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Operational Paper

Characteristics of water resources in Dalmatia according to established standards for drinking water

Nives Štambuk-Giljanović

ABSTRACT

The purpose of this study was to monitor and record the specific characteristics and properties of most of the important water resources in Dalmatia (southern Croatia) for a period of 5 years (1994–1998). A detailed account of their chemical content classification and concentration of salts is presented. Bacteriological pollution levels are indicated by the total coliform bacterial levels (MPN coli/100 ml).

The water characteristics are expressed by coefficients which represent the ratios between water components. The Ca/Mg eq ratio, SO_4/Cl eq ratio and K_1 and K_2 for bicarbonate hardness were calculated. The concentration of anions shows a stability from which it is possible to predict probable content and availability of salts in these waters. The hygienic characteristics of the water samples were expressed by the total coliform bacteria estimation (MPN coli/100 ml), the permanganate consumption ($KMnO_4$) and biological oxygen demand (BOD_5).

Typical karst waters in Dalmatia are moderately hard, the SO_4/Cl ratio is 0.38–1.6, they are non-corrosive (K_1 lower than 0.2), and not significantly mineralized (<500 mg/l minerals). Sulphate waters are generally hard, the SO_4/Cl ratio is higher than 1.6, and K_1 is 0.2–0.65. Marine waters are quite hard or hard, particularly at the river estuaries, the SO_4/Cl ratio is lower than 0.38, and K_1 is higher than 0.65.

The groundwater and springs in Dalmatia are less polluted than surface waters. A majority of these have a geometric average value of MPN coli <150/100 ml of water, observed in 24 out of 42 locations studied. The highest bacteriological pollution was found in nine locations where MPN coli >1,000/100 ml, and moderate pollution was found in nine locations where MPN coli was between 150–1,000/100 ml of water.

The overall changes in water quality can be correlated with the epidemiological prevalence of water-borne diseases, particularly bacterial diarrhoeas, and can reflect the demographic distribution of water-borne diseases, i.e. overall health status.

Key words | chemical content, geometric average of MPN coliforms, salt concentration, water classification

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INTRODUCTION

The aim of this paper is to present some data related to the systematic study of chemical and sanitary characteristics of the groundwater, springs and surface waters at 42 locations, and the classification of water resources in the Dalmatia region according to geographical areas.

The Dinaric karst region has abundant rainfall; the average annual rainfall is ca 1,500 mm (Štambuk-Giljanović 1994). Since this region covers an area of 57,000 km^2, the total quantity of water flowing into the Adriatic Sea and the Black Sea amounts to 57×10^9 m^3 per year. This quantity is significant considering the northern agricultural areas of Croatia where the amount of rainfall is 2.5 times less and the outflow coefficients are lower.

However, the amount of rainfall is unfavourably distributed so that the time distribution of rainfall and the outflow regime have an adverse influence on life and agriculture in this region. Dinaric karst is characterized by insufficient quantities of water during the summer months and a relatively excessive amount of rainfall during the winter and spring months (Matoković & Štambuk-Giljanović 1994).

In spite of the small amount of surface water, the abundance and complex circulation of groundwater is typical of Dinaric karst (Villalba 1995) and in accordance with the hydrogeological characteristics of the dominant rock types. The Adriatic coastal belt and the islands are mainly formed of sedimentary rocks and carbonates. The rock mass contains cretaceous limestones and dolomites (Ramanathan *et al.* 1994) and Eocene flysch whose properties influence groundwater circulation in the coastal area and on the islands (Bonacci 1991).

Cretaceous limestone is permeable, while Eocene flysch is an impermeable medium, i.e. a barrier which makes possible the formation of underground reservoirs and the appearance of springs at the boundaries of karst fields.

Other hydrographic characteristics of Dinaric karst include scarce and long surface waters with only a few tributaries with changeable capacities, a small number of springs, and a relatively great number of submarine springs along the coast (Slišković 1994).

The permeability of the karst soil allows a great quantity of dissolved organic and toxic matter to render it hygienically unsafe. The inland region of Dinaric karst is relatively scarcely populated since the largest agglomeration of population and industry is in the coastal zones. Hence, most of the surface water, but not groundwater, has preserved its natural characteristics (Štambuk-Giljanović & Matoković 1999).

According to the results of investigations carried out over a 5 year period (1994–1998), presented in this paper, it is possible to observe many regularities in the chemical content of the water and to classify the water resources according to chemical content and bacteriological pollution.

Water supply and health care institutions are especially interested in observing and monitoring the waters, and in preserving their quality. The scarcity of water today has a global character due to the decrease in both quality and quantity of water resources in the whole world; it is presumed that future wars will be waged over water resources. This is illustrated by the squabbles between Egypt and Sudan over the usage of Nile waters, and Turkey and Syria over the Euphrates waters. Investigations and estimations prove that global water consumption in the last century (1900–2000) increased 10-fold and will double by the year 2050 (Cox 1989).

METHODS

The water samples dealt with in this paper were taken on a monthly basis. The physical, chemical and microbiological analyses were carried out according to *Standard Methods* (APHA/AWWA/WEF 1995). The results of the chemical analyses (Van Grol 1995; Drukkerij De Eendrecht 1998) are expressed in mg/l, and the contents of important anions (chloride, sulphate and bicarbonate), important cations (calcium, magnesium, sodium) and hardness are also expressed in eq/l and % eq. Various coefficients are used in studying the water characteristics such as the determination of genetic origin, and comparing the composition of the analysed water with other types of water (e.g. with seawater) in order to identify the water sources.

Ca/Mg eq ratio

This ratio displays the influence of seawater upon freshwater. This frequently occurs in Dalmatia particularly if the sea is nearby. This ratio is constant in seawater (0.2), which means that the seawater contains 5 times more magnesium than calcium. In freshwater this ratio varies

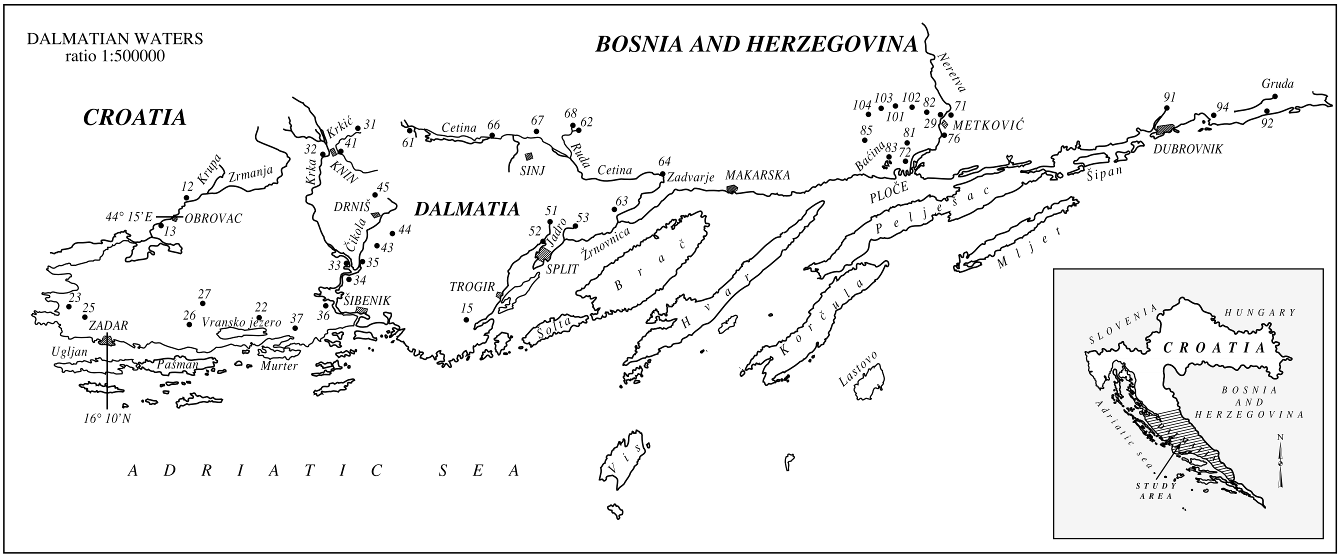

Figure 1 | Water sampling stations in Dalmatia: 12 Zrmanja river—Muškovci; 12 Zrmanja river—below Obrovac; 22 the Golubinka spring; 23 the Vlačina reservoir; 25 Bokanjac, groundwater; 26 the Biba spring; 27 the Kakma spring; 31 the Krka spring; 32 the Krka river below Knin; 33 the Krka river below Skradinski waterfall; 34 the Jaruga spring; 35 Torak; 36 Kovča, groundwater; 41 Pećina—Knin; 43 Banovača—Otavice; 44 Orovača—Kanjani; 45 Točak—Gradac; 51 the Jadro spring; 52 the Jadro estuary; 53 the Žrnovnica spring; 61 the Cetina spring; 62 Cetina below Trilj; 63 Cetina—Gata; 64 Cetina river—Zadvarje; 66 Mala Ruda; 67 Velika Ruda; 68 the Kosinac spring; 71 Neretva near Ada at Metković; 76 Neretva near Duvrat; 72 Neretva at the dam near Opuzen; 102 the Utopišće spring; 103 the Jezerine spring; 104 the Duboka Draga spring.

and ranges from 3–5. A lower ratio is indicative of the influence of seawater.

SO_4/Cl eq ratio

This ratio varies greatly in freshwater whereas in seawater it is constant (0.1). This means that seawater contains 10 times more chloride than sulphate; freshwater generally contains more sulphate than chloride. Since this ratio is quite constant and typical of some bodies of water, Buljan (1962) suggested a classification of all kinds of waters, based on this ratio, into the following geochemical types: rain, marine, sulphate and fossile types. In his classification Buljan included various types of water, i.e. water with various degrees of mineralization. In Dalmatian waters it was found that this ratio can be calculated in certain types of water using the average annual values (Štambuk-Giljanović 1999) and it falls within the following limits: marine–0.10 to 0.38; rain–0.38 to 1.6; sulphate–more than 1.6.

Water of optimal composition, without aggressive (corrosive) properties, contains a relatively small quantity of dissolved CO_2, it does not contain aggressive CO_2 and the ratio between the sulphate-chloride total and the alkali content, i.e. bicarbonate ions, is lower than 1:5. In water containing more sulphate and chloride this ratio will be disturbed, and the water will display more or less aggressive properties. Thus, some types of water, with an alkali content below 50 mg/l $CaCO_3$, are more aggressive than hard water since that ratio is unfavourable and almost all dissolved CO_2 is aggressive.

In this paper the coefficient used for the evaluation of water corrosiveness was calculated according to Larson & Scold (1958):

$$K_1 = (SO_4 + Cl)/CH \text{ eq} \quad (1)$$

where CH = carbonate hardness.

In addition, the ratio between non-carbonate hardness (NCH) and carbonate hardness (CH) was calculated and expressed as coefficient K_2 (Štambuk-Giljanović 1998):

$$K_2 = NCH/CH \text{ eq} \quad (2)$$

According to the coefficient K_1 values the water types were classified into three groups: (a) non-corrosive water with K_1 lower than 0.2; (b) water with low corrosiveness

Table 1 | Average values of the parameters for a 5 year period (1994–1998) of waters in Dalmatia (the Cetina catchment)

	Water						
Parameters	**Cetina spring Vukovića vrilo**	**Cetina below Trilj**	**Cetina Gata**	**Cetina Zadvarje**	**Mala Ruda**	**Velika Ruda**	**Kosinac spring**
Temperature (°C)	10	12	12	13	10.7	12.2	12
pH	7.5	7.6	7.6	7.7	7.6	7.7	7.5
CO_2 (mg/l)	8	6	6	5	10	11	6.4
Dissolved oxygen (mg/l); %	11;108	11;104	11;104	11;102	11.3;102	11.9;112	11.6;104
BOD_5 (mg/l)	2	2.6	2.5	1.8	1.4	1.6	1.4
$KMnO_4$ (mg/l)	6	8	9	8	4.7	5.3	6.8
NH_3-N (mg/l)	0	0.05	0	0	0	0	0
NO_2-N (mg/l)	0	0	0	0	0	0	0
Evaporation residue (mg/l)	214	230	236	215	230	216	196
Mineralization (meq/l)	8.28	9.34	8.94	8.6	8.44	8.34	8.36
Cl (mg/l)	11	16	16	16	10	11	12.3
eq/l	0.31	0.45	0.45	0.45	0.28	0.31	0.34
% eq	7.5	9.6	10.1	10.5	6.6	7.4	8.2
SO_4 (mg/l)	10	29	24	23	22	23	12
eq/l	0.21	0.6	0.5	0.48	0.46	0.48	0.25
% eq	5.1	12.8	11.2	11.2	10.9	11.5	6
HCO_3-$CaCO_3$ (mg/l)	181	181	176	168	174	170	179
eq/l	3.62	3.62	3.52	3.36	3.48	3.4	3.98
% eq	87.4	77.6	78.7	78.3	82.5	81.1	85.8
Hardness-$CaCO_3$ (mg/l)	200	211	207	200	206	203	196.5
eq/l	4.0	4.22	4.14	4	4.12	4.06	3.93
Ca-$CaCO_3$ (mg/l)	150	166	162.5	153.5	163.5	158	157.2
eq/l	3	3.32	3.25	3.07	3.27	3.16	3.14
% eq	72.4	71.1	72.7	71.5	77.5	75.8	75.1

Continued

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Table 1 | Continued

	Water						
Parameters	**Cetina spring Vukovića vrilo**	**Cetina below Trilj**	**Cetina Gata**	**Cetina Zadvarje**	**Mala Ruda**	**Velika Ruda**	**Kosinac spring**
Mg-$CaCO_3$ (mg/l)	50	45	44.5	46.5	42.5	45	34.3
eq/l	0.98	0.9	0.89	0.93	0.85	0.9	0.78
% eq	23.7	19.3	19.9	21.7	20.1	21.6	18.7
Na (mg/l)	3.7	10.4	7.6	6.7	2.3	2.5	5.9
eq/l	0.16	0.45	0.33	0.29	0.1	0.11	0.26
% eq	3.9	9.6	7.4	6.8	2.4	2.6	6.2
HPC/ml	50	300	240	34	30	35	80
TC (MPN/100 ml)	130	230	75	100	40	50	190
FC (MPN/100 ml)	75	115	25	33	40	21	114

HPC, heterotrophic plate count; TC, total coliforms; FC, faecal coliforms; K_1, ($Cl+SO_4$)/CH eq; K_2, NCH/CH eq; CH, carbonate hardness; NCH, non-carbonate hardness.

K_1 from 0.2–0.65; (c) corrosive and very corrosive water with K_1 higher than 0.65.

In water with low non-carbonate hardness the difference between coefficients K_1 and K_2 shows that the water has high non-carbonate hardness which is most frequently caused by the influence of seawater. The sodium content can be easily calculated from that difference. The K_2 coefficient in the raw water cannot be greater than coefficient K_1.

RESULTS

The collection of samples was distributed according to those catchments with the most important surface waters and geographical areas (Figure 1). Accordingly, Dalmatia was divided into 10 areas designated from 10–100. Locations within those areas are represented by units from 1 to 9. The results of chemical and microbiological investigations are presented in Table 1 (the Cetina catchment) as the average 5-year values (1994–1998). The results are expressed in mg/l, while the results for important cations and anions are also expressed in eq/l and % eq. In addition, Table 1 gives the Ca/Mg eq ratio, the SO_4/Cl eq ratio, and the K_1 and K_2 coefficients.

The concentration of anions in eq/l lines (bicarbonate ion, sulphate ion and chloride ion) and the range of coefficients by lines (K_1 coefficient, K_2 coefficient, and Ca/Mg eq ratio) for a 1-year period (1997/1998) in the Cetina catchment (Figure 2) show a fairly uniform water content in the Cetina spring (Vukovića vrilo). There is an increase in sulphate and chloride in the water of the Cetina section near Gata which decreases near Zadvarje. The graph presents only the anion concentrations since anions are important indicators for the properties of water; the anion content influences the cation types contained in water. The graph of chemical content shows that the influence of the sea can be even better observed according to the values of coefficients K_1 and K_2. The great difference between these coefficients shows the

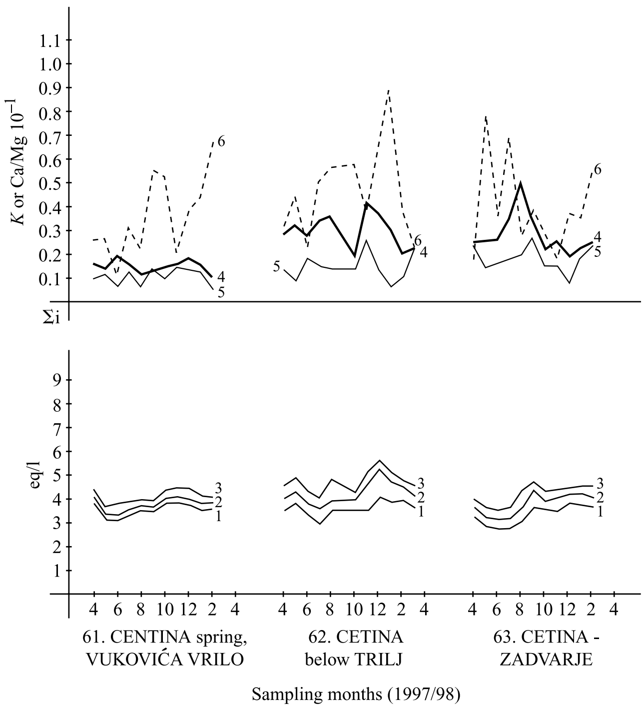

Figure 2 | Concentration of anions and coefficients in the Cetina catchment. In the lower graph the ordinate presents the concentration of anions in eq/l lines (bicarbonate ion, sulphate ion, chloride ion). The upper graph presents the range of coefficients by lines (K_1 coefficient, K_2 coefficient, Ca/Mg eq ratio). 1. HCO_3, 2. SO_4^{2-}, 3. Cl^-, 4. K_1=(SO_4+Cl)/CH, 5. K_2=NCH/CH, 6. Ca/Mg 10^{-1}, CH=carbonate hardness, NCH=non-carbonate hardness.

seawater sodium chloride influence, i.e. higher degree of water corrosiveness. It can be generally noted that the bicarbonate content in water, i.e. the alkalinity, is the most stable. This can be explained by the fact that the content of dissolved carbon dioxide in the water does not vary greatly and the analysed water contains a relatively small quantity of dissolved CO_2. Some water in the Zadar and Šibenik areas contains large quantities of dissolved CO_2 but the bicarbonate content is much higher than in other locations. The chloride and sulphate content in water varies more than the bicarbonate content.

The average annual values of the chemical composition are presented in a step diagram according to Rodgers (Figure 3) (Štambuk-Giljanović 1997; Aljtovski 1973). This step diagram can be used to predict the probable content and the quantity of salts in water.

Specific water characteristics can be determined according to specific measurement results so that water hardness data are used to classify waters into specific groups (Hesphanol & Prost 1994). The increased chloride content in Dalmatian waters shows the seawater influence and the increased sulphate content shows that water dissolves the calcium sulphate layers found in the soil. The water characteristics can be better defined using different coefficients.

All water classifications are connected by a co-ordinate system on the log-scale into a unique classification by considering the SO_4/Cl ratio, hardness, prevalent ions and the corrosiveness (Figure 4).

The points were determined by coordinates and the point at the intersection of the coordinates determines the water type according to all stated classifications. The greatest number of the analysed water bodies, and generally all water resources in Dalmatia, belong to typical karst water (Table 2). The groundwater and surface water in karst areas are moderately hard and when their content is optimal (140–215 mg/l $CaCO_3$), they have low non-carbonate hardness, their chloride and sulphate contents are small, they do not contain aggressive carbon dioxide and the Ca/Mg ratio ranges from 2.5 to 5. According to this graph (Figure 4), which combines all water classifications into a unique classification, sulphate and marine waters are mainly quite hard or hard, particularly in the river estuaries. Furthermore, the graph shows that the marine type water is very corrosive (K_1 higher than 0.65). The sulphate type water is less corrosive ($K_1 = 0.2$–0.65). Standard water is generally not corrosive, while water containing a greater quantity of carbon dioxide is more corrosive. This water can be classified into a specific group in Dalmatia, i.e. carbon-acid water. In other words, this water type is more similar to base water than to typical karst water according to its chemical content.

The hygienic characteristics of water are presented graphically in Figure 5. It is evident from the graph that groundwater and springs are less polluted than surface waters. According to the geometric average value of total coliform bacteria (MPN coli/100 ml) in all analysed waters (Table 3), taking into account the water resources in the environment, MPN coli bacteria can be divided into three groups:

1. The highest bacteriological pollution is found in water where the geometric average value of bacteria

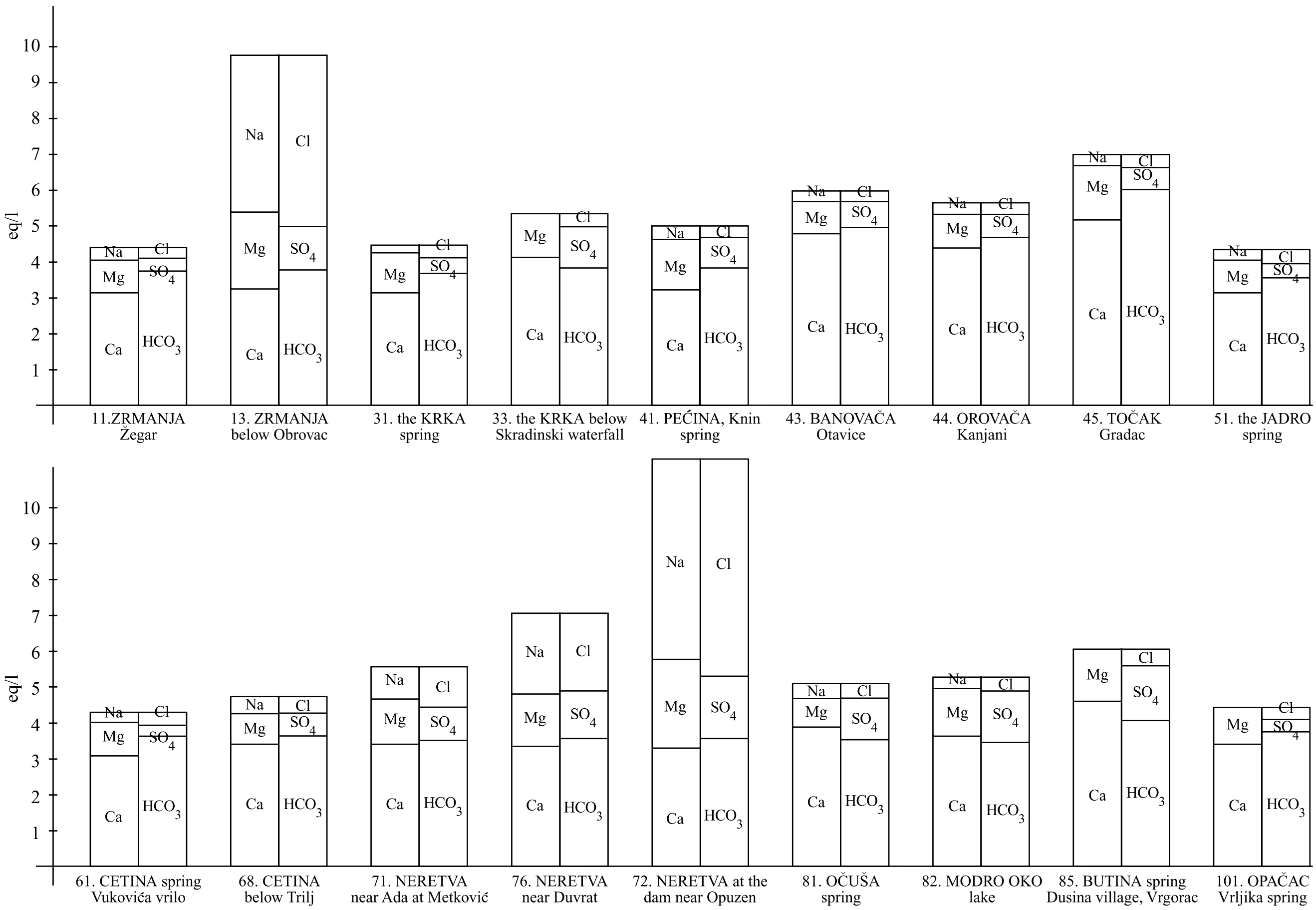

Figure 3 | Step diagram of the water chemical content in Dalmatia according to Rodgers, which presents the average annual values of the chemical composition (Štambuk-Giljanović 1997; Aljtovski 1973). The step diagram consists of two columns. The left column presents the average cation content in eq/l. The diagram height corresponds to the total quantity of cations and anions in the water. This step diagram can be used to predict the probable content and quantity of salts in waters.

is higher than 1,000. This refers primarily to river water with effluents of domestic waste water, and surface waters in agricultural areas exposed to environmental pollution: the Krka river near Knin, the Zrmanja river near Obrovac, the downstream sections of the Neretva river and the estuary of the Jadro river.

2. The second group, where the geometric average value of bacteria is 150–1,000, includes the surface waters not polluted by waste water: the upstream sections of the Zrmanja, Krka and Cetina rivers, the Vlačina reservoir and others. This group also includes some springs with no protective zones which are threatened by environmental pollution such as the Prud spring near Metković and the Biba spring near Biograd.
3. The water least polluted by bacteria includes water where the geometric average value of bacteria is lower than 150 per 100 ml. This group includes the majority of springs in Dalmatia as well as some river sections.

DISCUSSION

The knowledge of the chemical content of water, and the changes in the content caused by various external

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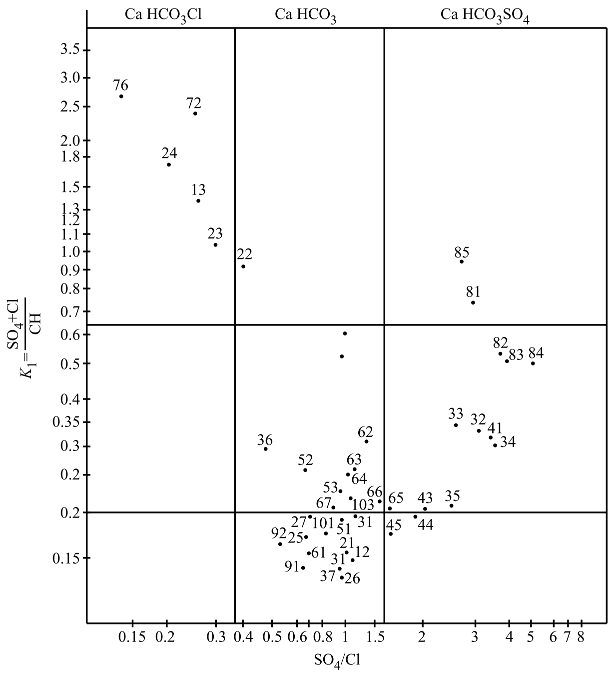

Figure 4 | Water classifications in Dalmatia considering the SO_4/Cl ratio, hardness, prevalent ions and the corrosiveness in a co-ordinate system on the log scale.

Table 2 | Average values of the parameters of a typical karst water type

Parameters	**Average**	**Range**
Evaporation residue (mg/l)	210	170–250
Total hardness, $CaCO_3$ (mg/l)	205	180–215
eq/l	4.1	3.6–4.3
Alkalinity, $CaCO_3$ (mg/l)	180	157–195
Chloride (mg/l)	12	9–13
Sulphate (mg/l)	13	10–30
SO_4/Cl ratio, eq/l	0.8	0.38–1.6
K_1 coefficient, eq/l	0.16	Less than 0.2
Type		Calcium-bicarbonate water

factors are of great importance for different purposes, so that interest in such investigations has greatly increased (Jürgen & Jülich 1995; Joris & Van Dem Bergen 1998). The chemical content can be used as a basis for water classification and predicting the content of other water bodies in a given area, e.g. for studying water circulation and for discovering ore mines, the construction of water supply structures and installations as well as for all hydrotechnical facilities, for water exploitation in industry, for irrigation and for water purification. It can also be used in epidemiological studies where the pathological conditions and illnesses in humans can be correlated with, and possibly explained by, the water chemical content. There are a great number of water resources in Dalmatia which represent exceptions to a typical karst water type. These are water types containing a great quantity of dissolved carbon dioxide, such as water in the Zadar and Šibenik areas. Furthermore, some waters contain a great quantity of sulphate, particularly in the Drnis area and near Sinj. In addition, many water types are influenced by seawater, particularly in the coastal areas, the groundwater on the islands and the water resources in the Ravni Kotari area.

The following factors should be satisfied in order to draw reliable conclusions as to the characteristics and specific properties of individual water resources: systematic analysis of the chemical content over a long period with a given frequency of sample taking; systematic processing of the obtained data, including statistical analysis and the application of various coefficients which enable a more efficient observation of water characteristics rather than individual results; classification of water resources according to the obtained data. This classification can be effected by taking into account the following factors: evaporation residue, i.e. the degree of mineralization; hardness; chemical content, i.e. prevalent ions; SO_4/Cl ratio; corrosiveness.

Water classification

The classification according to the degree of mineralization (Barclay *et al.* 1998) includes all types of water bodies as follows: freshwater up to 1 g/kg of minerals; mineral, salty water from 1 to 25 g/kg of minerals; seawater above 25 g/kg of minerals.

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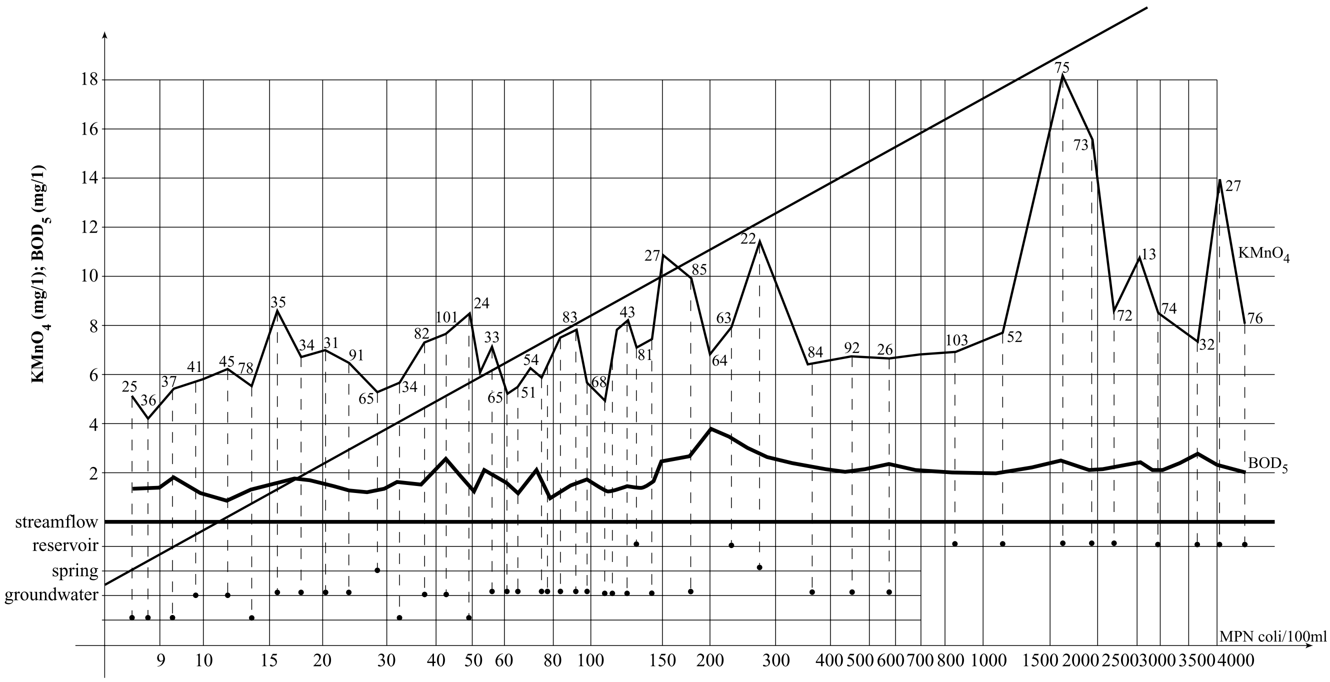

Figure 5 | The hygienic characteristics of water in Dalmatia. MPN coli/100 ml in particular water groups is represented by a point on the diagonal with the code of the water type, and the number of coliform bacteria can be read on the graph abscissa, where the MPN coli/100 ml is presented as a logarithmic ratio. The lower part of the graph shows the location of the water, either groundwater, spring, reservoir or streamflow. The ordinate presents the consumption of permanganate ($KMnO_4$) and BOD_5 (biochemical oxygen demand) in water and it can be seen that these indicators are not sufficiently sensitive since there is no correlation between those indicators and MPN coli.

This paper deals with fresh, not significantly mineralised, water containing less than 1,000 mg/l and most frequently less than 500 mg/l of minerals. If the degree of mineralization (anion sum and cation sum) is multiplied by 26.5, the evaporation residue can be calculated with a satisfactory degree of accuracy (Štambuk-Giljanović 1999).

The water type is most frequently determined according to hardness. The water classification by hardness can be considered together with the classification according to water chemical content since they are closely related. The analysed water hardness according to Klut (Rašić 1975) is as follows:

Very soft water: 0–70 mg/l $CaCO_3$
Soft water: 70–145 mg/l $CaCO_3$

Thus, in our study, we found moderately hard water with 140–215 mg/l $CaCO_3$ at the following locations: Zrmanja (above Jankovića waterfall), Vlačina, Jadro, Žrnovnica, Cetina, Ruda Mala, Ruda Velika, Kosinac, Ljuta and Gorica. Quite hard water, 215–320 mg/l $CaCO_3$, was found at Zrmanja (Obrovac), Kakma, Krka Knin, Pećna Knin, Banovača, Orovača, Neretva (Metković), Očuša, Modro oko, Klokun, Butina, Ombla, Vrljika (Imotski), Jezerine and Duboka Draga. Hard water, 320–530 mg/l $CaCO_3$, was found at Golubinka, Bokanjac, Biba, Kovča, Jandrić, Točak (Gradac) and all rivers near their estuaries.

According to the SO_4/Cl ratio the water can be classified into three types: rain water, where the ratio is 0.38–1.6; marine water, where the ratio is lower than 0.38; sulphate water where the ratio is higher than 1.6.

Table 3 shows that the arithmetic average value of coliform bacteria is generally much higher than the geometric average value. Assuming that the individual MPN coli should not exceed 5,000 per 100 ml, then the arithmetic average value of coliform bacteria (in 6–10 samples) should range from ca 3,000 per 100 ml and the geometric average value should range from 1,000–1,200 as MPN coli/100 ml. This could be accepted as a norm, i.e. as

Table 3 | Analysed waters according to the geometric average values of MPN coli/100 ml (1998)

Range MPN coli/100 ml	No. of samples	0	6,000–24,000	Arithmetic average value	Geometric average value
Middle of range			15,000		
Neretva Duvrat area	14		4	6,660	3,790
Krka river, Knin	14		8	16,900	3,600
Neretva Ada	14		5	6,357	3,500
Zrmanja river below Obrovac	6		2	5,600	2,600
Trn	14		4	5,770	2,630
Neretva river, Opuzen	14		5	4,360	1,920
Prunjak river	14		3	2,824	1,530
Crepina river	14		2	3,640	1,520
Jadro river estuary	10		1	2,862	1,370
Vrljika estuary	13		1	1,797	762
Vrljika	12		1	1,427	307
Butina spring	6			530	228
Zrmanja river—Žegar	6			182	150
Cetina river—Trilj	12			438	148
Ljuta Konavle spring	6	1		396	128
Banovača—Otavice spring	12			300	120
Zrmanja Muškovci river	6			278	120
Žrnovnica spring	12			168	94
Krka River Skrad. Buk	12			184	86
Klokun spring	10	1		530	71
Orovača Kanjani spring	12	3		72	67
Dorinovac spring	6				
Jadro spring	13			153	52
Očuša spring	13	1		122	47

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Table 3 | Continued

Range MPN coli/100 ml	No. of samples	0	6,000–24,000	Arithmetic average value	Geometric average value
Opačac Vrljika spring	12			64	46
Točak Velušić spring	4			43	43
Modro Oko spring	12			110	42
Vukovića Vrelo spring	12			130	36
Cetina river Gata	13	1		78	36
Cetina river Zadvarje	13	2		97	32
Ombla spring	6	2		25	24
Krčića spring	12	2		32	22
Točak Gradac spring	12	2		54	15
Pećina Knin spring	12	8		9	3

The table presents the following data: name of sample, frequency of findings of MPN coli ranging from 0–24,000, arithmetic average value MPN coli, geometric average value MPN coli.

a recommendation for evaluating the degree of pollution in surface waters of the second (II) category in the *Regulations on Water Classification* (Official Bulletin 1998).

MPN coli/100 ml is not very important since it can vary from one year to another so the water should be classified into different groups according to bacteriological pollution. The consumption of permanganate ($KMnO_4$) and BOD_5 (biochemical oxygen demand), are not sufficiently sensitive since there is no correlation between those indicators and MPN coli, therefore, the estimation of total nitrogen, total phosphorus, total carbon and other chemical parameters is necessary.

According to the Croatian Water Classification Act (Official Bulletin 1998) some water samples of the second (II) category should not contain more than 5,000 coliform bacteria per 100 ml. Table 3 shows that most samples from the group of the most polluted waters contain more than 5,000 bacteria in 100 ml. Consequently, this type of water belongs to the third (III) category of the classification for bacteriological pollution.

According to the Croatian Standard for Drinking Water (Official Bulletin 1994) the water supply should not contain any coliform bacteria, and the water in springs or wells, which are not subjected to chlorination, should not contain more than 10 coliform bacteria in 100 ml. Since all water resources in Dalmatia contain some coliform bacteria, all water should be treated by chlorination before being used.

CONCLUSIONS

Typical karst waters in Dalmatia are moderately hard, have a SO_4/Cl ratio of 0.38–1.6, are generally not corrosive (K_1 lower than 0.2) and are not significantly mineralized (most frequently less than 500 mg/l minerals). Sulphate waters are mainly quite hard or hard, with the SO_4/Cl ratio higher than 1.6 and with a K_1 coefficient of 0.2–0.65. Marine waters are quite hard or hard, particularly in the river estuaries, have a SO_4/Cl ratio lower than 0.38 and a K_1 coefficient higher than 0.65.

The groundwater and springs in Dalmatia are less bacteriologically polluted than the surface waters. A majority of these have a geometric average value of MPN coli <150/100 ml of water observed in 24 of 42 locations studied. The highest bacteriological pollution was found in nine locations where MPN coli >1,000/100 ml, and moderate pollution was found in nine locations where MPN coli ranges from 150 to 1,000/100 ml of water.

The water in most sources in Dalmatia has preserved its natural properties. Epidemiological studies should be carried out in order to correlate the chemical content and the bacteriological findings.

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