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Ecological status assessment of Pikrodafni stream (Attica, Greece), restoration and management measures

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ABSTRACT

During the last decade, the need for protection and restoration of urban streams has gained international recognition. Pikrodafni stream is one of the few remaining streams of Athens, Greece, which despite being subject to significant pressures, such as destruction of its riparian zone and illegal sewage disposal, still retains some of its important hydromorphological and biological characteristics. The objectives of this study aim toward (a) the identification of the most important pollution pressures, (b) the understanding of the dominant eco-hydrological processes of the stream, and (c) the design of efficient protection and restoration measures. For this purpose, a large number of environmental parameters (physicochemical, nutrients, microbiological, and biological components) at key points along the stream were monitored and analyzed at a monthly basis for a year. The results indicated heavy pollution pressures throughout the basin attributed to illegal sewage and garbage disposal. High concentration levels of nitrate, nitrites, ammonia, total coliforms, and dissolved oxygen were detected particularly at the lower reaches, and water quality was ranged from poor to moderate. Poor habitat biodiversity was also observed accompanied by the dominance of invasive plant species and illegal constructions covering most of the riparian zone. Based on the results of this study, the following conservation and management measures were initiated: (1) removal of certain invasive species and the planting of native vegetation, (2) establishment of a continuous monitoring water quality program at key points, where the most significant pollution sources are identified, accompanied by heavy penalties to the polluters, (3) erosion defense constructions to specific parts of the embankments by using bio-engineering techniques, and (4) removal of some of the existent flood control constructions from the streambed, which prevent fishes to move upstream. These measures are proposed within the context of the EU Water Framework Directive and imply the

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constant water monitoring and management in order to assess and adjust them appropriately, so as to achieve good ecological status.

Keywords: Pikrodafni; Urban stream; Monitoring; Restoration; Pollution

1. Introduction

During the last decades, sustainable development has been an important topic in most political arenas, and the agenda has been expanded to include the protection of environmental amenities and recreational resources in metropolitan areas, which are important elements of "urban sustainability" [1]. Accordingly, the recent trend of river and waterway management clearly shows the surge of efforts for "rehabilitation of rivers" [2]. River rehabilitation or restoration, which was originally started to deal with local environmental problems, such as degradation of water quality and ecosystem in Western Europe, has become one of the top priority agenda in water management in many countries (especially in developed countries) since 1980s [3].

The primary goals of rehabilitation projects include enhancing ecosystem functions and modifying the riparian landscape to a more natural state [4]. In particular, ecological improvements of urban streams, such as restoring streams to a natural state without channelization or redirection, have been justified by urban residents' increasing demands for green spaces where they might have ecological experiences, recreation, and education [5]. In essence, urban streams have great potential to function as a key part of an urban green infrastructure providing valuable ecosystem services to urban residents. Within the European Union, the Water Framework Directive 2000/60/EC (WFD) [6] has been the major legislative driver that specifies that hydromorphology should underpin good ecological status in streams and rivers. Hence, the WFD and the relevant national legislation impose the continuous monitoring of water bodies and the maintenance of their good ecological status within a specific timetable and specific measures. Restoration efforts in urban streams have primarily focused on channel reconfiguration and in-stream habitat improvements increasing heterogeneity, for instance, by adding meanders and physical structures such as wood, boulders, and artificial riffles [7,8].

Most urban streams in Attica region, Greece, have been significantly modified due to intense urbanization. Champidi [9] has documented the degradation of the two streams of Mesogeia basin, Erasinos, and Megalo Rema streams in eastern Attica. More particularly, they have observed low ratios of (sand + mud)/clay (average = 5.4), indicating the high-erosion soil risk mainly caused by deforestation, overgrazing, and inappropriate cultivation techniques. Chemical composition of those two streams presents high values of total hardness, heavy metals, and nutrients, nominating the inflow of sewage and industrial wastes. Despite the fact that Chalandri stream, in common with most streams of Attica plain, is one of the last areas of natural environment in the densely built-up Attica region, many indications of deterioration have been noted. Deposition of solid wastes and sewage have led to the shrinkage and the diversion of the riverbed, erosion of the embankments, and the degradation of the stream's chemical status [10].

The Pikrodafni stream is one of the few remaining urban streams of Attica, Greece, which is preserved in almost natural state and constitutes a valuable opportunity for restoration, improvement, and maintenance. Even though Pikrodafni stream is subjected to significant anthropogenic pressures, such as destruction of riparian zone and illegal sewage disposal, it still retains some of its important hydromorphological and biological characteristics.

Additionally, there is little reliable data on the environmental/ecological condition of the stream, its hydrologic behavior, flood risk, and the riparian zone that could be used for multiple purposes (controlled flood expansion through the creation of artificial wetlands, etc.). Consequently, environmental monitoring of the Pikrodafni stream is necessary in order to carry out the proper scientific planning of its rehabilitation, restoration, and exploitation/protection.

Thus, this particular study has as objectives (a) to identify the most important pollution pressures, (b) to understand the dominant eco-hydrological processes of the stream, and (c) to design efficient protection and restoration measures. For this purpose, a large number of environmental parameters (physicochemical, nutrients, microbiological, and biological components) at key points along the stream were monitored and analyzed at a monthly basis for a year.

2. Materials and methods

2.1. Study area

Pikrodafni stream is located in the south-eastern part of Attica (Fig. 1). Its total length is approximately

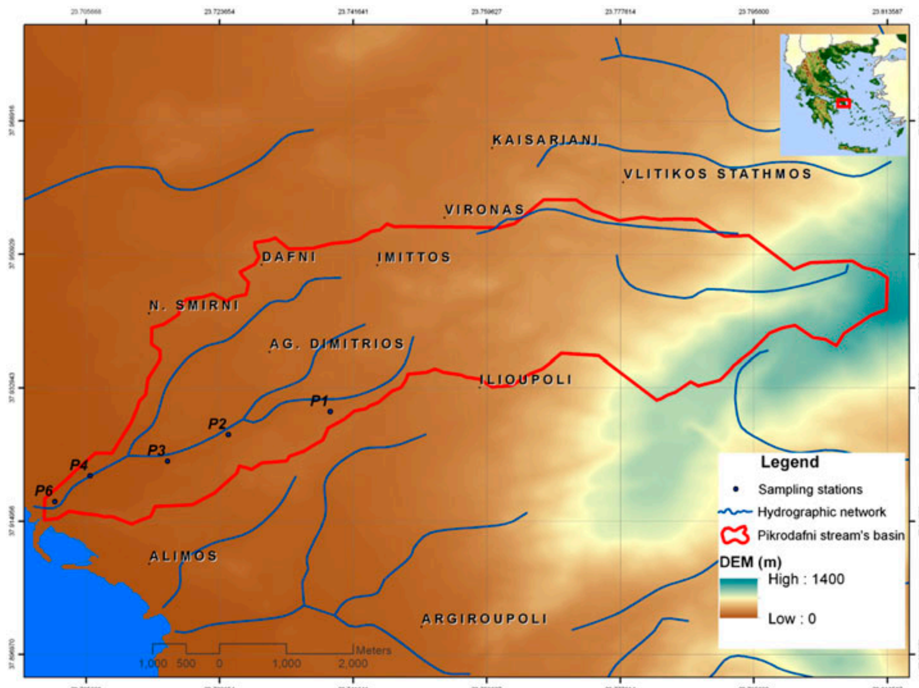

Fig. 1. Pikrodafni stream's catchment and sampling stations.

9.3 km, of which 6 km still retains natural conditions, while the rest is confined as an artificial canal. The natural environment of the stream is generally degraded due to the uncontrolled urban constructions along the whole riparian zone, the illegal waste disposal at certain points, as well as the sewage pipelines and the human interventions to the streambed. Mainly in upstream, between P1 and P2 sampling stations, there is the possibility of overflowing sewage pipelines which are combined with a minimal or no flow in certain points, and there is no ability to be self-cleaned. The stream's watercourse, hydromorphological formations, and the riparian zone indicate extensive human pressures, over the past 5 decades. However, there is evidence, such as riffles, pools, natural rubble silting, and the existence of the natural substrate, diverse and well-developed aquatic vegetation, which demonstrates ecological integrity in many sections of the river. Pikrodafni stream flows during most months of the year and is characterized by the presence of meanders, floodplain shores, and small pools.

2.2. Sampling network

Field measurements of physicochemical, hydromorphological, and chemical parameters were conducted monthly in a network of five (5) stations (Fig. 1) from July 2012 to June 2013. Macroinvertebrate fauna was collected in July and September 2012, while microbiological analysis was conducted in September and October 2012 as well as in February, April, and June 2013. The sampling network was established in order to cover the stream spatially, taking into account the anthropogenic pressures, the different habitats, and the hydromorphological conditions of the stream. Unfortunately, a heavy rainfall in February of 2013 made the access to the P2 station impossible, thereby the next sampling campaigns were limited to the other stations. Moreover, 2 automatic monitoring stations were installed in September 2012 at sampling stations P1 and P6, in order to constantly monitor the physicochemical parameters and the fluctuation of the water level at 1-h intervals. Portable instruments were used to measure water temperature, pH, electrical conductivity, dissolved oxygen concentration, total dissolved solids (T.D.S.), salinity, and turbidity. Water samples were collected and transported to the HCMR laboratory for analysis of microbial loads and major ions concentrations.

2.3. Collection of macroinvertebrate fauna

During the study, two sampling campaigns were performed at the selected sampling stations. Specifically, benthic macroinvertebrate samplings were carried out in July and September 2012. Benthic fauna collection was performed with the semiquantitative three-minute kick of the bottom (ISO 7828) from all possible microhabitats of each sampling site. Benthic macroinvertebrates were collected using a rectangular hand net of 0.25 × 0.25 m with a mesh size of 500-μm Nytex screen. Within three minutes, all identified microhabitats were covered. Benthic macroinvertebrates were transferred to the laboratory, preserved in 96% alcohol solution, and identified at the taxonomic level of the family, and where possible to species level.

2.4. Ichthyofauna

Fish composition and abundance data were collected during the sampling in the sites of the study area in October 2012 and July 2013. The field survey primarily comprised the use of a 24 volt backpack electrofisher (Smith-Root L24). Utilization of dipnets for scooping up fish and optical observations from above-water were also employed. At the collection points (usually 100 meter stretches of the stream), fish were identified, total length was measured (in size-class increments), and the specimens were released alive at the sampling site. For the sample to be representative of the site, all existing in-stream habitat types at each site were sampled (macrophyte beds, woody snags, bars, natural or artificial substrates at riffles, runs, and pools).

2.5. Monitoring of terrestrial flora and fauna

Test flora evaluations were carried out in autumn 2012, while in July 2013, eleven (11) representative points of the stream were recorded. The recording method is similar to the method used by Zogaris et al. [11], but the approach is a form of rapid visual evaluation using the DAFOR scale.

3. Results

3.1. Discharge estimation

Mean water discharge ranged from 0.004 (P2) to 0.025 m^3/s (P6). Mean flow decreased from upstream to downstream in the first two sampling stations (P1 > P2), while a slight increase was observed at P3 station. Moreover, a significant discharge increase was observed at stations P4 and P6 (Fig. 2). This can be attributed to a secondary branch of the hydrographic network that enters in the main stream bank between P3 and P4 stations (Fig. 1), and subsequently to local rainwater and illegal sewage pipelines.

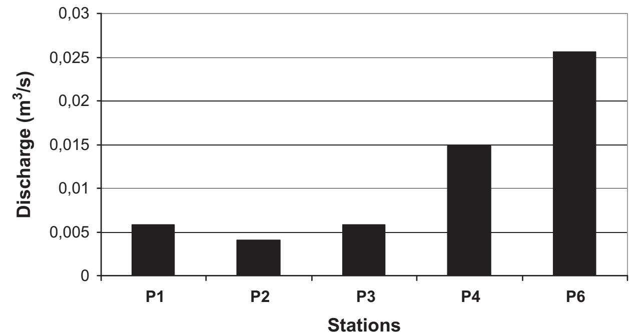

Fig. 2. Average discharge (m^3/s) of each station from July 2012 to June 2013.

3.2. Hydrochemical status of the Pikrodafni stream

According to pH measurements, the water of Pikrodafni stream is basic with values ranging from 6.57 (P2, 2/2013) to 8.75 (P4, 7/2012), and an average value of 7.6.

Dissolved oxygen concentration ranged from 0.93 (P1, 10/2012) to 14 mg/L (P1, 3/2013), with an average value of 7.7 mg/L, which characterizes the average annual water quality as high since it is greater than 7 mg/L [12]. P3, P4, and P6 stations had higher dissolved oxygen levels than P1 and P2 stations, whose water is characterized as of good and moderate quality, respectively [12]. The low concentration of dissolved oxygen at station P2 indicates the possible existence of high organic loads, which is usually triggered by the disposal of wastewater. Values of electrical conductivity ranged from 633 (P1, 2/2013) to 1,214 μS/cm (P4, 6/2013), with an average value of 927.3 μS/cm. The highest conductivity values during all ten sampling campaigns were measured at P4 station, a fact that indicates increased levels of dissolved salts and could be more attributed to the disposal of human wastes rather than to natural variation due to differential weathering or sea intrusion.

Nitrate concentrations were significantly higher in stations P3 and P4 during the entire sampling period. The high nitrate concentration in station P3 is most attributed to illegal wastewater disposal, which is confirmed by the high *Escherichia coli* levels (Table 1). The highest average nitrite, ammonium, and phosphate concentrations were measured at P1, P4, and P6 stations, and since their values during all sampling campaigns were greater than 0.23 mg/L for nitrites, 0.643 mg/L for ammonium, and 1.042 for phosphates, they were classified as bad quality based on the nutrient classification system [12]. Water quality at stations P1, P4, and P6 has been degraded probably due to the decomposition of organic matter, a procedure favored

Table 1
Average concentration values (mg/L) of D.O., certain nutrients, *E. coli* (cfu/100 mL) during all sampling periods, and chemical status characterization (high, good, moderate, poor, bad) [12]

Sampling station	D.O. (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)	NH_4 (mg/l)	Chemical status	*E. coli* (cfu/100ml)
P1	6.57	33.294	0.508	1.179	1.791	poor	300.5
P2	5.39	33.403	0.143	0.659	0.069	moderate	20 0
P3	9.32	50.370	0.030	0.478	0.104	moderate	996.8
P4	7.85	43.174	1.078	1.727	2.142	poor	1758
P6	8.99	40.319	2.652	2.228	2.751	poor	1908.6

during summer and enhanced by the influx of wastewater from the nearby houses. Water quality at station P2 (0.143 mg/L nitrites) and P3 (0.03 mg/L nitrites) was classified as poor and moderate, respectively. Concerning the ammonium concentrations, water at P2 (0.07 mg/L) and P3 (0.104 mg/L) stations is characterized as of good and moderate quality, respectively, and as of poor and moderate quality, taking into account the phosphate concentrations (Fig. 3). According to the microbiological analysis of September and October 2012 and February, April, and June 2013, station P6 presented the highest average concentrations of total coliforms (17,840 cfu/100 mL) and *E.coli* (1,909 cfu/100 mL). The concentration of the bacterial species *E. coli* in freshwater is considered to be a relatively good predictor of potential exposure to pathogens that can cause human health risks, and they proposed a geomean of 126 cfu/ 100mLs as a water quality standard. While single values somewhat higher than 100 cfu/100 mL might not indicate a major health risk or significant bacterial pollution, repeated values over 100 cfu/100 mL (e.g., at all stations) are likely to represent an ongoing source of fecal contamination (uncontrolled urban sewage disposal), that can potentially impact specific water uses such as primary recreation.

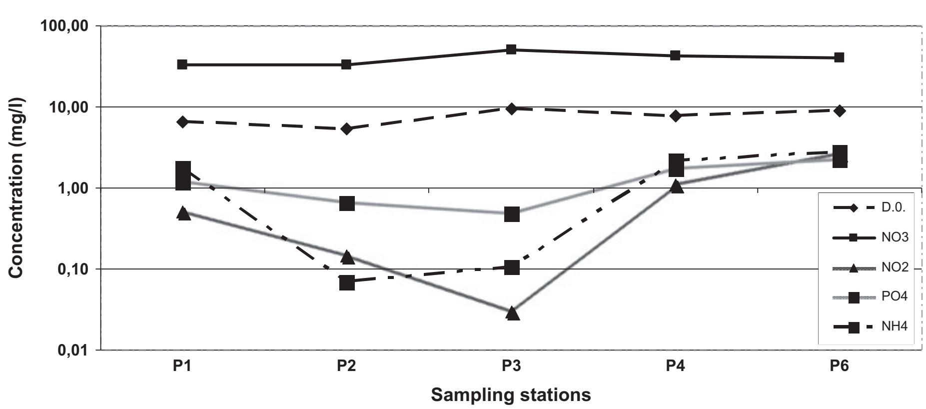

Fig. 3. Graph illustrating mean D.O., NO_3, NO_2, NH_4, and PO_4 concentrations (mg/l) during all sampling periods.

3.3. Monitoring of flora and fauna

Monitoring and recording of the flora showed that Pikrodafni stream is dominated by invasive species [11,13]. More than 50 species of invasive plants have been recorded in the riparian zone (human planted species are not included), while the native flora species of Attica is very limited and includes about 15 species. According to HCMR's scientists, the Pikrodafni stream is of limited ornithological interest compared to other wetlands of Attica. Along the monitored river side, sixteen (16) species of birds were observed, while the observation took place at the end of the breeding season and at the beginning of "autumn migration". There were also very few migratory birds. Since the abundance of birds is a good indicator for the assessment of the habitats state, the improvement of bird resources is essential. Concerning the abundance of fish, the most important fish species and one of the endangered vertebrates of the Pikrodafni stream is the eel (Anguilla anguilla) species ranked in the critically endangered animals by the International Union for Conservation of Nature (IUCN). The eel population at the lower watercourse of the river is satisfactory, and around 7 eels were observed in an area of 150 meters in mid-October 2012. Another recorded fish species is the mullet (Mugilidae). These species are abundant at certain periods of the year in the estuary and the lower watercourse of the stream. These fish constitute an important element of the river as they exist in high densities, they feed on filamentary algae that cover the bed bottom and support the food web as they are eaten by birds (particularly by herons).

3.4. Macroinvertebrate assemblages

Overall, macroinvertebrate fauna diversity was limited and dominated by pollution-tolerant species; Chironomidae (Diptera), Baetidae (Ephemeroptera), Physidae (Gastropoda), Tubificidae (Oligochaeta) were the most dominant families with relatively high abundances. The abundance of other species such *Orthetrum* sp., *Sympetrum* sp. (Odonata) was very limited.

3.5. Restoration and management measures

In order to achieve and maintain the good ecological potential of the Pikrodafni stream, several protection and restoration measures should be undertaken within the framework of the existing EU and national legislation.

One of the most important measures is the minimization of water pollution. As already discussed, two very important pollution pressures have been observed at the Pikrodafni stream and concern the uncontrolled and illegal disposal of urban wastewater and the disposal of solid waste along the entire stream. The first practice is mainly observed in constructions that have been illegally built inside the riverbed, while wastewater originates also from the overflow of adjacent sewage pipelines. Those types of discharge can significantly alter stream flow producing a relatively constant, nutrient-rich flow that is conducive to high levels of primary production and accrual of algal biomass. The biological component of a stream is commonly affected by urbanization, and a change in this component can be especially visible. Increased primary productivity often accompanies the increased urban nutrient load [14]. Thus, a continuous, operational, monitoring of the stream is recommended, in order to detect the most significant pollution sources and implement the "polluter pays" principle. The establishment of strict penalties should also be applied for waste disposal. Based on the WFD and the results of this study, a seasonal monitoring program of the chemical and biological parameters should be initiated and maintained, in order to regularly re-assess the ecological potential of the stream and suggest revised management and restoration measures if needed.

Stream hydrology has been the focus of many stream restoration projects as it is a key factor in stream ecological recovery [15]. Natural stream hydrology is altered by the construction of impervious surfaces and stormwater drainage systems, which reduce the infiltration of precipitation and increase the frequency, amplitude, and overall severity of floods [16]. For this reason, it is also proposed to remove the illegal constructions, in order to restore the riverbed and protect local citizens from floods. Regarding the riparian zones, it is suggested to remove certain invasive vegetation species and replace them (bio-engineering techniques) with native vegetation, especially where the common reed (*Arundo donax*) dominates and high-erosion risk has been observed. Concerning the tree planting, the usage of native shrubs and trees is highly recommended, especially in relation to the expected plant communities that may have already existed in the Pikrodafni stream. The most suitable trees for the downstream part are the willows, poplars (Populus alba), and alderwoods (*Alnus*), while for upstream, the Platanus (*Platanus orientalis*) and Mediterranean hydrophilous deciduous trees.

A project for habitat improvement should also be considered, especially for the habitats of eels (*Anguilla anguilla*) and mullets (Mugilidae), in order to attract more birds, and more specifically, some of the existent flood control constructions should be removed from the streambed, as they currently prevent fish to move upstream.

4. Discussion—conclusions

A diverse group of planners including engineers, biologists, governmental authorities, and local residents needs to be involved to identify the impacts of urbanization on the physical, chemical, and biological components of Pikrodafni stream, and create an effective rehabilitation plan. Urban stream research is an important theoretical and practical issue that considers the impacts of physicochemical procedures [17], hydrological alterations [18], and the biological community and its health [19,20] on ecosystem deterioration [21].

Stream restoration projects for ecological maintenance began in the 1970s. Germany, Austria, and Switzerland introduced a nature-friendly construction approach to urban streams named "Naturnaher Wasserbau" and applied it to restoration projects in artificially handled stream corridors [22]. The UK's Environment Agency introduced a natural stream restoration exemplar to ordinary restoration programs in the 1980s [22,23]. Numerous case studies of successful rehabilitation in developed countries have been extensively recorded. In Germany, restoration projects have focused on restoring natural stream continuity and ecological function in lotic ecosystems, such as those of the Enz and Neckar rivers [22]. In the UK, the restoration of impaired channelized ecosystems in the Cole and Skerne rivers has resulted in the re-establishment of meandering natural systems [22,23]. Austria undertook a similar physical habitat restoration project in the Alterbach River [22,24]. The United States has conducted several successful restoration projects for physical habitats and biodiversity, including the Kissimmee River project [25], the Corridor Master Implementation Plan of Trinity River [26], and the Hotophia Creek project [15,22,27].

Taking into consideration the study of Murdock et al. [28], who studied the flow, periphyton and nutrients of an urban stream, it is concluded that altering a single system component might not always improve overall stream health, even when that alteration is the restoration of a greatly impaired stream component back to a more natural state. While planning a successful restoration strategy adapted to Pikrodafni stream, combined approaches including hydrology, chemistry, and biota should be adopted.

This study is a scientific attempt to monitor the ecological status of the Pikrodafni stream, in the context of EU Water Directive Framework. During this research, there has been an effort to detect the most significant pollution pressures and design some initial conservation and management measures for the stream. The results (physicochemical, nutrients, total coliforms) indicated the water degradation of the stream, particularly between the stations P3 and P6, probably triggered by illegal sewage/refuse disposal and overflowing sewage pipelines. Poor biodiversity was also observed accompanied by the dominance of invasive plant species and illegal constructions covering most of the riparian zone. One of the positive results was the detection of eels (*Anguilla anguilla*) in the downstream of the hydrological basin. Based on those results, the initial restoration and management planning includes the following: (1) the removal of invasive vegetation species and the planting of native ones, (2) the development of a constant monitoring water quality program at certain points, (3) erosion defense constructions to specific small parts of the embankments by using bio-engineering techniques, and (4) the removal of some of the existent flood control constructions from the streambed. These measures imply the continuous environmental water monitoring and management in order to assess and adjust them appropriately, so as to achieve good ecological status for all the European water bodies.

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