Article

Human Health Risk Assessment of Air Pollution in the Regions of Unsustainable Heating Sources. Case Study—The Tourist Areas of Southern Poland

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Abstract: Air pollution is one of the main factors affecting human health. Air quality is especially important in the tourist areas developed with facilities for outdoor activities. During the winter season of 2017/2018, the concentrations of particulate matter (PM_{10}, $PM_{2.5}$, PM_1), CO, O_3, and NO_2 were studied in 12 attractive tourist villages in the surroundings of the Czorsztyn Reservoir in southern Poland. Air pollutant measurements were performed continuously, using a single ground-based Alphasense air sensor. Our assessment of human health risk (HHRA), arising from inhalation exposure to air contaminants, was calculated for both local inhabitants and tourists, based on actual measured values. It was found that pollutant concentrations exceeded both permissible and recommended levels of PM_{10} and $PM_{2.5}$. The mean total noncarcinogenic risk values were equal to 9.58 (unitless) for adults and 9.68 (unitless) for children and infants, under the resident exposure scenario. However, under the tourist exposure scenario, the mean total risk was equal to 1.63 (unitless) for adults and 1.64 (unitless) for children and infants. The risk to tourists was lower than that to inhabitants due to shorter exposure times. The target non-carcinogenic value of 1, calculated for PM_{10}, $PM_{2.5}$, and NO_2, was significantly exceeded in total risk, under the residential exposure scenario, in reference to all the local subpopulations. In the majority of the investigated locations, the total risk exceeded the value of 1, under the tourist scenario, for all the subpopulations analysed. $PM_{2.5}$ was recognised to be the most important contaminant in our risk analysis, in view of its share in the total risk value.

Keywords: health risk; air quality; ambient air; tourist resorts

1. Introduction

Air pollution is of major concern worldwide, as it places a large burden on public health. The research projects conducted in many places around the world for a number of years proved the existence of a relationship between the exposure to air pollution and the occurrence of various health effects [1]. Environment-related deaths are associated with respiratory, cardiovascular diseases [2–6], as well as cancer, in particular lung cancer [7–10]. Children, people with cardiovascular and respiratory diseases, diabetes, or obesity, and the elderly are particularly susceptible to pollution effects [4,6,11,12]. Ultrafine and fine particles penetrating the brain tissue can lead to a variety of chronic infections that may contribute in turn to the development of such neurodegenerative diseases as Alzheimer's disease [13]. Exposure to air pollutants is associated with increased mortality rates and reduced life expectancy, even at relatively low pollutant concentrations [14]. Air pollution is considered to be the main environmental risk factor accountable for premature deaths

worldwide [15–17]. It is estimated that about 417,000 people die prematurely in Europe every year [17]. The European Environmental Agency (EEA) described air pollution as the single largest environmental health risk factor in Europe [17]. Moreover, the International Agency for Research on Cancer (IARC) classified air pollution and particulate matter (PM), being a separate component of air pollution mixtures, as carcinogenic [10].

Air quality, including in particular dust pollution with PM_1, $PM_{2.5}$, and PM_{10}, raises public concern owing to severe air pollution in many locations in Poland, especially in the areas offering great natural and landscape values for tourists. It is worth mentioning that air condition is often worse in many frequently visited Polish small towns and villages than that in large cities. The public awareness of air pollution and the need for effective pollution control strategies force implementation of strict legislative measures and significant technological improvements, thus contributing to the reduction of particulate emission from industry, although household emissions are still high and uncontrollable. Such emissions are generated by cooking and heating stoves, boilers, and fireplaces, fired with coal or wood. In less affluent areas, poor-quality fuel is often used and burning diverse municipal solid waste is quite common, additionally increasing hazardous emissions. The local heating installations are usually characterised by low energy efficiency and very high emissivity. The situation is aggravated by the fact that the majority of Polish rural homes are poorly insulated and require high fuel consumption. This issue is particularly important in Poland, claimed to be the most polluted country among all the EU member states.

Similar findings were described in different geographical regions. Research from China [18] confirmed that some air pollutants, such as black carbon, organic carbon, carbon monoxide, particulate matter, polycyclic aromatic hydrocarbons, are generated via residential solid fuel burning in low-efficiency combustion technologies, especially in rural areas. The total energy consumption in the residential sector varies significantly depending on the development degree of the country, influencing the emission pattern of air pollutants. For instance, in China, the total energy consumption is equal to 11%, while for an average developed country it is equal to 35% [19].

In Eastern European countries, traffic emissions are placed in second place after the communal and household sector [20]. Modern society travels most often using their personal vehicles, which in Poland are on average 13 years old. Moreover, the increasing number of vehicles in general causes the increase of so-called traffic-related air pollution in the form of vehicle exhausts, secondary pollutants formed in the atmosphere, evaporative emissions, and noncombustion emissions like road dust or tire wear [21,22].

On the other hand, tourist areas do not stand alone, but appear increasingly often near city agglomerations or megacities. It has been reported [23–27] that urbanization has an impact on the emissions of greenhouse gases (GHGs) and other air pollutants that subsequently impact air conditions in rural and recreational areas.

However, in Poland, strict action plans for air pollution prevention and control have already been implemented [28], with promising strategies designed for a significant limitation of the availability of poor-quality fuels, including coal. Such integrated long-term regional prevention and control measures imposed allow for exploration of local challenges, as well as developing and updating strategy guidelines in recreation areas.

Natural areas are highly appreciated wherever the local conditions provide facilities for active recreation. In the mountainous area under consideration, the forms of active leisure are dominated by winter sports, so tourist travel increases mainly in the winter season. Ironically, it is quite common in that area that the home heating methods, used intensely in the winter season, are rather based on cheap poor-quality coal and wood burning in inefficient stoves. These days, tourists are highly aware of ecological issues and the impact of environmental pollution on human health. Consequently, informed selection of holiday sites becomes a crucial factor for the tourists' decisions. Thus, ambient air quality should be of special concern in the areas designed for leisure and recreation. Recognising the fact that the tourists' ecological awareness of environmental pollution is growing [29], the data regarding air quality become compelling in the tourist regions.

The mountainous region around the Czorsztyn Reservoir (Figure 1) is one of the most attractive tourist areas in southern Poland and it offers opportunities for outdoor activities to both local residents and tourists. The water reservoir is surrounded by the following physicogeographical regions: Orawa in the Nowy Targ Basin, the Gorce Mountains, the Pieniny Mountains, the Beskid Sądecki Mountains, the Spisz-Gubałówka Foothills, as well as the Slovak Magura Spiska Mountains [30]. Air quality depends strongly there on traffic concentration and combustion of poor-quality fuels for heating purposes, e.g., fine coal or coal flotation concentrate, as well as solid waste [31]. Since the region is dominated by the mountains, it is frequently visited in the winter season, as it provides opportunities for winter sports and outdoor activities. Our project was dedicated to air quality studies because tourist areas had been rarely investigated in Poland, under the national ambient-air quality monitoring network.

**Figure 1.** Czorsztyn recreational area in southern Poland (R. Klimek).

The locations that we selected for our investigation had not been fitted with national air quality monitoring stations, operated in Poland by the Central Inspectorate of Environmental Protection (GIOŚ) [31]. Air quality in the region of southern Poland had been also randomly investigated by sensors of the Airly company but the choice of their installation location stemmed from local social activities. Our measurements of air pollutant contents, taken on the holiday sites during the winter seasons of 2017 and 2018, revealed high and very high air pollution [31] based on the Common Air Quality Index (CAQI) [32]. The identification of a direct impact of air pollution on human health was more important for us than mere air quality measurements. Thus, the goal of the present study was to investigate the human health risk assessment (HHRA). We analysed the health risk factor arising from inhalation exposure to ambient air contaminants in the popular tourist region of the Czorsztyn Reservoir in the Carpathians, for both residents and tourists.

2. Materials and Methods

2.1. Study Area

Air quality was investigated in 12 attractive tourist locations (Figure 2), in the surroundings of the Czorsztyn Reservoir during the winter season of 2017/2018 [31]. The study area is a popular tourist destination both in summer and winter, owing to stable weather conditions. The analysed region is characterised by the presence of a large water

reservoir suitable for water sports. At the same time, the surrounding mountains provide facilities for winter sports such as skiing. All activities are mostly practiced outdoor and that is why air quality becomes a crucial issue in terms of human health risk.
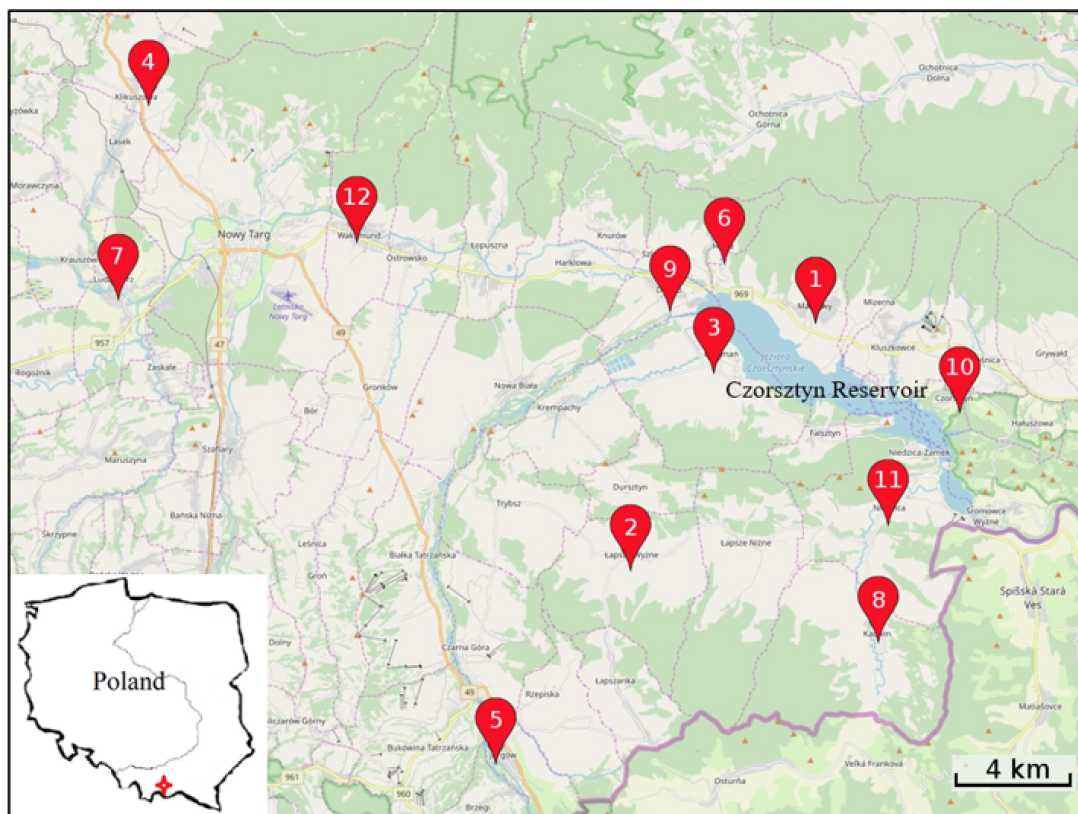
Figure 2. Air measurement sites in the villages surrounding the Czorsztyn Reservoir (modified after [31]); 1—Maniowy, 2—Łapsze Wyżne, 3—Frydman, 4—Klikuszowa, 5—Jurgów, 6—Huba, 7—Ludźmierz, 8—Kacwin, 9—Dębno, 10—Czorsztyn, 11—Niedzica, 12—Waksmund. The base map originates from the OpenStreetMap.

2.2. Air Pollutant Measurements

The concentrations of PM_{10}, $PM_{2.5}$, PM_1, CO, O_3, and NO_2 were measured continuously between 18 December 2017 and 9 March 2018. The duration time of these measurements was defined in the research project running at that time. Our air pollution content analyses involved real-time measurements within one second and average measurements, within three minutes. The results of the measurement were sent to and stored in the database in real time and the average hourly values of investigated pollutants were further used for health risk calculations. Sensor locations during measurements described the general city condition of air pollutants concentrations. The accuracy of the performed measurements was checked by comparison with the measurement values achieved under the regional monitoring system of the Chief Inspectorate of Environmental Protection in Poland in the winter season (for details see [31]).

Concentrations of air were performed, using an Alphasense air sensor (station model: Sensor AirSense Extended; date of manufacture: 26 February 2017; zero-chamber calibration conducted on 7 March 2017; station software: SenseOS v.2.0). The test measurement setting was as follows: ambient temperature: $-19\,°C \pm 2\,°C$, sensor temperature: $23\,°C \pm 2\,°C$, measurement duration: 7 h 30 min, synthetic air purity: N 5.0/99.999%.

2.3. Human Health Risk Assessment

No long-term pollutant content measurements were taken in the ambient air on the study area. Thus, the preliminary health risk assessment analysis, which had to answer

the general question of whether the health risk existed in the investigated tourist areas, was performed. For that reason, our risk assessment was based on mean values of the contaminant contents determined during the measuring period in the winter season of 2017/2018, respecting the conservative risk assessment principle that recommends to obtain the risk values that describe a worst-case scenario in the case of uncertain input data for calculation process. Based on the results of our measurements, human health risk (HHRA) was assessed in the inhalation exposure route. The United States Environmental Protection Agency (USEPA) methodology [33] specifies the following three exposure routes in the risk assessment analysis: inhalation, ingestion, and dermal contact. As inhalation is the most rapid exposure pathway [10,17,33], it was investigated in our research. The US EPA risk assessment methodology was applied in our calculations, as described below. Non-carcinogenic risk was defined with the use of the hazard quotient (HQ). The target non-carcinogenic risk value was set at 1 [33], indicating lack of negative health effect on humans when risk values were <1. Non-carcinogenic risk was calculated for NO_2, PM_{10}, and $PM_{2.5}$ because the reference values of those contaminants, i.e., the reference dose (RfD) for NO_2 and PM_{10} and the reference concentration (RfC) for $PM_{2.5}$, were available in the toxicological databases [34–36]. However, for all the measured contaminants, the average daily values of intake through the inhalation exposure pathway were estimated. In our investigations, both resident and tourist exposure scenarios were analysed. Under each exposure scenario, the following subpopulations were considered: adults (>7 years), children (1–7 years), and infants (0-1 year). To obtain the daily intake of pollutants through the inhalation exposure pathway, either exposure concentration (EC) or average daily dose (ADD) values were calculated according to Equations (1) [37] and (2) [33], respectively, depending on the available reference values:

$$EC = (C \times ET \times EF \times ED)/AT \qquad (1)$$

$$ADD = (C \times IR \times ET \times EF \times ED)/(BW \times AT). \qquad (2)$$

where EC, exposure concentration (mg/m^3); ADD, average daily dose (mg/kg-day); C, contaminant concentration in air (the measured values were converted to mg/m^3); IR, inhalation rate (m^3/h); ET, exposure time (h/day); EF, exposure frequency (days/year); ED, exposure duration (years); BW, body weight (kg); AT, averaging time: ED, in years $\times$ 365 days/year $\times$ 24 h/day, in hours.

The exposure parameters used in the analysed scenarios are given in Table 1.

Table 1. Exposure parameters used for the risk assessment calculations in the study.

Exposure Parameters	Adult	Child	Infant	References
	Resident scenario			
IR, inhalation rate per person (m^3/h)	0.83	0.31	0.19	[38,39]
ET, exposure time per person (h/day)	24	24	24	[40]
ED, exposure duration (years)	24	6	1	[41]
EF, exposure frequency (days/year)	365	365	365	site specific *
BW, body weight (kg)	70	16	10	[40]
AT, averaging time (hours)	210,240	52,560	8760	[40]
	Tourist scenario			
IR, inhalation rate per person (m^3/h)	0.83	0.31	0.19	[38,39]
ET, exposure time per person (h/day)	24	24	24	[40]
ED, exposure duration (years)	24	6	1	[41]
EF, exposure frequency (days/year)	62	62	62	site specific *
BW, body weight (kg)	70	16	10	[40]
AT, averaging time (hours)	210,240	52,560	8760	[40]

* site-specific; assumption: two weeks of holidays and every second weekend spent each year in a recreational area.

Although all the analysed pollutants were considered to be toxic, only non-carcinogenic risk was calculated, using the hazard quotient (HQ) values, according to Equations (3) [37] and (4) [33], with respect to the available toxicological data:

$$HQ = EC/RfC, \tag{3}$$

$$HQ = ADD/RfD. \tag{4}$$

where HQ, hazard quotient (unitless); EC, exposure concentration (mg/m^3); ADD, average daily dose (mg/kg-day); RfC, reference concentration (mg/m^3); RfD, reference dose (mg/kg-day).

The following RfD values were used for calculations: NO_2: 1.1×10^{-2} (mg/kg-day) [34], PM_{10}: 1.1×10^{-2} (mg/kg-day) [34]. The following RfC value was used for calculations: $PM_{2.5}$: 5.00×10^{-3} (mg/m^3) [35].

## 3. Results

3.1. Air Quality

The results of our air-quality examinations conducted on the investigated tourist areas of the Czorsztyn Reservoir were previously discussed in Adamiec et al. [31]. Air pollutant contents, measured during the winter season of 2017/2018, are gathered below in Figure 3.

Air quality was determined by using the air quality standards applied in Poland [42] and recommended by the World Health Organisation (WHO) [17], as well as in reference to the European Common Air Quality Index (CAQI) [32]. When analysing the pollutant contents during our sampling campaign, it was revealed that the 24 h quality guideline recommended for $PM_{2.5}$, set at 25 $\mu g/m^3$ [17] by WHO, was exceeded in 11 out of the 12 investigated locations (except for No 4. Klikuszowa). The permissible 24 h PM_{10} content, set at 50 $\mu g/m^3$ [17,42], was exceeded in 7 out of 12 locations. The mean contents of CO and O_3 8h did not exceed the permissible contents of 10,000 $\mu g/m^3$ [42] and 120 $\mu g/m^3$ [42], respectively. To determine air quality, comprising several pollutants at the same time, we applied the European Air Quality Index (CAQI) in our previous study [31].

Our results indicated that air pollution was high and very high in the investigated tourist areas, with PM_{10} and $PM_{2.5}$ being the main pollutants responsible for high pollution levels, with reference to the CAQI index grid [31]. Additionally, we observed a correlation between the negative temperatures on the Celsius scale during winter days and high pollutant contents in the air. Therefore, the air quality condition determined under the present study justified our reliance on the measured values of the investigated contaminants to carry out our risk assessment analysis.

3.2. Human Health Risk Assessment

The toxicological parameter values were available only for PM_{10}, $PM_{2.5}$, and NO_2. Consequently, the hazard quotient (HQ) values were calculated for those three contaminants. The estimated daily intake values could only be calculated for PM_1, CO, and O_3, and are they are presented here in Table S1 from Supplementary Materials. It was observed that the potential ADD values were decreasing, for all the pollutants, in the following order: children > infants > adults, under both resident and tourist exposure scenarios. Under the site-specific tourist scenario, the calculated ADD values were 6 times lower in comparison to the values obtained under the resident scenario.
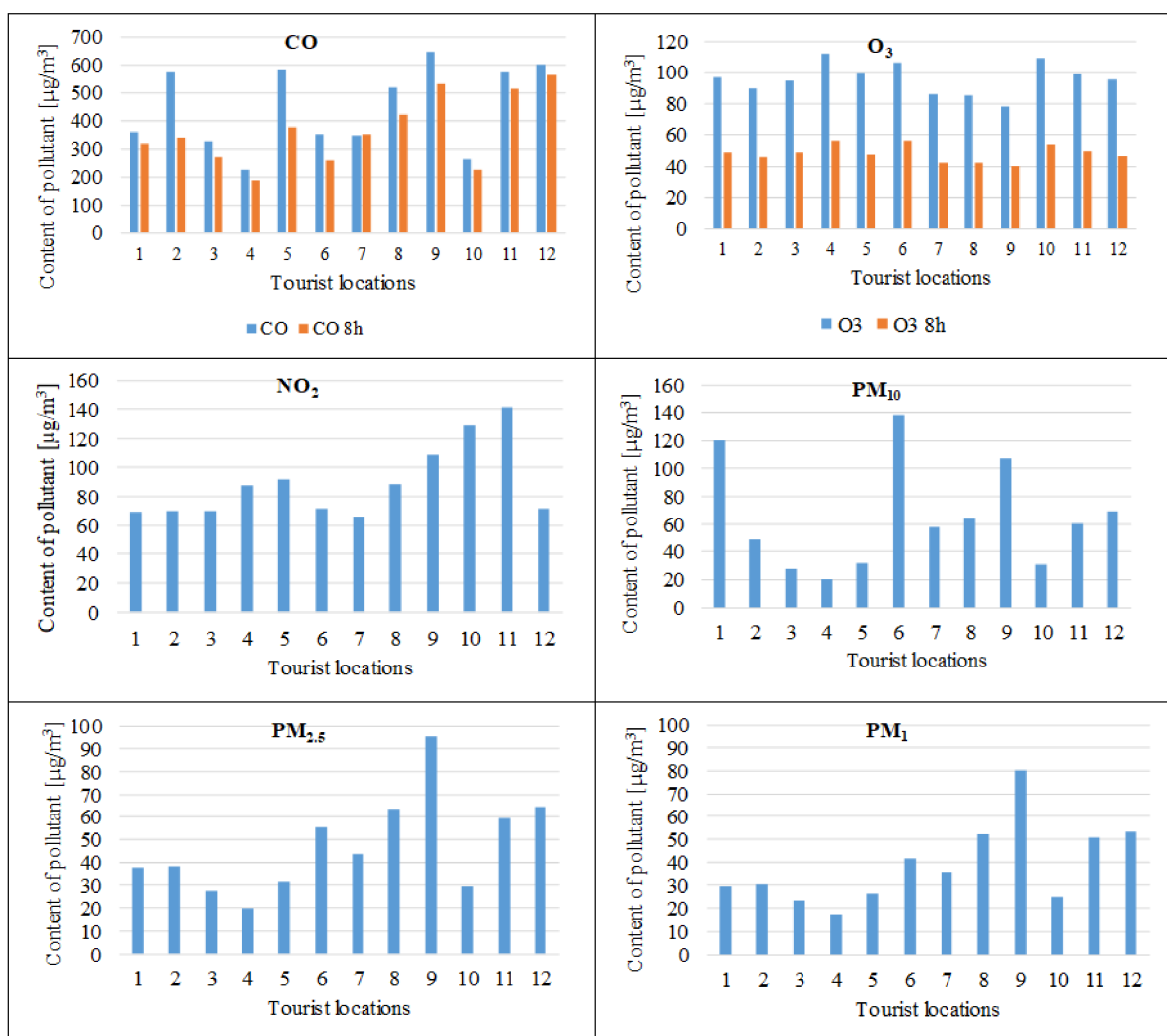
Figure 3. Mean pollutant contents measured in outdoor air on the research area during the measurement period in the winter season of 2017/2018 (for location numbers see Figure 2; modified after [31]).

The HQ values calculated for individual pollutants are presented in Table S2 from the Supplementary Materials. The total non-carcinogenic risk, calculated as the sum of the HQ values for $PM_{2.5}$, PM_{10}, and NO_2, significantly exceeded the target risk value of 1 under the resident scenario (Table 2). The highest total non-carcinogenic risk values exceeding the value of 10 were obtained for No. 9 Dębno, No. 12 Waksmund, No. 11 Niedzica, No. 8 Kacwin, and No. 6 Huba. Under the tourist exposure scenario, the total non-carcinogenic risk values did not exceed the target risk value of 1 in the cases of No. 3 Frydman and No. 4 Klikuszowa. $PM_{2.5}$ was identified as a contaminant, with the strongest impact on the total risk value, approaching a 100% share (Figure 4). The exposure concentration (EC) calculation methodology, applied to $PM_{2.5}$ to describe the estimated daily intake, indicated that the risk values did not depend on the body weight factor. Consequently, all subpopulations were equally exposed in terms of the inhalation route. Moreover, the exposure factor reached its maximum (equal to 1) in the inhalation exposure pathway, since people breathe each day all day throughout their lifetimes. In the individual cases of PM_{10} and NO_2, the calculated non-carcinogenic risk values indicated low to negligible risk, under both resident and tourist exposure scenarios.

Table 2. Total non-carcinogenic risk values in the study areas.

Tourist Location	Location Number	Resident Scenario			Tourist Scenario		
		Adult	Child	Infant	Adult	Child	Infant
Maniowy	1	7.74	7.87	7.87	1.32	1.34	1.34
Łapsze Wyżne	2	7.71	7.79	7.79	1.31	1.32	1.32
Frydman	3	5.59	5.66	5.66	0.95	0.96	0.96
Klikuszowa	4	4.08	4.16	4.15	0.69	0.71	0.71
Jurgów	5	6.44	6.53	6.52	1.09	1.11	1.11
Huba	6	11.29	11.43	11.42	1.92	1.94	1.94
Ludźmierz	7	8.84	8.92	8.92	1.50	1.52	1.51
Kacwin	8	12.83	12.93	12.93	2.18	2.20	2.20
Dębno	9	19.28	19.42	19.42	3.27	3.30	3.30
Czorsztyn	10	6.04	6.15	6.15	1.03	1.04	1.04
Niedzica	11	12.09	12.23	12.22	2.05	2.08	2.08
Waksmund	12	13.01	13.11	13.10	2.21	2.23	2.23
Mean		9.58	9.68	9.68	1.63	1.64	1.64
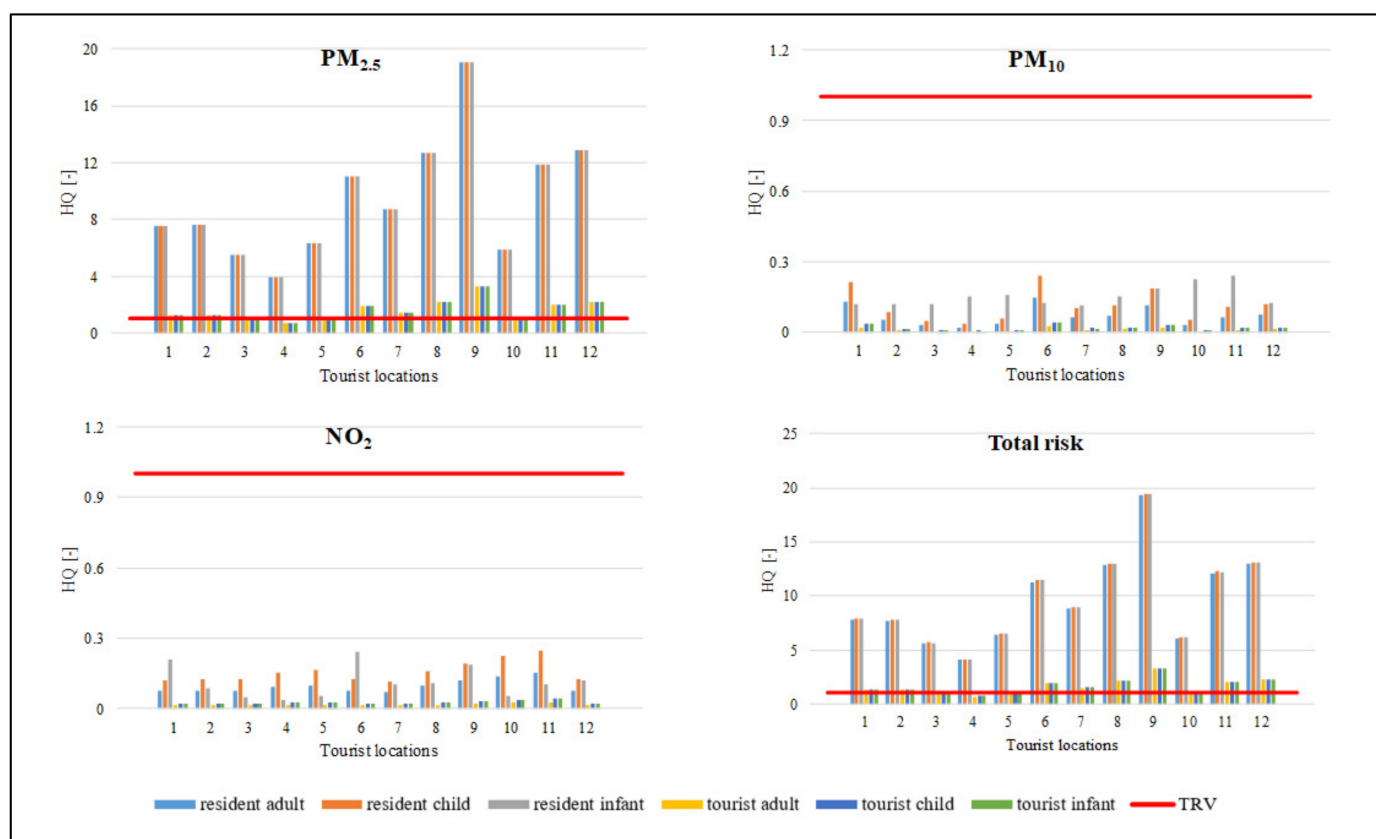
Figure 4. Non-carcinogenic risk values (HQ) for selected air pollutants in the study area (for location numbers, see Figure 2); TRV: target risk value.

4. Discussion

The matter of persistent air pollution and its related impact on health has been discussed for a number of years not only by health and environmental activists but also by researchers [43–49]. That issue remains especially urgent in the countries that have a lot to do in terms of environmental protection. That also includes Poland, where the implementation of the projects designed for air quality improvement requires time measured in years. Before that has been attained, the residents of polluted towns and cities will continue to live and breathe in unhealthy environments. Pollution is associated rather with large industrial cities and it is unexpected for it to occur in the tourist areas where good air quality is anticipated to be excellent by assumption.

Our research revealed that air quality was poor or very poor [31] in the popular areas of the Czorsztyn Reservoir, while the risk values associated with air inhalation, estimated in the present study, were comparable to those identified in large cities, for instance Kraków [43,44]. The main cause of this situation was that the study areas involved small towns developed mainly with single-family houses. Individual means of transportations dominated there. Moreover, the tourists travelled to those sites in their own vehicles, aggravating pollutant emissions. Furthermore, the main heating installations of the local houses were based on stoves burning poor-quality fuel and even solid waste.

In fact, anti-smog regulations were approved by the Małopolska Regional Government [28] with respect to the city of Kraków, as well as the surrounding areas. However, the implementation of those regulations prohibiting coal and wood burning requires time, heating system replacements, financial resources, and, in the first place, strong ecological awareness on the part of the local communities. Our research showed that, under the assumed site-specific scenario, the resident and tourist activities in the regions with elevated air pollutant concentrations generated significant health risks. Our study also confirmed the claims of health [50] and environmental [17] organizations stating that PM, including especially the <2.5 μm fraction, was the most important pollutant in the context of health risk [51].

Our research stays in line with the findings of Richardson et al. [52] who determined that a double disadvantage of low income and poor air quality was disproportionately concentrated in the East rather than the West of Europe. The results showed that 10% of the regions with the highest pollutant values also belonged to the 10% households with the lowest income. Poland was identified as one of such regions. The research of Richardson et al. [52] also indicated that air pollution caused by particulate matter was strongly related to mortality rates in Eastern rather than in Western Europe. Significant economic impacts were also stated by the European Environmental Agency (EEA) in accordance with air pollution. They were stated as follows: reducing life expectancy, increasing medical costs, and reducing productivity through working days lost [17].

As the air quality improvement will take many years, raising ecological awareness and taking specific actions to improve the environment's suitability for outdoor activities are the only immediate options to reduce poor quality air inhalation exposure. Analysts found that the awareness of ecological issues and environmental pollution was improving in the local communities. In particular, air quality is taken under consideration by the visitors when choosing holiday sites [53]. The studies of Yoon [54] indicated that the poor air-quality category was the threshold at which people begin to reconsider some of their outdoor activities, as well as change their travel plans [55–57]. According to Smith et al. [58] tourists reviewed their travel destinations in response to changes in local climate and environmental conditions [58]. Research of Chen et al. [59] indicated that air pollution might even scare tourists away. Consequently, air pollution, apart from health implications, may directly influence the economic situation of the areas where tourism is the main source of income [59].

It should be noted that during the periods of low temperatures, exceeded permissible or recommended pollutant concentrations were identified in all locations investigated under the present project. It was concluded that the most important factors determining the air quality in the study area involved burning poor-quality fuels in stoves for heating purposes (coal-fired boilers, fireplaces, and tiled and cooking stoves) [60–62]. That issue is especially important in health resorts, where air quality is one of the most important factors influencing their therapeutic value [63]. Researchers proposed to carry out an inventory of all hazardous smoke-, dust-, and gas-generating installations, together with the local thermal energy circulation, in the areas covered by our study. The main threat consisted in the inhalation of extremely toxic substances during the heating season. It was also proposed to educate the community members on air protection measures, with the promotion of good heating practices and energy-efficient systems. Promotion should

be extended by offering funds for the replacement of heating installations that would consequently improve life standards in rural households.

Limitations and Strengths of the Present Study

In our investigations, only non-carcinogenic risk was assessed. As to the pollutants that had been proved to be carcinogenic, no measured concentrations or reliable toxicological parameters were available to perform specific risk estimations. For this reason, our risk estimation results might be underestimated. On the other hand, the pollutant contents exceeded permissible and recommended values in ambient air in the south of Poland during most of the months [64], with regards to the conservative risk assessment principle. Consequently, in our research, we made assumptions about the winter pollutant contents in the inhalation exposure route. Moreover, since the determination of the concentration ratio between outdoor and indoor air pollutant contents has not been clearly defined yet [65], our risk assessment calculations assumed a worst-case scenario according to the outdoor air pollutants concentrations. This could have contributed to the calculated risk overestimation. Nevertheless, the risk values obtained under the present project evidently revealed that poor air quality posed significant risk to both residents and tourists.

5. Conclusions

Our studies determined health risk arising from the outdoor air inhalation pathway in the tourist regions, located in the surroundings of the Czorsztyn Reservoir. Non-carcinogenic risk values were assessed for $PM_{2.5}$, PM_{10}, and NO_2, on the basis of the available toxicological data. Total risk figures significantly exceeded the target risk values under the residential exposure scenario for adults, children, and infants. Under the tourist exposure scenario, the total risk value did not exceed the target risk value of 1, in the cases of 2 out of 12 analysed locations. $PM_{2.5}$ was determined to be the pollutant representing the highest share of the total risk value.

In summary, the current binding ban on poor-quality fuel burning and the campaign for the replacement of heating installations, under the regulations adopted in the Małopolska Region in 2017, can significantly improve air quality and lower health risk, as well as increasing the attractiveness of holiday sites for potential tourists.

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