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Quality Control of Drinking Water and Public Health.

A. PAPAIOANNOU*[1], P. PLAGERAS[1], E. DOVRIKI[1], K. KAKAVAS[1], P.TH. NASTOS[2] and A.G. PALIATSOS[3]

[1] Department of Medical Laboratories, Education & Technological Institute of Larissa, GREECE

[2] Laboratory of Climatology and Atmospheric Environment, Department of Geology and Geoenvironment, University of Athens, GREECE

[3] General Department of Mathematics, Technological Education Institute of Piraeus, GREECE

E-mail: papaioannou@teilar.gr

Abstract: The 60/2000/EU (WFD) and 98/83/EEU directives imposed rules and instructions for continuous monitoring and control the quality of drinking water. In the present study three representative areas, lowland (LL), mountainous (M) and coastal (C), have been selected for the collection of water samples, in the Prefectures of Larissa, Karditsa and Magnissia, central Greece. Physical: (electric conductivity (EC, μS/cm), pH, total hardness (TH, mg/L $CaCO_3$)), chemical (mg/L): (nitrate (NO_3^-), nitrite (NO_2^-), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), calcium (Ca^{+2}) and magnesium (Mg^{+2})) and microbiological: (*total coliforms, E. Coli, Enterococci, Pseudomonas Aeroginosa and Salmonella*) parameters have been determined and analyzed for the period 2004-05. The mean values of the studied physical and chemical parameters were found to be within the limits mentioned in the 98/83/EEC Directive. From the microbiological study can be concluded that the water was inapropriate for human consumption in many cases because of the presence of microbes. From the analysis of results (Student's t-test; $P<0.05$ and Mann-Whitney test; $P<0.05$), it reveals that there are significant differences on the water quality among the studied areas.

Key words: Drinking water, public health, physical parameters, chemical parameters, microbiological parameters, Larissa, Karditsa,Magnissia, Greece.

1 Introduction

It is well documented that the quality of drinking water is "strongly" correlated with the protection of public health. The studies that have been preceded up today show the need of undiminished investigation of these subjects.

The water problem in Europe can be summarized to the following:

- 20% of all surface water in the EU is seriously threatened by pollution
- 60% of all European cities overexploit their groundwater resourses
- 50% of wetlands have "endangered status" due to groundwater overexploitation
- The area of irrigated land in Southern Europe has been increased by 20% since 1985

All this knowlege allowed the E.U. to establish a number of directives which refer to the protection of the water resources and public health [1-11]. Already in the first article of directive 98/83 it is stated the level of quality that the potable water should have. This is judged essential for the protection of public health and the negative repercussions of bad quality of water are annihilated. The intention of the Drinking Water Directive (DWD) is to protect the health consumers' in the European Union, to make sure the water is wholesome and clean (free of unacceptable taste, odour, color) and has a pleasant appearance. To make sure drinking water is indeed healthy, clean and tasty everywhere in the EU, the DWD sets standards for the most common substances (so-called parameters) that can be found in drinking water. In the DWD a total of 48 microbiological and chemical parameters must be monitored and tasted regularly [12, 13]. Member States have to monitor the quality of the drinking water supplied to their citizens and this has to be done mainly at the tap inside private and public premises. Also the quality of drinking water used for food production industry has to be monitored to make sure it complies with the EU standards.

In the present study three representative areas, lowland (LL), mountainous (M) and coastal (C), and thirty six sites have been selected for the collection of water samples, in the Prefectures of Larissa, Karditsa (sixteen sites) and Magnissia (twenty sites), central Greece. Physical: (electric conductivity (EC, μS/cm), pH, total hardness (TH, mg/L $CaCO_3$)), chemical (mg/L): (nitrate (NO_3^-), nitrite (NO_2^-), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), calcium (Ca^{+2}) and magnesium (Mg^{+2})) and bacteriological: *Total coliforms* (TC), *E. Coli*, *Enterococci* (E), *Pseudomonas Aeroginosa (PA)* and *Salmonella (S)* parameters have been determined and analyzed for the period 2004-05. The mean values of all studied physicochemical parameters were found to be within the limits mentioned in the 98/83/EEC Directive.

2 Methodology and Instruments

In the present study are included two regions from the area of Thessaly, central Greece. Region A is constituted of the prefectures of Karditsa and Larissa while region B of the prefecture of Magnisia.In each region, three representative areas (lowland (LL), mountainous (M) and coastal (C)) were selected for the collection of water samples. More specifically, eight sites from LL area (Fyllo, Petrino, Itea, Sikeona, Orfana, Leuki and Falani) four sites from M area (Karitsa, Kranea, Akri and Elassona) and four sites from C area (Omolio, Stomio, Paleopirgos and Kokkino nero) in region A while four sites from LL area (Karla), six sites from M area (Almiros, Sourpi and Ferron) and ten sites from C area (Agria, Argalasti, Artemida, Pteleos and city of Volos) in region B were selected and water samples from every site were collected once every three months for a period 2004-2005.

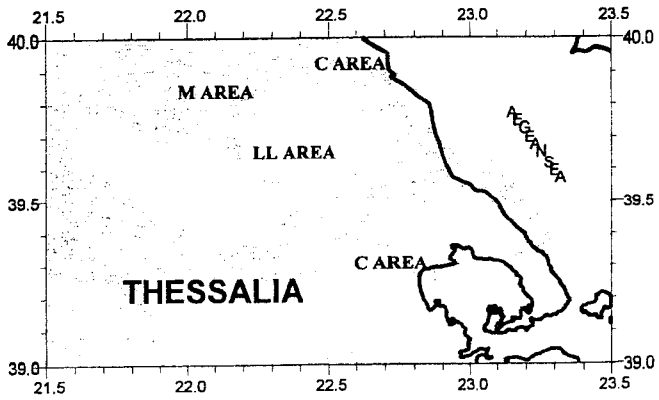

Figure 1. Map of the Thessaly and sampling areas

Volumes of 1lt-unfiltered water were collected in acid-cleaned high-density polyethylene (HDPE) containers, which are the most appropriate containers for the collection of water samples [14]. Samples were stored in the dark at 4 ^{0}C to minimize sample deterioration prior to analysis. Physical and chemical parameters were determined with the use of classical analytical techniques [12, 15]. The determination of nitrate and nitrite ions in the water was carried out spectrophotometrically using the methods described in APHA [15]. The chemicals used for the analysis were of analytical reagent grade and all solutions were prepared using HPLC water.

The information was recorded in an MS Excel database and processed using statistical software MedCalc version 6.15.000 and SPSS 12.0 for windows.

3 Results and Discussion

The determined physical and chemical parameter values during the study period are presented as mean±standard deviation. Table 1 presents the statistical characteristics of all the examined physical parameters in the region A and and Table 2 presents the statistical characteristics of all the examined physical parameters in the region B.

From the data of Table 1 and Table 2 it can be concluded that the values of physical parameters that were studied are found in the permissible limits that the directive 98/83 puts.

Table 1. Physical parameter of drinking water (mean ± SD)

	Region A		
Area	EC[a]	pH	TH[b]
LL	651.5 ± 213.7	7.82 ± 0.28	303 ± 87
M	415.7 ± 104.7	7.92 ± 0.26	158 ± 75
C	370.7 ± 315.7	7.42 ± 0.39	197 ± 174

[a]EC (μS/cm), [b]TH (mg/L $CaCO_3$)

Table 2. Physical parameter of drinking water (mean ± SD)

	Region B		
Area	EC[a]	pH	TH[b]
LL	718.5±447.2	7.71±0.26	267±212
M	775±353	7.80±0.37	249±160
C	1360±1064	7.63±0.45	335±244

[a]EC (μS/cm), [b]TH (mg/L $CaCO_3$)

The drinking water presents the smaller mean value of EC in coastal and mountainous areas while the highest in lowland-urban areas of the region A . EC mean values in the region B are also relatively low and progressively increase towards the coastal area. The pH means are higher than 7 because the slight alkaline character of water, and their spatial progressive increase is C-LL-SM, so the greatest mean of pH occurs in SM areas. The total hardness of the water is relatively small and presents the biggest value in LL area of the region A and in C area of the region B. The revalorization of water mainly in LL area can be attributed to intensive rural, industrial and urban activities that pollute the surface water and groundwater.

Similarly, Table 3 and Table 4 shows the statistical characteristics of concentration (mg/L) levels of all the examined chemical parameters in the two regions.

Data from Table 3 and Table 4 show that in region A, the drinking water in LL area has been polluted by nitrates while in the mountainous and coastal areas the pollution by nitrates is insignificant. In region B all the studied areas have been polluted by nitrates and the greatest mean value of nitrates occurs in the SM area. This can be attributed to the pollution of groundwater with nitrates because of the agricultural, industrial, tourism and urban activities (fertilizers, industrial and urban wastes). A possible negative health effect of high nitrate concentrations is methemoglobulinemia, especially for infants. None studied area presents high concentrations of nitrite. The presence of ammonium in drinking water declares the possibility of microbe's presence. The situation in this case is judged worrying and demands further investigation with parallel control of chlorination of water. The concentration of the cations, K^+, $N\alpha^+$, Ca^{+2} and Mg^{+2} in drinking water is in the acceptable limits that the directive 98/83 puts.

Table 3. Chemical parameter of drinking water (mean ± SD)

Parameter	Region A		
(mg/L)	LL area	M area	C area
NO_3^-	12.9 ± 25.2	4.6 ± 5.1	2.1 ± 1.9
NO_2^-	0.04 ± 0.10	0.00	0.00
K^+	1.69 ± 2.81	0.55 ± 0.74	0.21 ± 0.11
Na^+	68.8 ± 63.1	6.7± 4.5	5.6± 2.0
NH_4^+	0.11 ± 0.13	0.03 ± 0.05	0.07 ± 0.08
Ca^{+2}	65.5 ± 36.1	32.4 ± 19.7	61.2 ± 58.7
Mg^{+2}	21.5 ± 18.2	15.1 ± 16.0	13.3 ± 14.1

Table 4. Chemical parameter of drinking water (mean ± SD)

Parameter	Region B		
(mg/L)	LL area	M area	C area
NO_3^-	14.5±14.0	25.2±21.9	14.8±10.6
NO_2^-	0.00	0.01±0.01	0.01±0.01
K^+	1.57±1.26	1.39±0.81	2.31±2.98
Na^+	45.2±39.8	48.8±41.3	101.1±148.3
NH_4^+	0.00	0.03±0.05	0.06±0.09
Ca^{+2}	68.2±34.2	71.7±29.7	122.7±66.1
Mg^{+2}	42.3±26.5	33.8±16.5	73.8±54.1

The values of physical parameters are normally distributed, according to the Kolmogorov-Smirnov criterion. Moreover, statistical analysis for the comparison of physical parameter averages among the considered areas of the same region and between the two different regions was performed by the Student's t-test; $P<0.05$ was considered statistically significant. The results from the performed statistical analysis for the comparison of physical parameter averages among the considered areas in the region A are presented in Table 5.

Table 5. Results from the performed statistical analysis for the comparison of physical parameter averages among the considered areas of the same region (LL:lowland area, M:mountainous area, C:coastal area)

	Region A		
Areas	EC	pH	TH
LL vs M	P<0.05	NS	P<0.05
LL vs C	P<0.05	P<0.05	P<0.05
M vs C	NS	P<0.05	NS

The results from the performed statistical analysis for the comparison of physical parameter averages among the considered areas in the region B are presented in Table 6.

Table 6. Results from the performed statistical analysis for the comparison of physical parameter averages among the considered areas of the same region (LL:lowland area, M:mountainous area, C:coastal area)

	Region B		
Areas	EC	pH	TH
LL vs M	NS	NS	NS
LL vs C	P<0.05	NS	NS
M vs C	P<0.05	NS	NS

From the Table 5 and Table 6 it can be concluded that in region A there are significant differences between the LL –M and LL-C areas concerning the EC. Significant differences in the region A are also observed between LL-C and M-C areas concerning the pH, between LL-M and LL-C areas concerning the TH. In region B there are significant differences detween LL-C and M-C areas concerning the EC. The pH and TH parameters do not differ significant between the areas of region B.

The results from the performed statistical analysis for the comparison of physical parameter averages among different areas of the two regions are presented in Table 7.

Table 7. Results from the performed statistical analysis for the comparison of physical parameter averages among different areas of the two regions (LL:lowland area, SM:semi-mountainous area, C:coastal area, (A):region A and (B):region B)

Area	EC	pH	TH
LL(A) vs LL(B)	NS	NS	NS
LL(A) vs M(B)	NS	NS	NS
LL(A) vs C(B)	P<0.05	NS	NS
M(A) vs LL(B)	P<0.05	NS	NS
M(A) vs M(B)	P<0.05	NS	NS
M(A) vs C(B)	P<0.05	NS	P<0.05
C(A) vs LL(B)	NS	P<0.05	NS
C(A) vs M(B)	P<0.05	P<0.05	NS
C(A) vs C(B)	P<0.05	NS	P<0.05

The concentration values of K^+, Na^+, NH_4^+, Ca^{+2} and Mg^{+2} are normally distributed, according to the Kolmogorov-Smirnov criterion. The statistical analysis for the comparison of these chemical parameter mean values, among the considered areas of the same region and between the two different regions, was performed by the Student's t-test; $P<0.05$ was considered statistically significant. For the concentration values of the other chemical parameters (NO_3^-, NO_2^-,) that did not follow the normal distribution, the analysis was performed by the non-parametric Mann-Whitney test; $P<0.05$ was considered statistically significant. The results from the performed statistical analysis for the comparison of chemical parameter averages among the considered areas in the region A are presented in Table 8.

Table 8. Results from the performed statistical analysis for the comparison of chemical parameter averages among the considered areas of the same region (LL:lowland area, M:mountainous area, C:coastal area, (A):region A and (B) region B)

	Region A		
Parameter	LL vs M	LL vs C	M vs C
NO_3^-	NS	P<0.05	NS
NO_2^-	NS	NS	NS
K^+	NS	P<0.05	NS
Na^+	P<0.05	P<0.05	NS
NH_4^+	NS	NS	NS
Ca^{+2}	P<0.05	NS	NS
Mg^{+2}	NS	NS	NS

The results from the performed statistical analysis for the comparison of chemical parameter averages among the considered areas in the region B are presented in Table 9.

Table 9. Results from the performed statistical analysis for the comparison of chemical parameter averages among the considered areas of the same region (LL:lowland area, M:mountainous area, C:coastal area, (A):region A and (B) region B)

	Region B		
Parameter	LL vs M	LL vs C	M vs C
NO_3^-	P<0.05	NS	P<0.05
NO_2^-	NS	NS	NS
K^+	NS	NS	NS
Na^+	NS	NS	NS
NH_4^+	NS	NS	NS
Ca^{+2}	NS	P<0.05	P<0.05
Mg^{+2}	NS	NS	P<0.05

The results from the performed statistical analysis for the comparison of chemical parameter averages among the same areas of the two different regions are presented in Table 10.

Table 10. Results from the performed statistical analysis for the comparison of chemical parameter averages among same areas of the two regions (LL:lowland area, M:mountainous area, C:coastal area, (A):region A and (B):region B)

Parameter	LL(A) vs LL(B)	M(A) vs M(B)	C(A) vs C(B)
NO_3^-	NS	P<0.05	P<0.05
NO_2^-	NS	P<0.05	P<0.05
K^+	P<0.05	P<0.05	P<0.05
Na^+	NS	P<0.05	P<0.05
NH_4^+	P<0.05	NS	NS
Ca^{+2}	NS	P<0.05	P<0.05
Mg^{+2}	P<0.05	P<0.05	P<0.05

The results from the performed statistical analysis for the comparison of the chemical parameter averages among different areas of the two regions are presented in Table 11.

Table 11. Results from the performed statistical analysis for the comparison of chemical parameter averages among different areas of the two regions (LL:lowland area, M:mountainous area, C:coastal area, (A):region A and (B):region B)

Areas	NO3	NO2	K	Na	NH4	Ca	Mg
LL(A) vs M(B)	P<0.05	NS	P<0.05	NS	P<0.05	NS	P<0.05
LL(A) vs C(B)	P<0.05	NS	P<0.05	NS	NS	P<0.05	P<0.05
M(A) vs LL(B)	P<0.05	NS	P<0.05	P<0.05	NS	P<0.05	P<0.05
M(A) vs C(B)	P<0.05	P<0.05	P<0.05	P<0.05	NS	P<0.05	P<0.05
C(A) vs LL(B)	P<0.05	NS	P<0.05	P<0.05	P<0.05	NS	P<0.05
C(A) vs M(B)	P<0.05	P<0.05	P<0.05	P<0.05	NS	NS	P<0.05

The differences between the studied physical and chemical parameters among the areas of the same region and among the areas of the two different regions can be attributed (i) to the origin nutural constitution of the water in these areas and (ii) to the different use of land that deteriorates the water resources (agricultural, urban and industrial activities in LL area, agricultural activities in SM and C areas of region A, industrial activities in SM area, agricaltural activities in LL area, agricultural and tourism activities in C area of region B).

The bacteriological study was proceded in 72 water samples from LL area, 16 water samples from SM area and 32 water samples from C area of the region A. The results of analysis of microbiological parameters are given in table 12.

Data of Table 12 show that a big number of water samples are innapropriate for human consumption because of the presence of microbes. This can be attributed in the "not right" management of drinking water and more specifically in the defective chlorination, the problematic reservoirs of water storage and the old and bad network of water distribution.

Table 12. Microbiological parameters. Number of positive samples (N: total number of samples, TC: *Total Coliforms*, E: *Enterococci*, PA: *Pseudomonas Aeroginosa* and S: *Salmonella*)

Parameter	LL area	M area	C area
N	72	16	32
TC	7	10	17
E.Coli	4	4	6
E	1	2	0
PA	2	4	6
S	0	0	0

4 Conclusions

The quality of drinking water is "strongly" correlated with the protection of public health. The pollution of the environment and groundwater affects negatively the quality of water. The environmental problems met in the studied area may be considered as typical of many other areas in Greece. These environmental problems include: (i) pollution from the discharge of municipal sewage, industrial waste and agricultural runoff to the soils, (ii) uncontrolled disposal of municipal refuse, (iii) overuse of the water resources, (iv) uncontrolled use of pesticides and air spaying practices.

The problems that have appeared in the quality of drinking water in the studied areas can be mainly attributed to the nitrate and microbiological pollution.

The continuous monitoring and quality control of drinking water is essential for the protection of public health because of the bad management of aquatic resources in Greece and more specifically, the defective chlorination in certain regions, the old network of storage and distribution of drinking water.

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