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ENVIRONMENTAL MANAGEMENT

THE ECOLOGICAL DATABASE WATERS BASED ON CONSTRUCTING DIFFERENT INDICES ON VARIOUS WATER QUALITY CHARACTERISTICS

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ABSTRACT

The ecological approach to diseases facilitates understanding of the reasons for the multiplicity of causal factors and the finding of those on which the preventive measures will be easily and succesfully directed. This is the reason why the integration of space data is necessary for getting insights into the existing conditions from the ecological point of view.

The ecological need to sum up the research findings and to estimate the future water quality trends by observing the relevant parameters as influential environmental factors for the health of the population resulted in a relation database WATERS.

The water quality was evaluated by using the quality index based on the following nine parameters: temperature, mineralization, corrosion coefficient $K=(Cl+SO_4)/HCO_3$, dissolved oxygen, BOD_5, total N, protein N, total phosphorus and total coliform bacteria $(100\ mL)^{-1}$ (MPN coli $(100\ mL)^{-1}$) for which concentrations C_{95} are calculated. After completing nine parameters the results of C_{95} were recorded and transferred to the score table to obtain the q-value. The q-value used is an attempt to quantify the environmental factors which would otherwise be qualitative. For each parameter the q-value was multiplied by a weighting factor based upon the relative significance of the parameter. The nine resulting score values were then added to arrive at an overall water quality index (ΣS_{95}).

Individual indices are also presented, i.e. those related to total N and total phosphorus, total coliform/100 ml, corrosion coefficient K and the mineralization indicating the change in the water quality. Thus it is possible to evaluate which parameter or group of parameters influence the water quality. From the ecological standpoint the database WATERS integrates waters data and it is suitable for the several years study of trends of existing water supply conditions with special survey of the results of water quality analyses in view of the recognition of the actual pollution groups and individuals.

It is important to recognize the actual pollutants which are important factors in health problems of the general public and individuals. One gets information and plans necessary for interventions so that it is possible to apply computer techniques to the water pollution control.

***Key words**: water quality index, health database, human health, Dalmatia (South Croatia)*

1. Introduction

Human activities have severely affected the conditions of freshwater systems worldwide. Even though humans have increased the amount of water available by using dams and reservoirs, more than 40% of the world population still lives in areas with severe water shortages. Revenga et al. [1] estimated that this percentage will grow to almost 50% by 2025. Surface and groundwater is being degraded in almost all regions of the world thus aggravating the water supply problem.

In addition, lack of access to clean water continues to be a leading cause of illness and death in a great part of the developing world.

According to Valić [2], Primic-Žukalj [3] and Duraković [4] health is influenced by hereditary factors on one hand and by environmental factors on the other hand.

In addition, the problem of health care, starting from more acute exposures to unfavourable influences, is regarded as a very actual problem. Additionally, each year 400-1000 new chemicals are offered on the market so that the International List of Dangerous Substances in Transport consists of 3000 units according to Valić [2]. Consequently, the ecological approach to disease facilitates the possibility of understanding causal factors in the pathogenesis and discovering preventive measures which will be easily and successfully applied. For this reason space data integration is suitable for obtaining insight into the existing ecological situation.

In practice, ecological registries include ecological characteristics of the region and environment while disease registries mostly deal with the medical etiology of diseases, i.e. mainly factors monitoring.

In this paper special attention is paid to data referring to the volume of Dalmatian drinking waters, i.e. the environmental factors which significantly influence the quality of living standards.

Dalmatia (South Croatia) belongs to the Dinaric karst region which is abundant in rainfall. The average annual rainfall is ca 1500 mm according to Štambuk-Giljanović [5]. Since the Dinaric karst region covers an area of 57,000 km^2, the total water quantity flowing into the Adriatic and Black Seas amounts to 57 x 10^9 m^3 a year. This quantity is significant since the northern agricultural area of Croatia is 2.5 times smaller and the outflow coefficients are lower.

However, the rainfall quantity is unfavourably distributed so that the time distribution of rainfall and the outflow regime unfavourably influence daily life and agriculture in that 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.

The groundwater in Dalmatia mainly flows through fissures and, by its hydrochemical and bacteriological characteristics, is similar to surface water. This water contains a relatively small quantity of minerals; it generally contains a small quantity of dissolved carbon dioxide. It is often polluted by bacteria and is turbid. These characteristics of water in fissures are caused by a brief contact between the water and the soil and the rather bad filtration of the water through the soil.

Surface water can satisfy the ever increasing water demands by supplying water from large rivers and reservoirs with practically unexploitable water quantities.

Accordingly, modern purification techniques and possibilities for water distribution over long distances make it possible to satisfy the demand for safe drinking water in Dalmatia by intakes from the rivers and groundwater, i.e. spring water.

The water supply and health care institutes are especially interested in observing and monitoring Dalmatian water using the water quantity index so as to condense the data into a form more suitable for comparison and classification.

It is necessary to collect and process data relevant to describing waters in order to successfully protect the waters and develop effective environmental protection plans and basic postulates for water resource management.

Along with data processing, modernization demands the standardization of the code system to facilitate statistical processing and to obtain data over several years which can be compared with individual disease data.

In addition, the obvious important role that time plays in the epidemiology should always be emphasized. In chronical pathological conditions, 10-30 years can pass from the onstart of external manifestations to the full development of the disease (period of latent incubation). It is very important to first carry out longitudinal research of ecological factors and to then determine their correlation with the health condition parameters in order to predict at what point they may emerge after this latent incubation.

The objective of this paper is to organize health databases, especially logical structures with data stored through low and controlled redundancy, from an informatics standpoint. Thus, it is necessary to define a relational database for gathering and studying the water quality evaluation of drinking water in Dalmatia (South Croatia) based on developing different indices [6,7] on various water quality characteristics.

Further, an informatical prototype would represent a new scientific solution for classifying waters according to the water quality index, i.e. a methodological base for studying the ecological factors that influence human health.

As a prerequisite for defining the relationship between the segments of the system, it is necessary to define a new informatical code for the system solution.

2. Methods

In order to develop a solution for a code system and a relational database for WATERS the following computer methods are applied:

a) ecological documentation code system – the system analyzes procedures according to Štambuk-Giljanović [8], Lazarević et al. [9], IBM Corporation [10], Hammer [11], Matoković [12].

b) relational database - data modelling according to Tkalac [13], Date [14], Yang [15].

The basic parameters are determined [16] by analysing the standards, methods and the statistical research as well as ecological projects and by studying research related to health-ecological issues.

The water quality was evaluated by means of the water quality index [6,7] based on nine quality parameters: temperature, mineralization, corrosion coefficient, $K=(Cl+SO_4)/HCO_3$, dissolved oxygen, BOD_5, total N, protein N, total P and total coliform bacteria $(100\ mL)^{-1}$. The mean values and C_{95} values were calculated for these parameters which were assigned with score values from the Table 1 according to Štambuk-Giljanović [6,7] which show the range of possible results of parameters and their weighted water quality score values. The sum of scores of the mean values was expressed by ΣS, while the sum of scores of C_{95} values, was expressed by ΣS_{95} which represents the index.

Regarding the selection of parameters for the process of index determination from a total of nine parameters three parameters are the same as in SDD (Scottish Development Department) report [17,18] (temperature, dissolved oxygen and BOD_5) and three are substituted by others.

Mineralization was used instead of conductivity, while total N was used instead of total oxidable N, due to a high correlation degreee between these two parameters (0.82) and total coliforms were used instead of E. coli due to the legally determined MAC value of total coliforms.

Certain constituents or contaminants in the water including dissolved oxygen, carbon dioxide, anions (chloride, and sulphate) and acidity (low pH) increase the corrosive tendency of water.

Corrosive tendency is calculated by coefficient $K=(Cl+SO_4)$/alkalinity as $CaCO_3$ meq L^{-1} according to Larson and Scold [19]. The neutral pH range (7 to 8), with dissolved oxygen ratios equal to or below 0.25, indicates general resistance to corrosion, whereas increasingly higher ratios generally indicate more aggressive waters which damage the water supply system.

Temperature of 8-12^{o}C is chosen as optimal temperature and evaluated with the highest grade, i.e. 7 scores, above and below which the quality decreases. Optimal mineralisation for karst rift and surface waters is 350 mg L^{-1} and this value is scored with 7. The corrosion coefficient K in waters of optimal composition is not higher than 0.25. This is the result of the author's research [5]. An increased ratio indicates the corrosive water tendency and these waters are evaluated lower.

The percentage of dissolved oxygen is a crucial factor of aquatic life. A decreased percentage of oxygen saturation leads to anaerobic conditions. A high percentage of oxygen saturation in the surface layer in summer can suggest increased organic production due to the large quantities of total phosphorus and organic nitrogen in some river parts caused either by a more intensive growth, by plankton or by waste waters pollution.

In waters with an increased concentration of dissolved carbon dioxide the oxygen content was significantly lower. In these cases the decreased oxygen content was not caused by water pollution, regardless of the fact the waters with a decreased oxygen content were graded lower. Waters containing 90-105% of oxygen are graded optimally in accordance with the Water Classification Act [20] and this range is graded with 16 scores, above and below which the quality decreases.

The oxygen coefficient is calculated from saturation $O_2=MAC/(\bar{C}-t\sigma)$ which represents the reciprocal coefficient value of other parameters because a decrease in oxygen content deteriorates the water quality.

The Biochemical Oxygen Demand, BOD_5 suggests the degree of waterflow load with dissolved organic matters. Waters with a BOD_5 over 10-15 mgL^{-1} are of very low quality which usually suggests the influence of wastewater. Range 0-1.2 is optimal and is evaluated with 10 scores.

According to a several years long research of Dalmatian waters, free ammonia and nitrite were seldom found and all ingredients could not be used for quality evaluation. That was why protein N was determined. Waters containing 0-0.03 mg L^{-1} protein N are graded with 10 scores. The lowest content of total nitrogen in water from 0 to 006 mg L^{-1} is graded with 16 scores, and the limit value (MAC) for drinking water of 0.3 mg L^{-1} is evaluated with 12 scores.

Total P from 0-0.03 mgL^{-1} is evaluated with 12 scores.

MPN coli $(100\ mL)^{-1}$ is a classic parameter of microbiological water pollution and according to the Water Classification Act up to 200 coli in 100 mL of waters is permitted for first class waters. This value is taken as MAC and evaluated with 15 scores while the lowest number of coli from 0-50 is evaluated with 16 scores.

Arithmetic evaluation (S) is calculated by totaling the weighted water quality score value (q_iw_i) of parameters (i.e. individual products of water quality score value (q_i) and corresponding weighting (w_i) as follows:

$$S = \sum_{i=1}^{n} q_i w_i$$

where
q_i = the water quality score value of parameters on a continuous scale from 0 to 100,
w_i = the weighting factor of parameter i whose sum equals 1,
q_iw_i = the weighted water quality score value of parameter $_i$,
and
n = the number of parameters.

The highest value of the water quality score, q_i, is 100. This applies to the highest quality waters; natural waters are evaluated by a proportionately lower quality score depending on their quality.

For each parameter, both the maximum value of the weighted water quality score, M_i, and the ranges of the parameter for each score were modelled on the SDD approach, with final values chosen on the basis of the survey. Since an M_i value of 100 was arbitrarily chosen to be the maximum value of the weighted water quality score the weights for each parameter were determined by dividing M_i by 100, since the sum of M_i for all parameters equals 100, the sum of weights of water quality parameters equals 1 (Table 2).

Table 2. Parameter weightings.

Parameters	w_i
Temperature (°C)	0.07
Mineralization (mg/L)	0.07

Corrosion coefficient K	0.06
Dissolved oxygen (% saturation)	0.16
BOD_5 (mg/L)	0.1
Total nitrogen (mg/L)	0.16
Protein nitrogen (mg/L)	0.10
Total phosphorus (mg/L)	0.12
Total coliform (MPN/100 mL)	0.16
Total weighting	1.00

The evaluation and the index (S_{95}) are determined in relation to C_{95} and the concentration which includes 95% of the results is calculated from the equation:

$$C_{95} = \overline{C} + t\sigma$$

where $\overline{C}$ is the mean value, σ is the standard deviation, $t/\sqrt{n-1}$ is the value of a Student t-test for 95% of probability level.

The relation between the results and the number of scores which evaluated the results for each parameter were determined by curves obtained by the survey, i.e. empirically.

The rating curves between the results and the number of quality scores were constructed so that the results of weights were shown on the abscissa, while the water quality from 0 to 100 was shown on the ordinate in the coordinate system. The intersection of these two lines is a curve which most frequently has the form of an inverse hyperbole as in case of the evaluation of content quality or oxygen saturation since this parameter has an optimal value above or below which the quality decreases.

For more practical uses, the relationship between the results of weights and quality are shown in Table 1. For example, the results of the Golubinka water testing are given in Table 4 and appropriate weighted water quality score values are given in Table 1. Table 3. shows the maximum weighted water quality score values of the parameters.

Table 3. The maximum weighted water quality score values of the parameters

Parameters	Maximum number of scores $S = q_i \times w_i$
1. Water temperature, °C	7
2. Evaporation residue	7
3. Corrosion coefficient K= (Cl + SO_4)/alkalinity	6
4. O_2, % saturation	16
5. BOD_5	10
6. Total organic nitrogen	16
7. Protein N	10
8. Total P	12
9. MPN coli/100 ml	16
TOTAL	100

Table 4. Index estimation of the Golubinka groundwater
Results of tested water

Parameter	$\overline{C}$	C_{95}	weighted water quality score value (q_i x w_i)
1. Temperature (^oC)	14.6	16.1	5
2. Mineralization, mg/l	670	1240	3
3. K=(Cl+SO_4)/HCO_3	0.69	2	2
4. O_2, % saturation	86	67	9
5. BOD_5, mg/l	2.6	4.7	3
6. Total N-N, mg/l	0.366	0.66	8
7. Protein N-N, mg/l	0.013	0.028	10
8. Total P-P, mg/l	0.016	0.03	12
9. MPN coli/100	122	220	14
TOTAL			66

$\overline{C}$= mean value
C_{95}= $\overline{C} + t\,\sigma$ in which $\overline{C}$ = mean value, σ = standard deviation, t = value of a Student t-test for 95% of the probability level

The score sum of all nine parameters is the quality index of a particular water sample for the year
$I_P = \Sigma S = \Sigma\, q_i \text{ x } w_i$

When examining larger number of samples the index presents the mean value of particular indeces during the year
$I = \overline{I_P}$

Regarding the value of a particular index the highest and lowest index values are calculated at the significance level of 95%.

$$I_{95} = I \pm \sigma \frac{t}{\sqrt{n-1}}$$

where σ = standard deviation, t = standard value of a Student t-test for P = 95%, n = number of samples.

The index presents the sum of quality evaluations of nine (9) parameters so that it cannot be concluded the index value from which parameters more significantly influence the index value. In order to evaluate which parameter or group of parameters influence the water quality, three (3) other specific indeces are calculated: the index of nitrogen and phosphorus

$$I_{NP} = \left[\left(\sum (S_N + S_P)\right)/(16+12)\right] x100$$

MPN index

$$I_{MPN} = \left(\sum S_{MPN} / 16\right) x100$$

The chemical composition index from the evaporation residue and coefficient K:

$$I_{CH} = \left[\left(\sum (S + S_K)\right)/(7+6)\right] x100$$

The index serves for the classification of waters. Table 5. shows the classification of waters by index value.

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Table 5. Water classification after index value

Types of waters	Water quality index
Waters of 1 ST class	85-100
Waters of 2 ND class	70-85
Waters of 3 TH class	50-70
Waters of 4 TH class	30-50
Waters of 5 TH class lower than	30

The Croatian Water Classification Act [20] divides the waters (surface and underground) into five classes. The 1ST class includes water which can be used for drinking in its natural state or after being disinfected. The 2ND class includes water which cannot be used for drinking purposes without being treated.

The third class includes water used industry and agriculture which does not satisfy any specific demands. This water should be treated before being used for any specific purposes. The forth class includes water which can be used in regions with a water shortage and can only be used only after being treated. The fifth class includes water which cannot be used for any purpose since it does not satisfy criteria set forth in these legal requirements.

Data used for prototype implementation of the relational database WATERS are based on research results from the Institute of Public Health for the 1999-2002 period. Over 2000 data are included which represents a sufficient research sample.

3. Results and Discussion

The ecological relational database WATERS presents logical data integration of the information system. During the formation of a new model (as a starting point), the segments were taken, the stocks were removed, i.e. data redundancy was diminished by a normalization procedure. The final model contains the following segments:

a) water types
sampling (surface water, spring water, underground water)

b) water quality index
- ❖ PIX- particular sampling index (Fig. 1)
- ❖ PII – dynamics of indeces of sampling locations (Fig. 2)
- ❖ PIT – trends of indeces (Fig.3, I, I_{95}, I_{NP}, I_{MPN}, I_{CH})
- ❖ PIS – indeces of river waterflow stations (Fig. 4)

c) Information system support region – defined region data of the examination code system – parameters, subparameters and borderline values of the results and analyses.

Water quality classification by index (a number which is calculated from a few of the most important quality parameters and which should reflect the changes of these parameters in a representative way) is performed once a year by manual data processing and on chosen data groups.

This classification was sufficient for the implementation of computer methods developed according to the demands of data users: automatic calculation of water quality index, continuous monitoring of the index in a given period, continuous monitoring of index trends by comparing the examination results over a period of several years.

The application of the ecological relational database WATERS enables continuous monitoring of all examined parameters as well as of the index by sampling total water quality after performed standard sanitary chemical and microbiological laboratory analyses.

The annual indeces of water quality are monitored, i.e. their several years long trends (Figure 1). Since cumulative review data do not give adequate parameters in case of incident further research is extended by index analyses of particular sampling (Figure 2). For each particular sampling location it is possible to monitor the index influence of each particular sample on the overall water quality index.

In order to analyse correlations of the overall index over a several year long period, i.e. aberrations of indeces I_{95}, I_{NP}, I_{MPN} and I_{CH}, the research of the Cetina River waterflow has been performed over a several years long period (Fig. 3.). The index influence of each particular parameter or a group of parameters on the water quality can be seen. It is especially important that these data can be compared.

Since it was evident that the increase in Index I was mostly influenced by I_{CH}, i.e. I_{MPN} (typical for karst waters) and the decrease of Index I by I_{NP}, the influence of each particular I_{NP} was investigated in detail (i.e. the difference in the degree of pollution (Fig. 4)). It can be seen that the overall I_{NP} doest not display a real picture of the aquatorium conditions because differences of pollution by sampling are significant and they considerably influence the overall I_{NP}, i.e. the pollution degree obtained by each sampling is on an impermissible level so that the water is not suitable for drinking. At the Grab River location the index of total N and total P ranged from 58 to 100 during a three years period (2000-2002). According to this value, the water was in the first and in the third class.

The application of the relational database enables sample addition of attributes as well as the realization of new correlations and an additional realization of new correlations in accordance with the values of relational algebra.

In addition, the analyzes of ecological burdening (not yet sufficiently researched), with intensity and duration of exposure as well as possible reversibility of effects, will be included in ecological registries of geographically observed regions. By data integration with a methodologically prepared database WATERS, the meaning of age at the beginning of the exposure can be established which will be of great interest for primary prevention.

The presented database model WATERS, by which ecological factors are monitored, enables systematisation and quality processing of the large data quantity necessary for epidemiological research. Such models are suitable for directed research of different types (variations in volume of parameters). Ecological epidemiology is distinguished from other types of ecological assessment by the use of observational studies in the polluted environment to elucidate effects. The ability to observe and measure effects is potentially a major advantage because none of the complexities of pollutant transport, fate, exposure, proximate effects and ultimate effects needs to be approximated. The real world is speaking directly to the assessor. However, the real world complexity can mask effects, amplify effects, or generate pseudoeffects according to Glenn et al. [21].

Data included in this model are standardized in accordance with accessible domestic or international classifications which improved the quality of accumulated data and enabled their comparability at national and international levels. In this way, the prerequisites for linkage with some developed international informatical systems and databases are created (for instance INFOTERRRA, INFORMOS). INFOTTERA is an information system of human environment developed by a UN Organization – UNEP (UN Environment Programme). INFORMOS is a branch information system for environmental protection and improvement of human environment. Both were developed within MSNT (International System for Scientific – Technical Information) by SEV countries (Council for Mutual Economic Aid of East European countries) as quoted by Sepa [22].

4. Conclusion

1. The new ecological database WATERS (new logical system) was developed and is suitable for automatization of different water quality index calculations based on various water quality

characteristics, the continuous monitoring of water quality index by a momentary number of samples, continuous monitoring of index dynamics in a given period, continuous monitoring of index trends by comparing several years long results of examination, etc.

2. The code system enables an easy observation of the sampling quality which has not been examined at all (although it was necessary) since a great number of data outgrew manual registration. The possibility of changing parameters and adding data (attributes) is performed without changing the basic coding system. No informatical project could be meaningfully developed in this way without a prepared code system for monitoring data in a certain water examination area.

3. The model creates new possibilities for the following: 1. a quick insight into the existing conditions of the population from the ecological and health – ecological standpoints,2. improvement of daily work organization but also scientific research work because it allows the possibility of information parameters selection and directs the research at one's own discretion, 3. the extension of the code system content and database by adding new parameters in certain phases, and 4. the final integration of human environment data with other information system data.

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Figures

Figure 1. Trend of total water quality index-Grab
x: Year
y: Water quality index

Figure 2. Trend of total water quality index-Grab (individual and total)
x: Number of samples
y: Water quality index

Figure 3. Water quality evaluation by index – The Cetina watercourse
x: Sampling stations
y: Water quality index

Figure 4. Trend of NP water quality index-Cetina (individual and total)
x: Number of samples
y: Water quality index-I_{NP}

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