Development of a multi-parameter sensors network for monitoring the water quality of Kozani lignite mines region, Greece ♦

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Abstract
The present study is focused in the development of a water quality monitoring system of effluents and drainage from lignite mining activities in the region of Western Macedonia (Kozani), and in the investigation of potential impacts to the adjacent water resources by the installation and operation of an appropriate network of sensors. Particularly, the aim of this paper is to present the process of the design, installation and operation of a network initially consisting of three multi-parameter sensor systems, located in the wider lignite mines region of Kozani, in order to monitor the surface and underground water quality of the aquatic resources of the area. The basic physicochemical parameters measured by the multi-parameter sensors system included pH, temperature, conductivity, nitrate ions (NO_3^-), sulfuric ions (SO_4^{-2}), chloride ions (Cl^-) for a period of about ten months. Additionally, certain other complementary physicochemical parameters have been measured in selected samples collected from the same areas, in order to deduce an integrated view of water quality. The pH values ranged between 7.6 and 8.3 and remained quite stable in all three monitoring stations. Observed fluctuation in conductivity measured values from 188 to 1082 μS/cm was related to variations in water quality characteristics especially in the surface water monitoring sites. The wide NO_3^- content only in Ag. Dimitrios PPC Station was attributed to wastewater discharge. Detailed analysis of recorded measurements on a day-to-day level, especially for SO_4^{-2} and Cl^- values, revealed potential pollution incidents.

Keywords: water monitoring; water quality; multi-parameter sensors; Kozani; lignite mines.

1. INTRODUCTION

1.1 Generally

Western Macedonia and especially the region of Kozani, is one of the most important industrial areas in Greece, due to the presence of lignite mines and the operation of the Public Power Corporation's (PPC S.A.) Thermal Stations. Today, coal excavation activities often cause significant environmental impacts adversely affecting the aquatic ecosystems. Waste runoffs with a high pollution loading (Acid Mine Drainage) from regions with active or even abandoned coal mines, and from places where excavation and thermoelectric power stations byproducts (i.e. ash) are disposed, contribute to surface and underground aquatic resources pollution[1].

1.2 Continuous (on-line) water quality monitoring

Operation of a water-quality monitoring station provides a nearly continuous record of water quality that can be processed and published or distributed directly by telemetry to the Internet. The water-quality record provides a nearly complete record of changes in water quality that also can serve as

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the basis for computation of constituent loads at a site. Data from the sensors can be used to estimate other constituents, if a significant correlation can be established, often by regression analyses.
Physical and chemical measurements made in streams at frequent, discrete intervals provide a nearly continuous record of water quality in an aquatic environment. Major considerations in the design of a continuous water-quality monitoring station include selection of the monitor configuration, types of monitors and sensors, site selection, locations of the sensors in the aquatic environment, the use and calibration of field meters, and the actual operation of continuous water-quality monitors. Sensor and site selection are guided by the purpose of monitoring and the data objectives. The main issue in the placement of the sensors is the selection of a stable, secure location that is representative of the aquatic environment [2].
A primary goal of the 2000/60 WFD is the uniform and continuous monitoring and representation of all water bodies (surface, groundwater, etc) for the whole territory. Between the physical, chemical, biological and ecological parameters that should be monitored in appropriate frequency, there are several parameters that can be monitored in real time, and they are indicative of a general status of water quality (pH, conductivity, temperature, etc). Real time monitoring provides an extremely useful capability, which cannot be obtained by a sampling program. Today, technology permits the transmission and retrieval of data from every location. At the same time, there are sensitive areas where deterioration of surface water quality has been observed due to point sources, or a number of single incidents of pollution. In such cases, real time monitoring can help in taking preventive or suppressive measures, expanding from a simple data collection system to a warning system, by setting the acceptable value limits for each measured parameter, in the appropriate customized software [2,3,4].
In the present study, a water quality continuous monitoring stations network was installed within the environmentally “sensitive” lignite mines area of Ptolemaida in order to monitor the surface and underground water quality of the aquatic resources of the area and to investigate possible pollution incidents.

1.3 Multi-parameter sensors network

The monitoring stations network consisted of 3 stations. After a thorough study of the wider lignite mines area, 3 locations were selected for the installation of the water quality monitoring stations (Figure 1):

- Station 0033 was installed in “Soulou” water stream near a bridge within the lignite mines area;
- Station 0034 was installed in a water dril within the lignite mine area (near Station 0033);
- Station 0035 was installed in the effluent; of Ag. Dimitrios PPC Thermal Station.

The basic criteria taken under consideration for the location of the monitoring stations were the distance from the lignite mines, the proximity to surface and ground water, previous measurements records, accessibility, safety etc. All monitoring stations were installed to the corresponding positions within March 2010.
It should be noted that surface water runoffs from lignite mines area, after treatment in a sedimentation basins, are discharged to “Soulou” water stream [5]. During summer period the water from “Soulou” stream is used for irrigation. “Soulou” water stream ends in Lake Vegoritis, both of which are considered as “sensitive” aquifers according to current national legislation [6].

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Figure 1. Location of the water quality monitoring stations in Ptolemaida lignite mines area

2. METHODOLOGY

2.1 Multi-parameter sensors for water quality monitoring

For the water quality monitoring the Watertool II system was used. This system comprises in an probe containing the measuring elements (electrodes and other sensors) protected by a robust cylindrical metal casing (Figure 2). The other basic components are the digitizing and control/storage unit and a data transfer unit [7].

The Watertool II system can measure simultaneously up to 15 physicochemical parameters (channels); for the current study temperature, conductivity, pH, nitrate ions (NO_3^-), chloride ions (Cl^-) and sulfuric ions (SO_4^{-2}) were measured. Concentrations are measured with ion-selective electrodes (ISE) which along with the various sensors are fitted at the lower end of the probe [7,8,9].

The Watertool was deployed as a network of stations augmented with wireless telemetry (3G ADSM) in order to transfer data through the internet. Moreover, the system is supported with software for automatic measurements, electrodes calibration, performance of diagnostic tests and verification, processing and visualization of the data. The software may be used as warning systems, when pollutant concentrations exceed certain predefined thresholds.

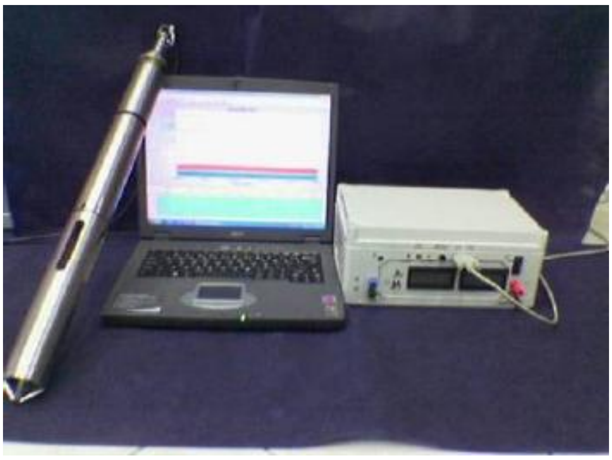

Figure 2. The multi-parameter sensors system (Watertool II)

Figure 3. Special boxes for the protection of the measuring equipment

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In order to ensure the efficient operation of the water quality monitoring systems special insulated air-conditioned boxes with metal frame were constructed (dimensions 1m x 1m x 1m) as presented in Figure 3. These boxes provide the necessary protection of the measuring equipment from exposition to:

- adverse weather conditions (rain, snow, etc),
- extreme temperature changes (>40 ^oC during summer or <-5 ^oC during winter) which might possibly affect the systems functionality
- vandalism, stealing etc

Calibration and operational control of the electrodes/sensors were performed periodically (monthly) in the laboratory using standard solutions in order to ensure the proper operation of the probes and the measurements reliability.

2.2 Installation and operation of monitoring systems - Difficulties and limitations

Since the beginning of this study and throughout the measurement period certain obstacles and limitations arose which, depending on their nature and importance, were confronted to a certain level in order not to affect the outcomes of the current study. These problems included:

Initial installation procedure of the stations

Licensing procedures and bureaucracy resulted in delay of the monitoring stations installation within the lignite mines area. In addition, during installation specific complementary infrastructure work was necessary (fixation of boxes with cement bases, wiring for electrification etc).

Start up/trial period

After installation of the water quality monitoring stations there was a startup/trial period where certain adjustments and tests took place in order to ensure the measurements reliability.

Data transfer and wireless connection

During the operation of the monitoring stations the wireless 3G connection (ADSM) for data transfer, periodically failed due to bad signal in the specific area. This situation caused problems both to the measurements data transfer as well as to the remote desktop control through appropriate software for monitoring the operation of the 3 stations. Several tests and adjustments were made in order to reinforce the wireless connection (change of rooter, use of external antenna etc); however the problem still existed. Finally, a certain software tool was developed and installed, which periodically checks the existence of wireless connection and in case of failure it restores the connection.

Various operational issues

These technical issues related to the software functionality, probes insulation etc.

Unpredictable incidents

During the operation some unpredictable incidents occurred, which although they were directly and efficiently confronted, they resulted to the failure of monitoring stations for a certain time period. Such incidents were:

- the loss of the metal protective shell of the electrodes in Watertool probe 0035 (possibly due to turbulent water flow or stealing) which was replaced;
- the accidental cut of the power supply wiring in Watertool probe 0033 from a heavy vehicle.

Lifetime of the electrodes

According to the supplier the electrodes have a life-time period from 6 to 12 months. After that period, depending on use, their performance is gradually reduced and their replacement is recommended in order to achieve reliable results. Periodically calibration and quality control with standard solutions (monthly) was performed in the laboratory for the electrodes replacement.

3. RESULTS AND DISCUSSION

The recorded data from the three monitoring stations are presented in the following diagrams as daily averages for a measuring period of about 10 months (from March 2010 to January 2011).

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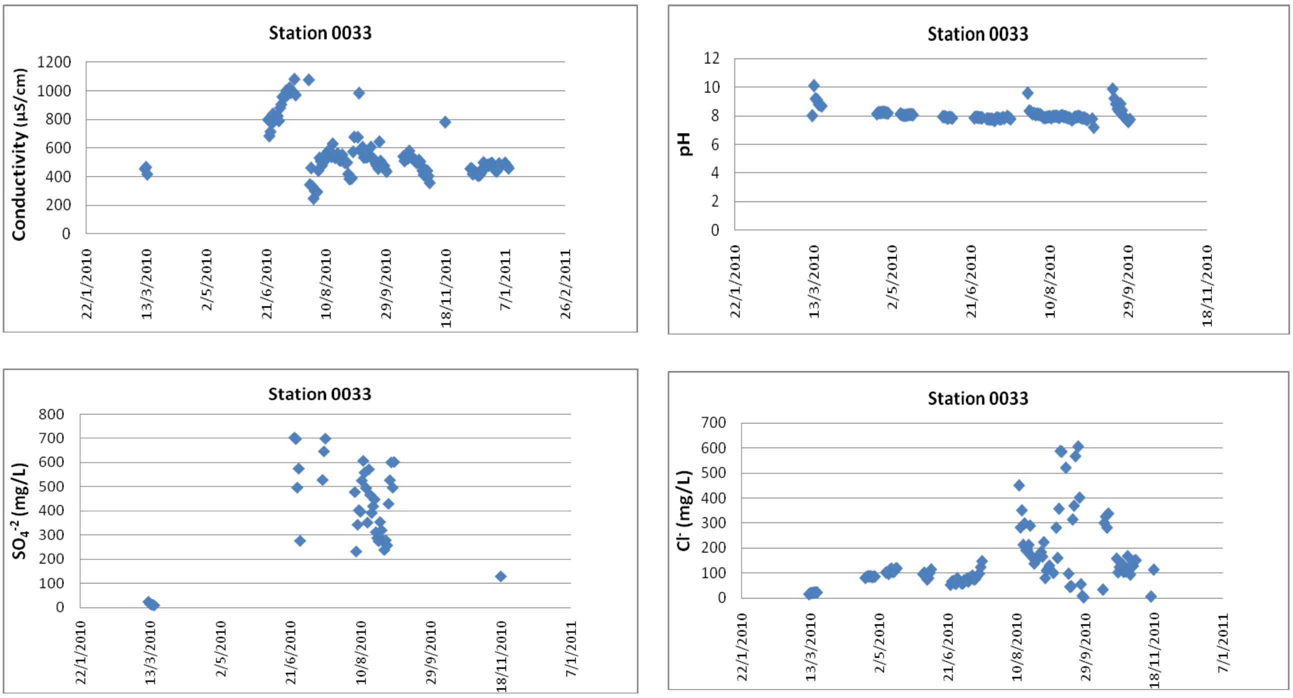

Figure 4. Conductivity, pH, SO_4^{-2} and Cl^- daily average values vs time from "Soulou" stream monitoring station (0033)

Regarding "Soulou" water stream (Station 0033 - Fig. 4) showed a rather wide conductivity fluctuation from 248 to 1082 μS/cm. The measured temperature values were found to be from 4 to 25°C, depending on the season. NO_3^- concentration were limited due to electrode's operational problems; however they varied from 12 to 19 mg/L. The pH values were quite stable with low fluctuations about 8. However, SO_4^{-2} and Cl^- average concentrations appeared higher than expected, especially during summer period.

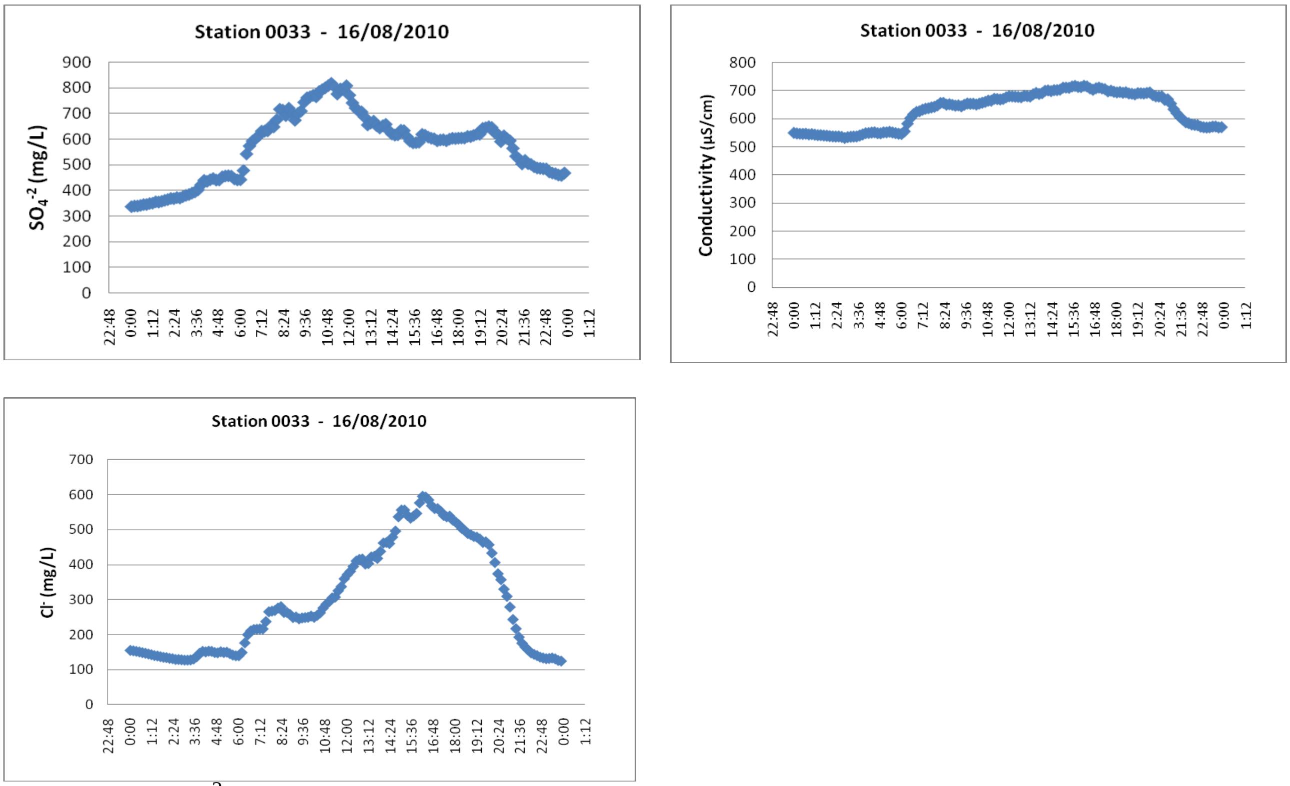

Figure 5. SO_4^{-2}, conductivity and Cl^- measurements on 16/08/2010 from "Soulou" stream monitoring station (0033)

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Detailed analysis of a day-to-day values (measurement every10 minutes) was performed; on 16/08/2010, as shown in Figure 5, a peak in SO_4^{-2} concentration took place with a maximum value of 809 mg/L. Furthermore this peak appeared to correlate with a corresponding increase in Cl^- and conductivity, indicating a pollution incident of the water stream.

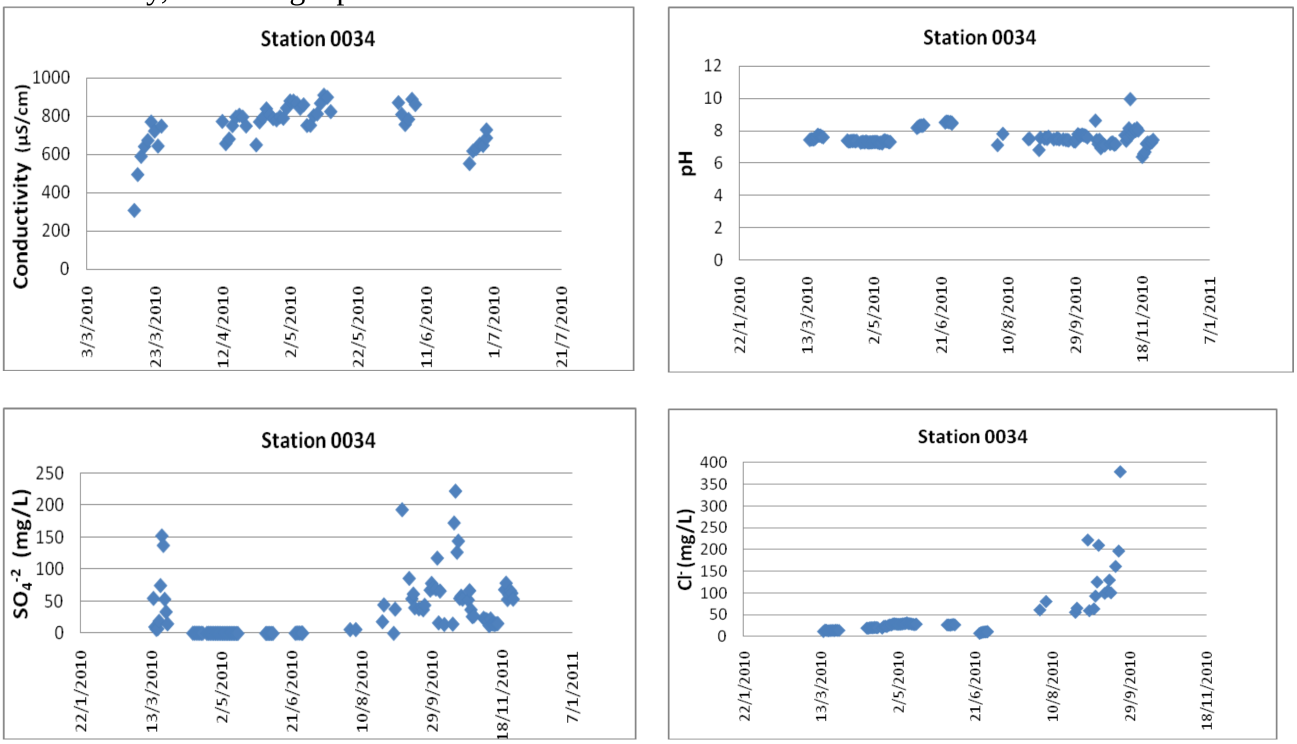

Figure 6. Conductivity, pH, SO_4^{-2} and Cl^- daily average measured values vs time from "dril" monitoring station (0034)

Data recorded from the water dril in the lignite mines area (Station 0034 - Fig. 6), showed a conductivity variation from 308 to 912 μS/cm. The measured temperature values were measured from 9 to 26°C, depending on the season. NO_3^- average concentration values were varied from 3 to 22 mg/L. The pH values appeared rather stable with an average value of 7.6. SO_4^{-2} and Cl^- average concentrations appeared to have some fluctuations, especially during August and September. It should be noted that the specific dril operated periodically and Monitoring Station 0034 received water from other dril of the lignite mines area when the particular one did not operate. This could explain the rather wide variation in the measured values. Detailed analysis of the values showed that (Figure 7), the observed peaks in SO_4^{-2} concentration was directly related to the corresponding pH values decrease. This could be an indication of Acid Mine Drainage; however further analytical investigation is required for the complete identification of the pollution origin.

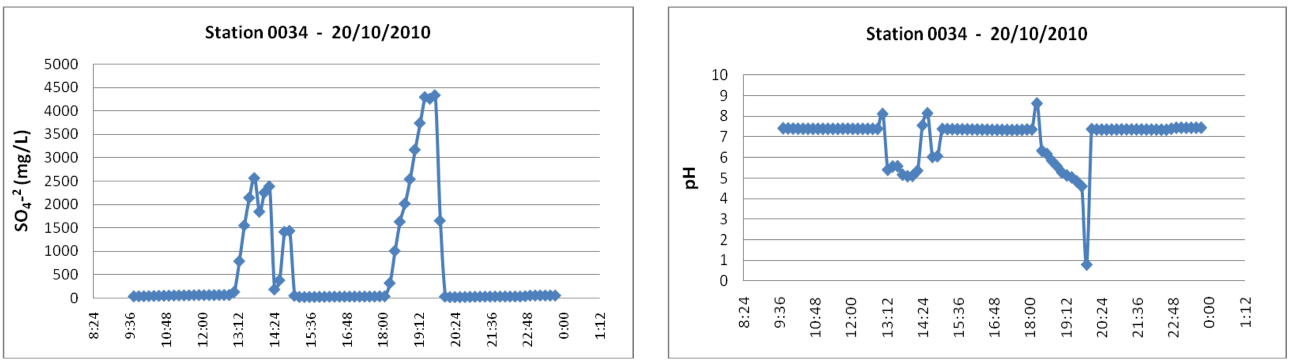

Figure 7. SO_4^{-2} and pH measured values on 20/10/2010 from "dril" monitoring station (0034)

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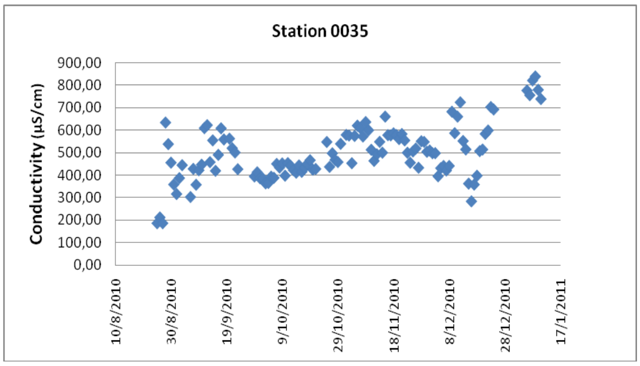

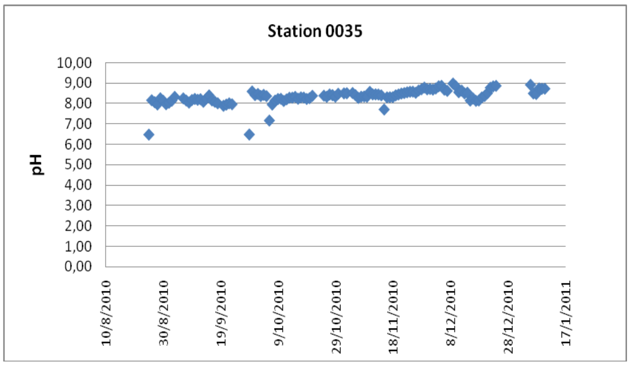

Figure 8. Conductivity and pH daily average measured values vs time from "Ag. Dimitrios" PPC monitoring station (0035)

Monitoring station of Ag. Dimitrios power plant (Station 0035 - Fig. 8) showed a rather wide conductivity distribution from 188 to 839 μS/cm, related to the discharge of the plant wastewater effluent. The temperature values ranged from 20 to 36^{o}C. The pH values were about 8.3. NO_3^- average concentration values were between 8 to 186 mg/L, and were attributed to the wastewater effluent characteristics. Cl^- average values varied from 13 to 316 mg/L. It should be noted that due to chemical treatment of the wastewater, the effluent stream presented significant variation in the quality parameters.

In addition to the above on-line measurements, certain other complementary physicochemical parameters have been measured, based on standard methods, on samples collected from the same points as the monitoring stations and the corresponding results are presented in Table 1.

Table 1. Physicochemical parameters (average values) measured in certain water samples.

PARAMETER	"Soulou" water stream	Water dril - lignite mines area
Turbidity (NTU)	72.1	1.22
Hardness (mg/L $CaCO_3$)	489	291
COD (mg/L)	64	35
BOD_5 (mg/L)	50	15
DO (mg/L)	55	17
SS (mg/L)	66	16
TSS (mg/L)	862	328
NO_2^- (mg/L)	0.43	0.007
NH_4^+ (mg/L)	0.878	1,76
Fe (μg/L)	105.6	<10
Al (μg/L)	<6	<6

4. CONCLUSIONS

On-line monitoring systems provide a very modern and useful tool for monitoring natural dynamic changes as well as pollution incidents in water resources. During the current study, a network of three multi-parameter sensor systems was installed in the wider lignite mines region of Kozani, in order to monitor the surface and underground water quality of the aquatic resources of the area and to investigate potential impacts due to pollution events. The design, installation and operation for about 10 months of this monitoring network led to the following conclusions:

- The sampling point selection, the measuring equipment durability/reliability, the protection of equipment, the systematical equipment calibration and the effective data transfer method are

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critical factors to the success of the on-line monitoring network operation; therefore special attention should be paid in the monitoring process.

- The pH values presented the highest stability with the lowest fluctuation in all three monitoring stations.
- Observed fluctuation in conductivity values appeared to relate directly to the changes in the water quality characteristics especially in the surface water monitoring sites.
- The NO_3^- values showed a wide dispersion only in Ag. Dimitrios PPC Station and was attributed to the discharge of the wastewater treatment plant effluents.
- Detailed analysis of recorded measurements on a day-to-day level, especially for SO_4^{-2} and Cl^- values, might reveal potential pollution incidents. Furthermore, correlation of certain parameters (i.e. SO_4^{-2}, Cl^- and conductivity or SO_4^{-2} and pH) could possibly be an indication of water pollution (i.e. due to Acid Mine Drainage effect).

Further research is required in order to evaluate the variation in water quality, as well as their correlation with pollution sources due to the mining activity, including:

- Expansion of the monitoring station network in the broader mining area of Western Macedonia;
- Application of statistical analysis (i.e. trend analysis) and modeling in order to develop a mechanism for water pollution prediction in the area [10].

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