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Comparison of Trend Analysis Models in Water Quality and Quantity Data in Lignite Mines in Western Macedonia, Greece.

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Abstract- In this study, daily measures of three water quality and quantity parameters from one monitoring Telemetric Stations (T.S.) were examined for trend. "PERSEAS" Research Team in cooperation with "Public Power Corporation" (DEH) of Greece, installed, operates and maintains four "R.E.MO.S." (Remote Environmnetal MOnitoring System) T.S., near the plant of "Kardia" & "Notio Pedio" mines in Western Macedonia, Greece. The two of the T.S., monitor the stagnant surface waters in the bottom of the mines while the other two, monitor ground water in specific well positions. The statistical sample of each one of the parameters consisted of 950 values based on daily measures for the period 2007 to 2009. Two statistical tests based on the least square method and one based on the Spearman's rank correlation test were used for the trend analysis. These tests were applied in the data of the one T.S. called "GEO–108".

I. Introduction

The purpose of trend detection studies by statistical tests is to assess if there is a significant trend in a time series. Water quality trend in natural systems reveal information about chemical and biological changes and variations due to man made or seasonal interventions [1,2,3].

Lignite mines is a new research area with high environmental concern. This is the reason that the research team "PERSEAS", undertook the task of development, installation, technical support, operation and maintenance of the telemetric network of water quality and quantity parameters of water [4,5]. The measurements in this study are recorded telemetrically by networks of integrated electronic "R.E.MO.S." T.S.

The parameters that were examined are Water Level (H), Electrical Conductivity of water (ECw) and pH. The research period is approximately 2.5 years, so the statistical sample of each one of the parameters, consist of 950 values. There were missing values which have been replaced with linear interpolation method. The measurements were taken hourly and reported as daily mean values.

The objects of the study are:

- The assessment of the water quality and quantity parameters in one T.S., called "GEO–108", which is situated in a well position in the mine of "Notio Pedio".
- The trend existence for the qualitative and quantitative parameters, using two statistical tests based on the least square method and one based on the Spearman's non parametric test.
- The best fitting of a trend line.

II. Materials and methods

A. Monitoring Network in Lignite Mines of PPC

The telemetric network, which is monitoring the water quality and quantity parameters in the plant of "PPC" in Western Macedonia Lignite Mines, is an integrated electronic – monitoring system. It consists of four (4) T.S. which monitor data on an hourly basis and report them as daily averages. The two (2) of them are located in observation wells named "GEO–108" and "GEO–117" both in the Mines of "Notio Pedio" and the other two (2), are located in pipe hydrants, which outflows from the pumping of stagnant water in the bottom – pit of mines. The one T.S. is settled in "Kardia" mine and is named "ANT–KARD" and the other is in "Notio Pedio" mine and is named "ANT–ONP" [6,7]

From the four (4) T.S. described above, "GEO-108" was selected for assessment of the measurements. The other three (3) T.S. were not chosen because the measurements had a lot of missing values. They had been stopped since the beginning of August 2009 due to serious damages from severe meteorological phenomena (storms and thunders).

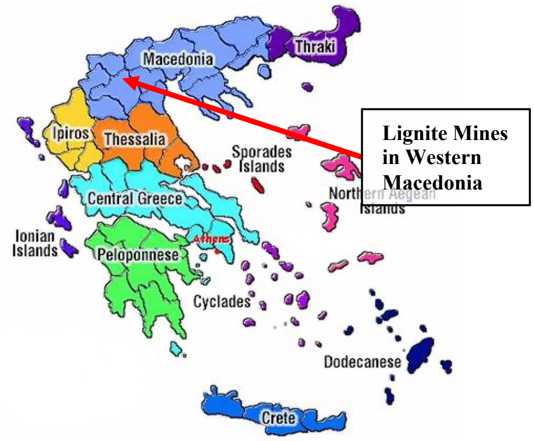

Figure 1. Position of Lignite mines in Western Macedonia, Greece

Figure 2. The T.S. "GEO–108"

So in total the monitoring period, with reliable and continuous data recordings, was approximately 2.5 years, from the beginning of 2007 to the middle of 2009.

B. Methodology

In order to examine any possible trend in a time series three tests were applied:

Linear Regression Approach

A basic approach to test for trend in a time series is a regression approach in which time t is the independent variable and the quality parameter Y_t, the dependent. The standard approach is to assume the linear model:

$$Y_t = a + b \cdot t + e_t \tag{1}$$

where e_t is a "random noise component".

The classical least-squares estimator for the slope b is given from the form:

$$\hat{b} = \frac{\sum_{t=1}^{n}(t-\overline{t})Y_t}{\sum_{t=1}^{n}(t-\overline{t})^2} \tag{2}$$

where $\overline{t} = (n+1)/2$ the average of 1,2,…,n. and n the length of the time series

Under the usual regression assumptions that is, when the residuals are independent and normally distributed with mean zero and variance σ^2, the estimated standard error of b is given by:

$$\hat{S}_1(\hat{b}) = \left[\frac{\sum_{t=1}^{n}(Y_t-\hat{Y}_t)^2}{(n-2)\sum_{t=1}^{n}(t-\overline{t})^2}\right]^{1/2}$$

where $\hat{Y}_t = \hat{a} + \hat{b}t$ and $\hat{a} = \overline{Y}_t - \hat{b}\overline{t}$

In this approach the test statistic of the null hypothesis $H_0 : b = 0$ (there is no trend) is $t_1 = \dfrac{\hat{b}}{\hat{S}_1(\hat{b})}$ and follows Student distribution with $n-2$ degrees of freedom.

Linear Regression Approach with correlated errors

Another procedure is that of estimating of b using the least squares estimator and testing its significance using a standard error that does not use the independent errors assumption of classical regression analysis. In this case Woodward (1993) [8], suggest another form for estimating the standard error of b:

$$\hat{s}_2(\hat{b}) = \left\{ 12c_0 / n(n^2-1) \left[1 + \frac{24}{n(n^2-1)} \sum_{s=2}^{n} \sum_{t=1}^{s-1} (t-\bar{t})(s-\bar{t}) c_{s-t} \right] \right\}^{1/2} \quad (4)$$

where c_k denotes the k^{th} autocovariance of the residuals e_t given by:

$$c_k = \frac{1}{n} \sum_{t=1}^{n-k} e_{t+k} \cdot e_t \quad (5)$$

The null hypothesis $H_0 : b = 0$ is rejected when the statistic $t_2 = \frac{\hat{b}}{\hat{S}_2(\hat{b})}$ is greater than the critical value $t_{n-2;a/2}$ for a two-tailed *t*- test (a is the level of significance).

Spearman's trend test

The Spearman rank correlation coefficient is described as:

$$R_{sp} = 1 - \frac{6 \cdot \sum_{i=1}^{n} (D_i \cdot D_i)}{n \cdot (n^2 - 1)}$$

where *n* is the total number of values in each time series, *D* is the difference and *i* is the chronological order number.

The difference between rankings is computed as $D_i = K_{xi} - K_{yi}$, where K_{xi} is the rank of a measured variable in chronological order and K_{yi} the series of measurements transformed to its rank equivalent, by assigning the chronological order number of a measured in the original series to the corresponding order number in the ranked series, *y* [9].

The null hypothesis, $H_0 : R_{sp} = 0$ (there is no trend), against the alternate hypothesis, $H_1 : R_{sp} \neq 0$ (there is a trend), is checked with the test statistic:

$$t_3 = R_{sp} \cdot \left[\frac{n-2}{1 - R_{sp}^2} \right]^{1/2} \quad (7)$$

where t_3 has Student's *t* distribution, with $n-2$ degrees of freedom. At a significant level of 5%, the time series has no trend if $t_{n-2,a/2} \leq |t|$

C. Results and discussion

The mean, variance and standard deviation of the three parameters for all the monitoring years (2007-2009) are presented in table 1.

Table 1: Mean, variance and standard division of the three parameters (2007-2009)

	Mean	**Variance**	**Std. Deviation**
H (m)	-40.76.16	72.036	8.48738
Ecw (μS/cm)	320.0140	2675.691	51.72708
pH	7.6	0.202	0.44989

The time series and the linear trend line for each parameter are presented in Figures 3, 4 and 5.

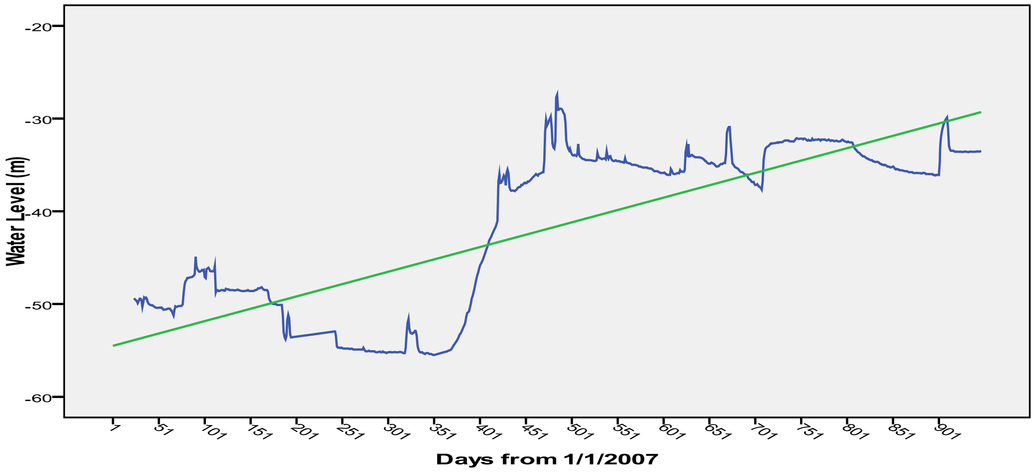

Figure 3 Observed data and trend line for Water Level

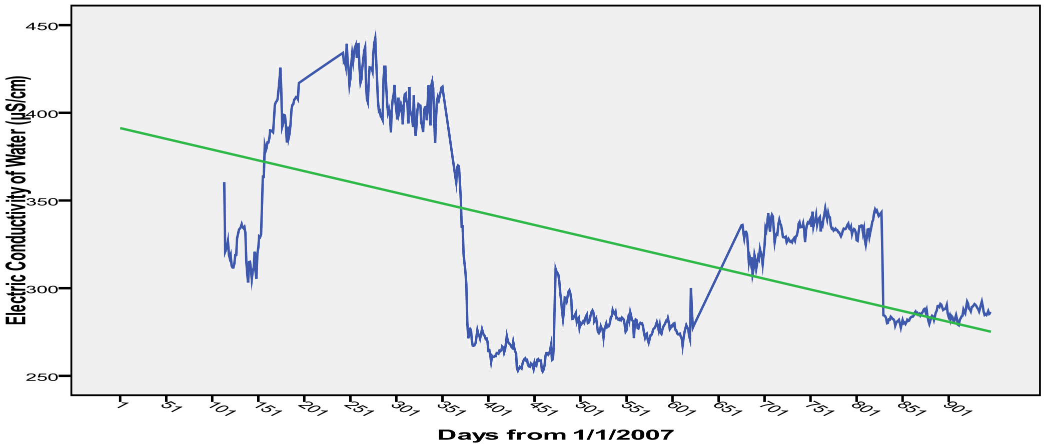

Figure 4 Observed data and trend line for Electric Conductivity of water

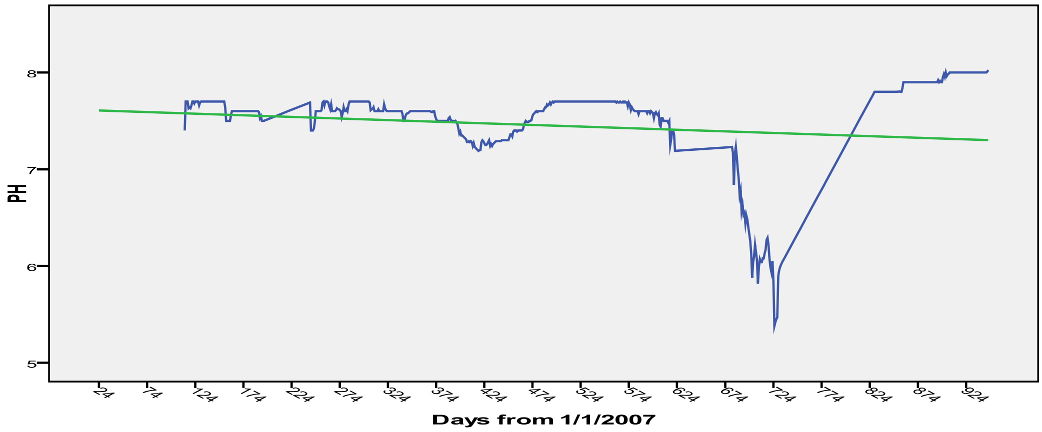

Figure 5 Observed and trend line of pH

For H, there were 924 measured data for the period 24/1/07 – 4/8/09 and 63 missing values. It is shown in Figure 3 that the H values fluctuate from -55 to -44 m for the first year (2007) of monitoring period. For the rest years (2008 and 2009), H values fluctuate from -55 to -27 m with small variations. For ECw, there were 834 measured data for the period 24/4/07 – 4/8/09 and 113 missing values. The measurements are considered as normal with values ranging from 300 to 440 µS/cm except of some isolated time increments where the values are below 300 from January 2008 to September 2008 and from April 2009 till the end of the monitoring period. For pH, there were 924 measures for the same period with H parameter, with 216 missing values. The values range from 6.0 to 7.7 by the beginning of 2007 to December of 2008. In December the values seemed to be lower (5.4 – 6.0) and considered to slightly acid range of pH.

The three statistical tests were applied for all the parameters. The slope of the regression line was estimated by the linear regression method. Table 2 provides the values of the parameter *b* of the linear trends and the values of the statistics t_1, t_2 and t_3.

Table 2: Values of the slope *b* of the regression analysis and the values of the statistics t_1, t_2 and t_3 for the parameters Water Level, Electrical Conductivity of water and pH

		Linear Regression Approach	**Linear Regression Approach with correlated errors**	**Spearman's trend test**
	b	t_1	t_2	t_3
H (m)	0.027	41.385	5.708360	33.7738
Ecw (μS/cm)	-0.123	18.436	2.414273	11.8202
pH	0.0006	5.018	1.624763	5.16348

D. Conclusion

The three statistical tests were applied to H, ECw and pH time series. For the parameters that were examined for trend H and ECw presented trend for every test at the 5% level of significance. For the parameter pH, trend is considered statistically significant at 5% level of significance for the linear regression approach and Spearman's trend test. For the linear regression approach with correlated errors, the trend is marginally significant at significance level 0.10 (10%). From Table 2 we can see that the statistic t_2 that take into consideration the autocorrelation in the data, are smaller than those based on usual regression assumptions. This means that the standard errors that take into consideration the autocorrelation in the data are larger.

Generally, the operation of the telemetric network of water quality and quantity parameters in Western Macedonia lignite mines is being continued normally. The monitoring data of all the parameters were fluctuated in normal predictable values. Problems occurred which are considered as normal for such telemetric networks, due to the extremely difficult weather conditions in the area of the mines in Western Macedonia.

Further research would be carried out, using the trend analysis for all the T.S. and applying more trend tests.

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