Indicator-Based Assessment of Environmental Hazards and Health Effects in the Industrial Cities of Upper Silesia, Poland

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Using an indicator-based approach, we assessed environmental hazards and related health effects in populations of industrial cities with more than 100,000 inhabitants in Upper Silesia, Poland, and analyzed the relationship between environment and health. We adopted the method developed by Dutkiewicz et al. for assessing large geographic areas. Based on routinely collected environmental and health data, two groups of indicators, environmental indicators (EIs) and health status indicators (HSIs), related to environmental contamination were selected. The EI and HSI values were normalized and aggregated into synthetic measures using Strahl's taxonometric method. The synthetic measures indicated the intensity of environmental hazards and health outcomes. We used a three-level index scale to compare and rank the cities under the study and, consequently, to facilitate decision making. Findings of the assessment identified cities where actions aimed at reducing environmental hazards and improving population health status should be established as priorities. These cities included Chorzów, Katowice, Sosnowiec, Bytom, and Zabrze. We found a high correlation between the synthetic measures of environmental indicators and the synthetic measure of health status indicators ($r = 0.77$), as well as a high level of consistency between environmental hazard indices and environmental-related health status indices (73%). This may indicate the existence of a causal relationship between the environmental contamination within industrial cities and the health status of their inhabitants. *Key words:* environmental hazards, environmental indicators, environment-related health status indicators, industrial cities, synthetic measures, taxonometric method. *Environ Health Perspect* 110:1133–1140 (2002). [Online 24 September 2002]

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Current knowledge indicates that environmental factors may affect health. Much of this knowledge is derived from studies of environmental epidemiology, where a key point is the link between human exposure to environmental hazards and health outcome. In many cases, however, it is difficult to identify and assess the environment–health links. One reason is that many environmental factors act simultaneously and many diseases have multiple causes, including nonenvironmental factors (Bertollini et al. 1996; EEA 1999; WHO 1983). Another reason is the lack of information on dose–response relationships for many environmental pollutants. Moreover, assessment of environmental impact on health requires quantitative data on exposure levels and their distribution in the study area; however, such data are often unavailable or insufficient. Existing monitoring data usually provide information on only a limited number of environmental pollutants in small areas.

Despite these difficulties, methods for analyzing environmental health problems in contaminated areas have been developed in recent years. The key objective of these research initiatives is to provide tools to create appropriate environmental health policies. One method uses environmental health indicators (EHIs) as measures for expressing the link between the environment and health; these indicators are presented in a form facilitating their interpretation for effective decision-making (Corvalán et al. 1996). The World Health Organization (WHO) has played a major role in developing and using EHIs (Corvalán et al. 1996). The development and use of EHIs was an integral element of the Health and Environment Analysis for Decision-Making (HEADLAMP) collaborative project among the United Nations Environment Programme (UNEP), the U.S. Environmental Protection Agency (EPA), and the WHO. The goal of HEADLAMP was to provide information on the health impacts of environmental hazards for policy-making and for addressing environmental health problems (Corvalán 1996; Corvalán and Kiellström 1995).

To support the development of EHIs, the WHO provided a conceptual framework, driving force–pressure–state-exposure–effect–action (DPSEEA), which adopted the simple pressure-state-response (PSR) sequence applied by the Organisation for Economic Cooperation and Development (OECD) for environmental reporting (Briggs and Wills 1999; Corvalán et al. 1996). The DPSEEA framework illustrates a chain of causes and effects. In the acronym, driving forces (*D*) refer to the factors that motivate and push environmental processes, including population growth, economic development, or technologic development. Pressure (*P*) is expressed by human occupation, production, or waste release. State of the environment (*S*) is expressed in terms of frequency or magnitude of natural hazards, the availability and quality of natural resources, and the level of environmental pollution. Exposure (*E*) refers to the intersection between people and environmental hazards. Effects (*E*) of exposure to environmental hazards may include a broad spectrum, from subclinical effects to illness or, in extreme cases, mortality. Within DPSEEA, action (*A*) may be taken at each point of the environment–health chain and may be protective, remedial, or preventive (Briggs and Wills 1999; Corvalán et al. 1996).

EHIs may include both environmental indicators and health indicators for which the relationship between human exposure to environmental hazards and health effects is known (Corvalán et al. 1996; Corvalán and Kiellström 1995). Wills and Briggs (1995) defined two categories of EHIs: *a*) health-related environmental indicators (HREIs) are environmental conditions or trends that may cause potential adverse health effects, and *b*) environmental-related health indicators (ERHIs) are health outcomes due to environmental causes or factors.

According to the concept of the DPSEEA framework, the most effective HREIs should express exposure levels. However, due to a lack of relevant data, environmental indicators that express exposure levels indirectly (e.g., air pollution concentrations or emission rates) are most frequently used in environmental hazard assessments. A survey of projects performed from 1970 to 1990 indicated that only 1% of all indicators (2 of 233 analyzed) related specifically to exposure, whereas 33% of indicators characterized source activity. Eight percent related to emissions, and

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12% to contaminant concentrations. Forty-five percent of indicators related to nonenvironmental issues (Wills and Briggs 1995).

In turn, health indicators should describe health outcomes caused by exposure to environmental hazards, when used for estimating health impact of environmental contamination (Corvalán et al. 1996). However, contamination of industrial areas with numerous toxic substances leads to combined exposure that results in nonspecific, aggregated, and varied health effects. To determine which health effects are environmentally related (e.g., infant mortality, mortality from diseases of the respiratory system), a relative risk assessment method may be applied (Dutkiewicz et al. 1996b, 1997, 1998).

To assess environmental hazards and related health effects in a given area, it may be necessary to use many individual environmental and/or health indicators. This could cause difficulties in interpreting the results of such an assessment and therefore may prevent decision makers from taking appropriate action related to environmental health protection. The use of composite indicators, which integrate individual indicators to a synthetic measure or an index, could simplify the complexity of environmental and health phenomena and consequently facilitate the decision-making process (Corvalán et al. 1996).

Aim of the Study

Research initiatives to develop composite environmental indicators and related health indicators have been undertaken in Poland in recent years (Dutkiewicz 1994; Dutkiewicz et al. 1996b, 1997, 1998; Mazurski 1994). However, these indicators related only to large geographic areas. Thus, a research gap has been observed for smaller areas, such as the lowest administrative units. Because of the complexity of environmental contamination, as well as the percentage of the population exposed to high levels of chemical contamination, the importance of such research has been particularly realized within industrial cities. To fulfil this gap, we undertook this study aimed at comprehensively assessing environmental hazards in Polish industrial cities and health outcome.

We identified potentially health-related environmental indicators and health status indicators, related to environmental contamination, which were then used as synthetic measures for assessing, comparing, and ranking the cities under the study. Consequently, these measures may serve as a basis for establishing environmental health policies and priorities.

Description of the Study Area

For the study area, industrial cities of Upper Silesia, Poland, that are inhabited by more than 100,000 people were chosen. They included Katowice, Bytom, Chorzów, Dabrowa Górnicza, Gliwice, Ruda Slaska, Sosnowiec, Zabrze, Jastrzebie-Zdrój, Rybnik, and Tychy.

Upper Silesia is a typical industrial region, with high levels of urbanization and high population density. The main types of industry include coal mining, power generation, iron and steel metallurgy, and nonferrous metal processing and mining (including zinc and lead ores and chemical and building material production). In 1995, 245 industrial plants were recognized as especially contributing to the poor air quality; 108 of these were located in cities inhabited by more than 100,000 people (US 1996). Exploitation of mineral resources and industrial activities resulted in high levels of air pollution, soil and surface water contamination, and accumulation of industrial wastes (Marchwinska et al. 1997; PIOS 1997; US 1996).

Within this region, two ecologic hazard areas (EHAs) were identified in the 1980s: the Upper Silesian Ecological Hazard Area and the Rybnik Ecological Hazard Area. These EHAs were recognized as areas of ecologic disaster (Kassenberg and Rolewicz 1985). In various classifications of EHAs where environmental contamination or degradation were taken into consideration, the Upper Silesian Ecological Hazard Area was most often ranked the highest among EHAs in Poland (Dutkiewicz 1994; Godzik and Poborski 1995; Kassenberg and Rolewicz 1985; Konczalik 1997).

Studies conducted in Upper Silesia demonstrated that the areas of highest air and soil pollution correspond with the highest infant mortality rates and incidence of respiratory system diseases in children (Norska-Borówka et al. 1990). Moreover, the range of excess mortality due to air pollution with respirable dust was estimated at 5–23% in Silesian cities comparing to cities in OECD countries (Herzman et al. 1995).

Another study found that elevated blood lead levels ($\geq$ 15 µg/dL) may be expected in 10,000–18,000 preschool children living in industrial towns of this region (Zejda et al. 1996). The studies also revealed that the occurrence of elevated blood lead levels was associated with the place of residence and the intensity of vehicular traffic (Zejda et al. 1996, 1997).

Infant mortality rate is higher in urban than in nonurban areas of Upper Silesia. Since the 1970s, the infant mortality rate (per 1,000 live births) has been higher each year in this region than in the entire country: In 1995, infant mortality was 13.6 in Poland versus 14.0 in Upper Silesia (WZMOZ 1997).

In Upper Silesia, the main causes of death are diseases of the circulatory system and malignant neoplasms. In 1995, comparing all regions of the country, the highest acute myocardial infarction mortality rate (per 100,000 people) was noted in Upper Silesia: 119.2, versus 74.7 in the entire country (WZMOZ 1997). Given the data from all administrative units of Upper Silesia, from 1985 to 1993, the highest age-standardized malignant neoplasms incidence and mortality rates were observed in the towns of this region, both for males and females (Zemla et al. 1999).

Because of significant environmental contamination with chemical substances as well as many adverse health effects observed in the inhabitants of Upper Silesia, remedial environmental activities in this region should be intensified, especially in the areas of industrial cities.

Methods

To assess environmental hazards and related health impacts in the study cities, we adopted the method recently developed by Dutkiewicz et al. (1996a, 1997, 1998) for assessing large geographic areas. This method uses two groups of indicators: environmental indicators (EIs) and health status indicators (HSIs), which are selected based on routinely collected environmental and health data. The values of the selected EIs and HSIs were normalized and aggregated into synthetic measures that allowed a complex assessment and ranking of studied areas.

Generally, the methodology encompasses the following main steps: selection of EIs and HSIs; construction of synthetic measures of EIs and HSIs; and division of each set of synthetic measures into groups using a three-level index scale. This approach employs two distinct methodologies: a relative risk method for selection of HSIs and a taxonometric method for synthetic measures construction.

Selection of EIs. In these studies, the selection of EIs followed analysis of environmental statistics and monitoring data from 1995, as published in national or regional environmental reports (Cimander et al. 1996; GUS 1996a, 1996b; Korzuch 1997; Terelak et al. 1994; US 1996). The analysis focused on these environmental data, which represent chemical hazards with the potential to pose health risks and was available in the same form for all cities with more than 100,000 inhabitants. Because data were lacking on exposure levels of specific groups of people, only environmental data that expressed indirectly the level of exposure (e.g., air pollution concentrations or accumulated industrial wastes) could be considered potential indicators. This information was related to a strictly defined city area, thereby indicating the number of potentially exposed people. In fact, the levels of environmental hazards are differentiated within the city area, and consequently cases of extremely low and high exposure to harmful substances occur. However, because more detailed data were not available, average values of environmental indicators were used to show average exposure of the entire population of a given city.

As a result of this analysis, the following EIs were selected:

- Air pollution indicator (API): aggregate indicator, defined as the sum of quotients of average concentrations of basic air pollutants (i.e., suspended particulate matter [SPM], sulfur dioxide, nitrogen dioxide, and National Ambient Air Quality Standards [NAAQS] for these pollutants)
- Soil contamination indicator (SCI): expresses (as a percentage) the level and extent of arable soil contamination for heavy metals in a given city area
- Accumulated industrial wastes indicator (AWI): provides the quantity of accumulated industrial wastes, per city area unit
- Indicator of untreated wastewater discharge to surface waters (WDI): expresses the volume of untreated wastewater discharged to surface water, per city area unit.

Selection of HSIs. HSIs were selected using a two-step procedure. The initial step involved identifying health status indicators related to environmental contamination. This pre-selection was carried out based on a survey of literature concerning human health effects of environmental contamination (Berciano et al. 1989; Biesiada et al. 1997; Bobak and Leon 1992; Derrienic et al. 1989; Dockery and Pope 1997; Dockery et al. 1989, 1993; Folinsbee 1992; Grazuleviciene 1997; Jarosinska et al. 1997; Jedrychowski 1995; Krzyzanowski and Wojtyniak 1991/1992; May 1988; Norska-Borówka 1997; Norska-Borówka et al. 1990, 1995; Ong et al. 1991; Ostro et al. 1991; Osuch-Jaczewska and Baczynska-Szymocha 1992; Pönkä 1991; Pope 1989; Seroka and Krzyzanowski 1984; Sunyer et al. 1991; Thurston et al. 1994; White et al. 1994; WHO 1987), which mainly included diseases or mortality from diseases of the respiratory system (Berciano et al. 1989; Derrienic et al. 1989; Dockery and Pope 1997; Dockery et al. 1989; Jedrychowski 1995; Krzyzanowski and Wojtyniak 1991/1992; May 1988; Ong et al. 1991; Ostro et al. 1991; Pönkä 1991; Pope 1989; Seroka and Krzyzanowski 1984; Sunyer et al. 1991; Thurston et al. 1994; White et al. 1994; WHO 1987), mortality from cancer (Dockery et al. 1993; Doll and Peto 1981; Ford and Bialik 1980; Jedrychowski et al. 1990; Zemla et al. 1999), infant mortality (Biesiada et al. 1997; Bobak and Leon 1992; Norska-Borówka 1995; Norska-Borówka et al. 1990, 1995; Osuch-Jaczewska and Baczynska-Szymocha 1992), and low birth weight or birth defects (Biesiada et al. 1997; Grazuleviciene 1997; Norska-Borówka 1997).

Also, findings of previous studies carried out in large geographic areas of Poland (Dutkiewicz et al. 1997), and data on the most frequent mortality causes in Upper Silesia (WZMOZ 1997; Zemla et al. 1999) were taken account in the pre-selection process. Moreover, a list of sentinel health events (SHEs), identified as indicators of undue exposure to environmental contamination (Rothwell et al. 1991), was considered essential for selecting HSIs.

SHEs include diseases identifiable through existing health reporting systems and deviations from normal biologic function requiring special surveys to detect (preclinical indicators of adverse health effect). The indicators of the first category include low birth weight, birth defects, spontaneous abortion, chronic respiratory disease in children, active leukemia in children, acute granulocytic leukemia in adults, aplastic anemia, asthma in children, dermatitis and dermatoses, skin cancer, malignant melanoma, lung cancer and bladder cancer in nonsmokers as well as primary liver cancer in nondrinkers. Deviations in neurologic, immunologic, renal, cardiac, hematologic, respiratory, reproductive, liver, and auditory functions were identified as indicators of the second category. These events occur in whole populations; however, an excess frequency of one of them may serve as warning signs of population exposure to environmental contaminants.

As a result of the literature survey, the following HSIs indicators were identified as potentially environmentally related and selected for further consideration: general infant mortality, infant mortality from congenital anomalies, infant mortality with low birth weight (< 2500 g), births with low birth weight (BLBW), and age-, sex-, and cause-specific mortality from diseases of the circulatory system [*International Classification of Diseases, Injuries and Causes of Death*, 9th revision; (ICD-9) 390–459], including ischemic heart disease (ICD-9 410–414) and acute myocardial infarction (ICD-9 410); malignant neoplasms (ICD-9 140–208), including malignant neoplasms of the stomach (ICD-9 151), colon (ICD-9 153), rectum, rectosigmoid junction, and anus (ICD-9 154), trachea, bronchus, and lung (ICD-9 162), female breast (ICD-9 174), and cervix uteri (180), as well as leukemias (ICD-9 204–208); diseases of the respiratory system (ICD-9 460–519), including bronchitis, pulmonary emphysema, and bronchial asthma (ICD-9 490–493); diseases of the blood and blood-forming organs (ICD-9 280–289); diseases of the skin and subcutaneous tissue (ICD-9 680–709); and congenital anomalies (ICD-9 740–759).

The second step of the selection process was based on the concept that environmental exposures may account for excess adverse health events in a given area when those events occur at a higher level than expected in a population. Therefore, HSIs that are significantly higher in cities with the highest EI values (region A), compared to the reference cities (region B), would be most appropriate for assessing health status related to environmental contamination. Thus, by analyzing EIs previously selected in this study, we established the following cities as highly contaminated areas (region A): Katowice, Bytom, Chorzów, Ruda Slaska, Sosnowiec, and Zabrze. The reference cities were identified among the least contaminated Polish cities, located outside of the EHAs. Thus, region B comprised four cities: Bialystok, Koszalin, Slupsk, and Olsztyn.

For comparing preselected HSIs in the cities of region A with region B, we used a relative risk assessment method (Polz 1996). To calculate relative risks, we used health data associated with preselected HSIs, combined with information on the age and sex structures of populations in region A and region B in 1995 (as obtained from the Central Statistical Office; Statistical Office, Olsztyn, Poland).

To identify HSIs that were highly related to environmental contamination, we adopted the following criteria, also applied in previous studies (Dutkiewicz et al. 1997, 1998; Indulski and Andryszek 1995): a relative risk (RR) > 1.2 (120%), which is an arbitrary criterion, and a lower confidence limit (LCL) > 1 (100%), with a significance level of $\alpha = 0.05$.

As a result of this final selection, four HSIs were identified as most closely related to EIs: mortality of males in the 30–59 age group from malignant neoplasms (ICD-9 140–208); mortality of males and females in the 30–59 age group from diseases of the circulatory system (ICD-9 390–459); mortality of males and females from diseases of the respiratory system (ICD-9 460–519); and BLBW.

To assess the health status of the cities' populations, we used HSIs in terms of mortality rates (incidences per 100,000 persons) and percentage of BLBW.

Construction of synthetic measures using the taxonometric method. To comprehensively assess the environmental hazards and health status expressed by the indicators, taxonometric methods of a comparative multicomponent analysis may be incorporated. The taxonometric methods allow normalization and aggregation of the variables, which vary with respect to nomenclature and numeric values, into one synthetic measure within a definite numeric interval (Andryszek 1984; Hellwig 1968; Strahl 1978). The taxonometric methods were applied to assess the health situation in the country (Andryszek

1993; Klima and Wydymus 1993), to evaluate the allocation of resources for environmental protection (Andryszek 1984), to analyze the relationship between mortality and life expectancy versus socioeconomic status in Poland (Kedelski 1983), and to assess environmental and health hazards in large geographic areas (Dutkiewicz et al. 1996a, 1997, 1998).

In this study, the selected EIs and HSIs were normalized and aggregated into synthetic measures using Strahl's taxonometric method (Strahl 1978), as applied in previous studies (Dutkiewicz et al. 1996a; 1996b; 1997; 1998; Indulski and Andryszek 1995). The synthetic measure (S_i) is the arithmetic mean of the normalized indicators:

$$S_i = \frac{1}{m}\sum_{j=1}^{m} Y_{ij}\text{norm}$$

$$Y_{ij}\text{norm} = \frac{\min Y_{ij}}{Y_{ij}}$$

where Y_{ij} = value of the *j*th indicator in the *i*th city area; Y_{ij}norm = normalized value of the *j*th indicator in the *i*th city area; $\min Y_{ij}$ = minimum value of the *j*th indicator in the *i*th city area; and m = number of indicators.

In this method, both the normalized values of the indicators and the values of the synthetic measures are within the range 0–1. The synthetic measures indicate the intensity of environmental hazards and health effects in the cities under study. The lowest value of the synthetic measure represents the worst environmental or health situation in a given city, and the highest value of the synthetic measure represents the best situation.

Indexing method. To make the findings of the assessment of environmental hazards in the cities and health status more simplified in terms of decision making, each set of the synthetic measures was expressed by indices in a three-level scale based on the method applied for the assessment of regional environmental and health hazards in Poland (Dutkiewicz et al. 1996a, 1997, 1998).

Thus, the synthetic measures were divided into three groups, to which index values were attributed, as follows:

$$S_i > \exp(A_i + 1/2\ \text{SD}_i) \qquad \text{Index 1}$$

$$\exp(A_i - 1/2\ \text{SD}_i) \le S_i \le \exp(A_i + 1/2\ \text{SD}_i) \qquad \text{Index 2}$$

$$S_i < \exp(A_i - 1/2\ \text{SD}_i) \qquad \text{Index 3}$$

where S_i = synthetic measure; A_i = arithmetic mean of natural logarithmic values of synthetic measures; SD_i = standard deviation for natural logarithmic values of synthetic measures; and exp = exponential function.

The index values were described as follows: index 1—low environmental hazards in a given city or the best environmental-related health status of inhabitants; index 2—medium environmental hazards or moderately good environmental-related health status, and index 3—high environmental hazards or the worst environmental-related health status.

Results

According to Strahl's method for normalization and aggregation of variables (Strahl 1978), we used four EIs to calculate the synthetic measures of environmental indicators (S_E), and four HSIs to calculate the synthetic measures of health status indicators (S_H) for

Table 1. Real and normalized values of selected EIs and S_E in the cities under the study.

City	API[a] Real	API[a] Norm	AWI (Gg/km^2) Real	AWI (Gg/km^2) Norm	WDI (hm^3/km^2) Real	WDI (hm^3/km^2) Norm	SCI (%) Real	SCI (%) Norm	S_E[a]
Upper Silesian cities									
Katowice	3.465	0.284	124	0.0040	0.08727	0.0007	78.2	0.43	0.179
Bytom	3.740	0.263	640	0.0008	0.11205	0.0005	92.8	0.36	0.156
Chorzów	3.600	0.273	281	0.0018	0.31818	0.0002	98.6	0.34	0.153
Dabrowa Górnicza	3.145	0.313	33	0.0152	0.01223	0.0049	85.7	0.39	0.180
Gliwice	3.260	0.302	695	0.0007	0.07388	0.0008	59.2	0.56	0.217
Jastrzebie Zdrój	3.735	0.263	1,621	0.0003	0.01279	0.0047	40.9	0.82	0.271
Ruda Slaska	3.100	0.317	344	0.0015	0.08462	0.0007	81.5	0.41	0.182
Rybnik	3.510	0.280	63	0.0079	0.01778	0.0034	33.3	1.00	0.323
Sosnowiec	3.485	0.282	3	0.1667	0.14615	0.0004	93.2	0.36	0.202
Tychy	2.760	0.356	3	0.1667	0.00244	0.0246	58.3	0.57	0.280
Zabrze	3.535	0.278	304	0.0016	0.04750	0.0013	69.1	0.48	0.191
Reference cities									
Bialystok	0.998	0.985	22	0.0227	0.00111	0.0541	33.3	1.00	0.516
Koszalin	0.983	1.000	0.5	1.0000	0.00006	1.0000	33.3	1.00	1.000
Olsztyn	1.535	0.640	8	0.0625	0.00227	0.0264	33.3	1.00	0.432
Slupsk	1.172	0.839	0.5	1.0000	0.00012	0.5000	33.3	1.00	0.835

Abbreviations: Gg, gigagrams; hm^3, cubic hectometer; Norm, normalized.
[a]Unitless.

Table 2. Real and normalized values of selected HSIs and S_H in the cities under the study.

City	Males, age 30–59[a] Real	Males, age 30–59[a] Norm	Males and females, age 30–59[b] Real	Males and females, age 30–59[b] Norm	Males and females, all ages[c] Real	Males and females, all ages[c] Norm	Infants (% BLBW) Real	Infants (% BLBW) Norm	S_H[d]
	Cause-specific mortality rates per 100,000 population								
Upper Silesian cities									
Katowice	203.11	0.55	211.64	0.44	44.37	0.27	8.50	0.61	0.468
Bytom	186.06	0.61	183.11	0.51	28.63	0.41	11.55	0.45	0.495
Chorzów	234.93	0.48	307.27	0.31	55.69	0.21	10.41	0.50	0.374
Dabrowa Górnicza	136.69	0.82	168.18	0.56	26.50	0.45	9.06	0.57	0.600
Gliwice	142.08	0.79	127.43	0.74	33.00	0.36	7.56	0.68	0.643
Jastrzebie Zdrój	136.93	0.82	177.65	0.53	28.61	0.42	6.48	0.80	0.641
Ruda Slaska	141.12	0.80	209.95	0.45	42.27	0.28	7.80	0.66	0.547
Rybnik	113.27	1.00	175.40	0.54	32.57	0.36	6.33	0.82	0.678
Sosnowiec	164.00	0.69	185.46	0.51	62.35	0.19	9.58	0.54	0.481
Tychy	192.59	0.59	156.35	0.60	32.13	0.37	7.03	0.73	0.572
Zabrze	172.37	0.65	208.65	0.45	47.32	0.25	7.95	0.65	0.501
Reference cities									
Bialystok	145.01	0.78	116.50	0.81	21.93	0.54	5.16	1.00	0.781
Koszalin	112.71	1.00	120.60	0.78	11.88	1.00	6.54	0.79	0.892
Olsztyn	129.24	0.87	93.93	1.00	27.45	0.43	6.47	0.80	0.776
Slupsk	142.97	0.79	121.05	0.78	24.49	0.49	9.06	0.57	0.655

Norm, normalized.
Codes represent the causes of death, as defined by the ICD-9: [a]140–208, malignant neoplasms; [b]390–459, diseases of the circulatory system; [c]460–519, diseases of the respiratory system. [d]Unitless.

the cities of Upper Silesia and the reference cities. Table 1 presents the real and normalized values of EIs, as well as S_E. Table 2 shows real and normalized values of HSIs, as well as S_H.

Each of the studied cities was also classified into one of three index groups associated with environmental hazards and related health status, which allowed comparison and ranking of cities (Table 3). Chorzów, Bytom, Katowice, Dabrowa Górnicza, Ruda Slaska, Zabrze, and Sosnowiec were classified as cities with high environmental hazards (index 3). Gliwice, Jastrzebie Zdrój, Tychy, and Rybnik were classified as cities of medium environmental hazards (index 2). No city of Upper Silesia met the index value of 1 for low environmental hazards. The worst environmental-related health status (index 3) was noted in Chorzów, Katowice, Sosnowiec, Bytom, and Zabrze. In the cities of Ruda Slaska, Tychy, Dabrowa Górnicza, Jastrzebie Zdrój, and Gliwice, the environmental-related health status was moderately good (index 2). Among Upper Silesian cities, only Rybnik was classified as a city of the best environmental-related health status (index 1). Chorzów was classified as a city of the highest environmental hazards and, at the same time, of the worst environmental-related health status.

Based on the classification of cities presented in Table 3, the consistency level between environmental hazard indices and environmental-related health status indices was also evaluated. Among 15 cities, 11 cities had the same index values for environmental hazards and health status: index 1—Olsztyn, Bialystok, Koszalin; index 2—Gliwice, Jastrzebie Zdrój, Tychy; index 3—Chorzów, Katowice, Bytom, Sosnowiec, Zabrze.

Thus, a high consistency level (73%) between environmental hazard indices and environmental-related health status indices was found.

Moreover, during the course of the study, we evaluated the correlation between S_E and S_H (Figure 1). The correlation coefficient, $r = 0.77$, was statistically significant, with a significance level of $p < 0.05$. Using reciprocal scales, Figure 1 shows that an increase of environmental contamination (i.e., decrease of S_E values) results in a rapid increase of negative health status indicators (i.e., decrease of S_H values).

We also evaluated the correlation between S_E and each individual normalized HSI. Analysis showed that S_E was most strongly correlated with mortality of males and females from diseases of the respiratory system ($r = 0.84$; $p < 0.05$) and with mortality of males and females in the 30–59 age group from diseases of the circulatory system ($r = 0.65$; $p < 0.05$). Lower correlation was observed for mortality of males in the 30–59 age group from malignant neoplasms ($r = 0.56$; $p < 0.05$). Correlation between S_E and percentage of BLBW was the lowest ($r = 0.39$) and statistically insignificant at $p < 0.05$.

Discussion

This study was based on the DPSEEA conceptual framework for the development of environmental health indicators and guidelines of the HEADLAMP project (Corvalán 1996; Corvalán et al. 1996; Corvalán and Kjellström 1995; Kjellström and Corvalán 1995) and was aimed at providing information on the local environmental health problems in a form usable for decision makers, scientists, and communities. The study also represents a continuation of the research on the development and use of EHIs which have been performed in Poland over recent years (Dutkiewicz 1994; Dutkiewicz et al. 1996a, 1996b, 1997, 1998).

The method used for assessment of environmental hazards and health outcome in industrial cities is based on environmental–health relationships, as well as a proper selection of two groups of indicators, EIs and HSIs. The selection of these indicators was based on environmental and health data routinely collected at urban administrative units, which is a main characteristic of HEADLAMP (Corvalán and Kjellström 1995), as well as the method of assessment for large geographic areas in Poland (Dutkiewicz et al. 1996a, 1996b, 1997, 1998). Among four selected EIs (API, SCI, AWI, and WDI), API and WDI were also taken into account in the assessment of large geographic areas (Dutkiewicz et al. 1997). Four HSIs, established as a result of the relative risk assessment, may point to the existence of cause–effect relationships between environmental hazards in the cities and the health status of their inhabitants.

Thus, it may be concluded that environmental contamination in industrial cities affects especially the mortality of males in the 30–59 age group due to malignant neoplasms (ICD-9 140–208), the mortality of males and females in the 30–59 age group due to diseases of the circulatory system (ICD-9 390–459), the mortality of males and females due to diseases of the respiratory system (ICD-9 460–519), and the percentage of BLBW. It should be also noted that two of the four selected HSIs, mortality of males and females in the 30–59 age group from diseases of the circulatory system and percentage of BLBW, were also selected as useful indicators for environmental-related health status assessment in large geographic areas (Dutkiewicz et al. 1997). Significant differences in mortality from diseases of the respiratory and circulatory systems, as well as from neoplasms, between cities of high environmental hazards and reference cities were also observed by Witkowski (1990). This confirms that HSIs were properly selected in our own study and may be considered as the most essential HSIs related to environmental contamination in the cities.

Among preselected HSIs concerning infants, percentage of BLBW was the only indicator that met both criteria of selection (i.e., RR > 1 and LCL > 1). These criteria were not met for infant mortality, infant mortality from congenital anomalies, and mortality of infants with low birth weight. In addition to the percentage of BLBW, mortality of infants

Table 3. Ranking of the cities and their classification within the index groups.

City	S_E	Ranking position according to S_E	S_H	Ranking position according to S_H
Index 3				
Chorzów	0.153	1	0.374	1
Bytom	0.156	2	0.495	4
Katowice	0.179	3	0.468	2
Dabrowa Górnicza	0.180	4	—	—
Ruda Slaska	0.182	5	—	—
Zabrze	0.191	6	0.501	5
Sosnowiec	0.202	7	0.481	3
Index 2				
Gliwice	0.217	8	0.643	10
Jastrzebie Zdrój	0.271	9	0.641	9
Tychy	0.280	10	0.572	7
Dabrowa Górnicza	—	—	0.600	8
Rybnik	0.323	11	—	—
Slupsk	—	—	0.655	11
Ruda Slaska	—	—	0.547	6
Index 1				
Olsztyn	0.432	12	0.776	13
Rybnik	—	—	0.678	12
Bialystok	0.516	13	0.781	14
Slupsk	0.835	14	—	—
Koszalin	1.000	15	0.892	15

Index 1, low environmental hazards in a given city or the best environmental-related health status of inhabitants; index 2, medium environmental hazards or moderately good environmental-related health status; index 3, high environmental hazards or the worst environmental-related health status.

with low birth weight also met the same criteria in previous studies (Dutkiewicz et al. 1997).

The selected EIs and HSIs refer to pressure, state, and effect components of the DPSEEA chain, respectively. Because of the scarcity of appropriate data on levels of exposure to toxic substances, the EIs selected in this study characterize exposure indirectly. Indirect indicators were also applied as a proxy for exposure for assessing large geographic areas in Poland (Dutkiewicz et al. 1996a, 1996b, 1997, 1998; Indulski and Andruszek 1995) as well as in projects performed in other countries (Wills and Briggs 1995). Thus, in this study, proxy EIs derived from higher up the DPSEEA cause–effect chain (i.e., pressure and state) are most useful for environmental health managers in terms of taking preventive actions to eliminate or reduce environmental hazards. This may be considered the most effective long-term approach.

Providing information on environmental hazards and health outcomes in a form easy to interpret and thus useful for decision makers required integrating selected indicators. For that purpose, taxonometric methods seem useful. The normalization and aggregation of indicators with taxonometric methods yield synthetic measures (Andryszek 1984; Hellwig 1968; Strahl 1978) that make comparative analyses of given areas possible. To calculate S_E and S_H in the cities of Upper Silesia, we chose Strahl's taxonometric method (Strahl 1978). This study proved that Strahl's method, successfully applied in previous studies for assessment of environmental hazards and health status in large geographic areas (Dutkiewicz et al. 1996a, 1996b, 1997, 1998; Indulski and Andryszek 1995), is also fully useful in smaller administrative units.

The synthetic measures indicated the intensity of environmental hazards and health effects, which were next expressed by indices in a three-level scale. Each of the studied cities could be classified into one of the three index groups (Table 3). Because only the average values of EIs could be used to reflect exposure of inhabitants, the applied classification method has deterministic character. Such a classification method was projected arbitrarily to serve for specific purposes (i.e., for categorizing and comparing Silesian cities with reference cities) and consequently to serve as a basis for establishing regional environmental health policies and priorities. The indices facilitated comparison and ranking of the cities under study and made the ranking outcomes more understandable, as well as more applicable for decision-making and actions aimed at mitigation of environmental impact on human health.

In cities characterized by index values of 3 for both environmental hazards and health status (Chorzów, Katowice, Sosnowiec, Bytom, and Zabrze), as presented in Table 3, actions aimed at reducing environmental hazards and protecting health should be priorities. Further, it is advisable to undertake detailed studies that would identify high-risk subpopulations in these cities.

Next, to improve health status, actions aimed at reducing environmental hazards should also be taken in Gliwice, Jastrzebie Zdroj, and Tychy. These cities were classified as having medium environmental hazards (index 2) and at the same time as having moderately good environmental-related health status (index 2; Table 3).

As for Dabrowa Gornicza, Ruda Slaska, and Rybnik, lower index values for health status (compared to the index for environmental hazards) were observed and may indicate that other factors positively influence health situation in these cities (e.g., better medical care or socioeconomic status). Further investigations should be taken to identify these factors.

The synthetic measures were used not only for the purpose of comprehensively assessing the cities, but also for analyzing the relationship between extent of environmental hazards and health status (Figure 1). Although the statistical findings cannot be the only argument for such relations, a high correlation between S_E and S_H (r = 0.77) may indicate that EIs and HSIs were selected properly and that a logical cause–effect relationship exists between environmental contamination within industrial cities and the health status of inhabitants. This correlation is higher than that found for large urban regions (r = 0.58) (Dutkiewicz et al. 1998). A comparison of environmental hazard indices with environmental-related health status indices also indicated a higher consistency level in the cities (73%) than in the large urban regions (65%) (Dutkiewicz et al. 1997). These findings may suggest that in the cities of Upper Silesia, where high levels of environmental contamination occur, environment–health relationships are much stronger than in other areas of Poland and therefore easier to identify and assess. The possibility of more precise and accurate identification and selection of EIs and HSIs at the local level may also contribute to the higher correlation between their synthetic measures in the cities' areas.

Correlation analyses showed that, of the four selected HSIs, only the percentage of BLBW was low correlated with S_E (r = 0.39) and not statistically significantly at $p < 0.05$. However, due to the results of the relative risk assessment, this HSI was included for construction of S_H because statistical correlation does not absolutely prove relationships between environmental contamination and health effects. The level of complex urban environmental hazards expressed as S_E appeared to be much more strongly associated with mortality from diseases of respiratory system, circulatory system and malignant neoplasm (r = 0.84, 0.65, 0.56, respectively).

It should be mentioned that environmental contamination is one of risk factors affecting human health, such as lifestyle, diet, genetic predisposition, access to medical care, socioeconomic status, and occupational hazards (Bertollini 1996; EEA 1999; Kirschner 1995; Polz 1996). The results of this study show, however, that environmental contamination may play an important role in deterioration of the health status of populations in industrial cities. Nevertheless, it is impossible

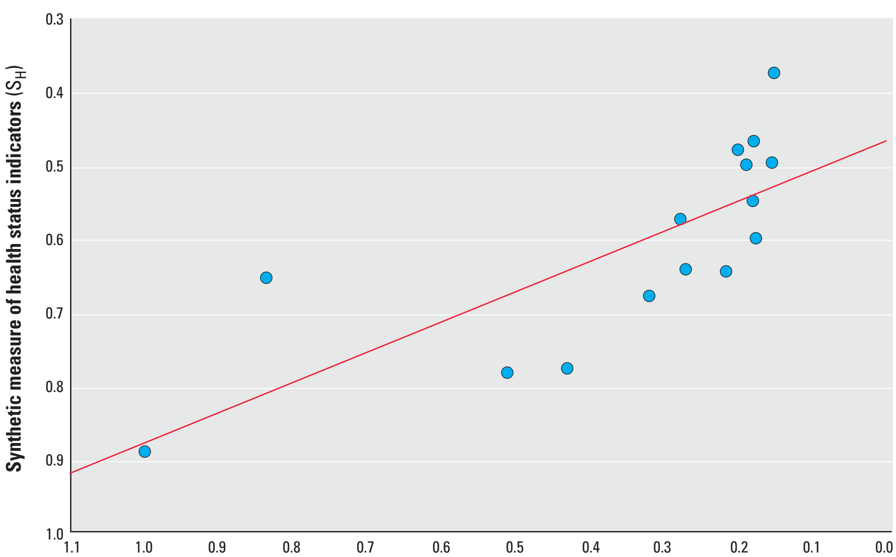

Figure 1. Correlation between S_E and S_H in Upper Silesian cities and reference cities (r = 0.77).

to quantify the contribution of environmental contamination to the health status of inhabitants without analyzing other risk factors.

In summary, it should be emphasized that this comprehensive assessment of environmental hazards and health status, providing such synthetic findings, might serve as a basis for setting environmental health policies in industrial cities of Upper Silesia. The results of this study may also help to identify the need for further environmental health research in industrial areas.

In future studies, questions of differentiation of exposure levels to environmental hazards in the city areas should be undertaken. They should especially concern cities classified as cities of the highest level of these hazards. To make evaluation of health effects more effective, the investigations should identify hot spots and use information on exposure levels of pollutants. However, such studies would require using methods different from those applied in this study.

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