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Trend analysis and assessment of water quality and quantity monitoring data in lignite mines of Western Macedonia, Greece

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ABSTRACT

PERSEAS research team in cooperation with Public Power Corporation (PPC–DEH) of Greece, installed, operates and maintains four R.E.MO.S. monitoring telemetric stations (MTS) in the plant of the mines of Kardia and Notio Pedio in Western Macedonia, Greece. Two of the MTS monitor the stagnant surface waters in the bottom-pit of the mines, while the other two monitor ground water in specific well positions. The monitoring parameters are water temperature – T_w, electrical conductivity of water – EC_w, pH, water level – H and discharge – Q. This study is focused on: a) The goodness-of-fit test, of the time series data to the normal distribution, using the Kolmogorov–Smirnov (KS) [1], non–parametric test of hypotheses; b) The assessment of the water quality and quantity monitoring daily data, based on approximately 2.5 years of monitoring period (2007–2009); c) The trend existence for the monitoring parameters, according to the method of the least squares estimator, apart from temperatures which present periodicity; d) The best fitting of a trend line using test statistics and student's distribution. It was found that "R.E.MO.S." network of water quality and quantity parameters in Western Macedonia lignite mines, is operating properly and serious technical problems have been confronted successfully.

Keywords: R.E.MO.S.; Monitoring telemetric station; Water quality assessment; Trend analysis; Lignite mines; DEH; Water management; Western Macedonia; Greece

1. Introduction

Human activities in lignite mines, mainly for electricity production, cause environmental problems which can be assessed and confronted only with the sampling and assessment of water quality and quantity data. These data are factors of great importance, are related to the conditions of environmental preservation and management and need to be monitored on a 24 h basis.

Measurements of water quality and quantity parameters are mostly sparse, not always reliable and cover very few geographic and environmental areas. The demand for reliable time–series data, has led DEH to proceed to a continuous, real–time, electronic monitoring so as to fulfil

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the requirements for the environmental preservation of the plant area [2,3].

DEH is obliged to monitor specific parameters of surface and ground water quality and quantity, in order to protect the aquatic ecosystems of a) River Soulou, the watershed of which receives the runoff water from DEH lignite mines of Western Macedonia and b) Lake Vegoritida the second deepest lake in Greece, which is the final natural receiver of Soulou waters.

PERSEAS research team undertook the task of development, installation, technical support, operation and maintenance of R.E.MO.S telemetric network in the mines of the lignitic center of Western Macedonia, Greece.

This study is focused on:

- The goodness of fitting the monitoring data to the normal distribution, using the KS non–parametric test of hypotheses.
- The assessment of the water quality and quantity parameters in two MTS. The first one is settled in a well position and the second one in a hydrant of stagnant water, both in the mine of Notio Pedio.
- The trend existence for the qualitative and quantitative parameters, apart from temperatures which present periodicity.
- The best fitting of a trend line, using test statistics and student's distribution.

The research period is approximately 2.5 years, from the beginning of 2007 to the middle of 2009. The measurements are taken hourly and reported as daily mean values. The measurements are recorded telemetrically and are teletransmitted by R.E.MO.S. integrated networks.

2. Monitoring network in lignite mines of DEH

2.1. Study area

R.E.MO.S. integrated telemetric monitoring networks have been installed and operated from PERSEAS research team in several areas all over Greece. The most recent of them is the one in the plant of DEH in the lignite mines in Western Macedonia, Greece. This network is monitoring specific determined water quality and quantity parameters. It consists of four MTS which monitor data on an hourly basis and report them as daily averages [2,3]. The two of them are located in observation wells named GEO-108 and GEO-117 both in the lignite mines of Notio Pedio and the other two are located in pipe hydrants, which outflows from the pumping of stagnant water in the bottom-pit of mines. One of the MTS is settled in Kardia mine and is named ANT–KARD and the other is settled in Notio Pedio mine and is named ANT–ONP. Similar older R.E.MO.S. networks have been installed in the Greek part of the catchment area of River Nestos from the Greek–Bulgarian borders to its estuaries in Northern Aegean Sea. These networks have provided very reliable data, which consists the base for the environmental preservation and water management of River Nestos catchment area [4–8].

The water quality and quantity monitoring data in the lignite mines of DEH are:

a) Water temperature T_w, °C
b) Electrical conductivity of water EC_w, μS/cm and
c) pH.

Furthermore, the MTS in the wells monitors water level H, m, while the MTS in the hydrants monitors discharge Q, m^3/h.

Only 2 from the total number of 4 MTS were selected for assessment of the measurements: a) ANT–ONP and b) GEO-108. The other 2 MTS were not chosen because of problems that occurred during the operation, such as natural disasters and reinstallations which have a serious economic cost to DEH.

Specifically in the year 2008, in GEO-117 MTS, moisture had destroyed the sensor of pH. In ANT–KARD MTS, the measurements were not recorded from late April 2008 to late September 2008 due to the reinstallation of the specific MTS in another position [2].

In the year 2009, the only MTS which was recording systematically was GEO-117. The other three MTS, had serious problems. Specifically, in GEO-108 all the measurements had been stopped since the beginning of August 2009 due to serious damages from severe meteorological phenomena (storms and thunders). The other 2 MTS of the stagnant surface waters ANT–ONP and ANT–KARD both stopped from the end of June 2009 till the end of the year 2009, due to similar phenomena, too. So finally the monitoring period, consisted of reliable and continuous data recordings, had duration of approximately 2.5 years, from the beginning of 2007 to the middle of 2009 and only for the two (2) MTS ANT–ONP and GEO–108, as described above.

2.2. Methodology

2.2.1. Goodness-of-fit test to the normal distribution

Using KS non-parametric statistical test, the goodness of fit assessment to the normal distribution is checked for the usual significance level of 5%. The KS goodness of fit test, is an one–sample test designed to assess the goodness of fit of a data sample to a hypothesized continuous distribution $F(x)$ [7,9,10]. The null hypothesis is formalized as:

Ho: Data variable x has a cumulative probability distribution $F_x(x) \equiv F(x)$.

Let $S_n(x)$ be the observed empirical cumulative distribution of the random sample, $x_1, x_2, \ldots, x_n$, which is also called empirical distribution. Assuming the sample data are sorted in increasing order, the values of $S_n(x)$ are obtained by adding the successive frequencies of occurrence, K_i/n, for each distinct x_i. Under the null hypothesis, one expects to obtain small deviations of $S_n(x)$ from $F(x)$. The KS test uses the largest of such deviations as a goodness of fit measure

$$D_n = \max\left|F(x) - S_n(x)\right| \tag{1}$$

for every distinct x_i. The sampling distribution of D_n is given in the literature [9]. Unless n is very small, the following asymptotic result can be used:

$$\lim_{n\to\infty} P\left(\sqrt{n}\cdot D_n \le t\right) = 1 - 2\cdot\sum_{i=1}^{\infty}(-1)^{i-1}\cdot e^{-2i^2t^2} \tag{2}$$

where $P\ (X \le t)$ is the probability of the random variable $X \le t$.

The KS test rejects the null hypothesis at significance level α, if $D_n > d_{n,\alpha}$, where $d_{n,\alpha}$ is such that $P_{H_0}\ (D_n > d_{n,\alpha}) = \alpha$ [9].

2.2.2. Trend existence and best fitting

There are several basic criteria for existence of trends like:

a) The non-parametric Spearman's criterion, [1]
b) The Kendall criteria, [10, 11]
c) Criteria for trace sudden trend [7,12,13]

Criteria for the best fitting of a linear regression line to the monitoring data and the significance test of its slope for a 5% significance level [7], are used to the present study.

In order to examine any possible trend in the water quality parameter values, the basic linear regression model is used, in which time t (in days) is taken as the independed variable and the quality parameter x_t is taken as the dependent variable [12].

Under the usual regression assumptions, that the residuals are independent and normally distributed with mean value zero and variance σ^2, the classic least square estimator for the slope is given by the formula:

$$\hat{\beta}_1 = \frac{\sum_{t=1}^{N}\left(t-\bar{t}\right)\cdot x_t}{\sum_{t=1}^{N}\left(t-\bar{t}\right)^2} \tag{3}$$

where $\bar{t} = \frac{(N+1)}{2}$ is the average of $1,2,\ldots N$.

The estimated standard error of slope $\hat{\beta}_1$ is obtained by the formula:

$$\hat{s}\left(\hat{\beta}_1\right) = \left\{\frac{\sum_{t=1}^{N}\left(x_t - \hat{\beta}_0 - \hat{\beta}_1\cdot t\right)^2}{(N-2)\cdot\sum_{t=1}^{N}\left(t-\bar{t}\right)^2}\right\}^{1/2} \tag{4}$$

where $\hat{\beta}_0 = \bar{x}_t - \hat{\beta}_1\bar{t}$.

The null hypothesis $H_0 : \beta_1 = 0$ (trend not present), is rejected when the statistic $\hat{\beta}_1 / \hat{s}(\hat{\beta}_1)$ is greater than the value of the student's distribution with N–2 degrees of freedom. The results of this test, concerning on the examined water quality and quantity parameters, are presented in Figs. 1–4 and 5–8 for ANT–ONP and GEO-108 MTS, respectively.

3. Results and discussion

The analyzed parameters of water quality and quantity are listed in Table 1.

3.1. Goodness-of-fit test for the parameters of ANT–ONP MTS

The significance over the parameters of Table 1, was much smaller than the significance level of $\alpha = 0.05$, which implies that none of these parameters are fitted to the normal distribution. The exception is the parameter of ECw in ANT–ONP MTS, where significance was found equal to 0.096 which means that the parameter marginally fits to the normal distribution [12,13]. In Figs. 1–4 the histograms and the fitted normal curves, for each one of the variables of ANT–ONP MTS (Table 1), are shown.

3.2. Assessment of the water quality and quantity parameters for ANT–ONP MTS

The statistical analysis of the water quality parameters time series from ANT–ONP MTS (Table 2) indicated that the mean values of ECw had been recorded higher than the allowable limits for potable water according to WHO (< 400 μS/cm) [14,19] and lower than the allowable limits according to Hellenic Ministerial Decree KYA 46399/4352/1986 (< 1000 μS/cm) [17]. Concerning on pH values, water with pH value equal to 7 is considered to be in the neutral range. pH values lower than 7, are assumed to be in the acidic range, while values greater than 7, in the basic range [16]. In ANT–ONP MTS, pH values were fluctuating from a minimum value of 6.51 to a maximum value of 8.36. Both the minimum and maximum recorded values (Table 2) are not harmful for organisms, are sufficient to support aquatic life in rivers and they are included in the range of acceptable determined limits, which range between 6.0 and 9.0, according to KYA 46399/4352/1986 [17]. The average pH value in this study was 7.43. Q had a mean value of 281.96 m^3/h and fluctuated between a minimum value of 43 m^3/h to a maximum value of 964 m^3/h (Table 2). T_w in ANT–ONP

Table 1
Parameters for which statistical analysis occurred

	ANT–ONP MTS	GEO-108 MTS
Distribution fitting	pH, EC_w, Q, T_w	pH, EC_w, H, T_w
Trend detection	pH, EC_w, Q	pH, EC_w, H

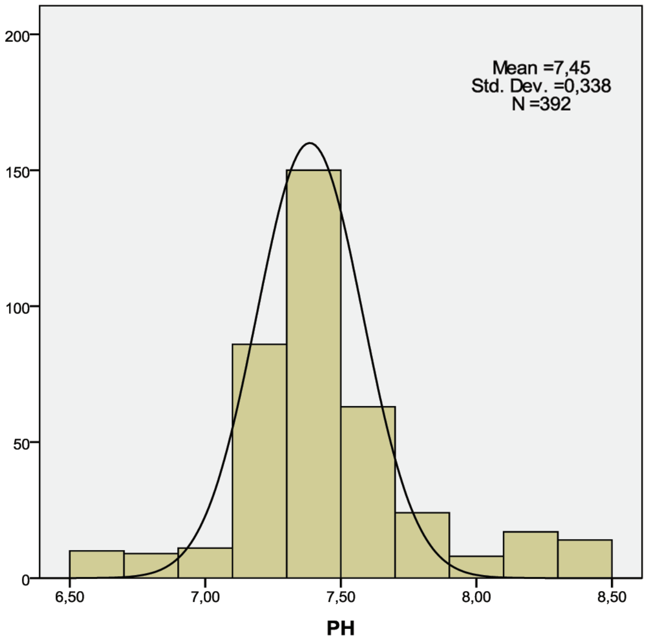

Fig. 1. Normal distribution fitting in parameter of pH in ANT–ONP MTS.

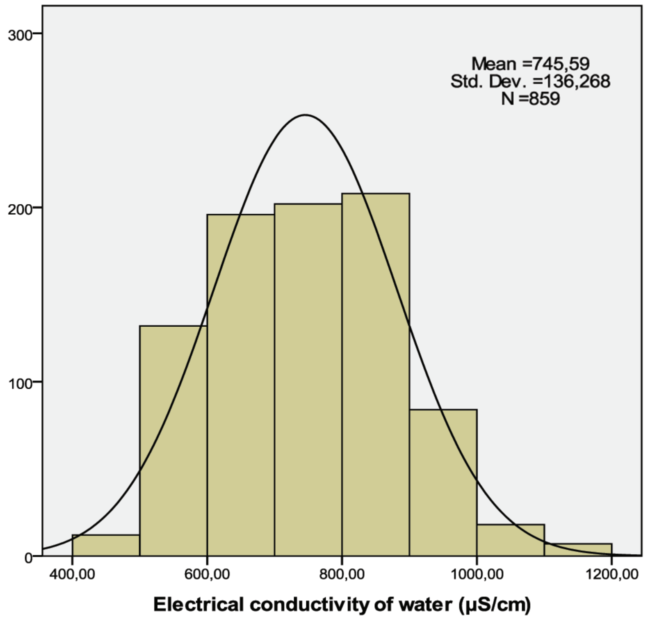

Fig. 2. Normal distribution fitting in parameter of EC_w in ANT–ONP MTS.

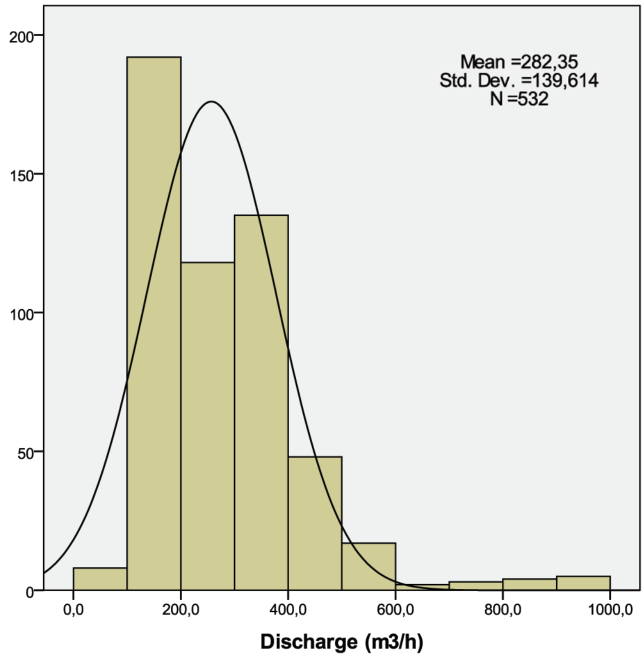

Fig. 3. Normal distribution fitting in parameter of Q in ANT–ONP MTS.

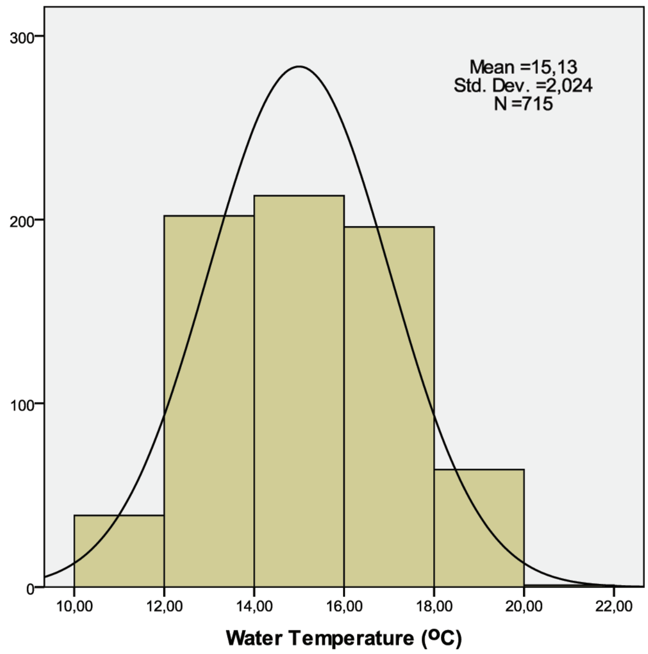

Fig. 4. Normal distribution fitting in parameter of T_w in ANT–ONP MTS.

MTS, generally did not exceed 20°C, except the maximum value that was found to be equal to 20.29°C. These temperatures are not dangerous for the aquatic life and fluctuate below the maximum allowable limits of 21.5°C for salmonids and 28°C for Cyprinids [17].

3.3. Trend existence and best fitting of a trend line of the monitoring parameters for ANT–ONP MTS

Concerning the trend detection of the parameters of pH, EC_w and Q for ANT–ONP MTS the following is concluded:

Table 2
Statistics of water quality parameters in ANT–ONPMTS

Parameter	Sample size	Mean value	Median value	Max value	Min value	Standard deviation	Percentiles 25/50/75th%
Discharge (Q), m^3/h	416	281.96	262	964	43	147.703	167.57/262/354
EC_w, μS/cm	726	748.56	743.33	1139.77	456.96	134.32	663.91/743.33/849.95
pH	339	7.43	7.38	8.36	6.51	0.3542	7.29/7.38/7.50
Water temp. (T), °C	637	15.16	14.96	20.29	11.19	2.0619	13.41/14.96/16.92

a) pH parameter (Fig. 5) presents a negative trend, which means that it decreases with time. The significance of the slope test was << 0.05. The equation of the line is

$$y = 7.8 - 0.002 \cdot t \quad (5)$$

The values are considered generally in the neutral range of pH with slight fluctuations from 6.51 to 8.36, during the study period.

b) EC_w parameter (Fig. 6) presents a positive trend, which means that its values increase with time. The significance of the slope test was << 0.05 and the fitted regression line is

$$y = 552.640 - 0.438 \cdot t \quad (6)$$

Measurements of EC_w are considered as normal-high, ranging from 600 to 1150 μS/cm, as described above.

c) Q parameter (Fig. 7) presents a negative trend with a significance << 0.05. The linear regression equation is

$$y = 550.788 - 0.425 \cdot t \quad (7)$$

The pumping operation in ANT–ONP MTS occurred with an average discharge equal to 282 m3/h.

3.4. *Goodness-of-fit test for the parameters of GEO-108 MTS*

In Figs. 8–11, the histograms and the fitted normal curve for each one of the variables of GEO-108 MTS (Table 1) are shown. The significance over these parameters, was much smaller than the significance level of α = 0.05, which implies that none of these parameters are fitted to the normal distribution.

3.5. *Assessment of the water quality and quantity parameters for GEO-108 MTS*

The statistical analysis of the time series, from GEO-108 MTS (Table 3) indicated that all the values varied in lower levels compared with those of ANT–ONP MTS.

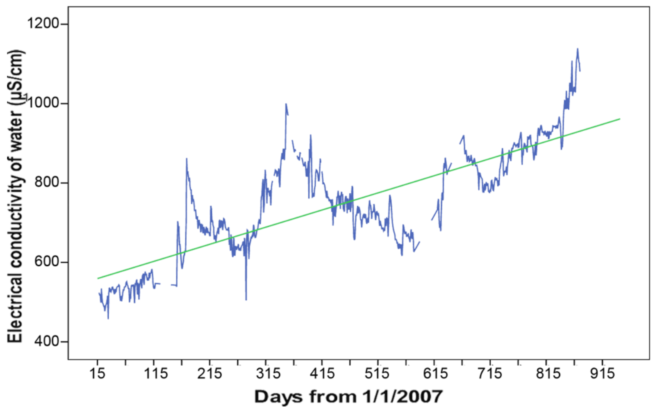

Fig. 6. Trend detection of EC_w in ANT–ONPMTS.

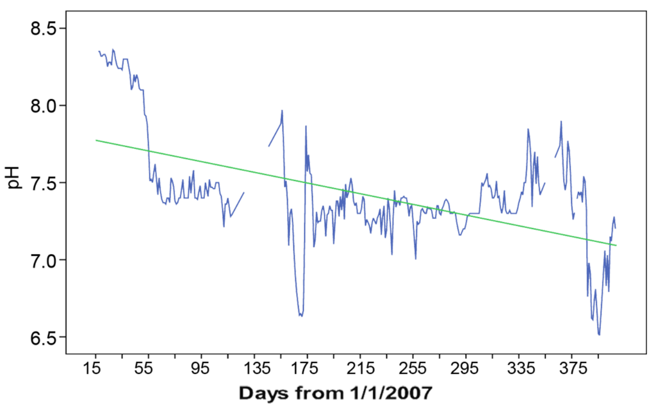

Fig. 5. Trend detection of pH in ANT–ONPMTS.

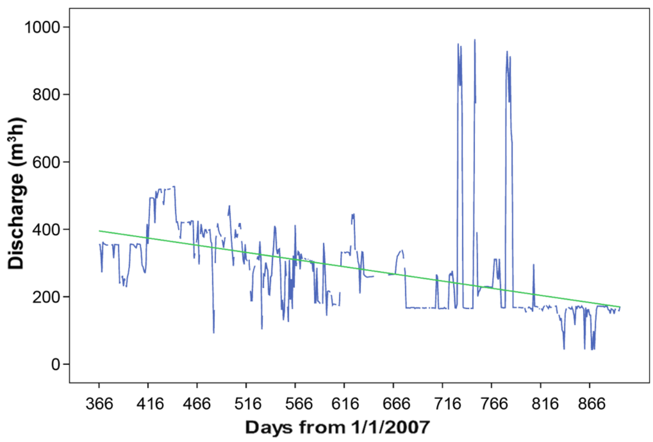

Fig. 7. Trend detection of Q in ANT–ONPMTS.

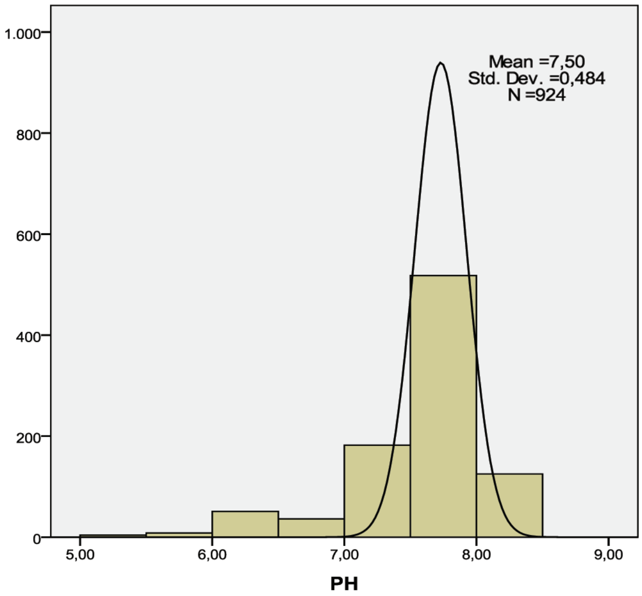

Fig. 8. Normal distribution fitting in parameter of pH in GEO-108 MTS.

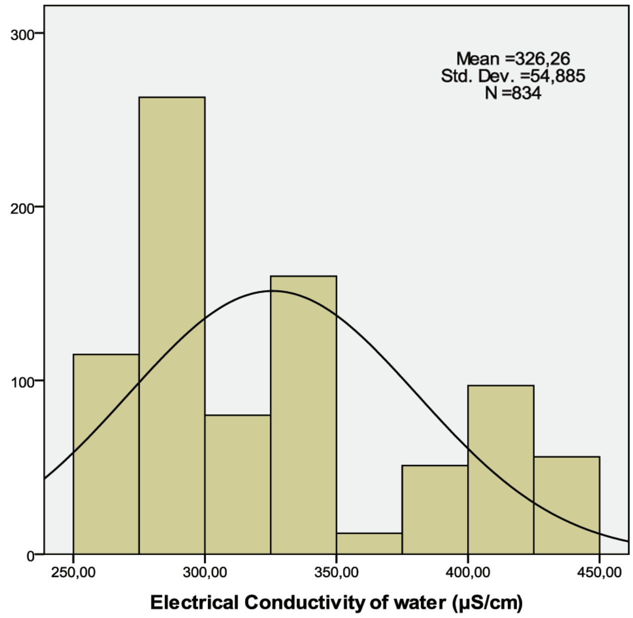

Fig. 9. Normal distribution fitting in parameter of EC_w in GEO-108 MTS.

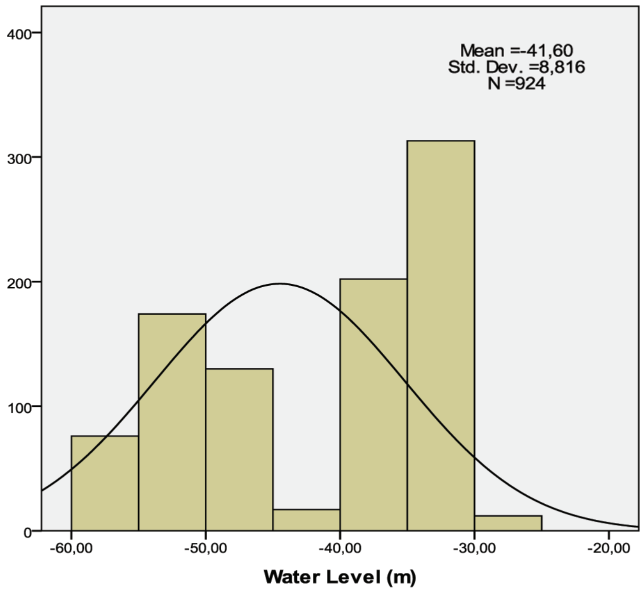

Fig. 10. Normal distribution fitting in parameter of *H* in GEO-108 MTS.

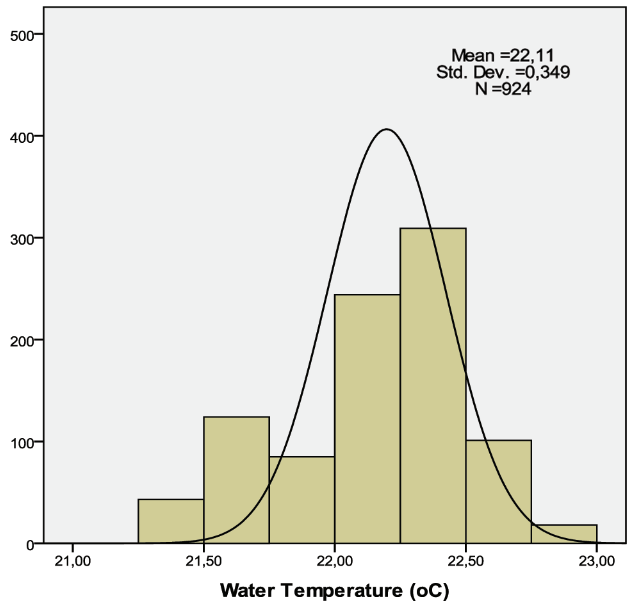

Fig. 11. Normal distribution fitting in parameter of T_w in GEO-108 MTS.

Concerning EC_w, the mean and the median values were 320.01 and 303.17 µS/cm, respectively. More than 50% of the values were below 400 µS/cm. This means that EC_w values are marginally harmless for use as potable water according to WHO [14] and completely safe, according to Hellenic Legislation [17]. pH values ranged from 5.38 to 8.20. Compared with the ANT–ONP MTS corresponding values, there is a greater range between the minimum and maximum value. In the case of GEO-108 MTS, the values were in the range of acceptable limits for the living biota, except of some isolated values which were recorded below 6.0 [17]. H had a mean value of –40.76 m and fluctuated between a minimum value of –55.49 m to a maximum value of –27.45 m. This is the groundwater

Table 3
Statistics of water quality parameters in GEO-108 MTS

Parameter	Sample size	Mean value	Median value	Max value	Min value	Standard deviation	Percentiles 25/50/75th%
Water level (H), m	861	–40.76	–35.89	–27.45	–55.49	8.4874	–49.14/–35.89/–34.16
EC_w, μS/cm	721	320.01	303.17	442.38	252.42	51.7271	280.12/303.17/339.53
pH	708	7.60	7.675	8.20	5.38	0.44989	7.50/7.68/7.90
Water temperature (T), °C	861	22.10	22.10	22.87	21.39	0.35783	21.9/22.1/22.3

level, which depends on the pumping or not from DEH. The pumping took place for lowering of the watertable in the bottom pit of the mines, so as the lignite excavations to occur safely. So, the watertable fluctuations have to do only with DEH operation and not with other uses such as irrigation or domestic use. The temperature (T_w) exceeded 20°C, which is assumed to be high for groundwater and consists a factor of further clarification from DEH and PERSEAS research team. This temperature is not harmful for biota [17].

3.6. Trend existence and best fitting of a trend line of the monitoring parameters for GEO-108 MTS

Concerning the trend detection of the parameters of pH, EC_w and H, for GEO-108 MTS, the following is concluded:

a) The significance of the test for pH (Fig. 12) was 0.677, so no significant trend was found. pH values ranged from 6.0 to 8.2 from the beginning of 2007 to June of 2009. Only in December the values seemed to be lower (5.38–6.0) and considered to be in the acid range of pH.

b) EC_w presents negative trend (Fig. 13). The significance of the slope test was << 0.05. The linear model is

$$y = 373.427 - 0.098 \cdot t \quad (8)$$

Measurements of EC_w are considered as normal [14,15,17] with values ranging from 300 to 440 μS/cm, except for some specific time increments, from January 2008 to September 2008 and from April 2009 till the end of the monitoring period, where the values were below 300 μS/cm.

c) H presents a positive trend (Fig. 14). The significance of the test was << 0.05 and the linear model is obtained

$$y = -53.453 - 0.025 \cdot t \quad (9)$$

H values fluctuate from –55 m to –46 m for the first year (2007) of the monitoring period. For the rest of the monitoring period (years 2008 and 2009), H values fluctuate

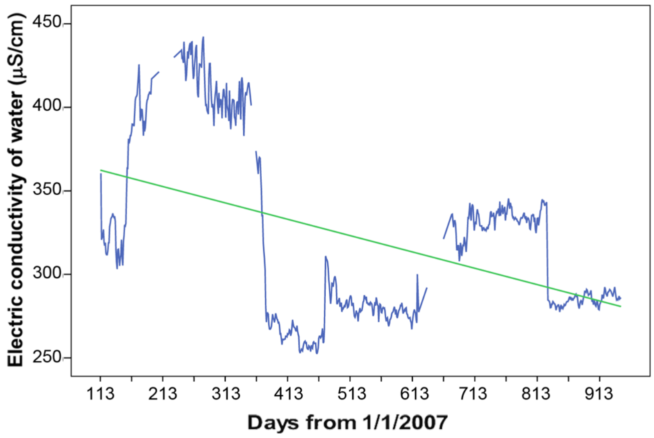

Fig. 13. Trend detection of EC_w in GEO-108 MTS.

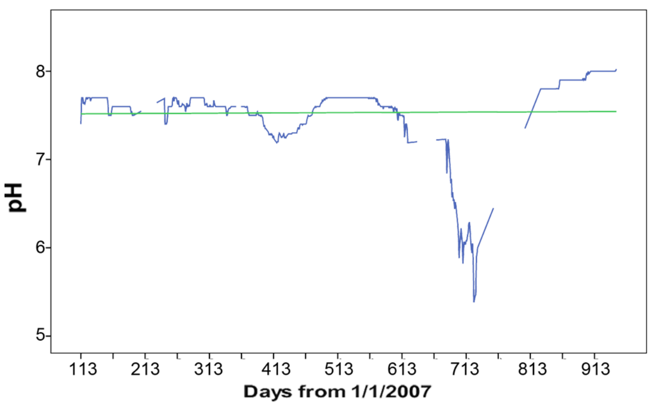

Fig. 12. Trend detection of pH in GEO-108 MTS.

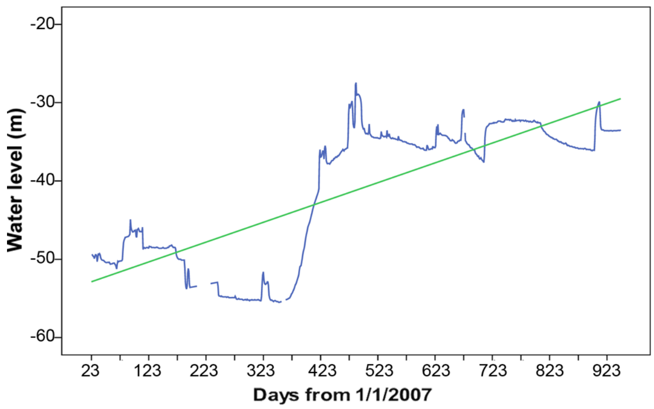

Fig. 14. Trend detection of H parameter of GEO-108 MTS

Table 4
The trend equations for the parameters of the two telemetric stations

ANT–ONPMTS		GEO-108 MTS	
pH	$y = 7.8 - 0.002 \cdot t$	pH	No trend
EC_w, μS/cm	$y = 553.640 - 0.438 \cdot t$	EC_w, μS/cm	$y = 373.427 - 0.098 \cdot t$
Q, m^3/s	$y = 550.788 - 0.425 \cdot t$	H, m	$y = -53.453 - 0.025 \cdot t$

from –55 m to –30 m with small variations, which was explained previously.

The trend equations of the time series for both MTS are presented in Table 4.

4. Conclusions

Using KS non-parametric statistical one–sample test, the goodness of fit assessment of a data sample to a hypothesized continuous distribution is checked. Specifically, the fit to the normal distribution is checked, for a significance level of $\alpha = 0.05$ or 5%. It was found out that only the ECw data in ANT–ONP MTS, where significance was found equal to 0.096, marginally fits to the normal distribution. None of the other parameters of ANT–ONP and GEO-108 MTS fits to the normal distribution.

The parameters of pH, EC_w and T_w, are not enough to clarify a clear status of the environmental condition of the surface and groundwater of the lignite mines, but are the compulsory ones that have to be monitored from DEH. The monitored waters in DEH lignite mines are not going to be used directly for domestic or agricultural used, but they are collected by the hydrographic network of River Soulou which discharge in Lake Vegoritida, the main receiver of runoff waters from DEH. This lake is the second deepest lake in Greece and is characterized by rich biodiversity. So, according to the National Ministerial Decree 46399/1352/1986 [17] for the condition standards of fresh water and the living conditions of fish (especially salmonids and cyprinids), the observed water quality parameters that DEH is obliged to monitor pH, ECw and Tw fluctuate in the acceptable determined limits, as it has been obtained from the analysis above. According to WHO [14], water is not found to be appropriate for domestic use, in terms of EC_w values in ANT-ONP MTS and marginally appropriate in terms of EC_w values too, in GEO-108 MTS.

All the parameters in both MTS presented trend, except of pH for GEO-108 MTS. Linear models were best fitted to all the parameters that presented trend, using the method of least squares, with the classic least square estimator for the slope. The null hypothesis was rejected or accepted, comparing the statistical value with the critical value $t_{n-2,\,a/2}$ for a two-tailed t-test, using student's distribution, where a is the 5% level of significance.

Generally, the operation of the telemetric network of water quality and quantity parameters in Western Macedonia lignite mines is being continued normally. Problems occurred but they were considered as normal for such telemetric networks, due to the difficult weather conditions in the area of the lignite mines in Western Macedonia. So in the year 2008 the pH sensor for GEO-117 MTS was destroyed and in the second half of the year 2009, all the other MTS had serious damages to their electronic equipments due to severe natural disasters (storms and thunders) and also due to the complexity of the measurement system. The monitoring network is successfully continuing to record valuable and reliable data. These data offers the opportunity of further statistical analysis, trend detection and assessment of water quality, which are the basis for the environmental protection and preservation by DEH and also the implementation of water management plans.

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