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A COMPLEX MODEL FOR ENVIRONMENTAL QUALIFYING AND FORECAST: CMEQ

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Abstract

A quantitative characterization of the environmental situation provides important information whenever a judgement of the environment's quality is formed or investments are planned or decisions are to be supported. Such a quantitative qualification of the environment may play an important role even on a regional scale when forming an opinion on the quality of the given region's environment or preparing regional strategies for environment protection or signing pacts for regional protection of the environment. The model and numerical examples to be shown in this paper describe the environment of a minor region by a parameter system of water, air, and soil quality. It is a task of the future to include ecological (biological) and social (economic) components into the model. In such a way, the model is *an approximative measure of the environment's state,* comparing the latter with computed quality categories, i. e., classifying the given state. If any of the quality parameters changes (e. g., the NO_x emission of a country is reduced), the environment's quality changes as well and the numerical value of this change can be expressed by the model.

Keywords: environmental modelling, matrix equations, environmental subsystems and qualifying.

The CMEQ Model

The environment is broken into subsystems the CMEQ model (*C*omplex *M*odel for *E*nvironmental *Qualifying*). The three most important groups of the subsystems are:

1. *Geosphere Subsystems:*
   - 1.1. Soil quality (lithosphere, pedosphere),
   - 1.2. Water quality (surface and subsurface water),
   - 1.3. Air quality.
2. *Biological (Ecological) Subsystems:*
   - 2.1. Microbiota,
   - 2.2. Flora,
   - 2.3. Fauna,
   - 2.4. Public health (human sanitation).

3. *Social (Economic) Subsystems:*
   3.1. Social environment,
   3.2. Urban environment,
   3.3. Noise, stink, vibration, waste, radiation, etc.
   3.4. Economic parameters,
   3.5. Environmental aesthetics.

The measurement of the state of the environment and its qualification may be carried out by taking these subsystem groups into account.

The Model for Environmental Qualifying

In the CMEQ model, subsystems and within it parameters are used for qualifying the environment. The relative quality values derived from the probability distribution of the parameters are:

$$0 \leq b_j \leq 1.0 .$$

All parameters are included in a $\mathbb{B}$ matrix in which any row represents the parameter series of one of the subsystems (e. g. of the water quality subsystem). The parameters are weighted by s_i weight numbers, or the $\mathbb{B}$ matrix is weighted by a $\mathbb{S}$ weighting matrix:

$$\mathbb{B}_{(m\times n)} = \begin{bmatrix} b^{(1)} \\ b^{(2)} \\ \vdots \\ b^{(j)} \\ \vdots \\ b^{(m)} \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1i} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2i} & \dots & b_{2n} \\ \vdots & & \ddots & & & \vdots \\ b_{j1} & b_{j2} & \dots & b_{ji} & \dots & b_{jn} \\ \vdots & & & & \ddots & \vdots \\ b_{m1} & b_{m2} & \dots & b_{mi} & \dots & b_{mn} \end{bmatrix},$$

where m: — is the number of environmental indices considered and
n: — is the number of parameters defining a given index.

Accordingly, weighting is carried out, as a first step, in the form of $\mathbb{B}\cdot\mathbb{S}$ where $\mathbb{S}$ is the new weighting matrix containing different weight vectors in each column.

The matrix product will be the following:

$$\mathbb{B}_{(m\times n)}\,\mathbb{S}_{(n\times m)} =$$

$$\begin{bmatrix} \sum_j b_{1j}s_{1j} & c_{12} & c_{13} & \dots & c_{1j} & \dots & c_{1m} \\ d_{21} & \sum_j b_{2j}s_{2j} & c_{23} & \dots & c_{2j} & \dots & c_{2m} \\ d_{31} & d_{32} & \sum_j b_{3j}s_{3j} & \dots & c_{3j} & \dots & c_{3m} \\ \vdots & & & \ddots & & & \vdots \\ d_{i1} & d_{i2} & \dots & \dots & \sum_j b_{ij}s_{ij} & \dots & c_{im} \\ \vdots & & & & & \ddots & \vdots \\ d_{m1} & d_{m2} & \dots & \dots & d_{mj} & \dots & \sum_j b_{mj}s_{mj} \end{bmatrix} =$$

$$= \begin{bmatrix} F_{k1} & c_{12} & \dots & c_{1j} & \dots & c_{1m} \\ d_{21} & F_{k2} & \dots & c_{2j} & \dots & c_{2m} \\ \vdots & & \ddots & & & \vdots \\ d_{i1} & d_{i2} & \dots & F_{ki} & \dots & c_{im} \\ \vdots & & & & \ddots & \vdots \\ d_{m1} & d_{m2} & \dots & d_{mj} & \dots & F_{km} \end{bmatrix},$$

where: $c_{1j} = \sum_j b_{1j}s_{1j}$, $d_{mj} = \sum_j b_{mj}s_{ij}$, etc.

As a next step, the matrices $\mathbb{C}$ and $\mathbb{D}$ are defined without being described here in detail. By using the latter matrices, the $\mathbb{F}$ matrix of results can be obtained as

$$\mathbb{F}_{(m\times m)} = \left(\mathbb{B}_{(m\times n)} \times \mathbb{S}_{(n\times m)}\right) - \mathbb{C}_{(m\times m)} - \mathbb{D}_{(m\times m)} =$$

$$\begin{bmatrix} \sum_j b_{1j}s_{1j} & 0 & 0 & \dots & \dots & \dots & 0 \\ 0 & \sum_j b_{2j}s_{2j} & 0 & \dots & \dots & \dots & 0 \\ \vdots & & & \ddots & & & \vdots \\ \vdots & & & & \sum_j b_{ij}s_{ij} & & \vdots \\ \vdots & & & & & \ddots & \vdots \\ 0 & 0 & 0 & \dots & \dots & \dots & \sum_j b_{mj}s_{mj} \end{bmatrix} =$$

$$= \begin{bmatrix} F_{k1} & 0 & 0 & \dots & \dots & \dots & 0 \\ 0 & F_{k2} & 0 & \dots & \dots & \dots & 0 \\ \vdots & & & \ddots & & & \vdots \\ \vdots & & & & F_{ki} & & \vdots \\ \vdots & & & & & \ddots & \vdots \\ 0 & 0 & 0 & \dots & \dots & \dots & F_{km} \end{bmatrix} .$$

In can be seen that by means of matrix operations a matrix of results has been obtained whose main diagonal contains the F_{ki} values of the environmental indices.

These F_{ki} values are *weighted* characteristics of the environment, i. e., quality measures of the various environmental subsystems. The last step is the weighting of these F_{ki} numbers. By using the F_{ki} elements included in the main diagonal of the $\mathbb{F}$ matrix, the following vector $\mathbb{f}$ can be generated, called *vector of environmental qualification:*

$$\mathbb{f}^* = [\, F_{k1}, \quad F_{k2}, \quad \dots, \quad F_{ki}, \quad \dots, \quad F_{km} \,] .$$

By weighting the subsystems with the $\mathbb{v}$ vector (i. e., by carrying out the second weighting), the *weighted number for environmental qualification* $\mathbb{Q}$ is obtained:

$$\mathbb{Q} = \mathbb{f}^*_{(m)} \, \mathbb{v}_{(m)} = [\, F_{k1}, \quad F_{k2}, \quad \dots, \quad F_{ki}, \quad \dots, \quad F_{km} \,] \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_i \\ \vdots \\ v_m \end{bmatrix} = \sum_{i=1}^{m} F_{ki} \, v_i \, .$$

The value of the $\mathbb{Q}$ index can be also written in the following form of double summarization:

$$\mathbb{Q} = \sum_{i=1}^{m} v_i \sum_{j=1}^{m} b_{ij} s_{ij} \, ,$$

where b_{ij} are the relative parameters of environmental qualification, s_{ij} are their weighting numbers and v_i are the weighting numbers of the various subsystems.

The index $\mathbb{Q}$ for environmental qualification can be also computed directly, by original matrix equation, since

$$\mathbb{F}_{(m \times m)} \, \mathbb{v}_{(m)} =$$

$$\begin{bmatrix} F_{k1} & 0 & 0 & \dots & \dots & \dots & 0 \\ 0 & F_{k2} & 0 & \dots & \dots & \dots & 0 \\ \vdots & & \ddots & & & & \vdots \\ \vdots & & & F_{ki} & & & \vdots \\ \vdots & & & & & \ddots & \vdots \\ 0 & 0 & 0 & \dots & \dots & \dots & F_{km} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_i \\ \vdots \\ v_m \end{bmatrix} = \begin{bmatrix} v_1 F_{k1} \\ v_2 F_{k2} \\ \vdots \\ v_i F_{ki} \\ \vdots \\ v_m F_{km} \end{bmatrix} = \mathbb{q}_{(m)} \, .$$

Let us now define the vector $\mathbb{e}_{(m)}$:

$$\mathbb{e}_{(m)} = \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \\ \vdots \\ 1 \end{bmatrix} \begin{matrix} 1.) \\ 2.) \\ \vdots \\ i.) \\ \vdots \\ m.) \end{matrix} \, .$$

The environmental qualification index $\mathbb{Q}$ will be:

$$\mathbb{Q} = \mathbb{q}^{*}_{(m)} \, \mathbb{e}_{(m)} = \left(\mathbb{F}_{(m\,m)} \, \mathbb{v}_{(m)} \right)^{*} \, \mathbb{e}_{(m)}$$

and can be also written in the form:

$$\mathbb{Q} = \left\{ \left[\left(\mathbb{B}_{(m\,n)} \, \mathbb{S}_{(n\,m)} \right) - \mathbb{C}_{(m\,m)} - \mathbb{D}_{(m\,m)} \right] \mathbb{v}_{(m)} \right\}^{*} \mathbb{e}_{(m)} \, ,$$

where $\mathbb{B}$ — is the matrix of parameters,
$\mathbb{S}$ — the matrix of weight numbers,
$\mathbb{C}$ and $\mathbb{D}$ — are matrices (not defined in this paper),
$\mathbb{v}$ — is the weight vector of the subsystems and
$\mathbb{e}$ — is the column vector defined above.

In the following practical computations the formula of double summarization will be adopted.

Computations Carried Out with the Model

In order to realize the calculations, a computer program has been developed for an IBM PC, in the program language Turbo Pascal, by using the translator program Borland V5.5 Turbo Pascal. The program can treat 10 types of graphical cards. It is a 'user friendly' type program, steered by

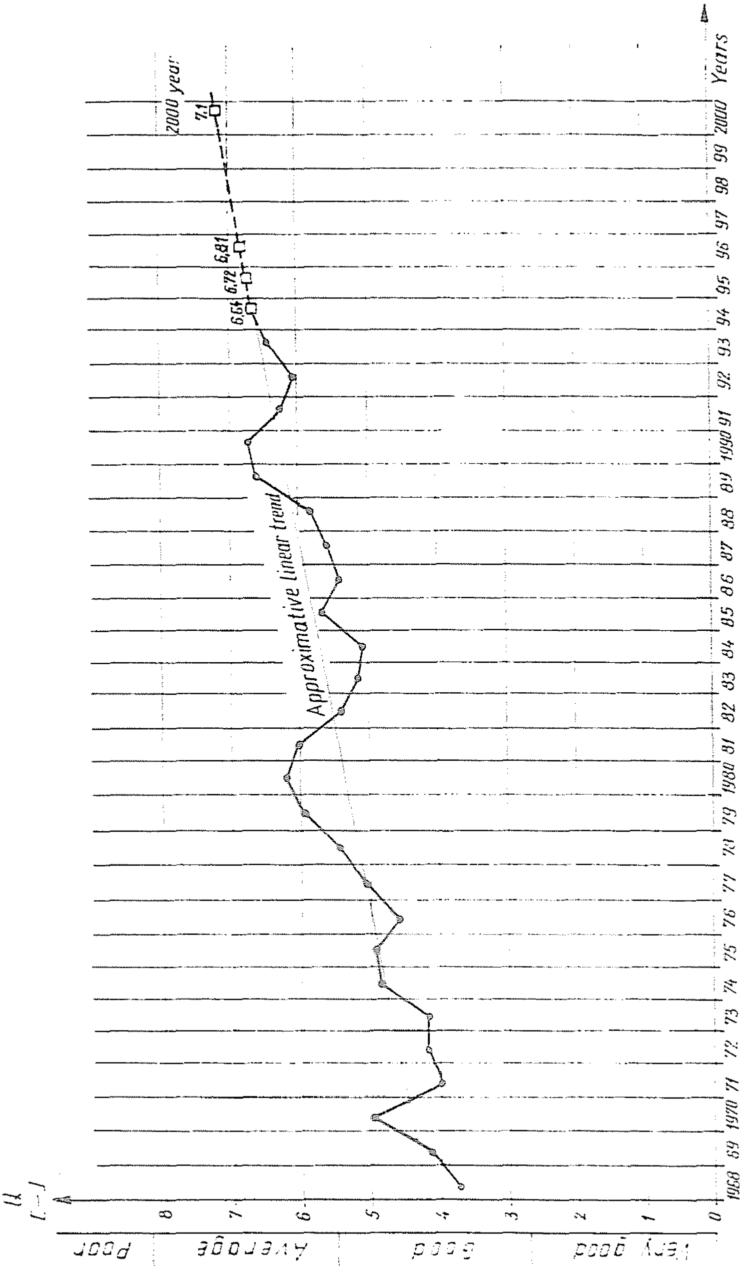
Approximative linear trend
2000 year
Years
6.64
6.72
6.81
7.1
Poor
Average
Good
Very good

Fig. 1.

Table 1

Quality class	Description of environment	Limit values of index Q
I.	Very good quality of environment without pollution	0.0 – 2.7
II.	Good quality of environment, slight pollution	2.7 – 5.5
III.	Average quality of environment	5.5 – 8.2
IV.	Poor quality of environment, strong pollution	8.2 – 11.0
V.	Very poor quality of environment, very strong pollution	11.0 <

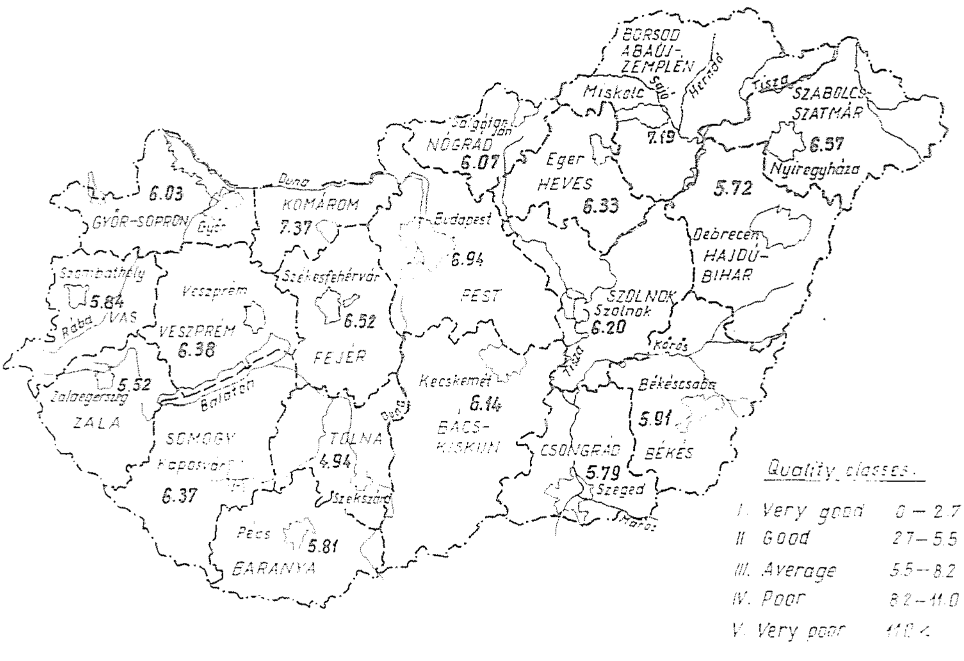

Fig. 2. Indices Q of the environmental quality of the counties of Hungary in 1980

a menu system, enabling quick data input, modifications, the determination of the index Q qualifying the environment's quality and displaying the results obtained.

First, the environmental quality classes were computed to which the numerical values of Q can be associated.

These classes are listed in *Table 1.*

The limit values of Q given in the above table could have been determined on the basis of the principle of class intervals of equal probabilities.

As a next step, computer runs were carried out aiming at the determination of the mean environmental quality of Hungary. The average indices were calculated for each year on the basis of the county indices. The time series of the Q values are shown in *Fig. 1* for the period from 1968 to 1993. The deteriorating quality of the environment can be seen from the graph of the time series. In the figure, the long-term forecast based on the linear trend has also been plotted, indicating that the environment's quality index Q is likely to reach (or at least to approximate) the upper limit value of the middle (III.) category by 2000. The regional distribution of the environmental quality index is shown in *Fig. 2* for the so far most polluted year of 1980. In the figure, a very clear distinction between polluted and less polluted counties can be seen.

Conclusions

Since the results of the model investigations carried out so far are based exclusively on factors of the geosphere (water, air and soil quality), the inclusion of other environmental factors into the study is highly recommended. The indices obtained until now provide only an *approximative characterization of the environmental quality.* Further development of the model including both an increase of the number of submodels and parameters as well as an improvement of computation techniques is under way. After these improvements the model, due to its basically dynamic character, will be very handy for making *forecasts.*

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