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Intermediate report on Water quality monitoring of Pikrodafni stream

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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" (Wheeler, 2000 in Dimitriou et al., 2014). Global population shifted rapidly from rural to mostly urban during the last century, with urban population increasing from 14% of the world's population (224 million) in 1900 to more than 50% in 2015 (3.9 billion).

Urbanization as a social, economic and territorial transition process, puts a considerable stress on socio-economic and ecological systems which has been of interest to the scientific community for many years. Recent researches (Eagleson, 2002; Groffman et al., 2002; Karr, 1999; Lowrance, 1998; Pinkham, 2000; Platt, 2006; Walsh et al., 2005; Zalewski, 2013 in Meltem and Azime, 2017) declare that the accumulation of people in cities have extensive and profound impacts on riverine systems.

According to Pinkham (2000), the characteristics and functions of urban rivers, which are one of the most modified aquatic ecosystems, are gradually weakened or lost. Throughout the history, expansion of anthropogenic activities led riverine systems to be polluted, culverted, buried or changed (alterations of the hydro morphological structure) which resulted to damaged & fragmented aquatic ecosystems (Meltem and Azime, 2017). For example, increases in total discharge, peak discharge, and flashiness have been reported in urban streams as impervious land cover increases within the watershed (Nelson et al., 2009; Schoonover, Lockaby, & Helms, 2006; Wu et al., 2013 in Wu et al., 2015). Floods are some of the most devastating, yet common, natural disasters affecting urban areas (Yoon et al., 2014; Zheng et al., 2009 in Yoon et al., 2016). The impact of climate change on the flood risk presented by urban rivers is of particular interest because such areas are typically densely populated (Birkmann et al., 2010; Feyen et al., 2008; Ford and Smit, 2004; Kim et al., 2013; Merz et al., 2010; Yoon et al., 2014 in Yoon et al., 2016). The exacerbation of urban river flooding by climate change will not only cause significant loss of life and property, but will also contribute to public health and social problems (Oven et al., 2012 in Yoon et al., 2016). It is therefore vital that society develops urban river management systems that can cope with and reduce the impacts of climate change, including flood damage (Kim et al., 2013; Schirmer and Schuchardt, 2001; Wardekker et al., 2010; Yoon et al., 2014; Zbigniew and Takeuchi, 1999 in Yoon et al., 2016).

Moreover, elevated concentrations of nutrients, metals and sediments have also been reported in urban streams (Deemer et al., 2012; Grayson et al., 1996; Hatt et al., 2004 in Wu et al., 2015). Phosphorus and nitrogen from fertilizer applied to lawns, sediment and salts from roads, and increased runoff from roofs delivered to streams rapidly via storm sewers have been identified as potential contributors to stream degradation in urban areas (Adachi & Tainosho, 2005; Fissore et al., 2011; Negishi et al., 2007; Ragab et., 2003 in Wu et al., 2015). Given changes in urban stream hydrology as well as habitat and water quality, biological communities are also likely to be affected (Walsh et al., 2005 in Wu et al., 2015).

In urban areas, with the improvement of river environments and the adjustment of the urban economy and land use, the redevelopment of urban waterfronts became a global phenomenon after the 1970s and 1980s (Zhang et al., 2002 in Jiang et al., 2016). The river protection and restoration movement, combined with positive changes in greenway planning, gradually almost became a how-to guide for open space planning, after the 1980s (Fabos, 2004 in Jiang et al., 2016). From the aspect of urban river corridor restoration, the ecological environment assessment of river corridors has become an important tool and process for protecting and making river policies. River health assessment involves a comprehensive evaluation of river hydrology, biology, and habitat conditions, providing basic data and information feedback for adaptive management of rivers to promote their sustainable development (Karr, 1999; Leppard & Munawar, 1992; White & Ladson, 1999 in Jiang et al., 2016).

Within the European Union, the Water Framework Directive 2000/60/EC (WFD, 2000 in Dimitriou et al., 2014) 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. 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 (Larson et al., 2001; Miller et al., 2010 in Dimitriou et al., 2014).

Most urban streams in Attica region, Greece, have been significantly modified due to intense urbanization. Champidi (2012; in Dimitriou et al., 2014) has documented the degradation of the two streams of Mesogeia basin: Erasinos and Megalo Rema.

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 (Dimitriou et al., 2014). 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. Consequently, environmental monitoring of the Pikrodafni stream is necessary in order to carry out the proper scientific planning for its restoration, and environmentally friendly exploitation. Thus, this particular study has as main objective to monitor and analyse a large number of environmental parameters (physicochemical, nutrients, total coliforms, hydrocarbons and heavy metals) at key points along the stream and detect the main pollution pressures. Specific measures will be proposed to reduce the water pollution impacts and restore the ecological status of the stream in a favourable level.

2. Methodology

2.1 Study area

Pikrodafni stream is located in the south-eastern part of Attica (Fig. 1). Its total length is approximately 9.3 km, of which 6 km still retains natural features, 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 (Dimitriou et al., 2014). Sewage pipelines probably exist in the lower part of the catchment (between P5 and P8 sampling stations, fig. 1) which are combined with a minimal or no flow in specific periods of time, which reduces the streams natural attenuation capabilities. The stream's riparian zone structure and vegetation indicate the extensive human interventions since alien flora species dominate while the biotic components of the stream are significantly degraded. However, there are still typical riverine habitats, such as riffles, pools, runs and the existence of natural substrate, as well as diverse aquatic vegetation, demonstrates some ecological integrity in many parts of the river. Pikrodafni stream flows during almost the entire year and is characterized by the presence of meanders, floodplain shores, and small pools (Dimitriou et al., 2014).

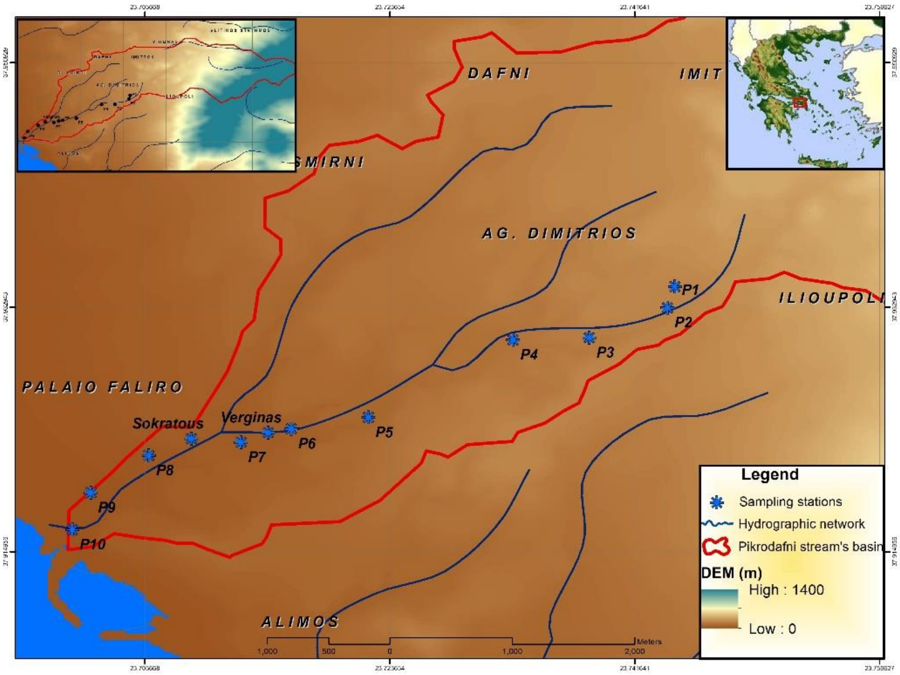

Figure 1. Pikrodafni stream's basin and sampling stations.

2.2 Sampling network and quality classification system

Field water samples for measurements of heavy metals, hydrocarbons, total coliforms and physico-chemical parameters were collected in October, November and December 2016, in a network of twelve (12) stations (Fig. 1). Sokratous and Verginas stations were added in the sampling network in December 2016, following the recommendation of the region of Attica due to illegal pollutants disposal, identified there in the past. This 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. The portable instrument Horiba U-50 Multiparameter Water Quality Checker was used to measure water temperature, pH, electrical conductivity, dissolved oxygen concentration and total dissolved solids (T.D.S.). Water samples were collected and transported to the HCMR laboratory for further analysis (nutrients, heavy metals, hydrocarbons, total coliform).

To classify the physicochemical status of the river's sites, the River Nutrient Classification System (Skoulikidis et al., 2006; Table 1) was applied for nutrients and the Norwegian system for dissolved oxygen (Cardoso et al., 2001; Table 1).

Table 1. River Nutrient and Dissolved Oxygen Classification System, NCS (Skoulikidis et al., 2006; Cardoso et al., 2001)

(Skoulikidis et al., 2006)		**High**	**Good**	**Moderate**	**Poor**	**Bad**
N- NO_3^-	mg/l	< 0.22	0.22-0.60	0.61-1.30	1.31-1.80	> 1.80
N- NO_2^-	mg/l	< 0.003	0.003-0.008	0.0081-0.03	0.031-0.07	> 0.07
N- NH_4^+	mg/l	< 0.024	0.024-0.060	0.061-0.20	0.21-0.50	> 0.50
P- PO_4^{3-}	mg/l	< 0.07	0.07-0.105	0.106-0.165	0.166-0.34	> 0.34
(Cardoso et al., 2001)						
Dissolved Oxygen	mg/l	> 9	> 6.4 and < 9	> 4 and < 6.4	> 2 and < 4	< 2

3. Results

3.1 Physicochemical status of the Pikrodafni stream

Water temperature of Pikrodafni stream ranged between 7.63 (P4, 12/2016) and 17.56 °C (P7, 10/2016), with an average value equal to 13.13 °C (Table 2). It should be noted that the day before the sampling trip of December, a snowfall occurred throughout Attica, resulting in low water temperatures (lower than 10 °C). According to pH measurements, the water of Pikrodafni stream is basic with values ranging from 6.95 (P10, 11/2016) to 8.46 (P1, 11/2016), and an average value of 7.97 (Table 2). Dissolved oxygen concentration ranged from 5.18 (P7, 10/2016) to 11.8 mg/L (P3, 11/2016), with an average value of 8.96 mg/L, which characterizes the average water quality as good since it is greater than 6.4 mg/L and lower than 9 mg/l (Cardoso et al., 2001; Table 1). The upstream stations (P1-P5) and two downstream stations (P8, P9), had higher dissolved oxygen levels (high quality) than P6 and P7 stations, whose water is characterized as of good quality. Water quality of stations Sokratous and Verginas were also characterized as of high and good quality, respectively (Cardoso et al., 2001) but this is probably caused from the limited amount of water and the fast flow that facilitated oxygen replenishment.

The values of electrical conductivity ranged from 532 (P9, 12/2016) to 1,001 μS/cm (P10, 10/2016), with an average value of 773.31 μS/cm (Table 2). The average values of conductivity in all stations ranged around 700-800 μS/cm without outliers and are considered normal based on the season and the geological conditions of the stream. The highest conductivity values during all ten sampling campaigns were measured at P5 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 variations. TDS concentrations ranged from 345 mg/l (P9, 12/2016) to 644 mg/l (P10, 10/2016), with an average value 497.59 mg/l (Table 2). TDS concentration is closely related to electrical conductivity values and are regarded normal and expected.

Table 2: Descriptive statistics of physicochemical parameters

Parameter	Units	N	Minimum	Maximum	Mean	Std. Dev.
pH	**-**	32	6.95	8.46	7.97	0.35
T	**°C**	32	7.63	17.56	13.13	3.33
D.O.	**mg/l**	32	5.18	11.8	8.98	1.77
Electr. Conductivity	**μS/cm**	32	532	1001	773.31	114.59
Salinity	**ppt**	32	0.25	0.5	0.36	0.07
TDS	**mg/l**	32	345	644	497.59	72.07

The average nitrate concentrations of all sampling periods were significantly high in all stations, resulting in the characterization of their water as of bad quality. The highest average nitrite, ammonium, and phosphate concentrations were measured at P8, P9, and P10 stations, and since their values during all sampling campaigns were greater than 0.07 mg/L for nitrites, 0.50 mg/L for ammonium, and 0.34 for phosphates, they were classified as of bad quality based on the nutrient classification system (Skoulikidis et al., 2006; Table 4).
Water quality at station P5 (0.03 mg/L nitrites) and P6 (0.009 mg/L nitrites) is classified as moderate. Considering the phosphate concentrations, water at P5 (0.216 mg/L) and P6 (0.185 mg/L) stations is characterized as of poor and moderate quality respectively while by taking

into account the ammonium concentrations these stations are classified as of moderate and good quality, respectively (Table 4).

The spatial trend of the physicochemical quality in Pikrodafni stream indicates a degradation from the upstream parts (P1, good physicochemical status) to the downstream sites (P8, P9, P10 – poor status). The intermediate sites (P2 – P7) are classified as of moderate physicochemical status (Table 4). Moreover, Sokratous and Verginas stations were characterized as of poor physicochemical status, since the concentrations of all nutrients exceed the relevant threshold values due to the significant pollution loads that are obvious in these stations. Moreover, the poor quality that is encountered in the deltaic sites (P8, P9 and P10) indicate potential impacts mainly from domestic sewage which is also confirmed by the relatively high concentrations of Total coliforms in these sites (Table 4; Table 5).

Table 3: Descriptive statistics of chemical parameters

Parameter	Units	N	Minimum	Maximum	Mean	Std. Dev.
N-NO_3^-	**mg/l**	32	4.89	12.83	9.19	2.08
N-NO_2^-	**mg/l**	32	0.001	1.36	0.098	0.25
N-NH_4^+	**mg/l**	32	0.009	10.74	0.75	2.23
P-PO_4^{3-}	**mg/l**	32	0.06	1.21	0.25	0.24

Table 4: Physiochemical classification of Pikrodafni stream's water samples

Sampling stations	N-NO_3^- (mg/l)	N-NO_2^- (mg/l)	N-NH_4^+ (mg/l)	P-PO_4^{3-} (mg/l)	D.O. (mg/l)	Physicochemical status
P1	11.197	0.016	0.016	0.075	9.600	**Good**
P2	8.042	0.015	0.041	0.108	9.333	**Moderate**
P3	8.257	0.009	0.015	0.133	9.030	**Moderate**
P4	8.622	0.003	0.031	0.160	9.480	**Moderate**
P5	9.215	0.030	0.080	0.216	9.377	**Moderate**
P6	9.179	0.009	0.032	0.185	8.323	**Moderate**
P7	8.101	0.004	0.015	0.146	7.513	**Moderate**
P8	11.728	0.467	0.343	0.222	9.457	**Poor**
P9	9.191	0.197	1.873	0.449	9.350	**Poor**
P10	8.970	0.146	1.631	0.417	8.477	**Poor**
Sokratous	5.128	0.207	10.736	1.209	9.200	**Poor**
Verginas	11.187	0.233	1.159	0.378	8.400	**Poor**

According to the microbiological analysis and the microbiological characterization of freshwaters (EPA, 2003b), the maximum average concentrations of Total Coliforms are detected at downstream stations and especially at P10 (12,345 cfu/100 mL; Table 5), which is characterized as highly contaminated according to the EPA standards (10,000 cfu/100ml, 2003). P8 and P9 stations are characterized as moderately contaminated since their concentrations are within the ranges of 1000 to 5000 cfu/100ml. All water samples exceed the threshold of 100 cfu/100ml, hence none of them is considered to be unpolluted. Along the stream, values greater than 100 cfu/100 mL are consecutively repeated (Table 5) indicating the existence of an ongoing source of faecal contamination (uncontrolled urban sewage disposal). Particular attention should be paid at Verginas and Sokratous stations, where the average total coliform concentrations measured, are extremely high, (19,190 cfu/100ml and 1.235.000 cfu/100ml respectively, Table 5).

Table 5: Average concentrations of total coliforms along Pikrodafni stream from 10/2016 to 01/2017

Sampling stations	Total coliforms (cfu/100 ml)				Total coliforms (cfu/100 ml)
	31/10/2016	22/11/2016	30/12/2016	19/01/2017	
P1	118	65	1,480	1,700	**840.75**
P2	128	90	1,400	700	**579.5**
P3	270	103	1,220	620	**553.25**
P4	74	41	600	760	**368.75**
P5	85	170	2,620	680	**888.75**
P6	28	19	940	600	**396.75**
P7	38	84	460	480	**265.5**
P8	860	1,400	2,160	650	**1,267.5**
P9	570	1,100	1,500	1,000	**1,042.5**
P10	350	630	1,400	47,000	**1,2345**
Verginas			1,380	37,000	**19,190**
Sokratous			670,000	1,800,000	**1,235,000**

3.2 Aliphatic and Polycyclic aromatic Hydrocarbons

Concerning the analysis of the aliphatic and the polycyclic aromatic hydrocarbons, the results indicated slight differentiations among the sampling dates. In particular, as the concentrations of aliphatic hydrocarbons are concerned, P1 stations is characterized as of low pollution (10/2016), contamination from weathered petroleum (11/2016) and low contamination (12/2016). Water of P2 station is uncontaminated (10/2016) while in 11/2016 and 12/2016 small quantities of fresh petroleum and contamination from fresh petroleum, respectively were detected (Table 6). P3 initially had low pollution (10/2016), was uncontaminated in 11/2016 whereas low contamination from fresh petroleum was detected in 12/2016. P4 was also uncontaminated in 10/2016, traces of light hydrocarbons were recognized in 11/2016 while in 12/2016, traces of fresh petroleum were observed. At P5 station, low pollution (10/2016), small quantities of fresh petroleum (11/2016) and traces of fresh petroleum were identified (Table 6). P6 station indicated traces of light hydrocarbons (10/2016), uncontaminated water (11/2016) and the detection of traces of fresh petroleum in 12/2016. Water of P7 was mainly uncontaminated except for the sampling of December, where traces of fresh petroleum were observed. P8 station was also uncontaminated with the exception of December where the water was characterized as highly contaminated from weathered petroleum. Both water of P9-P10 stations were low contaminated (Table 6).

Table 6: Main findings from aliphatic hydrocarbons analysis.

Stations	10/2016	11/2016	12/2016
P1	Low pollution levels	weathered petroleum	Low pollution levels
P2	Uncontaminated	small quantities of fresh petroleum	small quantities of fresh petroleum
P3	Low pollution levels	Low pollution levels	Low pollution levels
P4	Uncontaminated	Traces of light hydrocarbons	Traces of light hydrocarbons
P5	Low pollution from light hydrocarbons	Small quantities of fresh petroleum	Low contamination from both weathered and fresh petroleum
P6	Traces of light hydrocarbons	Uncontaminated	Traces of fresh petroleum
P7	uncontaminated	Uncontaminated	Traces of fresh petroleum
P8	-	Uncontaminated	High contamination from weathered petroleum
P9	Low contamination from weathered petroleum	Low contamination from weathered petroleum	Low contamination from fresh petroleum
P10	Low contamination from weathered petroleum	Low contamination from weathered petroleum	Low contamination from fresh petroleum
Verginas			Extremely high pollution from light hydrocarbons (C12-C24)
Sokratous			Very high pollution from fresh petroleum

Regarding the concentrations of polycyclic hydrocarbons, also slight differences were recognized. In 11/2016, water of P1-P9 stations indicated low PAH concentrations while at P10 relatively high concentrations of pyrolytic PAH were measured. On the other hand, in

11/2016 high PAH concentrations, petroleum originated compounds predominated, were analyzed at P1 while at stations P2-P8, P9 and P10 low PAH concentrations, petroleum originated compounds predominated, relatively high concentrations, petroleum originated compounds predominated and high PAH concentrations, pyrolytic PAH predominated, respectively were encountered (Table 7). Water sampling of 12/2016 revealed the most degraded water among all samplings, including high PAH concentrations, petroleum originated compounds predominated (P1, P2), relatively high concentrations, petroleum originated compounds predominated (P3, P4, P5, P6, P7, R8) and high PAH concentrations, petroleum originated compounds predominated (P9 and P10).

Table 7: Main findings from polycyclic hydrocarbons analysis.

Stations	10/2016	11/2016	12/2016
P1	Low PAH concentrations, petroleum originated compounds predominated	High PAH concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS, benzo(ghi)perylene exceeded the MAC-EQS	High PAH concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS
P2	-//-	Low PAH concentrations, petroleum originated compounds predominated	High PAH concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS
P3	-//-	-//-	Relatively high concentrations, petroleum originated compounds predominated
P4	-//-	-//-	Relatively high concentrations, petroleum originated compounds predominated
P5	-//-	-//-	Relatively high concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS
P6	-//-	-//-	Relatively high concentrations, petroleum originated compounds predominated
P7	-//-	-//-	Relatively high concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS

P8	-//-	-//-	Relatively high concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS, benzo(ghi)perylene exceeded the MAC-EQS
P9	-//-	Relatively high concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS	High PAH concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS
P10	Relatively high concentrations of pyrolytic PAH, benzo(a)pyrene exceeded the AA-EQS, benzo(ghi)perylene exceeded the MAC-EQS	High PAH concentrations, pyrolytic PAH predominated, fluoranthene and benzo(a)pyrene exceeded the AA-EQS, benzo(ghi)perylene exceeded the MAC-EQS	High PAH concentrations, petroleum originated compounds predominated, benzo(a)pyrene exceeded the AA-EQS, benzo(ghi)perylene exceeded the MAC-EQS
Verginas			Extremely high PAH concentrations, petroleum originated compounds predominated, naphthalene exceeded the AA-EQS, anthracene, fluoranthene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene exceeded the MAC-EQS
Sokratous			Very high PAH concentrations, petroleum originated compounds predominated, fluoranthene and benzo(a)pyrene exceeded the AA-EQS, benzo(ghi)perylene exceeded the MAC-EQS

Analysis of aliphatic hydrocarbons indicated very high pollution from fresh petroleum at Sokratous station and extremely high pollution from light hydrocarbons (C12-C24) at Vergina station (Table 6). Concerning the polycyclic hydrocarbons, very high PAH concentrations, petroleum originated compounds predominated were detected at Sokratous station and extremely high PAH concentrations, petroleum originated compounds predominated were observed at Verginas station (Table 7). Analytical results of aliphatic and polycyclic hydrocarbons concentrations are presented in the Appendix.

4. Discussion-Conclusions

A diverse group of scientists including environmentalists, engineers and biologists but also governmental authorities, and residents needs to be involved to create an effective rehabilitation plan. Urban stream research is an important tool that can illustrate the impacts on ecosystem deterioration (Kasahara and Hill, 2008) from the combination of urban physicochemical processes (Kaushal and Lewis, 2005), hydrological alterations (Konrad and Booth, 2002), and the biological community (An et al., 2006; Choi et al., 2011). Numerous case studies of successful rehabilitation in developed countries have been extensively recorded. Urban landscapes are complex systems for which identification of Drivers, Pressures and Impacts that are necessary to design restoration measures, can prove difficult.

We conducted this study examining Pikrodafni stream to quantify direct and indirect effects among the social system, the terrestrial landscape, and the stream processes on water quality indices including physicochemical parameters, nutrients, total coliform and hydrocarbon concentrations. This approach allowed us to identify important pollutant factors and the relative magnitude of their effects.

This study is a scientific attempt to monitor the water quality status of Pikrodafni stream, in the context of EU Water Framework Directive. During this research, there has been an effort to detect the most significant pollution pressures. The results (physicochemical, nutrients, total coliforms, hydrocarbons) indicated the water quality degradation of the stream, particularly at downstream stations and between the stations P6 and P9, probably triggered by illegal sewage and industrial waste disposal. Moreover, the average nitrate concentrations of all sampling periods were significantly high in all stations, characterizing the water as of bad quality while the total physicochemical status of almost all sampling stations (except for P1) is characterized as of moderate and poor, based on the dissolved oxygen and nutrient concentrations. Taking into account the hydrocarbon analysis, most of stations were uncontaminated, low contaminated or affected by traces of light hydrocarbons or small quantities of fresh petroleum. On the other hand, relatively high, high or very high and extremely high (Verginas station) PAH concentrations (petroleum originated compounds) were detected along the stream during all sampling campaigns indicating continuous water degradation from petroleum sources. These results indicate the necessity for continuous environmental water monitoring at certain points of the stream and legal investigations to enforce the polluter pays principle in the stream.

Moreover, several other activities could be implemented to improve the ecological status of the stream including:

1) Installation of an early warning system for pollutants inflow detection in hotspots along the stream
2) Potential Pollution sources identification through tracing techniques and in situ investigations for illegal pipelines and relevant human activities (eg car repairing sites).
3) Removal of man made materials from the river slopes and restoration of the natural vegetation
4) Environmental education program for the areas schools that will adopt and preserve parts of the stream

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6. APPENDIX

Table 1: Concentrations of aliphatic and polycyclic aromatic hydrocarbons along Pikrodafni stream.

31/10/2016	P1	P2	P3	P4	P5	P6	P7	P9	P10	AA-EQS	MAC-EQS
Aliphatic hydrocarbons (μg/L)	13.9	0.75	1.53	0.91	22.7	0.76	0.24	2.23	2.91		
U/R	5.0	2.9	4.4	1.6	0.8	3.5	0.4	7.2	7.4		
Polycyclic aromatic hydrocarbons (ng/L)											
Naphthalene	17.1	6.3	10.3	5.8	7.3	5.7	5.7	19.8	12.5	2000	130000
Acenaphthylene	0.60	0.30	0.51	0.30	0.37	0.14	0.13	0.53	0.63		
Acenaphthene	0.26	0.28	0.31	0.18	0.20	0.19	0.21	0.95	0.47		
Fluorene	0.23	0.31	0.26	0.18	0.13	0.18	0.19	0.49	0.47		
Dibenzothiophene	0.04	0.04	0.05	0.02	0.02	0.03	0.05	0.18	0.14		
Phenanthrene	1.13	0.95	0.76	0.55	0.46	0.45	0.59	3.11	2.27		
Anthracene	0.20	0.10	0.10	0.10	0.08	0.08	0.11	0.28	0.21	100	100
Fluoranthene	0.57	0.38	0.49	0.52	0.32	0.23	0.32	0.66	2.62	6.3	120
Pyrene	1.27	1.19	1.47	0.99	0.94	0.62	0.71	2.46	3.70		
Benzo(a)anthracene	0.26	0.06	0.06	0.19	0.06	0.05	0.05	0.17	1.95		
Chrysene	0.49	0.22	0.25	0.38	0.23	0.16	0.16	0.49	2.08		
Benzo(b)fluoranthene	0.37	0.07	0.06	0.28	0.08	0.09	0.05	0.10	2.95		17
Benzo(k)fluoranthene	0.11	0.02	0.02	0.12	0.05	0.03	0.01	0.04	1.02		17
Benzo(e)pyrene	0.54	0.09	0.09	0.19	0.10	0.08	0.07	0.16	1.35		
Benzo(a)pyrene	0.15	0.03	0.03	0.16	0.04	0.05	0.03	0.06	**1.82**	0.17	27
Perylene	0.04	0.00	0.01	0.04	0.01	0.01	0.00	0.01	0.39		
Indenopyrene	0.19	0.02	0.01	0.12	0.02	0.04	0.01	0.03	1.08		
Benzo(ghi)perylene	0.33	0.03	0.02	0.09	0.04	0.04	0.02	0.08	**0.86**		0.82
Dibenzo(ah)anthracene	0.05	0.00	0.03	0.04	0.00	0.01	0.01	0.01	0.32		
Methyl- naphthalenes	6.22	6.22	8.30	4.82	5.99	4.48	4.47	16.76	11.66		
Dimethyl- naphthalenes	5.12	5.27	4.35	2.70	4.32	3.91	3.77	17.05	7.40		
Trimethyl- naphthalenes	1.53	2.85	3.78	2.37	2.21	1.58	1.60	16.43	6.92		
Methyl- phenanthrene	2.98	1.86	1.17	0.84	0.91	1.24	1.08	19.31	6.47		

Dimethyl- phenanthrene	5.96	3.13	1.95	1.32	1.80	1.46	1.30	41.76	12.44		
Pyrolytic PAH	**4.4**	**2.1**	**2.5**	**3.1**	**1.9**	**1.4**	**1.4**	**4.3**	**20.1**		
Petroleum PAH	**10.1**	**5.9**	**3.9**	**2.7**	**3.2**	**3.1**	**3.0**	**64.2**	**21.2**		
ΣPAH	**425.4**	**29.8**	**34.4**	**22.3**	**25.7**	**20.9**	**20.7**	**141.0**	**81.7**		

AA-EQS: Annual average - environmental quality standard, MAC-EQS: Maximum allowable concentration - environmental quality standard

U/R: Ratio of unresolved to resolved compounds

22/11/2016	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**AA-EQS**	**MAC-EQS**
Aliphatic hydrocarbons (μg/L)	140	4.4	1.8	1.8	4.5	1.4	0.8	0.6	8.0	8.6		
U/R	32.2	6.8	3.2	2.3	3.1	4.1	4.4	2.8	8.6	8.1		
Polycyclic aromatic hydrocarbons (ng/L)												
Naphthalene	14.7	7.7	5.7	6.7	11.2	6.3	2.5	10.20	18.89	25.1	2000	130000
Acenaphthylene	1.5	0.2	0.2	0.2	0.9	0.1	0.1	0.12	0.83	2.24		
Acenaphthene	2.0	0.3	0.3	0.2	4.1	0.2	0.2	0.27	0.72	1.99		
Fluorene	6.1	0.2	0.2	0.2	2.7	0.2	0.1	0.22	0.67	2.41		
Dibenzothiophene	1.6	0.02	0.03	0.01	0.6	0.03	0.1	0.04	0.18	0.86		
Phenanthrene	27.9	1.1	0.8	0.6	12.0	0.5	0.4	0.63	3.28	14.0		
Anthracene	5.3	0.2	0.2	0.1	2.4	0.1	0.2	0.10	0.33	2.13	100	100
Fluoranthene	2.4	0.6	0.3	0.2	1.7	0.2	0.2	0.22	1.12	**12.2**	6.3	120
Pyrene	5.2	1.9	1.1	0.9	1.9	0.6	0.6	0.77	2.92	11.8		
Benzo(a)anthracene	4.2	0.3	0.1	0.1	0.2	0.02	0.1	0.03	0.46	6.63		
Chrysene	2.7	0.4	0.3	0.2	0.4	0.2	0.2	0.17	0.74	7.46		
Benzo(b)fluoranthene	3.5	0.1	0.03	0.02	0.2	0.02	0.1	0.05	0.41	6.04		17
Benzo(k)fluoranthene	1.0	0.01	0.1	0.03	0.1	0.03	0.03	0.01	0.13	2.23		17
Benzo(e)pyrene	5.3	0.2	0.1	0.1	0.2	0.1	0.1	0.08	0.48	3.43		
Benzo(a)pyrene	**2.48**	0.09	0.12	0.12	0.11	0.02	0.05	0.02	**0.27**	**4.84**	0.17	27
Perylene	0.4	0.02	0.02	0.02	0.01	0.02	0.03	0.01	0.05	1.06		
Indenopyrene	4.1	0.1	0.02	0.01	0.1	0.02	0.02	0.01	0.19	2.50		
Benzo(ghi)perylene	**4.9**	0.1	0.1	0.02	0.1	0.04	0.02	0.02	0.28	**2.17**		0.82
Dibenzo(ah)anthracene	0.7	0.02	0.1	0.01	0.02	0.02	0.03	0.01	0.05	0.79		
Methyl- naphthalenes	9.7	6.6	4.6	5.7	9.9	4.9	2.5	7.35	19.59	20.0		

Dimethyl- naphthalenes	7.7	3.9	4.2	4.1	8.9	5.6	1.7	4.24	12.01	12.6		
Trimethyl- naphthalenes	5.6	4.9	2.2	2.5	8.7	3.0	1.7	1.97	13.61	19.1		
Methyl- phenanthrene	22.7	4.6	2.6	1.6	3.2	1.3	3.6	0.85	13.87	17.3		
Dimethyl- phenanthrene	85.1	16.4	5.3	3.5	4.4	2.7	0.6	1.35	26.63	25.2		
Pyrolytic PAH	**36.8**	**4.0**	**2.3**	**1.8**	**5.1**	**1.2**	**1.4**	**1.40**	**7.11**	**61.2**		
Petroleum PAH	**135.7**	**22.0**	**8.7**	**5.7**	**19.5**	**4.4**	**4.6**	**2.83**	**43.8**	**56.4**		
ΣPAH	**226.6**	**50.0**	**28.6**	**27.3**	**74.0**	**26.0**	**15.1**	**28.7**	**117.7**	**204.1**		

AA-EQS: Annual average - environmental quality standard, MAC-EQS: Maximum allowable concentration - environmental quality standard

U/R: Ratio of unresolved to resolved compounds

30/12/2016	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**Sokr.**	**Verginas**	**AA-EQS**	**MAC-EQS**
Aliphatic hydrocarbons (μg/L)	11.1	26.6	5.3	1.8	7.8	1.7	1.6	53.5	13.0	22.5	327	95480		
U/R	4.9	1.8	6.3	3.9	5.7	4.5	4.6	11.5	1.9	1.8	4.1	3.7		
Polycyclic aromatic hydrocarbons (ng/L)														
Naphthalene	16.1	15.8	3.8	3.9	23.7	7.8	7.6	13.6	134.4	183.0	183.4	**2140**	2000	130000
Acenaphthylene	3.9	3.4	0.8	0.5	5.0	1.1	0.9	2.1	6.4	9.4	8.4	1858		
Acenaphthene	6.3	10.0	2.0	0.9	2.3	0.4	0.4	2.1	21.1	33.3	188.0	9600		
Fluorene	11.6	16.9	3.3	1.1	3.5	0.7	0.6	3.2	18.9	26.2	258.5	34899		
Dibenzothiophene	2.2	3.3	0.7	0.3	0.7	0.2	0.1	0.9	3.4	5.4	87.5	4658		
Phenanthrene	43.6	64.2	12.5	4.9	13.6	3.3	3.8	15.4	63.6	87.1	735.0	69692		
Anthracene	5.2	4.4	1.0	0.6	1.7	0.4	0.4	1.7	5.2	8.4	74.9	**3011**	100	100
Fluoranthene	7.6	8.7	2.7	1.9	5.4	2.9	3.8	8.3	14.8	36.5	**63.6**	**1677**	63	120
Pyrene	18.1	18.8	9.3	5.2	9.8	5.7	6.6	12.5	17.1	42.9	96.9	14611		
Benzo(a)anthracene	1.6	2.0	0.7	0.4	1.2	0.6	0.8	3.3	3.0	10.1	14.2	1773		
Chrysene	3.3	4.3	1.6	0.9	2.3	1.1	1.6	5.6	5.7	18.9	31.4	3880		
Benzo(b)fluoranthene	0.9	1.2	0.4	0.3	1.4	0.4	1.0	5.0	3.0	10.9	16.2	**143.2**		17
Benzo(k)fluoranthene	0.2	0.3	0.1	0.1	0.4	0.1	0.3	1.5	0.9	3.1	4.9	**29.4**		17

Benzo(e)pyrene	0.6	0.8	0.2	0.2	0.8	0.2	0.5	2.1	1.2	4.4	12.2	169.9		
Benzo(a)pyrene	**0.40**	**0.55**	0.15	0.12	**0.63**	0.16	**0.43**	**2.6**	**1.4**	**5.1**	**6.8**	**86.8**	0.17	27
Perylene	0.1	0.1	0.0	0.0	0.1	0.03	0.1	0.4	0.2	0.7	0.03	34.1		
Indenopyrene	0.3	0.4	0.1	0.1	0.4	0.1	0.3	1.7	0.8	2.7	4.0	9.9		
Benzo(ghi)perylene	0.4	0.6	0.2	0.1	0.5	0.1	0.3	**1.5**	0.7	**2.4**	**7.2**	**24.4**		0.82
Dibenzo(ah)anthracene	0.1	0.1	0.01	0.02	0.1	0.04	0.1	0.4	0.2	0.6	0.03	0.02		
Methyl- naphthalenes	103	56.0	7.9	4.9	20.3	4.8	5.1	23.4	627.8	821.5	1815	73825		
Dimethyl- naphthalenes	81.6	142	19.3	8.5	27.9	4.3	5.0	32.8	609.8	862.8	5185	379876		
Trimethyl- naphthalenes	158	274	62.6	26.8	46.2	10.0	11.4	52.0	556.9	970.8	6139	449520		
Methyl- phenanthrene	181	272	51.4	23.6	33.6	11.9	14.9	58.6	151.5	265.0	261.8	15939		
Dimethyl- phenanthrene	315	384	96.5	49.9	61.6	27.7	33.0	97.4	124.9	251.7	330.8	48583		
Pyrolytic PAH	**33.6**	**37.9**	**15.4**	**9.3**	**23.2**	**11.5**	**15.7**	**44.7**	**48.8**	**138.2**	**257.4**	**22439**		
Petroleum PAH	**540**	**720**	**160**	**78.4**	**108.8**	**43.0**	**51.7**	**171**	**340**	**603**	**1328**	**134215**		
ΣPAH	**962**	**1284**	**277**	**135**	**263**	**84.2**	**98.9**	**348**	**2373**	**3663**	**15525**	**1116041**		

AA-EQS: Annual average - environmental quality standard, MAC-EQS: Maximum allowable concentration - environmental quality standard

U/R: Ratio of unresolved to resolved compounds