Changes in air-pollution related behaviour measured by Google Trends Search Volume Index in response to reported air quality in Poland

Wojciech Nazar (wojciech.nazar@gumed.edu.pl)
Medical University of Gdansk: Gdanski Uniwersytet Medyczny

Katarzyna Plata-Nazar
Medical University of Gdansk: Gdanski Uniwersytet Medyczny

Research article

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Abstract

Background

Decreased air quality is connected to a higher number of hospital admissions and an increase in daily mortality rates. Thus, Poles’ behavioural response to sometimes elevated air pollution levels is vital. The aim of this study was to carry out analysis of changes in air-pollution related information seeking behaviour in response to nationwide reported air quality in Poland.

Methods

Google Trends Search Volume Index data was used to investigate Poles’ interest in air pollution-related keywords. PM10 and PM2.5 concentrations measured across Poland between 2016 and 2019 were collected from the Chief Inspectorate of Environmental Protection databases. Pearson Product-Moment Correlation and the $R^2$ correlation coefficient of determination were used to measure spatial and seasonal correlations between reported air pollution levels and the popularity of search queries.

Results

The highest PM10 and PM2.5 concentrations were observed in southern voivodeships and during the winter season. Similar trends were observed for Poles’ interest in air-pollution related keywords. All $R^2$ coefficient of determination values were > 0.5 and all correlations were statistically significant.

Conclusion

Poland’s air quality does not meet the World Health Organisation guidelines. Also, the air quality is lower in southern Poland and during the winter season. It appears that Poles are aware of this issue and search for daily air quality data in their location. Greater interest in air quality data in Poland strongly correlates with both higher regional and higher seasonal air pollution levels.

Introduction

Air pollution is defined as the contamination of the environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere [1]. It can be divided into indoor, and outdoor (ambient), air pollution. The most common indicators of air pollution are the atmospheric concentration of particles with a diameter of 10 microns or less and 2.5 microns or less, described respectively as coarse particulate matter 10 (PM10) and fine particulate matter 2.5 (PM2.5). These particles are composed of organic and elemental carbon, nitrates, sulphates and trace elements, including nickel, cadmium, arsenic and lead particles [2, 3]. The World Health Organisation (WHO) sets
the guideline values at 20 µg/m$^3$ annual mean and 50 µg/m$^3$ 24-hour mean for PM10 concentration and 10 µg/m$^3$ annual mean and 25 µg/m$^3$ 24-hour mean for PM2.5 concentration [4].

In 2016, about 90% of the world population was breathing polluted air. The highest levels of air pollution are found in low-income and middle-income countries. In Europe, the value of the PM10 annual mean concentration set by the WHO guidelines was exceeded at 51% of the stations supervised by the European Environment Agency and in all the reporting countries, except Estonia, Finland and Ireland [5]. As 36 of the 50 most polluted cities in the European Union are in Poland [6], the issue of air pollution is of particular importance in this country. The greatest contributors to the problem are coal-based economy and household heating systems [6]. Ambient air pollution is estimated to cause about 4,200,000 premature deaths worldwide. Major diseases linked to air pollution include ischemic heart disease, strokes, chronic obstructive pulmonary disease, acute lower respiratory tract infections and lung cancer [4].

It is of high importance that individuals exposed to polluted air take active steps to reduce associated risks. To reduce direct exposure to high outdoor particulate matter concentrations people can, for example, avoid exercising outdoors or close to high-traffic areas [7], stay indoors and close windows, or utilise air-purifiers. However, before active prevention, it is crucial that individuals understand what air pollution is in general. It may be possible to achieve this passively, for instance by governmental promotion of the issue [8]. This said, what would likely be more effective is active and purposeful information seeking, self-education and acquisition of air pollution awareness by individuals. This process can be illustrated by, for example, societal emphasis on the importance of checking your local daily air quality index. This in turn can be measured by investigating the popularity of relevant search terms entered into internet search engines, for example with the use of the Google Trends Search Volume Index (SVI). It shows the level of interest in a given search term, by a specifically located population within the specified time period. If this data is compared to the reported national air quality data, an analysis of people’s response to reported air pollution levels can be performed.

The aim of this study was to carry out spatial and seasonal analysis of changes in air-pollution related information seeking behaviour measured by the prevalence of specific keywords in the Google Trends Search Volume Index, in response to nationwide reported air quality in Poland.

**Materials And Methods**

**Keyword search**

First, authors proposed keywords related to air pollution. As Google Trends displays only a relative level of interest in a given search term, keywords were entered into KWFinder [9], a keyword research tool, part of a suite of SEO tools developed by Mangools, to find words with significant general search volume based on absolute values.
After initial analysis, seven keywords were selected. Subsequently, keywords were entered into Google Trends [10], to generate data. The search was performed in Polish. Three of the initially selected keywords: “air purity” (czystość powietrza), “PM2.5” and “PM10” were rejected, as data related to these keywords was available only nationally, making voivodeship-level spatial analysis impossible. Eventually, four keywords were selected: “smog” (smog), “air pollution” (zanieczyszczenie powietrza), “air quality” (jakość powietrza) and “air purifier” (oczyszczacz powietrza). Based on the KWFinder data, the average annual search volumes for these keywords were 19,900, 11,000, 8,600 and 66,700, respectively. This amounts to a total number of about 420,000 searches over a four-year period. The validity of the selection as related to air pollution was confirmed by checking that entering them into the Google search engine [11] resulted in a display of general information about smog and air pollution (1st keyword), particulate matter concentration maps and pollution alerts (2nd and 3rd keyword) or air purifiers (4th keyword).

Keyword-specific daily search Index between 01.01.2016 and 31.12.2019 was extracted from Google Trends for further analyses. This period was selected as at the beginning of 2016 Google introduced an improvement to their Google Trends data collection system [10]. 2020 was not included as the ongoing COVID-19 pandemic [12] may have affected people's behaviour which would result in biased data.

Google Trends shows interest in a given keyword using a search volume index. The relative value indicating the popularity of a term on a selected day ranges between 0 and 100. A value of 100 is ascribed to the day during which a keyword was searched the greatest number of times in the given investigated time frame (in this case between 2016 and 2019). A value of 0 expresses a relative quantity of search queries for the analysed phrase of less than 1% of its greatest popularity over the given time period. All data was accessed and downloaded on 09.11.2020. The Google Trends analysis was based on the methodology framework proposed by Mavragani et al. [13].

**Air quality data**

The data collected by the Chief Inspectorate of Environmental Protection between 2016 and 2019 inclusive was included in the analysis [3].

To analyse seasonal air quality changes, data for daily 24-hour (24h) mean PM10 and PM2.5 concentrations were taken into account. In total, for the 2016-2019 period, records from 1182 monitoring stations reporting PM10 concentrations, and 468 monitoring stations reporting PM2.5 concentrations were analysed, which amount to over 600,000 24h-concentration data points.

To analyse spatial relationships, the same data points collected in the same monitoring stations were used. However, due to the availability of straightforward summary data, to minimize the risk of miscalculations, a database that summarises air pollution in Poland for years 2000-2019 was used [3].

The division of Poland into 16 voivodeships was used in the spatial analysis. In each voivodeship a city or an agglomeration of up to two large cities was selected in order to investigate potential differences in
air quality and SVI values between rural and urban areas.

Data analysis

All data was analysed in Microsoft Office Excel 2016 software developed by Microsoft Corporation. The analysis included the following variables:

- mean monthly SVI for each keyword (averaged over four years of analysed data)
- mean annual voivodeship SVI for each keyword (ditto)

This fragmentary data was then combined and the following data was calculated:

- mean annual voivodeship SVI (averaged over voivodeship values for individual keywords)

For 24h PM10 and PM2.5 concentrations the analysis included the following variables:

- mean monthly concentration values (averaged over four years of analysed data).
- mean annual concentration values for each voivodeship and each individual urban area (ditto).

Corresponding data sets were paired to investigate the spatial and seasonal changes in actual air pollution levels and the popularity of the search queries related to them. Next, the data was plotted on graphs. As the data points on each graph suggested linear correlation, the Pearson Product-Moment Correlation coefficients, $R^2$ coefficient of determination and p-values were calculated to determine the strength of association between the variables [14, 15]. The threshold of statistical significance was set at p<0.05.

Results

Spatial analysis

The highest mean 2016-2019 PM10 concentrations were observed in the Opole (42.6), Cracow (38.5) and Łódź (36.7) urban areas, while the lowest were observed in the Bialystok (20.9), Tricity (22.4) and Szczecin (22.9) urban areas (Figure 1). Similarly, the highest PM2.5 concentrations were observed in the Opole (29.7), Cracow (29.4) and Łódź (24.0) urban areas. However, the lowest ones were recorded in the Szczecin (13.5), Tricity (15.8) and Bydgoszcz (15.9) urban areas (Figure 2). The Pearson coefficient and the $R^2$ for the correlation between the mean voivodeship’s SVI and mean monthly PM10 concentrations were equal to 0.76 and 0.58 respectively. For the correlation between mean voivodeship’s SVI and mean monthly PM2.5 concentration the values were 0.81 and 0.66, respectively. Both correlations were statistically significant (p=0.0006, p=0.0001, Figure 1, Figure 2).

Figure 1 Mean urban area's Search Volume Index in relation to mean annual PM10 concentration

Figure 2 Mean urban area's Search Volume Index in relation to mean annual PM2.5 concentration
The greatest mean SVI for the years 2016-2019 was observed in the Małopolskie (94.5), Śląskie (75.8) and Dolnośląskie (63.8) Voivodeships. The lowest one was recorded in the Warmińsko-Mazurskie (18.8), Podlaskie (23.3) and Lubuskie (23.8) Voivodeships (Figure 3). The highest mean 2016-2019 PM10 concentrations were observed in the Śląskie (39.8), Dolnośląskie (35.0) and Łódzkie (34.9) Voivodeships, while the lowest were in the Podlaskie (21.0), Warmińsko-Mazurskie (22.9) and Zachodniopomorskie (23.3) Voivodeships (Figure 3). The same trend was recorded for PM2.5 concentrations, however the values were equal to 28.1, 26.8, 25.5 and 15.6, 15.9, 16.2, respectively (Figure 4). The Pearson coefficient and the $R^2$, for the correlation between mean voivodeship SVI and mean monthly PM10 concentration were equal to 0.73 and 0.54. For the correlation between mean voivodeship SVI and mean monthly PM2.5 concentration the values were 0.64 and 0.41, respectively. Both correlations were statistically significant ($p=0.0013$, $p=0.0077$, Figure 3, Figure 4).

**Seasonal analysis**

The greatest mean monthly SVI value was observed for January (29.7), followed by December (26.5) and November (25.6). Conversely, the lowest values were noted for July (3.0), August (3.3) and June (3.8, Figure 5). Mean monthly PM10 concentrations [$\mu g/m^3$] were the highest for January (35.6), February (43.4) and March (47.7), while the lowest were for July (17.7), June (19.0) and August (19.1, Figure 5). The same trend was observed for mean monthly PM2.5 concentrations. However, the values were 39.4, 34.7, 27.6, and 11.0, 11.6, 11.8, respectively (Figure 6). The Pearson coefficient and $R^2$ for the correlation between mean monthly SVI and mean monthly PM10 concentration were equal to 0.87 and 0.76. For the correlation between mean monthly SVI and mean monthly PM2.5 concentration the values were 0.90 and 0.80, respectively. Both correlations were statistically significant ($p=0.0001$, $p<0.0001$, Figure 5, Figure 6).

**Discussion**

**PM10 and PM2.5 concentration changes in Poland**

Neither any individual urban area’s, nor any voivodeship’s air quality complies with the WHO air quality guidelines in either annual mean PM10 or PM2.5 concentrations [4]. Moreover, in the Cracow and Opole urban areas the PM10 concentrations were about twice as high as recommended, while the PM2.5 concentrations were about three times higher (Figure 1, Figure 2). The same situation is observed in the whole of the Małopolskie and Śląskie Voivodeships, where these urban areas are located. On the other hand, in other urban areas, for example Białystok, Tricity and Szczecin, as well as their corresponding
voivodeships, the mean annual atmospheric PM10 concentration was just slightly higher than advised by the guidelines. However, the PM2.5 concentrations in these locations were still about 50% higher than recommended by the WHO (Figure 3, Figure 4).

For the most polluted regions, the data from the Chief Inspectorate of Environmental Protection reports is in line with independently collected data in other studies [16, 17]. Moreover, these and other studies [18] show that in these regions submicron PM1 concentrations are also elevated and that the smaller the particle, the more toxic it is [18].

When it comes to seasonal air pollution distribution, the WHO-recommended annual PM10 concentrations were met in June, July, and August (Figure 5, Figure 6). On the other hand, in the November-March period the WHO guidelines were greatly exceeded. Annual PM2.5 requirements were not satisfied in any month, but in June, July and August these values were only slightly exceeded. Again, a similar pattern was observed by other researchers [16–18].

Air quality in Poland follows spatial trends, as, in general, the southern regions of the country are more polluted than the northern regions [19]. This gradual improvement in air quality may be caused by increased proximity to the Baltic Sea and the predominantly lowland character of the northern part of the country. These factors allow air to be seamlessly and continuously exchanged [20]. On the other hand, southern regions of Poland are made up of upland, mountainous regions [21] and have heavily coal-based economy and energy production [22]. Also, larger cities in the south are located in basins and valleys. Such environmental conditions reduce air movement, cause its trapping, and result in the formation of smog and decreased air quality [23].

A seasonal pattern of particulate matter concentration changes is also observed. Air quality is much worse in winter than in summer which is confirmed by other studies [16, 17]. This happens due to temperature inversion episodes that occur throughout the whole year, but they are more frequent and intensive in the winter season [23, 24].

**Poles’ interest in air pollution**

Whether people are aware of elevated pollution levels in their local area or not is an important issue. Evidence for this interest can be seen in the high mean Google Trends SVI values found in the Cracow or Opole urban areas, and in the corresponding voivodeships. Moreover, a strong linear correlation [14] between the annual level of air pollution in a given area, and the frequency of air-pollution related search queries is observed (Figure 1 to Figure 4). This means that the higher the mean yearly concentration of PM10 and/or PM2.5 concentration in a given area, the more frequently people are looking for their local air quality indexes, for example searching online for “air quality” or “air pollution”. It was also found that the Google Trends SVIs have higher correlations with PM concentrations for urban areas’ than for voivodeships’. Thus, it can be said that people who live in cities are more aware of the problem. Of all calculated R² coefficients of determination the highest one was observed for the correlation between PM2.5 concentration and urban areas’ SVI. On the other hand, the weakest correlation was observed for
PM2.5 concentration and voivodeship’s SVI. The correlations observed for PM10 concentration and voivodeship’s SVI as well as urban areas’ SVI are placed in-between the PM2.5-related correlations. Thus, it cannot be definitely stated whether changes in PM2.5 or PM10 concentration are more connected with changes in Poles’ air pollution-related information-seeking behaviour. Also, the Wrocław (Dolnośląskie Voivodeship) and Cracow (Małopolskie Voivodeship) datapoints are located far above the trendline. Therefore, residents in these locations search more for information on air pollution in comparison to communities in other areas with similar PM10 and PM2.5 concentrations. On the other hand, Łódź (Łódzkie Voivodeship) and Poznań (Wielkopolskie Voivodeship) residents pay less than average attention to pollution.

Even stronger correlations were found between mean monthly SVI values and seasonal air quality variations. Similar to geographical distribution, the greater the seasonal PM10 and/or PM2.5 concentration, the greater Poles’ interest in air-pollution related search queries. Thus, Poles recognize the importance of checking their local daily air quality index in general, and especially in the winter season when smog is the most harmful [23, 24]. However, there is still space for improvement, as during March and April air pollution appears to be underestimated, as evidenced by relatively lower number of searches for air quality data despite still relatively high pollution levels (Figure 5, Figure 6). On the other hand, November and December data points are situated over the trend line. Therefore, in this period Poles pay more than average attention to air quality relative to the reported levels of air pollution. This may indicate general public expectation of smog before and during winter. Nonetheless, significant pollution levels are also present during the spring season.

**Comparison with other studies**

Our study demonstrates a strong positive relationship between reported levels of air pollution in Poland and air pollution related information seeking behaviour. This suggests that Poles are aware of risks posed by air pollution, and undertake steps to obtain specific data, and that this awareness is in line with actual levels of the environmental hazard (both seasonally and geographically). Awareness and staying up to date are the crucial first steps in the primary prevention. It is also vital that people respond to pollution alerts and engage in protective behaviour against the threat. This includes staying indoors, purifying indoor air or avoiding outdoor activity when and where air pollution levels are higher [25]. These behaviours are primary prevention strategies too. Studies carried out in China and the US found that people reduced their outdoor activity when atmospheric PM2.5 concentration rose [26–28]. Other research showed that individuals limited their transportation-related physical activity and spent more time at home when particulate matter concentrations increased [27, 29]. These results show that people not only search for the information on their local air quality index but use it as a guideline to adapt their behavioural patterns. To date, no such study has been carried out in Poland [30]. Nevertheless, based on internationally available data it can be assumed that Poles who check air pollution levels are likely to respond to them and take steps to protect themselves. Nonetheless, future studies investigating this problem are necessary.
Despite growing general awareness and specific information seeking and self-protection behaviours, an increased number of hospital admissions correlates with the worse air quality in Poland [31, 32]. A similar trend is observed worldwide [33–35]. Moreover, it was demonstrated that short-term exposure to polluted air correlates with increased mortality [36]. This includes cardiovascular and respiratory diseases’ cause-specific mortality rates [31, 32, 37, 38].

**Future perspectives**

Our study as well as others on the same subject show that people are aware of air pollution and execute primary prevention strategies [39] to protect themselves from potential harms. However, the general public may not link air pollution with its potential to increase the prevalence and/or exacerbation of cardiovascular or respiratory diseases, and therefore they may not recognize the symptoms in an early stage of disease exacerbation. Late admission to hospital increases the probability of death which results in greater mortality rates [31, 32, 37, 38]. Thus, general public may not be aware of secondary and tertiary prevention measures, which aim to reduce the impact of a disease that has already occurred [39]. For example, some researchers propose that there is no link between the chronic inflammatory skin diseases symptoms and air pollution, which has been shown with the use of Google Trends SVI analyses [40, 41]. Also, increased air pollution levels may exacerbate the course of ongoing chronic diseases [42] and affected individuals may not know that. Therefore, starting with chronically ill patients and individuals who live in the most polluted regions worldwide, there is a need for health promotion programs focused on air pollution-related secondary and tertiary prevention strategies, including accurate symptom recognition. Such interventions would result in faster responses to rapid, acute exacerbation of chronic disease symptoms and would probably reduce the cause-specific mortalities related to high air pollution levels, both in the short and long-term.

Last but not least, the greatest contributors to the problem of air quality in Poland are coal-based economy and household heating systems [6]. In order to reduce the hospital admission and mortality rates potentially caused by air pollution as well as to comply with WHO air quality guidelines, there seems to be a very urgent need for a shift towards a more ecological energy production sources.

**Limitations**

Due to the use of databases, the data was not directly collected by the authors, and thus this study is subject to methodological limitations. The meteorological monitoring stations that measure PM10 and PM2.5 concentrations were pre-existing and arbitrarily positioned. This may have generated bias in the data, as the concentration of particulate matter is highly dependent on measurement location. However, similar trends in air quality observations were made by other studies which used their own measurement stations [16–18]. Also, as mentioned in the Google Trends methodological framework [13] sometimes Google Trends SVIs may differ, even though the keywords used are the same, for example because the search query was embedded in quotation marks. To reduce this bias, all keywords analysed in this study were always entered without quotation marks, plus signs or any other special characters. Only spaces were used to separate double-word keywords, allowing for the broadest tracking possible. Lastly, Google
Trends SVI shows the relative, not the absolute number of search queries. However, correlation coefficients can be calculated from either absolute or relative values, thus the calculations in this study remain valid.

**Conclusion**

Neither any urban area’s nor any voivodeship’s annual ambient particulate matter concentration complies with the WHO air quality guidelines for either annual mean PM10 or PM2.5 concentrations. It was also found that the south of Poland is more polluted than the north. WHO-advised annual PM10 concentrations were satisfied in June, July and August, but the desired PM2.5 concentrations were not achieved at any time of the year. It appears that Poles are aware of this issue and search for daily air quality indices for their location. At the same time, Poles’ interest in air quality index strongly correlates with both regional and/or seasonal air pollution levels.

**Abbreviations**

Search Volume Index (SVI)

Particulate matter 10 (PM10)

Fine particulate matter 2.5 (PM2.5)

The World Health Organisation (WHO)

**Declarations**

**Ethics approval and consent to participate**

Bioethics Committee of the Medical University of Gdańsk had given its approval to carry out this study. Bioethics Committee of the Medical University of Gdańsk approval number: NK BBN/707/2020.

**Consent for publication**

Not applicable

**Availability of data and materials**

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare that they have no competing interests.
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Authors' contributions

WN and KPN developed the study concept and wrote the manuscript. KPN applied for the approval of the Bioethics Committee of the Medical University of Gdańsk. WN analysed the data statistically.

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