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THE IMPACT OF AIR QUALITY AND METEOROLOGICAL CONDITIONS INCLUDING VISIBILITY ON TOURISM: THE CASE OF ZAKOPANE (POLAND)

Abstract

The aim of the study was to investigate the impact of air pollution and meteorological conditions on visibility in Zakopane, the most popular tourist destination in southern Poland. To achieve this objective, correlation analysis, multiple linear regression analysis and random forests were used. In addition, an analysis was performed of the occurrence of episodes of elevated pollutant concentrations and basic statistical characteristics of visibility, meteorological conditions and air pollution. Meteorological parameters (air temperature, relative humidity, total precipitation, wind speed, atmospheric pressure and visibility) and concentrations of air pollutants; particulate matter (PM_{10}) and gaseous pollutants (SO_2, NO_2) were recorded from 2010 to 2019. The data came from a monitoring station located in Zakopane-MpZakopaSien. It was found that high concentrations of air pollutants SO_2 and PM_{10}, along with relative humidity (RH), were the most important parameters affecting visibility limitation in Zakopane. Concentrations and indirectly also visibility were largely influenced by increased automobile traffic due to tourist activity, as well as emissions from apartment/building heating (combustion of various fuels). Understanding the relationship between air pollutant concentrations, meteorological conditions and visibility is a prerequisite and the basis for the scientific formulation of air pollution prevention and control policies in places where monitoring is particularly important.

Keywords: visibility, air pollution, meteorological parameters, tourism

WPŁYW JAKOŚCI POWIETRZA I WARUNKÓW METEOROLOGICZNYCH, W TYM WIDOCZNOŚCI, NA TURYSTYKĘ: PRZYPADEK ZAKOPANEGO (POLSKA)

Abstrakt

Celem pracy było zbadanie wpływu zanieczyszczeń powietrza i warunków meteorologicznych na widoczność w Zakopanem, najpopularniejszej miejscowości turystycznej w południowej Polsce. Do realizacji tego celu wykorzystano analizę korelacji, analizę regresji liniowej wielokrotnej oraz lasy losowe. Ponadto przeprowadzono analizę występowania epizodów podwyższonych stężeń zanieczyszczeń oraz podstawowych charakterystyk statystycznych widoczności, warunków meteorologicznych i zanieczyszczenia powietrza. Parametry meteorologiczne (temperatura powietrza, wilgotność względna, suma opadów, prędkość wiatru, ciśnienie atmosferyczne i widzialność) oraz stężenia zanieczyszczeń powietrza; pyłu zawieszonego (PM_{10}) i zanieczyszczeń gazowych (SO_2, NO_2) rejestrowano od 2010 do 2019 r. Dane pochodziły ze stacji monitoringu zlokalizowanej w Zakopanem – Mp Zakopane. Wykazano, że wysokie stężenia zanieczyszczeń powietrza SO_2 i PM_{10} wraz z wilgotnością względną (RH) były najważniejszymi parametrami wpływającymi na ograniczenie widzialności w Zakopanem. Na stężenia i pośrednio na widoczność duży wpływ miał wzmożony ruch samochodowy związany z działalnością turystyczną, a także emisja z ogrzewania mieszkań/budynków (spalanie różnych paliw). Zrozumienie zależności pomiędzy stężeniami zanieczyszczeń powietrza, warunkami meteorologicznymi i widocznością jest warunkiem wstępnym i podstawą do naukowego formułowania polityki zapobiegania i kontroli zanieczyszczeń powietrza w miejscach, gdzie monitoring jest szczególnie ważny.

Słowa kluczowe: widoczność, zanieczyszczenie powietrza, parametry meteorologiczne, turystyka

1. Introduction

The tourism sector is starting to pay more attention to air quality issues [1]. Nevertheless, despite many studies analysing the impact of tourism activities on air quality, there are few articles in Europe including Poland that would link pollutant concentrations to meteorological conditions and visibility. Atmospheric visibility is an important environmental parameter that depends on meteorological conditions and air quality [2]. Visibility is defined as the greatest horizontal distance at which the visual contrast between a visible dark object and its background is sufficient for human eyes to see and recognize it [3]. Visibility is also an important issue for road traffic, maritime transport shipping, combat operations, recreational activities and tourism [4]. One particular element that determines the attractiveness of a tourist destination is air quality, analysed by emissions of solid and gaseous pollutants, particulate matter and chemical compounds [5]. Brimblecombe and Zhou and their team showed that reduced visibility related to air pollution is associated with changes in tourism choices and health effects, and were able to demonstrate that tourism has a statistically significant and adverse impact on poor air quality (PM_{10}) [6, 7]. There are also interesting studies that consider the problem inversely, indicating that air pollution has a detrimental effect on tourism, as it contributes to a decline in the number of visitors to a destination [5, 8], worsens the health of visitors [9] and can create a negative image of the destination [10]. From whichever side you look at the topic of air pollution and tourism, the problem is one that is interesting and important to study. An analysis of available measurement data for 2012–2020 for measurement stations located in Małopolska clearly shows that there are pollutants whose permissible content in the air is exceeded several times during the year throughout the province, with some of the exceedances being multiples of the permissible value [11]. It is also important to determine the trends of indicators, such as pollutant emissions and their improvement or deterioration [1]. Air quality is not only a factor that directly and indirectly affects health, but also an important determinant of the quality of life [12]. Tourist cities that simultaneously serve as industrial and administrative centres and important transport hubs become centres with high levels of air pollution [1].

In addition to air pollution, meteorology plays a key role, and is an equally important environmental factor that affects tourists' perceptions, experiences and behaviours [13]. According to research in the field of environmental psychology, which deals with the problem of how humans affect the environment and, conversely, how the environment affects humans, weather and poor air quality can exacerbate anxiety and cause depression [13, 14], as well as affect a person's emotional state [15, 16].

The main purpose of this study is to analyze the levels of pollutant concentrations in Zakopane, taking into account meteorological conditions including visibility, in relation to the standards contained in the Regulation of the Minister of the Environment of August 24, 2012, which amended the regulation on the levels of certain substances in the air [17].

2. Materials and Methods

2.1. Research area, air quality data, meteorological parameters and visibility observation

The study was performed based on measurement results obtained from the MpZakopaSien (λE =19°57′; φN = 49°17′) monitoring station for atmospheric air quality and meteorological conditions, located in Zakopane in the southern part of Małopolska province. Zakopane, which lies at the foot of the picturesque Polish Tatra mountains, hosts hundreds of tourists every year, not only from Poland, but also from the entire world. It has had the status of a city health resort since 1886. Zakopane, dubbed the winter capital of Poland, has at its disposal a full range of tourist attractions, ski slopes and, above all, breath-taking mountain views.

The study made use of data from the period of 2010–2019, made available by the Measurement Data Bank (https://powietrze.gios.gov.pl/pjp/archives), maintained by provincial environmental inspectors. The study used 24-hour data for PM_{10} concentrations. For NO_2 and SO_2, 1-hour measurements were made available, from which 24-hour average data were then calculated using Statistica software. The meteorological data were compiled from ogimet.com and come from a station belonging to the Institute of Meteorology and Water Management (IMGW), where measurements are made according to instructions. Meteorological parameters include air temperature, wind speed and direction, atmospheric pressure, total precipitation, relative humidity and visibility. Visibility measurements were executed using an automatic visibility meter equipped with an atmospheric phenomena detector. It fulfilled the functions of a visibility meter using light scattering measurements and an atmospheric phenomena detector. Horizontal visibility measurements were made within the range of 10–50 km. Table1 presented below, contains basic information about the analysed monitoring stations in Zakopane, including the type of station, its location in relation to geographical coordinates, its surroundings (station background), the types of pollutants studied and the year in which measurements began.

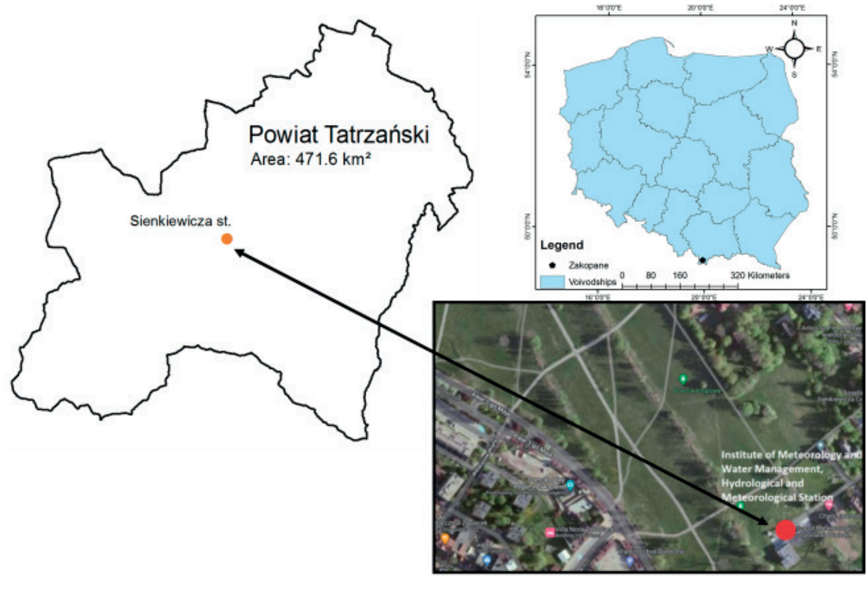

Fig. 1. Location of the measurement station in Zakopane (Poland)

Source: own study

Table 1. Basic characteristics of the monitoring station in Zakopane

Tourist city	Year in which monitoring started	Address	Environment	Φ	λ	Station type	Measured Impurities
Zakopane	2003	Sienkiewicza St.	Meadow in the centre of Zakopane, a short distance to Krupowki St, in the court of hotels, restaurants and busy road	49,293564	19,960083	Manual/ automatic	PM_{10}, $PM_{2.5}$,SO_2, NO_2 ,NO_x, O_3 benzene

The article presents such statistical analyses such as:

- Analysis of basic statistical characteristics of measurement series;
- Analysis of the occurrence of episodes of elevated pollutant concentrations;
- Correlation analysis of pollutant concentrations and meteorological parameters including visibility;
- Regression analysis between air pollution and meteorological conditions and visibility;
- Random forest analysis.

The basic statistical characteristics of the measurement series were established using the basic functions available in the Statistica 13 programme. The data used for the analysis meet the normality condition and this resulted in the use of Pearson's correlation coefficient [18] in the given situation. For the correlation analysis, visibility was assumed as the dependent variable, and PM_{10}, NO_2, SO_2 and meteorological conditions including average air temperature, wind speed, relative humidity and atmospheric pressure were assumed as independent variables.

2.2. Random Forests

Random Forest (RF) is a modelling-based method that uses regression and classification issues [19] and random feature selection [20] that works by constructing decision trees during the learning process. The good generalization ability obtained by random forest models has made this method one of the most widely used algorithms in the field of data mining [21]. A random forest consists of many interrelated trees, which allows a consistent prediction [22]. The random forest is considered highly accurate for classification algorithms [23]. The advantages of the RF method are its robustness to anomalies present in the measurement data (highly outliers, missing data strings, partially correlated input variables), resistance to overfitting, improved predictive ability compared to the regression decision tree method and the possibility of reliably assessing the impact of individual variables on the outcome of a simulation based on the ranking of predictors [24]. The random forest has been popularized in many fields in recent years, including air quality-related research, such as predicting $PM_{2.5}$ concentrations from satellite images [25, 26] and eliminating meteorological disturbances in pollutant concentrations [30], as well as for predicting trends [27]. The results of many analyses prove that the random forest method is effective in assessing air quality [28, 29, 30].

The purpose of this analysis was to evaluate the ability of the random forest prediction model to predict visibility. A decision was made to use a classification model to perform visibility prediction, given the multiplicity of parameters and nonlinear relationships between these parameters. The value of the fit coefficient of less than 0.75 in the regression model further testified that a good decision has been made in choosing the classification model. Our approach allowed us to identify predictors and determine the importance ranking of variables affecting visibility in as many as seven classes (≤ 3 km, ≤5 km, ≤10 km, ≤15 km, ≤ 19 km, ≤ 24 km, ≤ 29 km), taking into account various meteorological conditions (RH relative humidity, atmospheric pressure, air temperature, precipitation, and wind speed along with the main directions: N,E,S,W) and air quality parameters (including PM_{10}, NO_2, and SO_2 concentrations), as well as the season-defining variables. Those variables had not been analysed to such an extent before and the results were obtained using Statistica software. At the stage of construction of the random forest model, no more than 200 trees were analysed [19, 31]. The optimal number of trees was searched for by trial and error until the best match between the calculation results and measurements was obtained. Data for model construction were divided into learning (80%) and testing (20%). Decisions on the range of classes and overall distribution were made on the basis of visibility variability, taking into account the predictive capabilities of the model and its best fit.

3. Results

3.1. Basic statistical characteristics of the measurement series

Tables with basic statistical characteristics for the tourist destination Zakopane are presented below. The analysed meteorological parameters are air temperature, relative humidity, wind speed and air pollutant concentrations (PM_{10}, SO_2, NO_2) recorded in 2010–2019. The results of the average levels of pollutants were classified according to two seasons: the winter heating season, a time period from October 1 through March 31 (October, November, December, January, February and

March) and the warm (non-heating) season, from April 1 to September 30 (April, May, June, July, August and September). According to the Ministerial Regulation on the levels of certain substances in the air of August 24, 2012, the level of PM_{10} particulate matter should not exceed the standard of 40 μg/m³ during the calendar year [17].

Based on Table 2, it was found that concentrations of PM_{10} permissible levels in the warm season from 2010 to 2017 did not exceed standards and remained stable, however, a negative trend of increasing air pollution after 2017 can be seen, which should be taken into consideration. Air pollution is a complex mixture of elements, among which particulate matter is the main air pollutant that is hazardous to public health. Its seasonal variability is complex and location-dependent, making it a year-round air quality problem [32]. The situation is completely different during the cold season. From 2010 to 2018, pollutant concentrations exceeded the permissible standards for PM_{10}; a change can be seen only after 2018 when pollutant concentrations begin to decrease. Zakopane is one of the most important and popular points on the tourist map of Poland and Central Europe, both in summer and winter seasons. It is characterized by frequent high concentrations of harmful substances in the atmospheric air, especially in the cold months. This is due to geomorphological and climatic factors, while at the same time there is a high intensity of tourist activities that are a source of air pollution [33].

Table 2. Average annual values of PM_{10}, in tourist destination of Zakopane in 2010–2019

Year	PM_{10}					
	warm season			cold season		
	Mean ± SD	Min	Max	Mean ± SD	Min	Max
2010	24.20 ± 9.89	5.00	65.00	66.06 ± 43.08	7.00	216.00
2011	22.02 ± 8.76	6.00	48.00	64.17 ± 39.83	7.00	202.00
2012	20.59 ± 8.31	7.20	47.40	59.95 ± 46.58	8.00	227.70
2013	17.59 ± 5.75	6.80	36.90	48.26 ± 43.47	5.50	221.30
2014	19.34 ± 8.82	3.20	56.40	52.49 ± 36.79	4.80	175.00
2015	21.40 ± 8.37	4.30	48.00	44.62 ± 29.11	4.80	176.90
2016	19.29 ± 8.36	5.10	60.10	43.96 ± 36.22	6.80	200.90
2017	17.81 ± 6.31	5.80	41.60	41.59 ± 30.98	4.40	149.90
2018	25.08 ± 15.81	5.40	113.10	50.61 ± 25.85	10.60	134.80
2019	22.64 ± 13.46	4.70	83.30	32.04 ± 22.63	5.50	144.20

Legend: Mean ± SD—mean pollutant concentration ± standard deviation expressed in μg/m³ , Min—minimum concentration of pollutant expressed in μg/m³ , Max—maximum concentration of pollutant expressed in μg/m³

Source: own study

According to the Ministerial Regulation on the levels of certain substances in the air of August 24, 2012, NO_2 levels should not exceed the standard of 40 μg/m^3 during a calendar year. Despite the lack of exceedances of the permissible value, an unfavourable phenomenon of an increase in pollutant concentrations has been recorded since 2017 (Table 3), mainly during the winter season. This gives rise to certain concerns, because in cities such as Zakopane programmes are being introduced to reduce pollution levels. Tourism is a significant contributor to the deterioration of the environment through the generation of traffic pollution especially in the form of NO_2 [34].

Table 3. Average annual values of NO_2, in tourist destinations Zakopane in 2010–2019

Year	NO_2					
	warm season			cold season		
	Mean ± SD	Min	Max	Mean ± SD	Min	Max
2010	12.93 ± 4.36	5.04	24.96	28.25 ± 14.49	4.67	64.96
2011	13.64 ± 3.81	5.67	30.39	30.10 ± 14.96	7.25	66.61
2012	12.26 ± 3.31	4.38	25.96	36.34 ± 24.55	5.91	159.92
2013	13.56 ± 5.22	4.67	31.63	29.08 ± 19.01	2.06	112.09
2014	13.80 ± 4.67	4.46	26.50	23.23 ± 11.72	2.33	76.00
2015	12.86 ± 5.75	3.01	33.61	24.46 ± 12.83	4.88	71.61
2016	13.90 ± 4.59	4.95	27.27	23.22 ±14.81	3.42	74.90
2017	12.64 ± 4.56	4.59	26.14	26.10 ± 17.61	3.91	89.75
2018	17.13 ± 8.63	2.75	61.45	30.60 ± 14.91	4.79	77.99
2019	14.51 ± 10.11	3.68	64.27	21.90 ± 12.31	2.85	61.33

Legend; Mean ± SD—mean pollutant concentration ± standard deviation expressed in μg/m^3 , Min—minimum concentration of pollutant expressed in μg/m^3, Max—maximum concentration of pollutant expressed in μg/m^3

Source: own study

The lowest number of cases of noncompliance with the permissible levels in Zakopane was recorded in 2010–2019 for SO_2 (Table 4). According to the standards specified in Regulation [17], the maximum permissible value of air pollution is 20 μg/m^3. Both in the warm and cold seasons, the permissible value was not exceeded, but in the cold season in 2010 (19.54 μg/m^3) and 2011 (18.65 μg/m^3) pollution levels were close to being exceeded. A worrying trend has been noticeable in the warm season since 2017, where SO_2 pollutant concentrations have been increasing. Maximum pollutant concentrations in 2019 (36.60 μg/m^3) are threefold higher than in 2010 (10.63 μg/m^3).

Table 4. Average annual values of SO_2, in tourist destinations Zakopane in 2010–2019

Year	SO_2					
	warm season			cold season		
	Mean ± SD	Min	Max	Mean ± SD	Min	Max
2010	2.96 ± 2.03	1.00	10.63	19.54 ± 12.13	1.13	52.67
2011	3.63 ± 2.24	1.00	11.48	18.65 ± 15.45	3.00	85.09
2012	3.91 ± 2.10	1.20	15.10	11.82 ± 11.75	1.80	59.00
2013	4.38 ± 2.96	1.70	18.20	17.49 ± 12.07	2.20	62.50
2014	3.68 ± 1.64	1.30	10.40	13.13 ± 9.08	1.70	39.00
2015	5.50 ± 2.96	1.50	14.40	14.15 ± 9.24	1.80	56.70
2016	5.44 ± 2.06	2.00	13.00	17.73 ± 14.68	2.10	74.40
2017	4.95 ± 1.82	2.00	11.90	14.87 ± 14.71	1.60	71.90
2018	6.21 ± 4.98	1.70	36.70	17.70 ± 8.72	4.10	45.40
2019	7.26 ± 5.80	1.90	36.60	9.26 ± 4.59	3.50	28.50

Legend: Mean ± SD—mean pollutant concentration ± standard deviation expressed in μg/m3 , Min—minimum concentration of pollutant expressed in μg/m3, Max—maximum concentration of pollutant expressed in μg/m3

Source: own study

The below Figure 2 presents air temperature, atmospheric pressure and wind speed in the period of 2010–2019 in Zakopane. Meteorological parameters are one of the important factors that affect air quality [35]. In Zakopane, an increase was recorded in the annual temperature (Figure 1) by as much as 2°C (2010 – 5.4°C ; 2019 – 7.5°C). The highest average wind speed (Figure 1) occurred in 2019 (6.00 km/h), and the lowest one in 2010 (4.67 km/h). A significant increase in wind speed of 1.33 km/h has been ascertained in the analysed years. Wind speed has a stimulating effect on mixing processes, and in addition in the case of large urban agglomerations constituting a cluster of emitters, and it has an impact on the displacement of pollutants outside the city. Therefore, a decrease in the height of pollutant concentrations is usually observed as wind speed increases [36–38]. Atmospheric pressure does not indicate variability during the analysed period and is at about 915 hPa. In 2010, the average annual precipitation was 1645.4 mm, almost twice as much as in 2012 (884.5 mm). The flood that occurred in Poland in the first half of 2010 was, next to the 1997 flood, one of the largest natural disasters in Poland, and was caused by intense rainfalls in May and June 2010 in the south of the country [39]. Precipitation can also have a variable effect on the concentration of air pollutants through the removal of gaseous pollutants and the deposition of particulate matter through chemical processes [40]. Liu and his team similarly found summarizing temperature, relative humidity and atmospheric pressure to be the dominant factors in changes in pollutant concentrations [41].

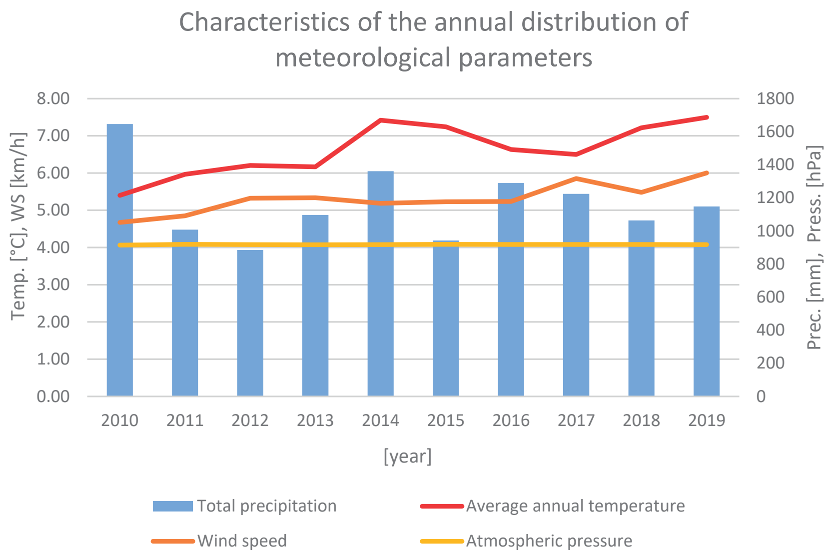

Fig. 2. Basic statistical characteristics of meteorological conditions in Zakopane from 2010–2019

Source: own study

Below is Figure 3 presenting the change in visibility range with relative humidity in the period from 2010 to 2019. Numerous scientific papers consider relative humidity as the most important meteorological factor affecting visibility [42–44]. This led to the decision to combine the two variables on one chart. Visibility can be reduced by polluted air and high relative humidity [45]. Studies have shown that the effect of relative humidity on hygroscopic particle growth can cause visibility alterations [46]. Therefore, visibility is significantly affected by the PM load, as well as meteorological factors, such as for example relative humidity that contributes to its reduction. The graph clearly shows that as relative humidity increases in 2014 (80.10%), visibility decreases (17.91 km), and conversely, the increase in visibility in 2011 (22.28 km) is typical of lower relative humidity (78.21%). Humidity affects the aerosol extinction coefficient, through hygroscopic chemical components in aerosols, such as sulphates, nitrates and some organics, which can take up water vapour to increase their size and thus increase the aerosol's scattering capacity and albedo [47]. Consequently, visibility will drop drastically when ambient relative humidity is high at the same aerosol mass concentration level [48]. Therefore, in addition to particle concentrations, ambient relative humidity also has a significant impact on visibility, and the quantitative relationship between pollutant concentrations and visibility varies with humidity [49].

Monthly variations in visibility, humidity and air pollutant concentrations in the air (averages for the entire period 2010–2019) are presented in Figure 4.

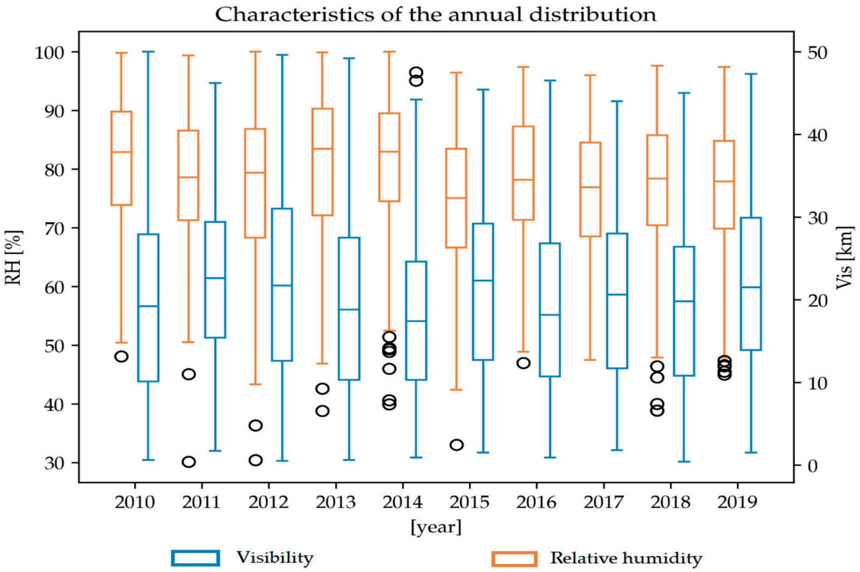

Fig. 3. Basic statistical characteristics of visibility and relative humidity in Zakopane in 2010–2019

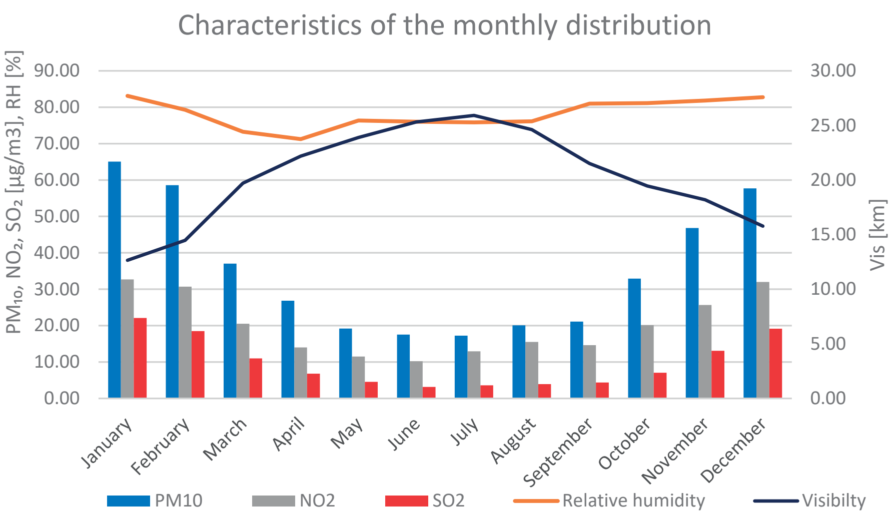

Fig. 4. Monthly fluctuations of meteorological parameters, air pollution and visibility in Zakopane in 2010-2019

Source: own study

Monthly average concentrations for PM_{10}, SO_2, NO_2 showed the highest concentrations in January and February, after which we notice a decrease in pollutant levels starting in March and again from September an increase in levels PM_{10}, SO_2 and NO_2. Visibility presents a clear temporal variation, the highest visibilities are recorded in July (25.93 km), and the lowest ones in January (12.65 km). Relative humidity, as well as pollutant concentrations, show monthly variability. The highest relative humidity values are represented in January, February, September, October, November and December. In addition, when we look at the graph as a whole, we can see that as pollution levels and relative humidity decrease in the warm months (May, June, July and August), visibility increases markedly.

3.2. Analysis of the occurrence of episodes of elevated PM_{10} concentrations in Zakopane

Table 5 specifies the limits' exceedance thresholds for pollutant concentrations. In a 24-hour period, the exceedance value according to the Regulation may not exceed 50 μg/m^3, and the permissible frequency of exceeding the permissible level in a calendar year is 35 days [17]. The second threshold > 100 μg/m^3 is an alert threshold that calls on state institutions to inform the public about an episode of elevated pollutant concentrations [50].

Table 5. The number of days with exceedances of the limit value PM_{10} (L > 50) and (L > 100) in Zakopane in 2010–2019

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
L > 50	**85**	**102**	**70**	32	**85**	**71**	**54**	**55**	**57**	28
L > 100	**36**	**34**	**31**	**8**	**18**	**4**	**15**	**14**	**6**	**1**

*The years in which the standards set out in Regulation [17] have been exceeded shall be indicated in bold

Source: own study

Episodes of elevated pollutant concentrations, in recent years, have been a very common phenomenon in Poland and are colloquially referred to as "smog." Although Poland has undergone a significant industrial transformation over the past 20 years, with a marked decrease in particulate pollution, episodes of PM-related smog are still common, especially in the southern part of the country [51–53]. Today, notion of smog most frequently applied to above-normal urban air pollution arising from emissions from low emitters (residential and automobile combustion) under certain meteorological conditions (especially temperature inversions) [53]. The smog phenomenon (which can be physically perceptible as a noticeable burning smell or manifested as reduced visibility) occurs in unfavourable meteorological conditions, such as atmospheric stagnation, low wind speed and high relative humidity [54]. 2011 recorded the most frequent number of days where exceedances of standards occurred (102 days), followed by 2010 (85 days) and 2014 (85 days). An episode of elevated concentrations of pollutants is a situation of one or several days of elevated concentrations of PM_{10}, in which there is a significant exceedance of the daily permissible level for PM_{10} (50 μg/m^3). In the case under analysis, we can no longer speak of episodes, but of chronic long-term exposure to high concentrations of pollutants. Long-term exposure to particulate matter is strongly associated with ischemic heart disease, cerebrovascular disease, COPD, lung cancer and acute lower respiratory tract infections [55]. In addition, the analysis pointed to a significant number of days where pollutants exceed 100 [μg/m^3]. The most frequent occurrences are in the early years of the analysis 2010 (36 days), 2011 (34 days), 2012 (31 days) and as the years go by, this was found to become less frequent.

3.3. Correlation analysis between harmful air pollutants including meteorological conditions

Pearson's correlation coefficient was calculated between visibility and meteorological conditions and air quality data: PM_{10}, SO_2 and NO_2. The correlation between the daily average values of the parameter was determined. All analyses were performed at a significance level of $p < 0.05$. Table 6 presents all data to show significant as well as non-significant correlations of variables. The bolded analysis results in the tables indicate statistical significance of correlations at the 0.05 level.

Table 6. Correlation between air pollution along with selected meteorological parameters and visibility in Zakopane in 2010–2019 divided into cold and warm seasons

Variable	PM_{10}	NO_2	SO_2	Relative humidity	Average temperature	Wind speed	Atmospheric pressure	Precipitation
Visibility (all period)	**-0.344**	**-0.364**	**-0.316**	**0.516**	**-0.520**	**-0.054**	0.027	-0.017
Warm season	**-0.156**	**-0.134**	**-0.200**	**-0.523**	**0.369**	-0.046	**0.072**	**-0.108**
Cold season	**-0.301**	**-0.254**	**-0.312**	**-0.470**	**0.510**	0.034	**-0.067**	0.004

Source: own study

The above Table 6 of the correlation analysis clearly shows the relationship of visibility with the levels of pollutants such as PM_{10}, NO_2, SO_2 in the warm and cold seasons, confirming the impact of air quality on visibility range. It can be inferred from the table that as pollution levels increase, especially in colder days, visibility decreases. This relationship is also confirmed by studies performed by foreign researchers that point to a negative correlation between visibility and air pollution concentrations [56]. Emissions can cause visibility to deteriorate, which makes visibility an important indicator of particulate pollution [57, 58]. Therefore, the long-term visibility trends can indicate a change in air pollution status [59, 60]. Relative humidity adversely affects visibility by reducing its range, and its impact may be seen throughout the year. Relative humidity and wind are key meteorological parameters for understanding seasonal variability in visibility [61]. Wind can affect PM concentrations by generating and depositing PM, and windy conditions also lead to pollutant dilution by bringing fresh air into the city. RH affects the efficiency of aerosol dispersion through hygroscopic effects [56, 62, 63]. In the whole analysed period without a seasonal division and in the cold season, there was no significantly statistical relationship at the accepted confidence level between precipitation and visibility. In the warm season, a relationship has been proven, but it is quite weak and it is difficult to state unequivocally the effect of precipitation on visibility in warmer periods. This information is very valuable because rainfall frequency is one of the factors affecting the average annual number with low visibility [64]. Rainfall reduces the concentration of air pollutants through wet deposition and as an effect it can increase visibility [40]. Statistical analysis did not show a correlation between atmospheric pressure and visibility, only a breakdown by season showed a relationship, but it is so weak that it is difficult to conclusively establish a relationship on the studied variable which is visibility.

3.4. Regression analysis between air pollution and meteorological conditions and visibility

Table 7 shows a stepwise regression analysis intended to determine visibility as a linear combination of meteorological and air quality data. Stepwise regression analysis allows only those variables, predictors, which significantly predict the dependent variable to enter the model. Consequently, from the tangle of sometimes redundant variables that contribute nothing to the model, we obtain those variables that actually affect the prediction of the dependent variable. The paper uses stepwise backward regression because it involves, in the first step, constructing a model that contains all potential explanatory variables, and then gradually eliminates variables so as to keep the model with the highest value of the coefficient of determination while maintaining the significance of relevant parameters. Atmospheric pressure may not affect visibility in a direct way, but it may be relevant to other meteorological parameters and air pollutants that affect visibility. As studies have shown, higher concentrations of pollutants are recorded with high-pressure systems. High-pressure centres generate downward air movements (settling of air masses), and also promote the formation of, for example, an urban heat island with specific air circulation in the mixing layer above the city. Such situations are usually accompanied by relatively lower wind speeds, which consequently contribute to an increase in the values of pollutant concentrations in the near-surface air layer. Zakopane is situated in a valley among the Tatra Mountains where specific climatic conditions prevail, and the above mentioned phenomenon is compounded by the presence of mountains and affects visibility. In a study by Fu et al. (2008) the long-term persistence of high concentrations of air pollutants was associated with the influence of extensive high-pressure centres. These favoured the subsidization of air particles and increased the stability of the atmosphere, resulting in the formation of subsidization inversions in the lower and middle troposphere. In such conditions, visibility is very limited [65].

Table 7. Regression equations established between the unit and the total concentration and meteorological parameters and visibility from Zakopane in 2010–2019

N	Model Regression	R	R^2	R^2Corrected	F	p-Value	BS
3148	Vis = (-0.075 * Press) + + (-0.386 * RH) + (0.481 * Tav) + + (0.073 * SO2) + 116.739	0.661	0.436	0.436	611.42	0	7.884

Source: own study

Eight independent variables were used for needs of the regression analysis. Predictors influencing the form of the model include atmospheric pressure, air humidity, air temperature and SO_2 concentration. These are the variables that have an effect on visibility in Zakopane. The analysis showed that the multilinear model fits the data collected in Zakopane and predicts visibility with a correlation coefficient of R = 0.661. The result indicates a significant relationship between visibility and meteorological parameters and concentrations of harmful pollutants in Zakopane. The largest positive influence on the form of the model in Zakopane was the air temperature (0.481), which increases the range of visibility as it increases. Next was air humidity (-0.381), which reduces visibility as it increases. The statistical analysis indicated that the regression model was well fitted to the observed data. The regression analysis confirmed the hypothesis that there is a relationship between visibility and concentration levels, as well as meteorological parameter.

3.5. Rankings of importance of variables and their impact on visibility

Table 8 presents the importance ranking of variables that influence visibility in Zakopane in the period 2010–2019. Classification tasks were used for the analysis to group data from the viewpoint of different ranges of visibility. Based on results of a modelling analysis of the random forest algorithm, it was found that the highest validity (importance) on the form of the model in Zakopane is exerted by relative humidity (RH). Kim and his team obtained similar results, identifying

Table 8. Importance ranking of variables for the model created for the destination Zakopane in the years 2010–2019 on the basis of data of meteorological parameters and pollution concentrations

Validity of predictors													
Vis ≤ 3KM	Validity	Vis ≤5 KM	Validity	Vis ≤10 KM	Validity	Vis ≤15 KM	Validity	Vis ≤19 KM	Validity	Vis ≤24 KM	Validity	Vis ≤29 KM	Validity
RH [%]	1.000	RH [%]	1.000	RH [%]	1.000	RH [%]	1.000	RH [%]	1.000	RH [%]	1.000	RH [%]	1.000
Atmospheric pressure [hPa]	0.632	T_{av}	0.757	T_{av}	0.923	T_{av}	0.893	T_{av}	0.802	T_{av}	0.752	T_{av}	0.621
SO_2	0.630	NO_2	0.536	SO_2	0.601	SO_2	0.548	SO_2	0.543	SO_2	0.542	PM_{10}	0.525
T_{av}	0.565	SO_2	0.525	PM_{10}	0.503	PM_{10}	0.506	PM_{10}	0.488	PM_{10}	0.528	SO_2	0.504
Precipitation [mm]	0.531	PM_{10}	0.481	NO_2	0.440	NO_2	0.441	NO_2	0.428	NO_2	0.431	NO_2	0.451
PM_{10}	0.352	Atmospheric pressure [hPa]	0.454	Precipitation [mm]	0.395	Precipitation [mm]	0.340	Atmospheric pressure [hPa]	0.352	Atmospheric pressure [hPa]	0.399	Atmospheric pressure [hPa]	0.374
NO_2	0.308	Wind speed [km/h]	0.419	Atmospheric pressure [hPa]	0.392	Atmospheric pressure [hPa]	0.325	Precipitation [mm]	0.305	Precipitation [mm]	0.329	Wind speed [km/h]	0.362
Wind speed [km/h]	0.281	Precipitation [mm]	0.343	Wind speed [km/h]	0.314	Wind speed [km/h]	0.320	Wind speed [km/h]	0.288	Wind speed [km/h]	0.320	Precipitation [mm]	0.301
N	0.129	season	0.182	season	0.188	season	0.172	season	0.201	season	0.217	season	0.166
season	0.120	W	0.106	N	0.100	N	0.133	N	0.100	W	0.111	W	0.156
S	0.039	N	0.089	S	0.067	W	0.087	W	0.096	N	0.081	S	0.087
W	0.028	E	0.052	W	0.067	S	0.062	S	0.083	S	0.075	N	0.079
E	0.011	S	0.048	E	0.061	E	0.047	E	0.058	E	0.054	E	0.065

Source: own study

RH as the most important predictor affecting visibility prediction with the use of random forest [66]. RH and its gradient were found to be more significant predictors than air temperature [67]. In addition, the random forest analysis for visibility up to 3 km confirms results obtained in the regression analysis (Table 6). Both analyses point to relative humidity, atmospheric pressure and air temperature and SO_2 as the most important variables determining visibility in Zakopane. The important predictor for visibility above 5 km, just behind relative humidity, is air temperature. For visibility over 5 km, the key factor influencing the form of the model following relative humidity is air temperature. SO_2 is the air pollutant that has the greatest importance and influence on the form of the model, followed by PM_{10} and NO_2. As the visibility range increases, the importance of precipitation decreases. The analysis did not show that wind direction, along with seasonality, has a significant impact on the form of the model. The random forest model has satisfactory predictive capabilities owing to high values of ACC-accuracy SENS-sensitivity coefficients. The prediction evaluation for the models we obtained is as follows: for model vis ≤ 3km ACC = 90.09%, SENS = 98.86%, for model vis ≤ 5 km ACC = 88.56%, SENS 98.83%, for model vis ≤10 km ACC = 83.78%, SENS = 95.14%, for model vis ≤ 15 km ACC = 90. 61%, SENS = 98.57%, for model vis ≤ 19km ACC = 80.47%, SENS 90.44%, for model vis ≤ 24km ACC = 80.61%, SENS = 86.80%, for model vis ≤ 29km ACC = 83.55%, SENS = 86.13%. The random forest model allowed us to understand and provide valuable information for future research to improve the accuracy of visibility prediction.

4. Discussion

The article is one of the first attempts to link air pollution and meteorological conditions with visibility in Zakopane. The primary objective of the paper was achieved by determining the influence of individual variables on visibility. The analysis presented in the paper shows that visibility in the tourist city of Zakopane is primarily affected by SO_2 and PM_{10} concentrations, caused by increased traffic and diffuse emissions from low sources and RH humidity. Control of coal and biomass burning, vehicle exhaust and industrial emissions can lead to significant improvements in visibility, as they have the greatest impact on the values of pollutant concentrations. Atmospheric pollutants can cause reduced visibility, so this is crucial to the interest in air pollution research and climatology [68]. A positive phenomenon has been ascertained, and namely the downward trend in pollution levels in recent years, especially PM_{10}. The year 2019 was the first one in which the permissible frequency of exceedances of the permissible level did not exceed the standard specified in the regulation [17] and amounted to 28 days (the maximum permissible frequency of exceedances – 35 days). Monthly changes in visibility show that with the decrease in pollution levels and relative humidity in the warm months (May, June, July and August) visibility tends to increase significantly, in contrast to the cold months (October, November, December, January, February, March), where visibility decreases due to higher pollution levels and unfavourable meteorological conditions (high humidity, low temperatures and wind speeds). The information level for PM_{10}, which was restrictively lowered after 2018, has been exceeded only once, where in 2010 such a situation occurred as many as 36 times. The reason for an improvement in air quality in Poland is the introduction of so-called POPs (Air Protection Programs), and their practical implementation allowed achieving a reduction in pollution levels. The corrective measures taken should be aimed at implementing long-term strategies aimed at reducing the risk of negative impacts of pollution on the environment [69]. To better understand the problem of visibility, it is necessary to link meteorological parameters with air pollution. Indirect reductions in visibility are influenced by meteorological parameters. An increase of 2.1°C in annual temperature was ascertained (2010 – 5.4°C; 2019 – 7.5°C). Analyses of meteorological conditions are closely related with climate change, especially in mountainous areas, since mountain ecosystems are very sensitive and vulnerable to climate change [12]. As relative humidity increases, visibility decreases, and conversely, increased visibility is typical of lower relative humidity. Correlation analysis showed a relationship between visibility and meteorological conditions, mainly relative humidity and air temperature. In addition, the correlation analysis confirmed the influence of seasonality on visibility range. In the cold season, stronger correlations were observed between visibility, pollution levels and meteorological conditions than in the warm season. The regression analysis confirmed the results of the correlation analysis, indicating that meteorological parameters had a stronger effect on visibility than air pollution. The random forest analysis for visibility in the range up to 3 km confirms the results obtained in the regression analysis. Both analyses point to relative humidity, atmospheric pressure, air temperature and SO_2 as the most important variables to determine visibility in Zakopane. In many countries around the world, visibility is used as an indicator of the degree of air pollution and can also be used as a surrogate for assessing human health impacts where basic monitoring is not possible [54]. There are studies the conclusions of which are the same as those drawn here. Of particular note is a study performed by Wang and team that defined visibility as the public's intuitive understanding of air quality and also finding relationships between PM concentrations, visibility and ambient relative humidity. For a given PM concentration, higher RH values are associated with lower horizontal visibility. Consequently, both PM concentrations and relative humidity give rise to changes in atmospheric visibility [44]. Rataj and Holewa-Rataj [11] noted a decrease in both maximum and average PM_{10} concentrations measured in the air over the past three heating seasons (2017/2018, 2018/2019 and 2019/2020). Although there are still significant exceedances of air quality standards in Małopolska, it should be noted that the measures taken in the province to improve air quality are slowly yielding results. However, their consolidation requires that such measures be taken with equal force in all municipalities of the Małopolska province.

This paper presents the combined effect of meteorological conditions along with pollutant concentration levels on visibility. The paper demonstrates the importance of conducting reliable monitoring of air quality and meteorological conditions, including visibility, as it can be taken as a substitute for measurements, particularly in places where it is particularly important due to increased tourist traffic, and provide theoretical guidance for the sustainable development of regional tourism. The problem of air pollution also affects tourism. Tourist destinations that have poor air quality may lose their appeal, as tourists may begin to avoid these places [70]. Tourism, whether "blamed" or "wronged," also becomes a "victim" of the effects of environmental degradation, which reduce the attractiveness of tourist destinations such as Zakopane [12].

5. Conclusions

The statistical analysis and discussion carried out for the purpose of the article has led to some interesting conclusions. In mountain destinations such as Zakopane, unlike tourist cities located in the lowlands, the main influence on visibility is exerted by meteorological conditions followed by pollution concentrations. The reason for this phenomenon are the specific local and topographical conditions in the mountains related to the terrain, which determine the formation of meteorological conditions and pollution concentration levels. Visibility in the tourist town of Zakopane is mainly affected by relative humidity and atmospheric pressure, as well as concentrations of SO_2 and PM_{10}, arising from increased traffic and low-level emissions from individual houses. The analysis of air quality along with meteorological parameters is particularly important in sensitive areas, areas with increased traffic where tourist functions simultaneously combine with health function of the destination. The results of the analysis, discussion and conclusions justify the need to carry out such research work, as they raise issues that are currently very important from the point of view of human life.

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