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Systematic Review of Factors Related to $PM_{2.5}$ Exposure on the Risk of Type 2 Diabetes Mellitus

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Abstract

Diabetes mellitus is a major public health problem in many countries, and most of them are type 2 diabetes mellitus (T2DM). Air pollution is thought to contribute to the T2DM incidence, and one of the most important pollutants is $PM_{2.5}$. This study aimed to determine factors related to $PM_{2.5}$ exposure and individual factors in increasing the risk of T2DM based on a systematic review. The PRISMA was used as a method of data collection and selection. Of 176 relevant articles identified and screened, 12 articles from various countries published in 2013-2021 were synthesized in this study. Results showed that long-term $PM_{2.5}$ exposure, high $PM_{2.5}$ concentrations, and living in densely-populated areas, close to roads, and in areas with industrial activity could increase the risk of T2DM. Population with an older age (>40 years) and a BMI of overweight or obese were more vulnerable. However, men and persons who stopped or never smoked were also at higher risk; thus, further studies need to be carried out along with other risk factors. A future study is recommended to determine the effects of $PM_{2.5}$ exposure on the incidence of T2DM in Indonesian populations.

Keywords: air pollution, individual factors, $PM_{2.5}$, systematic review, type 2 diabetes mellitus

Introduction

Noncommunicable diseases are the major cause of death and disability globally, one of which is diabetes, standing out as one of the most prevalent among them.[1] As of 2021, the International Diabetes Federation (IDF) reports that approximately 537 million adults aged 20-79 years are currently living with diabetes, and this number is expected to rise further.[2] Type 2 diabetes mellitus (T2DM) constitutes over 90% of these cases, with a consistent annual increase attributed to factors such as population aging, economic development, and escalating urbanization, leading to unhealthy lifestyles and increased consumption of food associated with obesity.[3] Analyzing global diabetes prevalence in adults (20-79 years), the 2021 IDF data reveals that China (140.9 million), India (74 million), Pakistan (33 million), the United States (32.2 million), and Indonesia (19.5 million) have the highest numbers of diabetes cases.[2] The 2018 Indonesian Basic Health Research indicated a 2% prevalence of diabetes mellitus among individuals aged ≥15, signifying an increase from the 2013 rate of 1.5%.[4] Furthermore, a primary risk factor for diabetes in 2017 was ambient air pollution, contributing to 13.4% of deaths and 15.4% of Disability-Adjusted Life Years (DALYs).[5]

Pollutants that play a major role in increasing the risk of T2DM include particles <2.5 μm in diameter ($PM_{2.5}$), nitrogen dioxide (NO_2), particles <10 μm in diameter (PM_{10}), and nitrogen oxides (NO_X).[6] Ambient (outdoor) air pollution in cities and rural areas was estimated to cause 4.2 million premature deaths worldwide per year in 2016. These deaths were mostly due to exposure to fine particles 2.5 microns in diameter or less ($PM_{2.5}$). Due to its fine size, $PM_{2.5}$ can penetrate the lung barrier and enter the circulatory system, which can increase mortality or morbidity over time.[7]

$PM_{2.5}$ can enter the body through the respiratory system and then enter the lungs, and some can even enter the bloodstream. Concerning T2DM, $PM_{2.5}$ can penetrate the lung barrier and enter the circulatory system.[7] At this stage, $PM_{2.5}$ in the air enters the body through the respiratory tract and enters the lungs until it penetrates the alveoli. Then, during the gas exchange process between the alveoli and blood vessels, $PM_{2.5}$ will diffuse into the blood vessels, causing oxidative damage, endothelial dysfunction, and inflammation, resulting in insulin resistance, which in turn causes T2DM.[8]

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A study in South Korea in 2020 showed an increased risk of increased blood glucose levels with short and medium-term air pollution exposure that was more pronounced among 65-year-old diabetic men.[9] Another study in India in 2019 identified an independent association between urban environment and insulin resistance in adults older than 20 years, in which those living in urban areas had higher levels of Homeostatic Model Assessment for Insulin Resistance (HOMA-IR) assessments than those in rural areas. The largest increase was found for populations living within 20 km of the city center.[10] A previous study conducted in 2019 in Indonesia showed a significant relationship between the incidence of T2DM in urban and rural communities; however, this difference is also due to other factors, such as individual factors, cultural and socioeconomic differences, and lifestyle patterns in urban and rural areas.[11]

For its gradual onset, the impact of $PM_{2.5}$ exposure on T2DM varies based on factors such as the duration of exposure, concentration levels, individual or population sensitivities, and other associated risk factors.[6] Extensive studies on this matter, particularly in Indonesia, are limited. A systematic review was conducted to address this gap, analyzing literature from around the globe. This study aimed to explore how factors related to $PM_{2.5}$ exposure and individual characteristics could contribute to an elevated risk of developing T2DM, drawing insights from various studies conducted in different countries. Compared with other systematic review studies, this study was carried out with a focus on studying a more specific relationship between environmental factors ($PM_{2.5}$ exposure) and individual factors with T2DM.

Method

This study took place in 2022 and used a systematic review design with a qualitative approach (meta-synthesis). Systematic study or systematic review is a research method that implements studies, reviews, structured evaluations, classifications, and categorizations based on several evidence bases that have been produced previously.[12] While, meta-synthesis is a data integration technique to obtain new theories or concepts or a deep and comprehensive level of understanding by narratively synthesizing previous study results.[13] This study's analysis unit was secondary data from both national and international scientific journal articles published in 2013-2022. To access the literature, a database belonging to the Universitas Indonesia (UI) Library (remote-lib.ui.ac.id), was used and connected to various subscription literature databases. The database is free for the UI academic community to access.

The data collection and selection method were based on guidelines called Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA) protocol.[14] The PRISMA protocol is developed to facilitate transparent, complete reporting of systematic reviews and has been updated (PRISMA 2020) to reflect recent advances in systematic review methodology and terminology. The selection process with PRISMA 2020 is a checklist and flow diagram consisting of identification, filtering, and literature inclusion processes (Figure 1).

Identification

a. Literature Search

During the literature search phase, relevant keywords concerning $PM_{2.5}$ exposure and its correlation with the T2DM incidence were inputted into the search field of the UI library database (remote-lib.ui.ac.id). The keywords are T2DM, $PM_{2.5}$, and Fine PM. This search employed the Boolean Operator, utilizing both AND and OR codes to refine the search parameters. The keyword-based search yielded a total of 176 pieces of literature.

b. Duplicate Removal Before Filtering Process

During this phase, a deduplication procedure was conducted to eliminate redundant literature. This process was executed through a database automation engine or a reference manager application, specifically Mendeley, throughout the literature export process. Additionally, parameters such as the publication year, literature type, language, and file availability were incorporated as boundaries (Figure 1). By entering these limits, 73 pieces of literature were eliminated, and 103 were obtained. At this stage, the deduplication process or removal of duplicate literature was also carried out before the filtering process using database automation tools and through the literature export process to Mendeley. A total of 6 pieces of literature were deleted using automation tools and manually during the literature export process to Mendeley, bringing the total literature obtained at this identification stage to 97 pieces of literature.

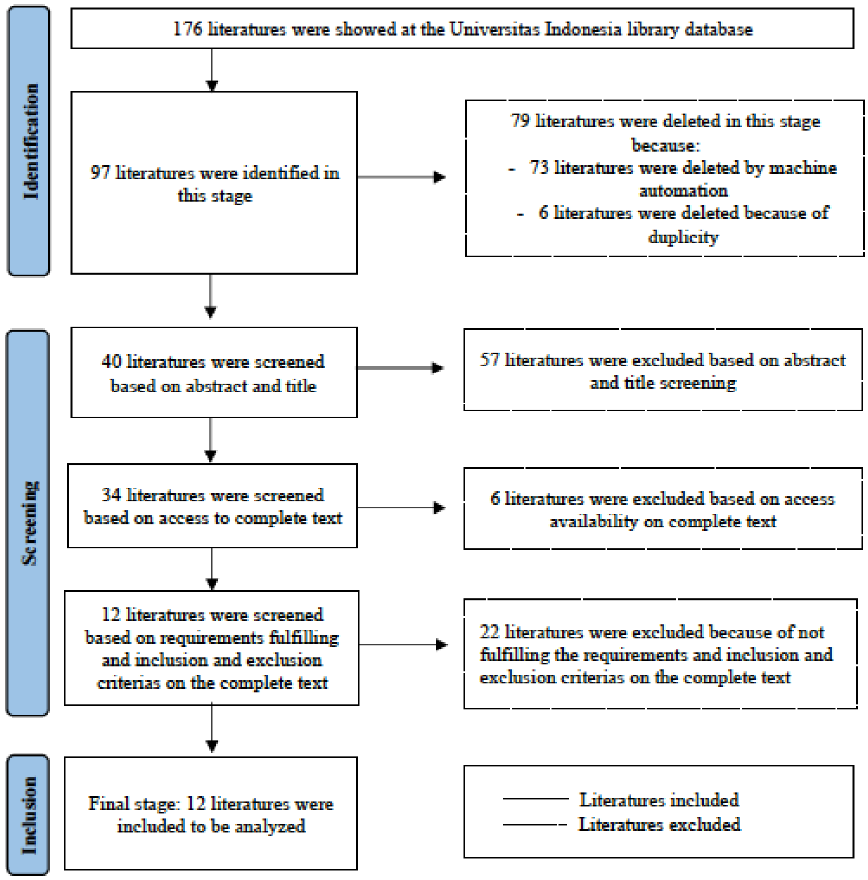

Figure 1. Literature Identification Results Using PRISMA 2020 Flow Chart

Screening

a. Title and Abstract Screening

Once identified, the next step was to screen the title and abstract (Figure 1). In this process, literature that still had duplicates was identified by screening the abstracts and titles obtained using an abstract checklist of PRISMA 2020.[14] Apart from identifying the title or abstract, filtering was carried out based on the research topic and variables studied. If duplicate or inappropriate literature were found, the literature would be excluded. In this stage, 57 pieces of literature were eliminated because they did not match the research topic and variables. Next, a total of 57 pieces of literature were scanned again in their entirety for full text.

b. Literature Screening with Full-Text

After screening the title and abstract, the next step was screening the literature with full text (Figure 1). First, the amount of literature obtained in the initial screening process was reduced by the number of literature excluded from screening in the title and abstract. After that, the literature was filtered again by reducing literature that did not have complete text or could not be accessed. At this stage, elimination was done twice: eliminating six pieces of literature that did not have complete texts.

c. Fulfillment of Conditions

In the next process, the literature was selected for full text using the conditions made in the inclusion and exclusion criteria (Figure 1). Following the PRISMA protocol, inclusion criteria in this study were based on study and publication characteristics. The study characteristics include the Population, Intervention, Comparison, Outcomes, and Study (PICOS) framework:[15] Population (the entire study population exposed to $PM_{2.5}$), Intervention (exposure to $PM_{2.5}$ along with other risk factors), Comparator (not included in this study), Outcome (the incidence of T2DM), and Study Design (all literature selected in the form of non-experimental quantitative research that could answer research questions). Publication characteristics included the year of publication within 10 years (2013 to 2022), the language used (English), and publication status in the form of journal articles and scientific research. The exclusion criteria were the literature in the form of a literature review or book review, the literature used experimental studies, the literature documents were incomplete, and the literature did not cover the variables to be studied.

After reviewing all literature texts at this stage, the next step was to enter the total number of excluded literature and the reasons for the exclusion. At this stage, the literature eliminated consisted of 22 pieces that were unsuitable for research inclusion and exclusion criteria (study on population, exposure to $PM_{2.5}$, T2DM as health outcome, non-experimental quantitative research). In the final stage (inclusion), 12 pieces of literature were included for systematic review research.

Inclusion

In this final step, the amount of literature that had been selected and was ready for data analysis was entered (Figure 1). In this study, only one database was used: remote-lib.ui.ac.id. Therefore, no further stage was carried out to filter literature from other databases.

Results

A total of 12 pieces of literature were synthesized in this study (Table 1) obtained from several databases connected to the UI Library database. The oldest literature published was in 2013, and the latest was in 2021. The 12 pieces of literature synthesized were international journal articles with research locations in the United States, China, England, Canada, Mexico, Germany, Hong Kong, Chinese Taipei, and Denmark. In these pieces of literature, T2DM was discussed in terms of case prevalence and incidence. The case of T2DM in these pieces of literature was obtained with percentages ranging from 1.5%-12.9% for case incidence and 4.24%-14.9% for case prevalence. While the characteristics of subjects for each piece of literature also varied, on average, they were adults and elderly.

Table 1. Distribution of Individual Characteristics and Type 2 Diabetes Mellitus in the Literature

Literature	Author (Year)	Study Location	The Number of Study Subjects	Individual Characteristic							T2DM	
				Age (years, mean±SD)	Sex (%)		BMI (kg/m³, mean±SD)	Smoking (%)			Prevalence	Incidence
					F	M		N	Q	C		
1[16]	Liu *et al*. (2016)	China	11,847	59.3±10.6	53.5	46.5	21.5±2.1	63.8	9	27.2	14.9%	
2[17]	Liu *et al*. (2019)	China	39,191	60.3±9.3	61.9	38.1	26.2±3.7	75.3	10.1	14.6	9.5%	
3[18]	Dimakakou *et al*. (2020)	England	502,504	61.5±4.5	39.5	60.5	≥25		-		4.24%	
4[19]	Park *et al*. (2015)	The United States	6,814	64.3±9.4	47	53	31±5.9	49.8	38.1	12.6	12.01%	12.1%
5[20]	Qiu *et al*. (2018)	Hong Kong	61,447	72.4±5.5	65.5	34.5	27.5±2.5	65	20.7	14.3	13.5%	1.5%
6[21]	Hansen *et al*. (2016)	Denmark	28,731	56.5±8.1	100	-	26±4.4	31.5	28.5	40		3.9%
7[22]	Weinmayr *et al*. (2015)	Germany	3,607	60.5±7.5	44	56	29.8±4.7	39	40	21		9.1%
8[23]	Lao *et al*. (2019)	Chinese Taipei	147,908	46.7±12	37.2	62.8	26±3.7	66.2	6.8	27		3.2%
9[24]	Li *et al*. (2021)	England	449,006	56.6±8.1	54.3	45.7	27.4±4.8	55	34.6	10.4		4.06%
10[25]	Coogan *et al*. (2016)	The United States	33,771	38.7	100	-	≥25	53.5	46.5			12.9%
11[26]	Chilian-Herrera *et al*. (2021)	Mexico	2006: 2,275 2012: 2,297	51±13	60	40	≥25	47.2	22.8	30		8.3%–11.3%
12[27]	Chen *et al*. (2013)	Canada	62,012	54.9	48.7	51.3	≥25	76		24		10.1%

Notes: F = female, M = male, BMI = body mass index, N = never smoking, Q = already quit smoking, C = currently smoking, T2DM = type 2 diabetes mellitus.

Based on the results of identifying $PM_{2.5}$ risk factors in the literature (Table 2), the risk factors are $PM_{2.5}$ exposure duration and $PM_{2.5}$ exposure concentration, which were discussed in all 12 pieces of literature. In contrast, the risk factors for $PM_{2.5}$ exposure are discussed in five pieces of literature: Literature 1, 4, 6, 7, and 12. Individual risk factors, including age and body mass index (BMI), are discussed in all 12 pieces of literature. Risk factors for sex are discussed in 10 pieces of literature: Literature 1, 2, 3, 4, 5, 7, 8, 9, 11, and 12, and smoking behavior risk factors are discussed in 11 pieces of literature: Literature 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, and 12. The next step is synthesizing the analysis of the relationship of each risk factor from the significance of the relationship obtained from the results of statistical measurements in each literature.

Table 2 shows that $PM_{2.5}$ exposure (exposure duration and $PM_{2.5}$ concentration) has a significant relationship with T2DM, except in Literature 4. However, in Literature 4, T2DM has a significant relationship with the distance between population and source of pollutant. Among individual characteristics, T2DM has a significant relationship with age, sex, BMI, and smoking behavior, except in Literature 7, in which no significant relationship is found between T2DM and smoking behavior.

Table 2. Relationship between $PM_{2.5}$ Exposure and Individual Factors with Type 2 Diabetes Mellitus

Literature	$PM_{2.5}$ Exposure			Individual Characteristic							T2DM	
	Exposure Duration (Years)	$PM_{2.5}$ concentration (μg/m³)	Distance between population and source of pollutant	Age (years)	Sex (%)		BMI (kg/m³, mean ± SD)	Smoking (%)			Prevalence	Incidence
					F	M		N	Q	C		
1[16]	1*	72.6*	Higher cases of study subjects living in rural areas*	>58*		46.5*	>25*			27.2*	14.9%	
2[17]	3*	73.4*	No data	≥65*		38.1*	≥25*	75.3*	10.1*		9.5%	
3[18]	1*	(per 1 μg/m³ yearly average increase of $PM_{2.5}$ concentration)*	No data	>56*		60.5*			No data		4.24%	
4[19]	3	17.3	27% of study subjects lived near the road**		47**		>30**	49.8**	38.1**		12.01%	12.1%
5[20]	12*	35.8*	No data	≥65*	65.5**		25-30 and >30*	65*	20.7*		13.5%	1,5%
6[21]	5*	18.1*	Estimated incidence of cases in population living in urban areas: 3.5 per 1,000 persons per year**		-			31.5*	28.5*			3.9%
7[22]	2**	16.7**	Living within 100 m of a main road has a >30% higher risk of T2DM*	≥65*		56*			No significant relationship			9.1%
8[23]	2*	26.5*	No data	>46*		62.8*	<23*			27*		3.2%
9[24]	1*	10*	No data	>56*		45.7*	25-30 and >30**			10.4*		4.06%
10[25]	9*	13.9*	No data	≤40**	-		<25*			46.5*		12.9%
11[26]	6*	25.5*	No data	>64**		40*	25-30 and >30*	47.2*				8.3%–11.3%
12[27]	6*	10.6*	17% of study subjects living in urban areas; 83% of study subjects living in manufacturing sector area**	<50 and >65**		51.3*	25-30 and >30**		No significant relationship			10.1%

Notes: F = female, M = male, BMI = body mass index, N = never smoking, Q = already quit smoking, C = currently smoking, T2DM = type 2 diabetes mellitus.
* Significant relationship ** No significant relationship

Discussion

Description of T2DM in the Literature

The T2DM case in the 12 selected pieces of literature was obtained with percentages ranging from 1.5%-12.9% for case incidence and 4.24-14.9% for case prevalence (Table 1). The case prevalence rate in this literature was considered high because it was greater than the global case prevalence rate in 2021 (10.5%) and the estimated global case prevalence in 2030 (11.3%) and 2045 (12.2%), according to the IDF.[2] Among the 12 pieces of literature included, there were studies with a prevalence of T2DM cases above 10.5%: Literature 1 (14.9%) in China, Literature 5 (13.5%) in Hong Kong, and Literature 4 (12.01%) in the United States.[16,19,20]

The Relationship between the Incidence of T2DM and Risk Factors for $PM_{2.5}$ Exposure

The exposure duration factor in this study was identified through the duration of observation of air quality, especially $PM_{2.5}$. The duration of long-term exposure was considered to influence the incidence of T2DM, a chronic disease. This is in accordance with the definition of diabetes mellitus, a chronic metabolic disease that requires a long time to cause damage to organs or affect the body.[28] Based on the results of the literature synthesis (Table 2), it can be seen that the 10 pieces of literature[16-18,20,21,23-27] taken show a significant relationship between the duration of $PM_{2.5}$ exposure and the incidence of T2DM. In these pieces of literature, long-term observations of $PM_{2.5}$ concentrations significantly associated with T2DM were observations with a minimum time span of 10 months (considered equal to one year) and a maximum of 12 years. A study conducted for ten months in China showed that long-term exposure to $PM_{2.5}$ was positively associated with a significant increase in the prevalence of T2DM, fasting blood glucose, and HbA1c levels, while, in this study, there was a 14.9% prevalence of T2DM.[16] Furthermore, a study conducted over 12 years in Hong Kong shows that long-term high exposure to PM2.5 can increase the risk of prevalence and incidence of T2DM in the population, which in this study had a T2DM prevalence of 1.5% and 13.5%.[20]

Regarding the $PM_{2.5}$ concentration factor in influencing the incidence of T2DM, 10 pieces of literature[16-18,20,21,23-27] indicated a significant relationship, with the average concentration of annual $PM_{2.5}$ ranging from 10 μg/m^3 – 73.4 μg/m^3. The average concentration of all these studies exceeded the threshold value for air pollution concentrations from the World Health Organization (WHO), in which annual average maximum concentration for $PM_{2.5}$ is 5 μg/m^3.[29] High concentrations of $PM_{2.5}$ exposure, especially with continuous intensity or long-term duration, would have an impact on individual health, including T2DM.[6] For comparison with case prevalence data, the highest concentration of $PM_{2.5}$ exposure was in a study in China, in which the annual average was 73.4 μg/m^3 with a prevalence of 9.5%.[17] The lowest $PM_{2.5}$ exposure concentration was in a study conducted in Germany, in which the annual average concentration was 16.7 μg/m^3 with a prevalence of 9.1%.[22] Even though the difference in prevalence was small, a study in China had stronger results as it had a significant relationship, while a study in Germany showed no significant relationship.

Apart from the risk factors of duration and concentration, the risk factor of distance between the respondents and $PM_{2.5}$ was also considered to play a role in influencing the T2DM risk. Several pieces of literature[16,19-21,27] have been synthesized to discuss the distance between places. In those pieces of literature, all the study subjects were living with a primary source of exposure, such as roads (Table 2). In a study stating a significant relationship, Literature 1 discussed that location of residence was related to $PM_{2.5}$ exposure in causing the incidence of T2DM. In this study, the cases were mostly identified in rural areas.[16] Meanwhile, a study in Germany discussed the distance between the location of residence and the main road, where respondents who lived 100 meters from the main road had >30% higher risk of experiencing T2DM compared to respondents who lived >200 meters from the main road.[22] Another study related but not significant stated that study subjects living in urban areas with a density of ≥5,220 people/km^2 had a higher incidence of T2DM compared to the subjects living in rural and provincial areas.[21] Then, Literature 12 stated that the T2DM risk was higher in study subjects living in Southern Ontario with higher $PM_{2.5}$ concentration levels compared to urban areas because it was an area with a large manufacturing sector.[27]

Individual Risk Factors

Literature 1 showed a significant relationship in the prevalence of T2DM in older individuals, which in this study was above the median age (>58 years).[16] Literature 2 showed that individuals aged ≥65 years had a significant association with increased fasting blood sugar levels and a higher prevalence of T2DM.[17] Literature 3 stated that individuals aged >56 years had an increased risk of T2DM.[18] Literature 5 showed that individuals ≥65 years of age were associated with a significant increase in the prevalence and incidence of T2DM.[20] Literature 8 and 9 showed that individuals older than the average population significantly increased the incidence of T2DM.[23,24] These results aligned with previous theories related to age risk factors that changes in human physiology decrease after 40 years, and the increased risk of T2DM and glucose intolerance can be due to degenerative factors, which is decreased body function at the age of ≥45 years.[30,31]

Literature 1 showed a significant result: the risk of T2DM was 22%-135% higher in male respondents.[16] Literature 2 showed a significant relationship between study subjects who were older and male.[17] Literature 3, 8, and 9 also stated that males were more experienced with T2DM.[18,23,24] However, different results were found in Literature 5, which showed a significant relationship in female study subjects.[20] The results from the literature largely showed differences from previous theories, showing that females likely have a higher risk of developing T2DM because their cholesterol was higher than males and the amount of fat in body weight was higher in females, which makes females at 2-3 times higher risk of suffering from T2DM.[32,33]

Literature 1, 2, and 3 showed a significant relationship: subjects with higher BMI values had a higher risk of the impact of $PM_{2.5}$ exposure on the risk of T2DM.[16-18] Literature 5, 6, 9, and 11 showed that the study subjects who were overweight (BMI 25 kg/m^3-30 kg/m^3) and obese (BMI ≥30 kg/m^3) had a higher risk of the impact of $PM_{2.5}$ on T2DM.[20,21,24,26] In contrast, Literature 8 showed contradictory results in which long-term $PM_{2.5}$ exposure had a stronger relationship with developing T2DM in study subjects with a BMI <23 kg/m^3.[23] Literature 1, 2, 3, 5, 6, 9, and 11 show strengthening of the obesity risk factor statement that overweight (BMI 25 kg/m^3-30 kg/m^3) and obesity (BMI ≥30 kg/m^3) could increase risk of T2DM.[16-18,20,21,24,26]

Several pieces of the literature showed a significant relationship between smoking behavior and the influence of $PM_{2.5}$ exposure on the risk of increasing T2DM. A significant relationship was shown in Literature 1, 8, and 9 among smoker respondents,[16,23,24] in Literature 2, 5, and 6 among respondents who had stopped and never smoked,[17,20,21] and in Literature 11 among respondents who had never smoked.[26] Smoking behavior with the incidence of T2DM in the literature has mixed results but tends to be different from previous theories. The risk factors for smoking behavior can be a risk in increasing the incidence of T2DM in individuals who are or have consumed it, especially with frequent intensity. This is because insulin sensitivity can decrease due to nicotine and other dangerous chemicals contained in cigarettes, which, after some time, can potentially cause diabetes.[34-37] Results that were not in line with this theory were identified due to other factors included in the statistical analysis, the study area tending to have high concentrations of air pollution, and the uneven number of respondents regarding smoking behavior characteristics.

Overview of the Relationship between $PM_{2.5}$ Exposure and Individual Risk Factors in Increasing the Risk of T2DM

According to previous theories, T2DM was hypothesized to result from the interaction of environmental, biological, and behavioral risk factors.[6] Air pollution as one of the environmental variables has been proven to disrupt the body's balance, such as insulin resistance, changes in endothelial function, inflammation, increased blood pressure, and changes in blood lipid levels, which, over time, could cause T2DM.[6] Several previous studies also showed that this increased risk was related to pollutant concentration, duration of pollutant exposure, and location.[9,10] Apart from that, the smaller particle size was also thought to increase its effect in causing the incidence of T2DM.

Previous theories and studies were proven through this systematic review study. Based on the analysis of relationship between each variable in risk factors for $PM_{2.5}$ exposure in increasing the incidence of T2DM, 12 pieces of synthesized literature showed that the influence of $PM_{2.5}$ exposure in increasing the risk of T2DM could be seen in long-term exposure, ≥1 year, with high exposure concentrations even above the WHO's threshold value (>5 $\mu g/m^3$), and within a distance or location with industrial activity or high mobility which could work together to increase the T2DM risk. In addition, individual risk factors were also analyzed on the population at risk. The individual risk factors in this study identified to increase the risk of exposure to $PM_{2.5}$ in causing T2DM were older respondents (>45 years), male, with an overweight BMI (25 kg/m^3-30 kg/m^3) and obesity (≥30 kg/m^3), and having a habit of never or quitting smoking showed an association in increasing the impact of $PM_{2.5}$ exposure on T2DM.

The diverse result is because diabetes mellitus is a multifactorial disease, which means that many environmental and individual factors can influence it.[38] In addition, the incidence and prevalence of T2DM vary by geographic region because genetic and environmental factors influence the epidemiology of diabetes.[39] People of different ethnic origins have different specific phenotypes, which increases their risk of developing T2DM.[40] This is proven through systematic studies which use data from the research literature in various countries.

Limitations

This study used a systematic review method because the initial study was conducted during the COVID-19 pandemic, and large-scale social restrictions made it difficult to carry out in the field. The shortcoming of this study was the literature came from various countries, but not from Indonesia because of the keywords' limitations. Therefore, not all the literature in the database was identified. Besides, the variables could not fully describe the relationship between $PM_{2.5}$ exposure and the incidence of T2DM, and many other variables from the environmental and individual factors can still be studied.

Conclusion

Exposure to $PM_{2.5}$ has a relationship with the risk of T2DM through three interrelated risk factors: long-term exposure duration, exposure concentration, and location of residence. Individual risk factors related to the impact of $PM_{2.5}$ exposure on T2DM are age, sex, BMI, and smoking behavior. T2DM is a multifactorial and chronic metabolic disease, which, in this study, is proven to occur due to interactions between environmental and individual factors over time. Since no study has examined the relationship between PM2.5 exposure and T2DM in Indonesia, it is crucial to conduct a study to determine the effect of $PM_{2.5}$ exposure on the incidence of T2DM in the population in Indonesia. For systematic review studies, it is also recommended to use a larger database to capture more studies and produce better study results. Studies on other risk factors (compounds or other particulates) and individual factors (lifestyle, economics, and education) must be included to elevate the knowledge and prove previous theories.

Abbreviations

IDF: International Diabetes Federation; T2DM: type 2 diabetes mellitus; UI: Universitas Indonesia; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols; BMI: Body Mass Index; WHO: World Health Organization.

Ethics Approval and Consent to Participate

This study has been approved by The Research and Ethics Committee of the Faculty of Public Health, Universitas Indonesia, with Ethical Clearance Letter Number: Ket- 375/UN2.F10.D11/PPM.00.02/2022.

Competing Interest

The authors declare no conflict of interest.

Availability of Data and Materials

This study used secondary data from scientific journal articles published in 2013-2022, accessed from the Universitas Indonesia Library database (Remote-Lib UI).

Authors' Contribution

RPS conceptualized, designed, and interpreted the data. LF prepared the initial draft and editing.

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