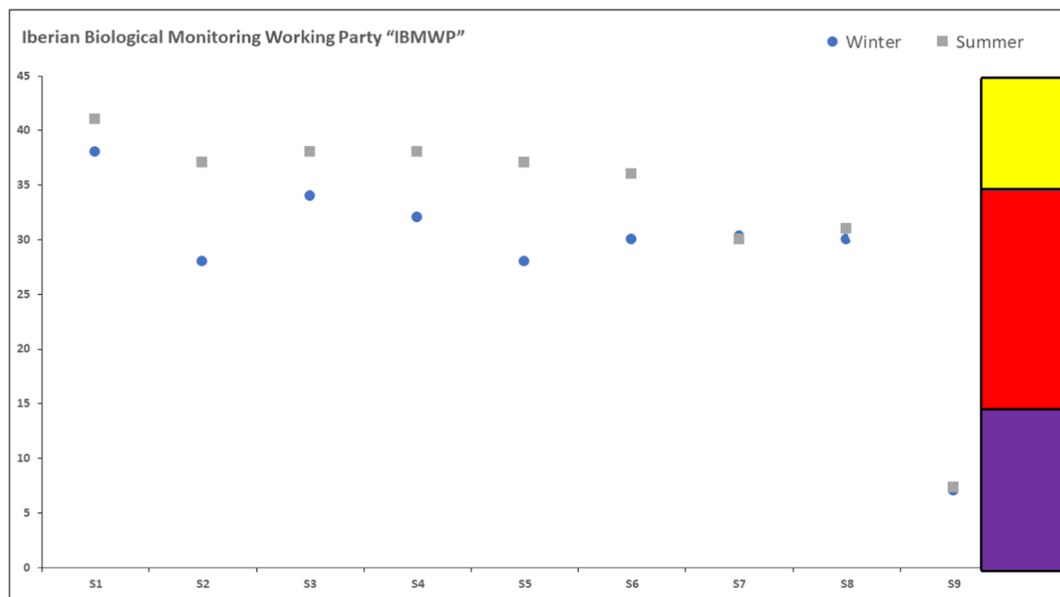


Fig. 8 Values of the IBMWP index for the studied stations (S1 to S9), in Oued ZAT, Morocco during wet (January 2021) and dry (June 2021) periods

geo-morphological, hydrological, physicochemical, and biological characteristics. Essentially, a water body type represents a consistent entity with minimal natural environmental variations, which serves as a reference point for detecting human-induced impacts (Munné & Prat, 2004; Thorp et al., 2006).

Physicochemical monitoring of water quality

The basin experiences an increase in temperature downstream (Rego & Rocha, 2014). This is because the ZAT basin is characterized by a dominant Mediterranean climate and is strongly influenced by altitude (Benkirane et al., 2022). The basin recorded an

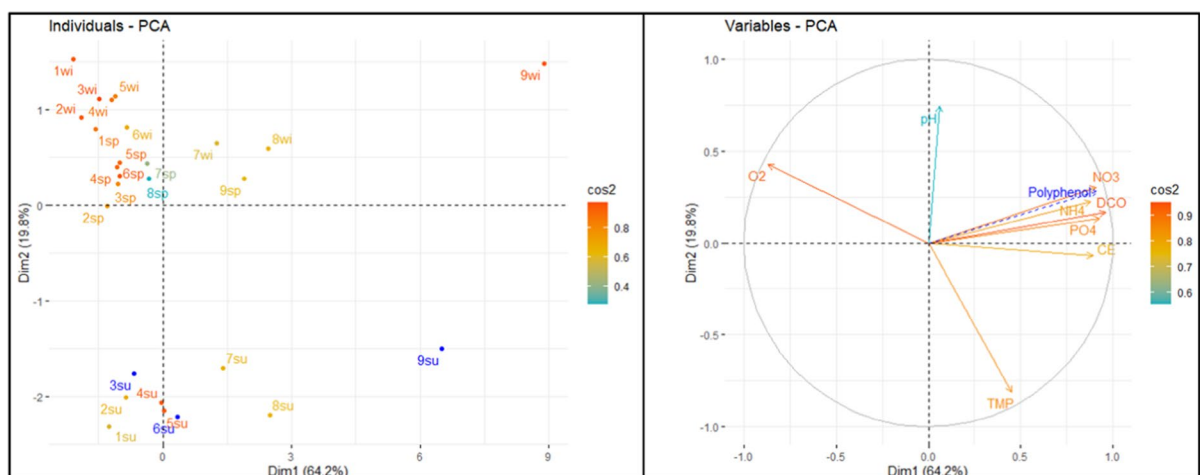


Fig. 9 Principal component analysis (PCA) among nine water quality parameters between January and June 2021 at nine sites along the ZAT River, Morocco. Summer (*su), Spring (*sp), winter (*wi), station number (*)

alkaline pH in most stations and all seasons, because the pH is influenced by the geology of the site (Young et al., 2005), except for the first station in summer, which recorded a pH close to neutrality and which may be related to a low flow, and high temperature, which led to the concentration of ions. Therefore, its pH decreases. The same explanation is found in a similar study (Prathumratana et al., 2008). Alternatively, this could be attributed to the melting of snow in summer, which has not yet taken the geological characteristics of the basin, especially at the top of the mountain. Snow is known in many studies with a $\text{pH} < 7$ (Schofield, 1977).

The increase in conductivity after point 7 is mainly due to the beginning of the net appearance of human influence, i.e., the decrease in flow due to the withdrawal of water by irrigation canals, the recharge of the aquifer (Bouimouass et al., 2020), and the presence of olive oil industries (Benaddi et al., 2022a, b), and the beginning of the concentration of the population near the valley leads to increased urban pollution (Daniel et al., 2002). In addition, the increase in conductivity in summer is mainly related to the lack of flow and the increase in water evaporation after temperature increase (Bellos & Sawidis, 2005).

Stations 1 to 6 were characterized by good stability in oxygen concentration. Oxygen stability in the water is related to the temperature and land slope (Rajwa-Kuligiewicz et al., 2015). When the temperature is low and the slope is high, the oxygen saturation of the water increases (Cox, 2003). Stations 7, 8, and 9 are located in an area known for its low slope and high temperature. Point 9 is also characterized by a high concentration of urban pollutants, which also contributes to the decrease in oxygen (Sidabutar et al., 2017).

For the pollutants (COD, polyphenol, NH_4 , NO_3 , PO_4), the lower the flow and the larger the pollution sources are, the higher the percentage of contaminants in the water is (Bellos & Sawidis, 2005; Sidabutar et al., 2017), and this is the case for stations 7, 8, and 9.

In addition, the olive oil industries are a very dangerous source of pollution for the rivers (Pavlidou et al., 2014). This is recorded at stations 7, 8, and 9 during the winter, which is known to be the operation of these factories and as evidence that the source of this pollution is the olive groves. There is an increase in the concentration of polyphenols in stations 7, 8, and 9. For point 9, in addition to the strong presence of olive factories, there is also pollution from the

landfill and slaughterhouses, as well as the presence of a city in the area that does not purify its wastewater. All of these factors affect surface water quality (Benaddi et al., 2022a, b; Daniel et al., 2002; Smeti et al., 2019).

The findings from the weight index analysis demonstrate a correlation among the stations located within water body 3, indicating minimal human influence on this water body and its ability to maintain its original state from upstream to downstream (Gurnell et al., 2016; Lyche Solheim et al., 2019; Reyjol et al., 2014). Additionally, the results reveal that the combination of decreasing slope, rising temperature, and human pollution significantly contribute to the degradation of water quality during the summer (Durski et al., 2017). This is evident in stations 7 and 8, which exhibit considerably poorer conditions compared to the stations within water body 3. Furthermore, the study highlights the significant impact of urban pollution on deteriorating water quality, resulting in poor conditions (Unda-Calvo et al., 2020). This division of water body 4 into two classes is supported by the results obtained using the Moroccan weighted index, emphasizing the effectiveness of physical parameters as indicators for determining the quality of river water bodies.

Biological monitoring of water quality

Only 13 families are found in the valley, which supports the region's low biological diversity. This is mostly caused by climatic causes because the valley dried out before winter, depleting it of its natural richness. According to a study conducted in rivers with a Mediterranean climate, streams and rivers have variable flow as a result of seasonal precipitation patterns, which has a significant impact on the biota of these distinctive systems (Abessolo et al., 2021; Cid et al., 2017). The area can be subjected to extreme flooding or drought, generating periods of intermittency in perennial systems. As a result, the environment for macroinvertebrate evolution is less stable (Cid et al., 2017).

Insects are the most important elements present at 69% and are known to adapt to climate influence. Similar findings are made from studies done in various Mediterranean and tropical rivers, where the benthic communities are dominated by insects that are seen to be quite prevalent and numerous at different times of the year and to exhibit some temporal

stability in the rivers (Guellaf & Kettani, 2021; Masese et al., 2009; Saal et al., 2021; Voudouris, 2012).

The study shows a progressive decrease in the number of species from top to bottom, which is indicative of the deterioration of the ecological field, as confirmed by similar experiments (Guellaf & Kettani, 2021; Qalmoun et al., 2022).

The results also show a deterioration of quality during winter, which coincides with the period of exploitation of olive groves and the effects of olive mill wastewater, increasing the concentration of pollutants that negatively affect living organisms (Pavlidou et al., 2014; Simyrdanis et al., 2018; Smeti et al., 2019). This may also be caused by the fact that before the arrival of winter, the region experienced a long period of drought (Abessolo et al., 2021; Cid et al., 2017).

The region also saw the emergence of two families during summer. And the reason for their emergence at the beginning of summer could be the high moisture left by the spring period, which has a significant precipitation and flow, resulting in a soil saturated with moisture that contributed to its role in the recovery of biodiversity (Camargo et al., 2004; Koumba et al., 2017; Lakhloufi et al., 2021).

The results obtained from the analysis of the IBMWP index reveal a similarity among the stations within water body 3, suggesting limited human impact on this particular water body and its ability to retain its natural condition along its course from upstream to downstream (Munné & Prat, 2004; Thorp et al., 2006). The results also show that the further downstream you go, the more the quality of the water bodies deteriorates. Waterbody 2 shows a medium quality, despite the climate challenge, and this is shown even in the direct studies, with the upstream remaining resistant to the downstream (Guellaf & Kettani, 2021; Qalmoun et al., 2022). As for water body 3, it recorded medium quality in the summer, similar to the winter, which recorded poor quality, which is probably the impact of the past drought before the winter of 2021 on the quality more than any other factor (Czerniawska-Kusza, 2005; Floury et al., 2013). In the case of water body 4, specifically in stations 7 and 8 located upstream, the quality deteriorated in summer, which confirms that the decrease in flow and the increase in anthropogenic impact are two major factors, as shown by other work (Bellos & Sawidis, 2005; Sidabutar et al., 2017). In the case of water body 4, specifically in station 9 located downstream, known for

recording high concentrations of pollutants, it obtained a very low-quality score, with only two families (Simuliidae and Chironomidae) present. According to a previous study, they are known to be resistant to high levels of pollution (Lakhloufi et al., 2021).

Principal component analysis

PCA also confirmed that station 9, which belongs to water body 4, is positively associated with pollutants, and this is due to the distinction of this region in the presence of a city with a positive correlation difference with temperature in summer. Other study sites with urban influents also show comparable and concordant results (El Hmaidi et al., 2020; Talhaoui et al., 2020; Vatanpour et al., 2020).

As for stations 7 and 8 belonging to water body 4, they are positively associated with pollutants due to the appearance of artificial pollutants, the lack of flow, and the beginning of the concentration of population near the river. With a positive correlation with summer temperature. A similar study yielded the same results and confirmed that decreasing water flow results to lowest level dilution and thus an increase in pollutant concentrations (Kumar et al., 2019).

As for the other stations located in water bodies 2 and 3, it appears that they are more sensitive to the variation of oxygen concentration, which is more sensitive to climatic factors. The lower the precipitation, the lower the flow, and the higher the temperature, the more the river loses its capacity to retain oxygen (Cox, 2003; Rajwa-Kuligiewicz et al., 2015).

The PCA can distinguish between the stations in water body 4 since those water bodies have high and medium pollution concentrations. Due to their similar low concentrations, the PCA is unable to distinguish between the water body 3 and water body 2 stations. As a result, using PCA as a method to confirm the typology and classification of a water body is challenging. We can also consider that the PCA gives us the possibility to merge water body 3 and water body 2 and to consider them as one homogeneous water body.

Relationship between classification to typology

The typology of the water bodies generates 4 water bodies in the basin of the ZAT. According to the hypothesis of the creation of water bodies, a water

body type is characterized by similar natural ecological conditions, encompassing factors such as geomorphological, hydrological, physicochemical, and biological characteristics. Essentially, a water body type represents a consistent entity with minimal natural environmental variations, which serves as a reference point for detecting human-induced impacts.

The classification is based on the physicochemical Moroccan index and the biotic index. The classification of the water bodies exhibits homogeneity in terms of chemical quality when human influence is minimal or during periods of high river flow, for example, WB3. However, when human influence increases and river flows decrease, water bodies become heterogeneous regarding chemical quality and no longer represent a stable entity, for example, WB4.

Water body typology and classification are essential concepts in hydrology and water resource management, playing a vital role in understanding and effectively managing water resources. Typology involves categorizing water bodies based on natural attributes, while classification groups them according to specific criteria or purposes for management, regulatory, or administrative reasons. These concepts contribute significantly to the comprehension and sustainable management of water resources (Kagalou & Leonardos, 2009).

A type of water body can be defined as a group of lakes or rivers sharing common natural ecological conditions in terms of geo-morphology, hydrology, physicochemical, and biological characteristics. A type can thus be considered a homogeneous entity with limited natural environmental variability, allowing the definition of a reference from which the impact of human origin can be detected. This is precisely what is concluded in this study, the effect of the pressure exerted by human activity on the modification of the natural and homogeneous structure of the water body.

Conclusions

This study is conducted to divide the ZAT Valley into water bodies according to European standards, which are based on natural criteria, in order to develop a methodology for dividing small, low-flow rivers, especially in arid and semi-arid environment. In order to assess the methodology used

and to determine water quality and environmental status of each water body, monitoring of the ZAT River was carried out for a period of six months (winter, spring and summer 2021) at nine sampling stations located near the water bodies. The results show the possibility of dividing the basin into four water bodies. Based on the physicochemical index and the biotic index, water bodies exhibit homogeneity in terms of chemical quality when human influence is minimal or during periods of high river flow. This indicates that they maintain a stable state with minimal natural environmental fluctuations. However, when human influence increases and river flows decrease, water bodies become heterogeneous in terms of chemical quality and no longer represent a stable entity.

The results showed that the anthropogenic impact is structural and permanent, and that it has a strong influence on water quality, especially for low flows below 5.47 m³/s, with an increase in the pollutant load to 3764 kg COD/day. The results also showed that the effect decreases considerably when the flow rate exceeds 5.47 m³/s, for the same pollutant load. The results show that the upper water bodies are characterized by a better quality in summer than in winter. Because of the drought that is before the winter of 2021, the winter is characterized by poor quality in terms of biological richness.

The results show that the upper water bodies of the river are very sensitive to seasonal temperature changes and variable changes in oxygen. As for the lower water bodies, they are highly sensitive to changes in industrial and urban pollutants, as well as to the lack of flow, which records the worst quality indicators.

The results showed a significant difference in pollutant concentrations in water body 4 confirming that anthropogenic influence is a major factor in the classification of water bodies. The results also confirmed the negative impact of the town of Ait Ourir on the water quality of the river at this location.

This research has given a vision of the importance of dividing rivers into water bodies to monitor the river's quality. It also stressed that integrating anthropogenic and natural parameters is necessary for low-flow rivers for the typology and classification of water bodies. This study suggests that countries with intermittent flows in semi-arid environments need to strengthen research to produce a new water body allocation

grid linking river flow and pollution load Table 6 supplementary.

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Data availability Data could be shared upon request.

Declarations

Competing interests The authors declare no competing interests.

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