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Estimation and Evaluation of Some Interdependencies of Environmental Conditions, Welfare Standards, Health Services, and Health Status

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ESTIMATION AND EVALUATION OF SOME INTERDEPENDENCIES OF ENVIRONMENTAL CONDITIONS, WELFARE STANDARDS, HEALTH SERVICES, AND HEALTH STATUS

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FOREWORD

The principal aim of health care research at IIASA has been to develop a family of submodels of national health care systems for use by health service planners. The modeling work is proceeding along the lines proposed in the Institute's current Research Plan. It involves the construction of linked submodels dealing with population, disease prevalence, resource need, resource allocation, and resource supply.

A national health care system is closely connected to the national economy and its environment. It is therefore necessary to consider the important links and interactions involved. This paper briefly summarizes research recently carried out in Poland that analyzes some of the interdependencies relating health status to welfare standards.

Recent publications in the Health Care Systems Task are listed at the end of this report.

Andrei Rogers
Chairman
Human Settlements
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ABSTRACT

The building of complex models of socio-economic development especially on the regional level, requires the knowledge of important relations and feedbacks between the health status of a population and the indices describing welfare standards such as environmental conditions, income level, and public services. In developing a family of submodels of national health care systems for use by health service planners, it is important to consider the environmental impact on health status as well, since the environment forms one of the most significant external subsystems influencing health care. Needless to say, more effort is needed in modeling the links between health care systems and the national economy.

In this paper, a set of basic health standard relationships are postulated. Through this the consequences of resource allocation policies can be determined, thus aiding the decision-making process. Proposed formulae are estimated on Polish statistical data using cross-sectional analysis, and a critical evaluation of the significance of these relationships is given.

CONTENTS

ESTIMATION AND EVALUATION OF SOME INTERDEPENDENCIES OF ENVIRONMENTAL CONDITIONS, WELFARE STANDARDS, HEALTH SERVICES, AND HEALTH STATUS

1. INTRODUCTION

Recent developments in industry, modifications in the welfare of populations, and changes of environmental conditions have contributed to alterations in health status. Generally, it is rather difficult to define these transformations, not to mention their quantification. The aim of this paper is to estimate some simple, econometric relationships that describe aspects of the health of a population as a function of the indices that characterize these changes. The authors believe that such an approach may contribute to a better evaluation of the present day situation in the health care domain, may show the potential dangers in this sphere of activity, and finally, may induce some positive changes in trends. It is worth noting that some hypotheses about the significance of the relationships could have had more practical meaning if the statistical data had been more comprehensive at the time of the study.

The major motivation of the study is simply to provide a regional development model (RDM) (e.g., Kruś et al. 1980) with a tool that predicts the average health of the population as a function of production, consumption (including health care services), the emission of pollutants, and other factors that correspond to a particular development scenario. Thus the method is based on a model that has as input variables the quantities generated by the RDM that in some aggregate sense describe conditions of life in a region. Development models (e.g., Kruś et al. 1980) usually operate with some aggregate variables. However, intuitive models relating the health status to the environment are based on detailed measures of the concentration of pollutants (e.g., $SO_2[\frac{\mu g}{m^3}]$, the weight of sulphur dioxide $[SO_2]$ per cubic meter of air) that directly affect the human organism. Thus the variables describing the environment envisaged by RDM and the intuitive model do not correspond exactly with one another. This can be overcome by

a) building a simple and efficient model describing the diffusion of pollutants
b) building a model that evaluates health status, based on pollution concentration data

Unfortunately, none of the links in the hypothetical chain shown in Figure 1 can be made in Poland at present. This is because the existing diffusion models are highly complex and still need more disaggregated input data than the RDM can provide (Pudykiewicz 1980). Furthermore, the data available to the authors describing pollution concentration are collected only in certain geographical locations and not in all areas (see Borkowska 1979, and Atmospheric Pollution Yearbook 1974). These data include two groups of pollution: water (biological oxygen demand and contamination by feces) and air (SO_2 concentration, dust concentration and dust fall). They could not be used in our study, however, because they were not comprehensive enough. Hence, the assignment of average health indices [see Yearbook of Health Care in Poland in 1978 (1979)] to such environmental data is almost impossible. Taking the above into account, the authors decided to investigate the significance of hypotheses concerning the impact of emission aggregate data on the health of a population since the models obtained can be

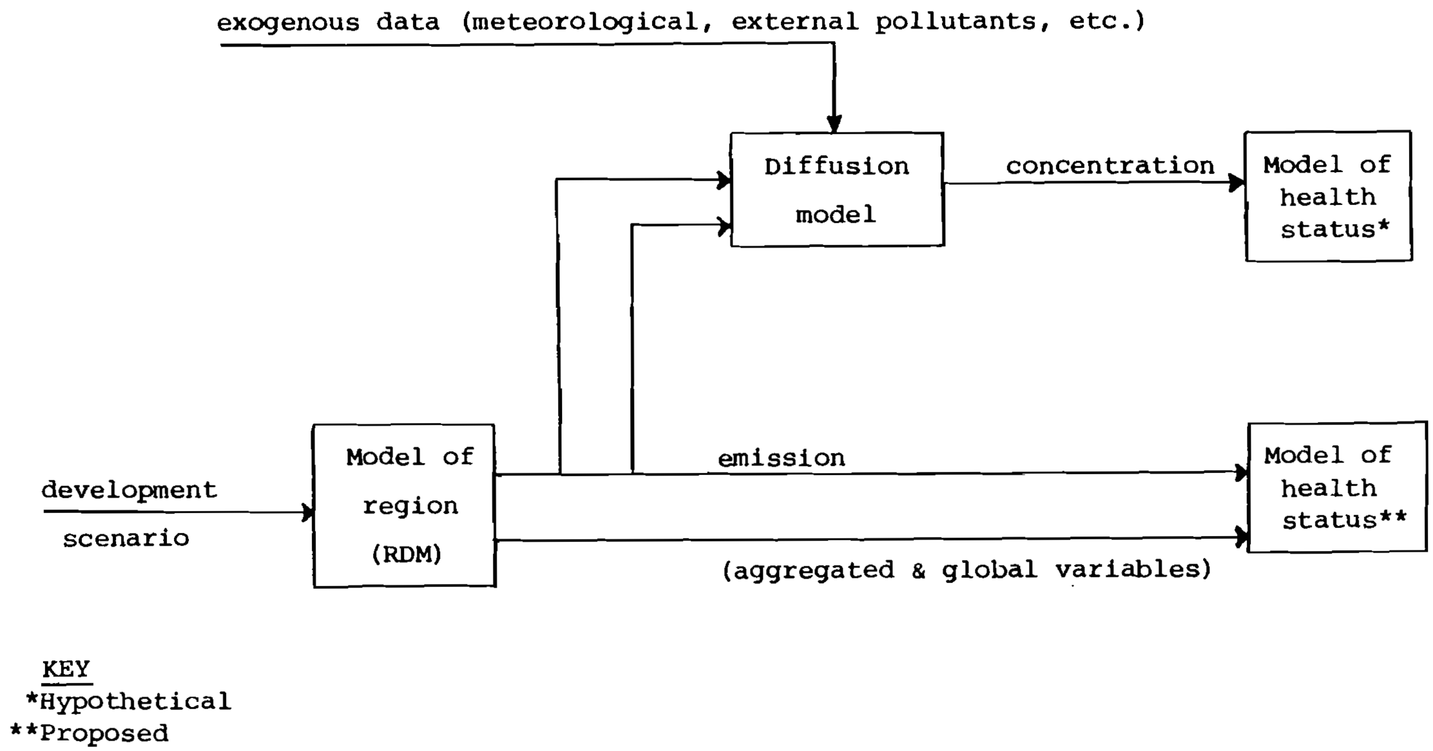

Figure 1. Potential ways of modeling the health status.

used as tools only if the hypotheses have been tested.* The place of the proposed model and its connection with the RDM is shown in Figure 1.

However, it has to be emphasized that the structure proposed, which is based on emission data, obviously has drawbacks, because it does not take into account the effects of pollutants imported from outside the region.** Thus the approach presented is a compromise between the availability of statistical data and what is ideally required. Its practical outputs should be viewed, therefore, as an examination of the broad impact of development scenarios on a population's health status and the relative degree of influence the various pollutants have on health.

Taking into account the above-mentioned compromise, Bojańczyk and Krawczyk (1980) set forth a number of indices describing standards of life by means of emission data (considered the explanatory variables) and indices of the health status (explained variables). The hypotheses were then tested for their significance through a multiple regression analysis. The relationships were obtained, by a cross-sectional analysis, using statistical data provided by 49 Polish voivodships (administrative areas) for the year 1978.

In this paper, only those groups of indices are presented for which the respective relations proved to be statistically significant in Bojańczyk and Krawczyk (1980). The complete set of indices is broader, containing more measures of welfare standards.

It should be borne in mind that according to the standard rules of regression analysis, the hypothesis concerning the significance of a relationship is accepted only when the null hypothesis is statistically rejected. The conclusions obtained by this method, which is based on a cross-sectional analysis,

*A similar approach was presented in North and Merkhofer (1975) and Buehring et al. (1976).

**Unfortunately in some regions, imported pollutants contribute to 30% of the total pollution (measured in terms of concentration) (Juda 1980).

do not consider the dynamics of the processes under consideration. Thus their use in prediction is restricted to systems that are not supposed to change very much--at least in the short run (say, 2-4 years).

2. INDICES DESCRIBING WELFARE STANDARDS

According to the analysis carried out in Bojańczyk and Krawczyk (1980), the description of welfare standards is given by a series of indices of natural units.*

The first are indices describing the natural environment quality

x_1 - various gas emissions in tons per hectar

x_2 - water purification coefficient (amount of non-purified industrial wastes and municipal sewage related to water consumption in tons per ton)

x_3 - population density (number of inhabitants per km^2 --a measure of social environment)

The choice of these indices assumes an obvious correlation between the emission and concentration of pollutants as well as the somewhat unreliable functioning of the water purification system.

The second is an index describing the welfare standard

x_4 - energy consumption in kilowatt hours per person

This characterizes <u>the level of wellbeing</u> which is at present more important and significant in Poland, rather than the income level.**

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*Some other methods of describing welfare standards are considered in the publications of Hellwig, 1968; e.g., a certain kind of multi-criterial approach aimed at comparisons of different regions or systems.

**Some measures of income have been considered in Bojańczyk and Krawczyk (1980), but have been omitted in the further analysis due to the fairly weak explanatory features.

The third are indices describing the health care services level

x_5 - number of physicians per 10^4 population

x_6 - number of beds in general hospitals per 10^4 population

The chosen indices describe the accessibility to health care services. Hence, they also describe the levels of the services in each area.

The authors are convinced that the above series of indices do not exhaust the subject of welfare standards. It is possible to make each group richer or to add new ones. Kostrzewski et al. (1973), among others, have worked on this topic. However, the authors feel that estimation and evaluation of the relationships describing the impact of these indices on health status may become a useful and interesting tool for planners and decision makers.

3. INDICES OF HEALTH STATUS

In this paper, as in Bojańczyk and Krawczyk (1980), the health status of the society is described by a set of indices (in natural units) that characterize to some extent, the two states of "bad health": disease and death. Thus the two phenomena, morbidity and mortality, have been considered. Morbidity and mortality figures are those most often met in World Health Organization publications: e.g., Official Record WHO (1973), and others such as Kostrzewski et al. (1973) and Shigan (1978). These papers give comparative studies of the health status for different countries.

A natural and broadly applied method of tackling the health status problem is by analyzing the data of disease frequency, disease stage (earlier, advanced, or terminal) and death rates. Unfortunately, information on morbidity (new cases of disease in a time unit adopted for an analysis) and prevalence (all cases of disease) are quite insufficient.

Basically, the routine statistical data in Poland consist of registered patient cases only, which is a rather typical situation for most countries. The data for latent patients (ill persons unaware of being ill) and unregistered patients (ill persons aware of being ill but staying away from health care services) are unavailable. However, it is possible to calculate morbidity, mortality, and prevalence rates using programs elaborated at the International Institute for Applied Systems Analysis in Laxenburg, Austria (see Shigan 1978; Fujimasa et al. 1978; Kitsul 1980; Klementiev 1977). Unfortunately, some of these programs require, as a prerequisite, very expensive screening analyses for the representative subpopulations. This drawback cannot be overemphasized, since it limits the applicability of such modeling procedures.

Finally, the statistical data give the number of health services rather than the demand for health services, which would better characterize the health status of the society (Shigan 1978). (That is, they describe the realized demand, which is usually equal to the supply level.)

In this paper, three groups of indices have been proposed. The data are taken from routine statistical yearbooks [Yearbook of Health Care in Poland in 1978 (1979) and Yearbook of Voivodships in 1978 (1979)], which implies the acceptance of their well-known limitations:

a) indices describing the process of health care services delivery (treated as some measures of morbidity*)

y_1 - number of consultations with physicians (or dentists) per inhabitant

y_2 - number of patients in general hospitals per 10^4 population**

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*The indices of both a) and b) describe the approximate size of population afflicted with a disease.

**It would be more interesting to disaggregate this number according to disease group specification in c), but the data are not available.

b) morbidity indices - morbidity (new cases) in chosen disease groups per 10^5 population*:

y_3 - influenza

c) mortality indices - number of deaths per 10^5 population caused by diseases from the following disease groups:**

y_4 - cancer
y_5 - cardiovascular diseases
y_6 - respiratory diseases

4. VERIFICATION OF THE SIGNIFICANCE OF THE HYPOTHESES

4.1 General Remarks on the Regression Analysis

The set of programs for multiple regression analysis developed in the Systems Research Institute (Identification Programs for Mathematical Models 1977) has been used to test the significance of postulated linear relationships (linear type $y = ax + e$) between the welfare standards and health status indices. The indices describing welfare standards $x = [x_1 \ldots x_6]$ may be grouped in three classes:

(1) x_1, x_2, x_3 - describes the quality of the environment
(2) x_4 - denotes the level of welfare
(3) x_5, x_6 - measures the supply of health services

The index describing the health status is $y = [y_1 \ldots y_6]$

For a given type of regression model (linear or nonlinear), the above-mentioned package calculates and performs

- regression coefficients (matrix)
- regression model significance tests
- regression coefficients significance tests

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*Data for morbidity rates for disease groups given in c) is required.

**The postulated impact of the natural environment quality on morbidity was the main motivation of this choice.

The run begins with the full model (including all the input variables) and eliminates automatically non-significant coefficients until the final version of the model is obtained. This version has all the coefficients significant and/or minimal residual variance.

Note that once a regression model has been obtained, it must be analyzed carefully. A regression analysis is a useful tool in the early stage of determining the probability (postulated) relationships between inputs and outputs. However, one should not use it as a decisive criterion for the evaluation of cause-and-effect relationships.

4.2 Verification Results

The package of programs and procedures described in section 4.1 has been used to analyze the regression relationships between the index of health status (y) and indices of welfare standards (x). In the sequence proposed in section 3, the final forms of linear regression models are now given.

The models obtained are characterized by three parameters that define the significance of the regression relationships

- (F) - value of standard F-Snedecor test (at 0.05 significance level)
- (σ) - estimator of the square root of residual variance
- (ρ) - multidimensional correlation coefficient

In Figure 2 and the remaining figures in this section, the average values of input and output variables have been denoted with broken lines. In several cases, the essentially multidimensional models have been obtained, i.e., more than one input variable is significant. In such cases, it is necessary to project the received regression hyperplane on the two-dimensional plane (parametrically dependent on average values of other

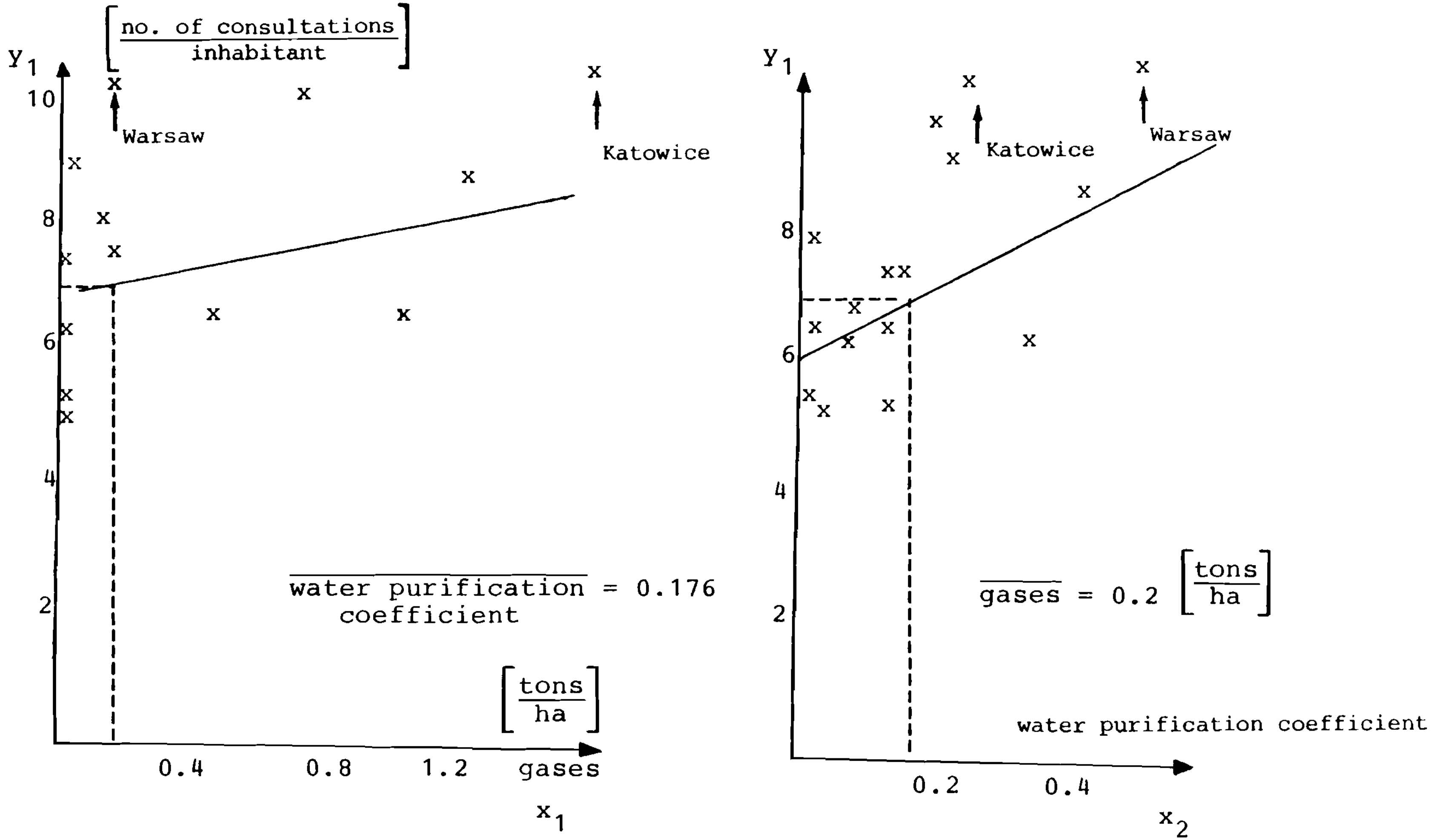

Figure 2. Regressional dependence of the number of physician consultations on the pollution indices. (Because of overprinting, the data points do not total 49 in the diagrams presented.)

input variables). Therefore, these figures are for illustrative purposes only.*

The first regression model that will be presented here is the one referring to the number of consultations given by physicians (and dentists) per inhabitant (see Figure 2):

$$y_1 = 5.89 + 1.33 \cdot x_1 + 4.97 \cdot x_2$$

$$F = 10.88 \; (>F_{crit}=2.99), \; \sigma = 1.36, \; \rho = 0.64$$

where F_{crit} has been calculated for N=49 with the number of degrees of freedom corresponding to the type of model.

Observe that the medical consultation rate (treated as a certain measure of morbidity, see section 3) depends on the environment quality, i.e., on gas emissions (x_1) and on the amount of non-purified water (x_2).

The second regression model refers to the number of patients in general hospitals per 10^4 population (Figure 3):

$$y_2 = 938.0 + 15.24 \cdot x_5$$

$$F = 7{,}624 \; (> F_{crit} = 2.56), \; \sigma = 166.0, \; \rho = 0.69$$

where the number of observations equals 49.

The results of the analysis show that the number of patients is explained by the number of physicians per catchment population. They confirm the general opinion that the number

*In the figures, Warsaw is the biggest urbanized area with a relatively high welfare standard and health services level, and Katowice is the heavy industrialized region with probably the poorest environmental standard.

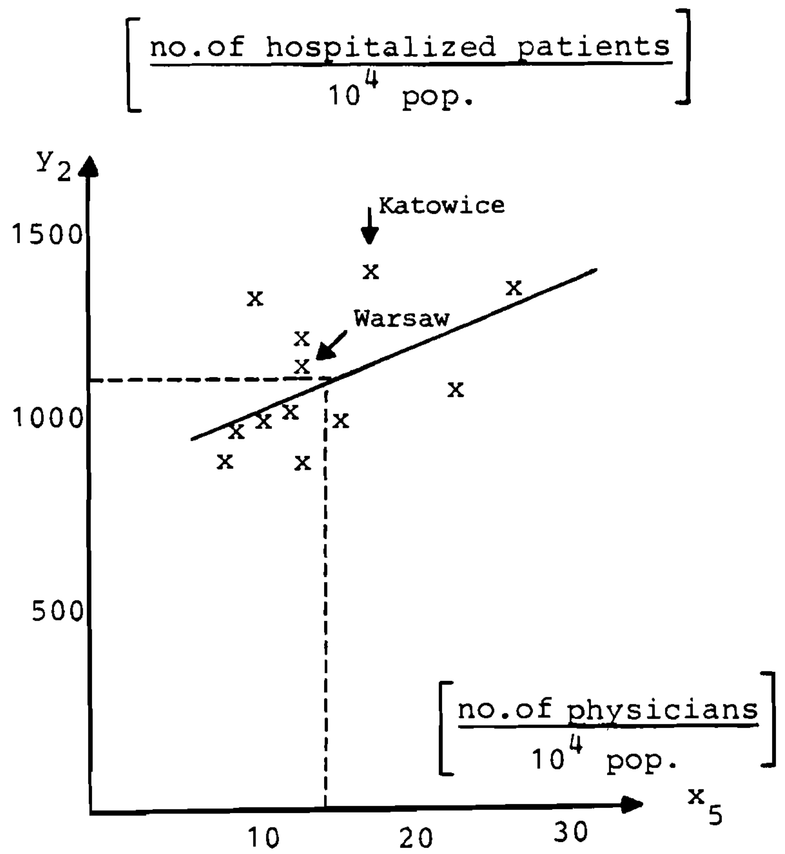

Figure 3. Regressional dependence between the hospitalized patients and the number of physicians.

of physicians is far from the satisfactory saturation level*. It seems that at present and in the near future, every increase in the number of physicians enables the admission of more patients (and therefore decreases the number of patients on waiting lists). In the health care systems of centrally planned economies such as Poland, there is usually a connection between the increase in the number of physicians and the increase in the number of beds, a phenomenon referred to as a standard or norm ratio. The concept of standards (or norms) is fundamental in the planning practice of ministry and regional administrative bodies.

The third model gives the number of people suffering from influenza (y_3) (new cases) per 10^5 population (Figure 4):

$$y_3 = 3900.0 + 10.23 \cdot x_3 + 154.60 \cdot x_5$$

$$F = 3.516 \ (> F_{crit} = 2.29), \ \sigma = 4417.0, \ \rho = 0.53$$

Thus the morbidity rate for influenza depends on:

-- population density with a positive coefficient (the higher the population density, the closer the interpersonal contacts that influence the morbidity rate of infectious diseases)
-- the number of physicians per catchment population also with a positive coefficient

The latter result can by no means by unexpected whereas at present, the number of physicians per 10^4 population is fairly low [15.0 in Poland, 19.4 in FRG, 23.1 in Hungary, see Yearbook of Health Care in Poland in 1978 (1979)]. An increase in the number of physicians would, of course, result in better health diagnoses and better detection of illnesses. As soon

*The saturation level is itself a controversial concept (Shigan 1980; Silver 1972).

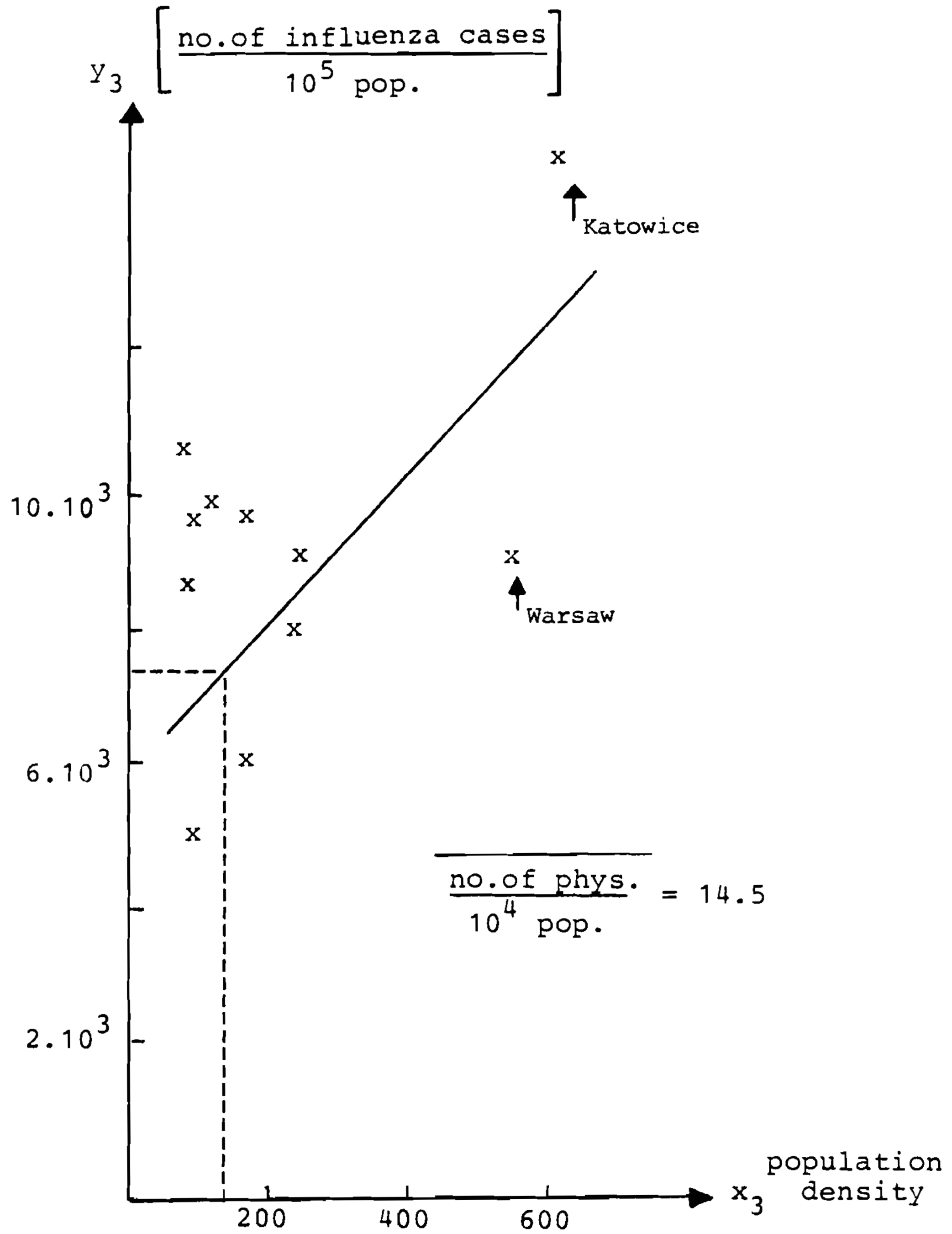

Figure 4. Regressional dependence between the number of new influenza cases and the population density.

as the demand level is reached, a further increase in the number of physicians would improve the standard of health services and lower the morbidity level.

The fourth regression model measures the number of deaths caused by cancer (y_4) per 10^5 population* (Figure 5)

$$y_4 = 136.5 + 38.5 \cdot x_2 + 0.047 \cdot x_3 + 0.095 \cdot x_4 - 0.343 \cdot x_6$$

$$F = 8.714 \ (> F_{crit} = 2.02), \ \sigma = 13.8, \ \rho = 0.71$$

From the fourth regression model (Figure 5), it can be seen that the death rate for cancer disease depends on:

-- water purification efficiency, population density, and energy consumption with positive coefficients. (These quantities influence the morbidity level.)

-- number of beds with a negative coefficient. (It is necessary to enlarge facilities of in-patient health service to improve the conditions of therapy.)

The fifth model describes the number of deaths caused by cardiovascular diseases (y_5) per 10^5 population (Figure 6):

$$y_5 = 589.2 + 0.299 \cdot x_3 - 3.98 \cdot x_6$$

$$F = 9.061 \ (> F_{crit} = 2.29), \ \sigma = 64, \ \rho = 0.61$$

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*Here, it would be methodologically more justified to take the emission data of pollutants from the past (let us say 5-8 years earlier) because the disease process has its own dynamics. However, these data were not at our disposal, and the regional shares of pollution in the total pollutant emission do not vary much within this time interval.

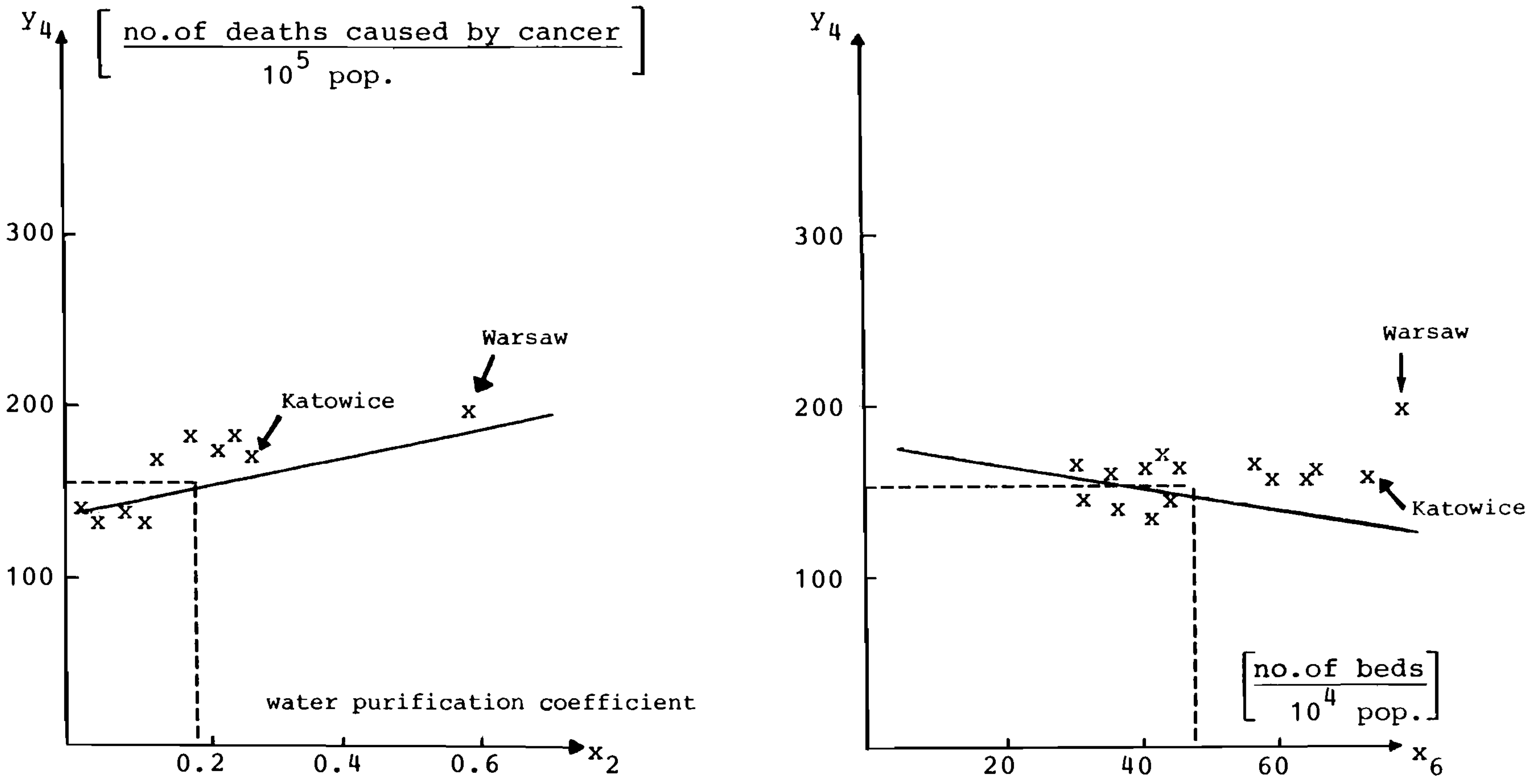

Figure 5. Regressional dependence relating the number of cancer deaths to the water purification efficiency and to the accessibility of hospitals.

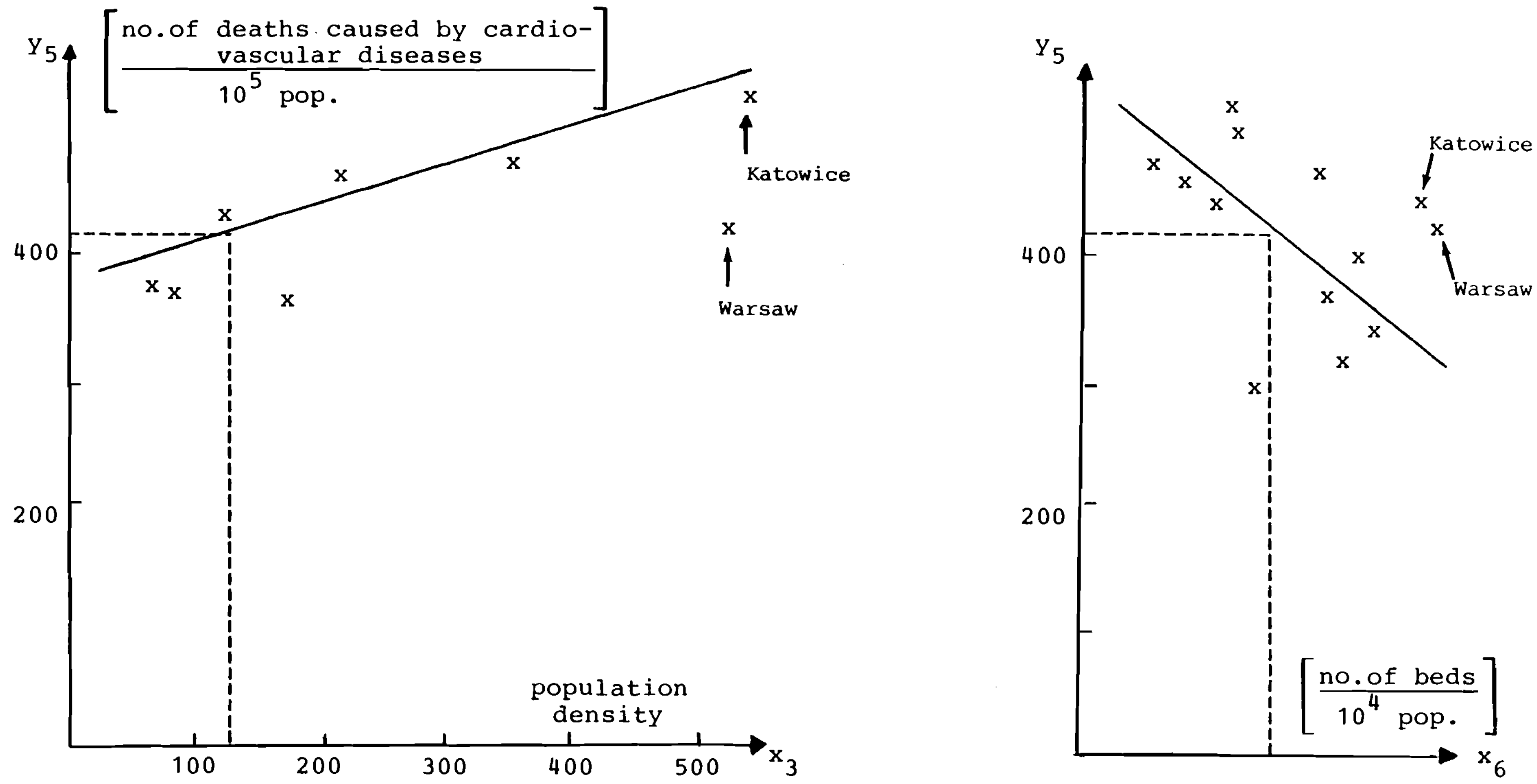

Figure 6. Regressional dependence relating the number of deaths caused by cardiovascular diseases to the population density and the accessibility of hospitals.

In this model as in the fourth model, the mortality rate for cardiovascular diseases depends on:

-- population density with a positive coefficient (impact on morbidity for "civilization disease")

-- number of beds with a negative coefficient (see explanation for the fourth model)

The sixth model gives the number of deaths caused by respiratory diseases per 10^5 population (Figure 7):

$$y_6 = 87.09 - 0.465 \cdot x_6$$

$$F = 4.346\ (> F_{crit} = 2.56),\ \sigma = 14.0,\ \rho = 0.5$$

The last model shows a regressional dependence of the mortality rate for respiratory diseases on the number of available beds with a negative coefficient. It is very similar to the fourth and fifth models.

5. CONCLUDING REMARKS

The conclusions resulting from the above testing of the hypotheses is summarized here:

-- In three models, a relatively significant dependence of outputs (indices y) to the number of beds in hospitals has been manifested, especially mortality indices (from group c in section 3). This suggests that an improvement of hospital conditions could effectively contribute to the amelioration of the health status in Poland.

-- The water purification process may have been responsible for some mortality.

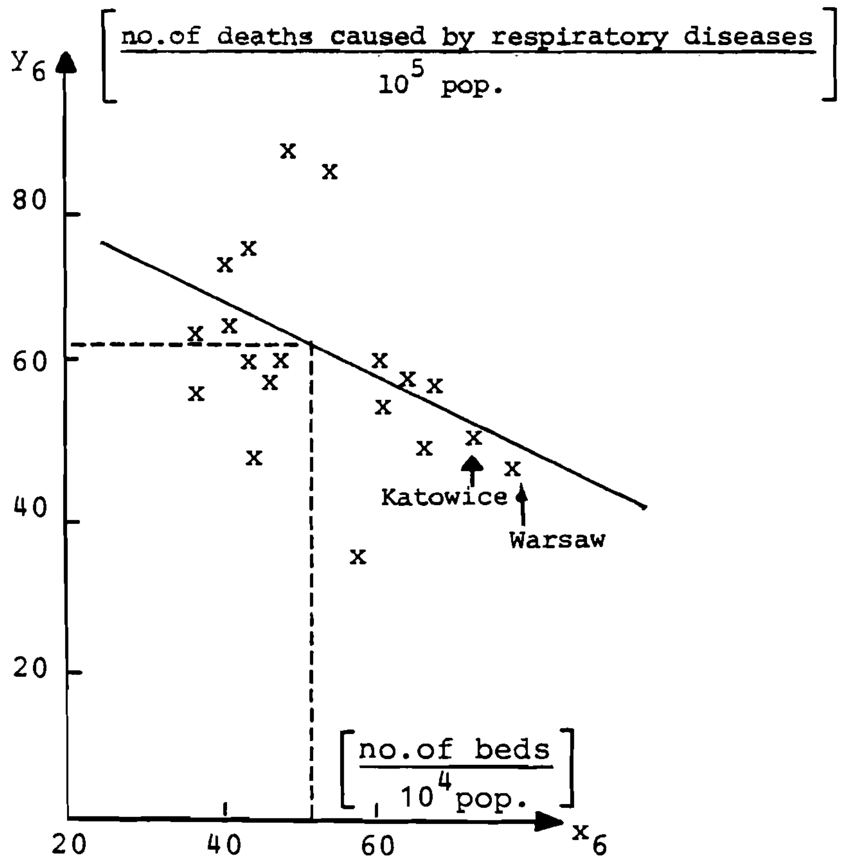

Figure 7. Regressional dependence between the number of deaths caused by respiratory diseases to the accessibility of hospitals.

-- An apparently unexpected lack of dependence between the proposed indices describing the natural environment and some morbidity measures has been noticed (see more detailed analysis in Bojańczyk and Krawczyk (1980). According to the authors, this is because: a) the indices proposed describing the emission of pollutants are in fact an insufficient measure of the deterioration of the environment (see Lave and Freeburg 1973, Werk 1977 and North and Merkhofer 1975); b) an average level of the environment pollution with respect to the whole country has not reached the critical point.

-- An apparently unexpected increase in the given morbidity measure (the number of hospital visits, etc.) (group a in section 3) with an increase in the number of physicians has pointed to the nonsaturation demand situation for health care, which supports the widely accepted opinion of the demand for health care seeming to be insatiable (Shigan 1978; Kostrzewski 1973).

It should also be borne in mind that this study has been retrospective, i.e., the information about the welfare standards defined in section 2 was not especially adapted to the health status indices (section 3)--nor was the reverse done.* Both groups of indices have been received from routine statistical publications [Yearbook of Health Care in Poland in 1978 (1979), and Yearbook of Voivodships in 1978 (1979)]. In the future a prospective study should be made. Werk (1977) and Lave and Freeburg (1973) present possible use of some prospective methods where the sets of input and output variables are less numerous, but the statistical data are very rich and especially chosen. However, this kind of approach requires substantially larger expenditures.

*Some subpopulations could be chosen and analyzed, e.g., the groups exposed to well-defined environmental hazards.

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