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Espacios y Territorios

Causal relationships of health risk of air pollution in industrial area

Relaciones causales del riesgo para la salud de la contaminación del aire en una zona industrial

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Abstract

Air contamination is one of the serious problems for the environment and the health of society. Air contamination risk assessment, health effects assessment tools are used to identify the place and time of public health effects and risk prevention strategies to reduce negative health effects. Considering that there may be a relationship between factors affecting risk, in this study, interactions between them are investigated using Fuzzy Decision Test and Experimental Evaluation Method (fuzzy DEMATEL). The cause of the health air

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contamination risk in an industrial area are the activity of industrial complexes and port (D+R=45.98, D-R=2.09) and the presence of hydrogen sulfide (46.82, 2.61), benzene (50.87, 2.87), sulfur dioxide (43.87, 4.32) and PM10 (53.51, 5.63) and the effects of these factors will affect the amount of carbon monoxide (39.56, -4.47), ozone (38.80, -4.20), nitrogen dioxide (50.33, -1.62) and PM2.5 (44.18, -1.26). Hospitals and nursing homes (49.01, -2.58), schools (50.99, -0.59), storage and industrial facilities, roads (45.72, -0.59), urban core (51.38, -0.55) and Natural zones, agriculture and waterways (48.86, -0.17) are affected by other factors. Population density is also affected by cause factors. Population density has a two-way relationship with PM2.5. The main human and social factors include GDP per capita and urbanization rate. Hydrogen sulfide has a one-way relationship with population density. People who work in certain industries may be exposed to higher amounts of hydrogen sulfide than the general population. These industries include the production of rayon textiles, pulp and paper factories, oil and natural gas drilling operations, and wastewater treatment plants. Therefore, by controlling the activity of industrial complexes, port and the amounts of hydrogen sulfide, benzene, sulfur dioxide and PM10 in the ambient air can be prevented from the effects after that.

Keywords: Air contamination, Cause and Effect Modeling, Environmental Planning, Health Risk, Fuzzy DEMATEL

Resumen

La contaminación del aire es uno de los graves problemas para el medio ambiente y la salud de la sociedad. La evaluación del riesgo de contaminación del aire, las herramientas de evaluación de los efectos en la salud se utilizan para identificar el lugar y el momento de los efectos en la salud pública y las estrategias de prevención de riesgos para reducir los efectos negativos en la salud. Considerando que puede existir una relación entre los factores que afectan el riesgo, en este estudio se investigan las interacciones entre ellos utilizando la Prueba de Decisión Difusa y el Método de Evaluación Experimental (DEMATEL difuso). Con base en los resultados, las variables causantes en este sistema incluyen complejos industriales y puerto, sulfuro de hidrógeno, benceno, dióxido de azufre y PM10. Las variables de efecto en este sistema incluyen monóxido de carbono, ozono, hospitales y residencias de ancianos, dióxido de nitrógeno, densidad de población, PM2,5, escuelas, instalaciones industriales y de almacenamiento, carreteras, núcleos urbanos y zonas naturales, agricultura y vías fluviales. La causa del riesgo de contaminación del aire para la salud en una zona industrial es la actividad de los complejos industriales y portuarios y la presencia de sulfuro de hidrógeno, benceno, dióxido de azufre y PM10 y los efectos de estos factores afectarán la cantidad de monóxido de carbono, ozono, nitrógeno. dióxido y PM2.5. Los hospitales y residencias de ancianos, las escuelas, las instalaciones industriales y de almacenamiento, las carreteras, el núcleo urbano y las zonas naturales, la agricultura y las vías fluviales se ven afectados por otros factores. La densidad de población también se ve afectada por factores causales. Por lo tanto, al controlar la actividad de los complejos industriales, el puerto y las cantidades de sulfuro de hidrógeno, benceno, dióxido de azufre y PM10 en el aire ambiente se pueden evitar los efectos posteriores.

Palabras claves: Contaminación del aire, Modelado de causa y efecto, Planificación, Riesgos para la salud, Fuzzy DEMATEL.

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1. Introduction

Multi-criteria decision analysis (MCDA) is a branch of theoretical science and mathematics (Belton & Stewart, 2002; Hansen & Devlin, 2019). There are many MCDA techniques (Bisdorff et al., 2015; Cinelli et al., 2021; Greco et al., 2016), These methods score and rank problem options (Cinelli et al., 2021). MCDA techniques are applied in order to make sustainable development decisions. Despite the uncertainty in all decision-making environments, the analysis of incomplete and ambiguous information in decision analysis is still a challenge (Ezbakhe & Pérez, 2021). This method is also used in environmental planning processes (Keisler & Linkov, 2014; Kiker et al., 2005; Mustajoki & Marttunen, 2017; Voinov et al., 2016). Due to the existing relationships between political, social, environmental, ecological and economic parameters, decision-making in environmental projects is not a simple process (Kiker et al., 2005). Environmental planning and decision-making is essentially an analysis characterized by social, environmental, economic and political judgments. Several options must be considered and evaluated according to different criteria, resulting in a large volume of data that is often inaccurate or contains uncertainty

(Lahdelma et al., 2000). Multi-criteria assessments are also used in the prioritization of health ***effect***s and support the decision-making processes of health risk management. Multicriteria analysis has been used by various researchers as they investigate different health ***effect***s by modeling the preferences of policymakers and practitioners (Montibeller et al., 2020). Air contamination is undoubtedly a serious risk to human health and the main ***cause*** of environmental deterioration and destruction of natural ecosystems (Anwar et al., 2021), which should be investigated at local, regional and global scales. Industrial activities are known to be important sources of emissions of a wide range of pollutants (European Environment Agency (EEA), 2018; Prüss et al., 2016; Rovira et al., 2020). Most people are exposed to various air pollutants for a long time. This exposure can have important ***effect***s on the natural environment and human health (Apte et al., 2018; Chriscaden & Osseiran, 2016; Janke, 2014; Jung et al., 2019; Lelieveld et al., 2019; Rich et al., 2019; Wu et al., 2019). A very dense population and a large number of emission sources are important factors in air contamination in city (Izquierdo et al., 2020; Stewart et al., 2017). Air contamination may be a major open wellbeing issue. A critical number of epidemiological ponders appear the relationship between air quality and a wide run of unfavorable wellbeing impacts, inferring the noteworthy part of air contamination in causing disease burden. Air health risk assessment can play a key part in advancing person and worldwide wellbeing and disease prevention (Bhat et al., 2021). Risk assessment is used as a tool to evaluate health ***effect***s in order to determine the place and time of the ***effect*** on public health and risk prevention strategies to reduce negative health ***effect***s (McKenzie et al., 2012). Fuzzy DEMATEL is used to determine the relationship and action and reaction between factors affecting risk, so the factors affecting risk are identified. These factors have long-term or short-term effects on risk (Ahmadi et al., 2020). There are various methods, such as some MCDM methods, by which causal relationships between factors affecting risk are analyzed. DEMATEL is a method that has the most suitable features among MCDM methods. In other MCDM methods, elements are considered independent, but DEMATEL plays a role in identifying relationships between elements. In this method, causal relationships between factors are shown in a diagram. Therefore, the concept of strength of relationships becomes quantitative and the findings become simpler. DEMATEL achieves practical results to solve complex problems, especially by using fuzzy logic, the results are displayed more accurately and realistically. One of the features of this method is that it is easy to implement and saves time and money. Therefore, this method is combined with fuzzy logic to achieve the research objectives (Mohammadfam et al., 2019). The health risk of exposure to pollutants has been investigated in different studies using different tools. Jia et al. (2021) studied the odor pollution and health risk of industrial activities in a river delta in China. Based on Jia et al. (2021) study, benzene and 1,3-butadiene were the main pollutants for non-carcinogenic and carcinogenic risks of VOCs. Luo et al. (2021) mentioned that the main sources of polycyclic aromatic hydrocarbons in Beijing, China were traffic and burning of coal or biomass. Bauwelinck et al. (2022) concluded that long-term exposure to air contamination was associated with an enhancement risk of lung cancer mortality. According to the results of the study by Zhang et al. (2021), the release of industrial materials was not the main ***cause*** of carcinogenesis, and the use of solvents was the main ***cause*** of carcinogenesis risk. The results of Yang et al. (2021) showed that exposure to air contamination is positively related to the possibility of visual impairment. Tunsaringkarn et al. (2015) pointed out that the risk of a mixture of chemicals may be much greater than the risk of each chemical alone. Liu et al. (2021) calculated the regional ***effect*** by combining carcinogenic risk values with population density. The use of population density provides a more comprehensive perspective to assess regional ***effect***s. In Li et al. (2020) research on asphalt pavement, 1,3-butadiene, benzene, and trichloroethylene had the highest chronic health risks for humans. According to the studies, it is clear that the pollutants released from different industries have harmful ***effect***s on people's health. Examining the health risk of exposure to pollutants and their ***effect***s is done through various tools, but in no research case, the internal relationships between hazard and exposure parameters have been considered in the calculation of health risk. Therefore, this issue is addressed in this research.

2. Method

2.1. Hazard and exposure assessment

DEMATEL technique stands for Decision Making Trial and Evaluation. The DEMATEL technique was presented by Fonetla and Gabus in 1971. This method examines the intensity of relationships in the form of scoring, searches for feedbacks along with their importance, and accepts non-transferable relationships (Jeong & Ramírez, 2018; Shahi et al., 2018). One of the methods of analyzing system parameters that is used to solve complex problems and determine relationships between criteria is the DEMATEL method (Gupta & Barua, 2018). This technique is based on matrix instruments and graph theory, using the knowledge and experience of experts and groups, it creates a visual structure based on the causal relationship between different parameters (Jassbi et al., 2011; Lin & Wu, 2008; Wu & Lee, 2007), It calculates the degree of ***effect*** and degree of ***cause*** of each parameter, maps a causal diagram, determines the group to which the parameters belong (***cause*** group or result group), and then identifies the main parameters that best deal with the problems (Kiani & Standing, 2018). It is important that this method creates a direct relationship matrix between different parameters based on experts' opinions. Because real problems are often complex, the degree of ***effect*** between different parameters is uncertain, and the understanding of the problems varies among experts. Therefore, their decisions are usually not quantifiable values but are described by terms such as "better", "satisfactory", etc. In order to deal with the problem of fuzzy evaluation of experts, in this research, the fuzzy triangle method is chosen to process the initial direct correlation matrix to improve the accuracy of the DEMATEL method. Obviously, the form of triangular fuzzy numbers is not suitable for matrix functions. It should be defuzzified, transformed into values, and a new direct correlation matrix should be created (Selerio et al., 2022; Zhang et al., 2023). Based on the standard process of risk assessment, hazard and exposure assessment is performed using the Fuzzy DEMATEL method in this study as follows (Seker & Zavadskas, 2017):

1. Hazard identification (concentration of polluting elements) and exposure parameters
2. Distribution of Fuzzy DEMATEL questionnaire among experts
3. Using a fuzzy scale to evaluate experts' opinions
4. Making the fuzzy average matrix of direct connection
5. Normalizing the fuzzy matrix of direct connection
6. Calculation of the complete connection fuzzy matrix
7. Calculation of the ***effect***s and ***cause***s of hazard and exposure parameters
8. Determining the final weight of hazard and exposure parameters
9. Draw a ***cause*** and ***effect*** diagram

10. Interpretation of hazard and exposure assessment results

2.2. Correlation and causation

If the values of two or more variables change so that by enhancing or reducing the value of one variable, the value of the other variable also changes (although it may be in the opposite direction); For example, if an enhancement in working hours is associated with an enhancement in income, there is a relationship between the two variables "working hours" and "income". If the two variables "price" and "purchasing power" are considered, assuming a fixed income, the ability of a person to buy these goods reduces with the enhancement in the price of goods. The correlation coefficient indicates the degree and direction of the relationship between two or more variables. But the correlation between variables does not mean that when one variable changes, the values of other variables also change. Causality shows that one event is the result of another event; it means that there is a causal relationship between these two events. This is also called ***cause*** and ***effect***. In theory, it is easy to distinguish these two types of relationships. One action or event can ***cause*** another (e.g., smoking enhances lung cancer risk) or it can be related to another (e.g., smoking is associated with alcoholism but does not ***cause*** alcoholism). However, in practice, it is difficult to establish clear ***cause*** and ***effect*** compared to establishing correlation.

3. Results

Based on extensive review of scientific sources and collection of experts' opinions, fuzzification of connections matrices, their de-fuzzification and determination of definitive relationships between factors in the system have been designed. Figure 1 shows the internal relationships of the variables. Ozone, carbon monoxide, sulfur dioxide, PM2.5, hydrogen sulfide, industrial complexes and port, storage and industrial facilities, and roads do not have internal relationships, but other factors have internal relationships.

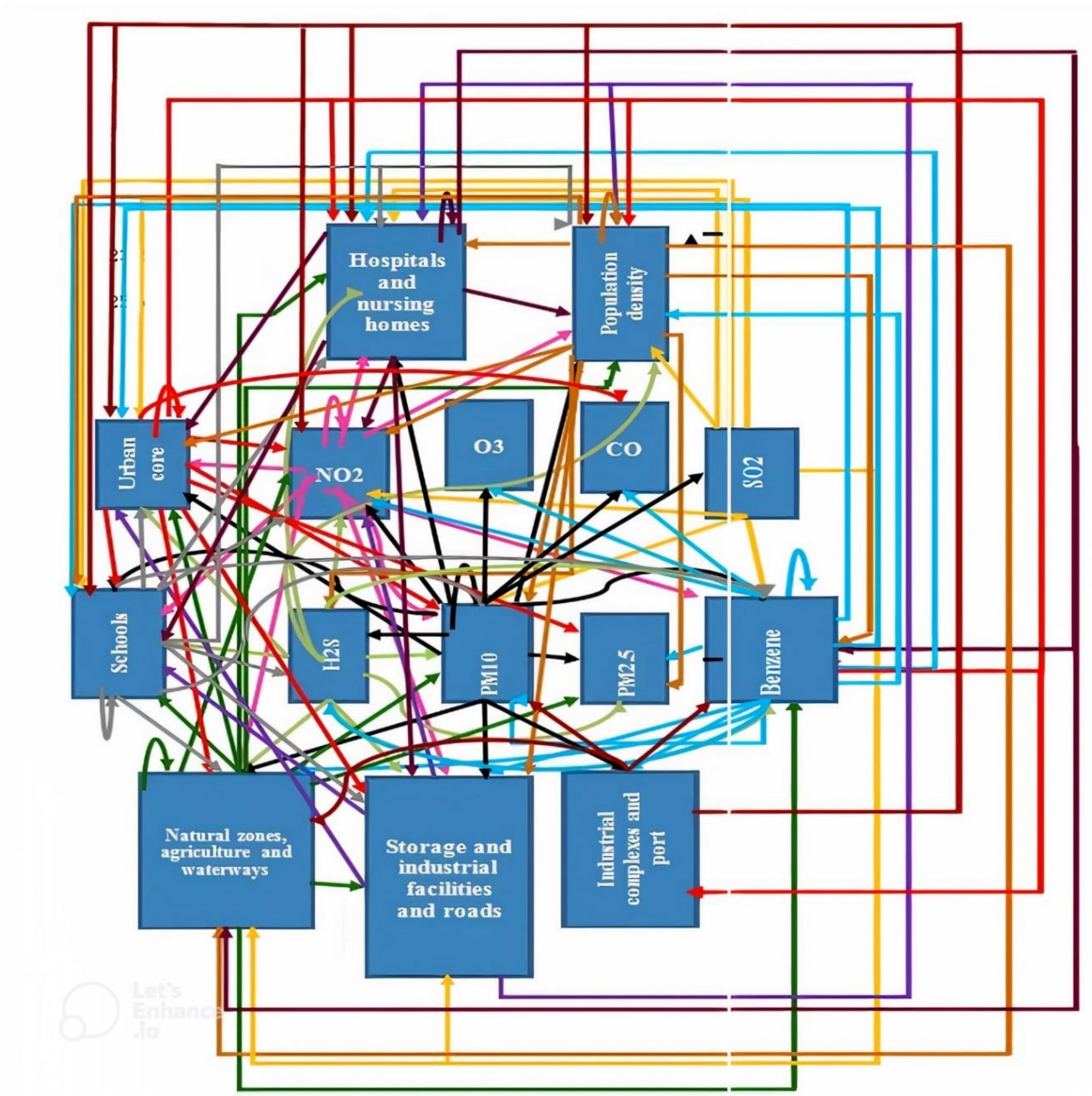

Figure 1. Internal relationships between variables in the air contamination risk system in the industrial area

Source: Own elaboration

According to Table 1, PM10, benzene and population density have the highest influencing degree (D) and the highest direct and indirect effects on other factors in the air contamination system.

Table 1. The final output of the causal model

Criteria	D	R	***D+R***	***D-R***	W	Wfinal

NO2	24.36	25.97	50.33	-1.62	48.71	0.07
O3	17.30	21.50	38.80	-4.20	34.59	0.05
CO	17.54	22.01	39.56	-4.47	35.08	0.05
SO2	24.09	19.78	43.87	4.32	48.19	0.07
H2S	24.72	22.10	46.82	2.61	49.43	0.07
PM10	29.57	23.94	53.51	5.63	59.13	0.08
PM2.5	21.46	22.72	44.18	-1.26	42.92	0.06
Benzene	26.87	24.00	50.87	2.87	53.74	0.08
Natural zones, agriculture and waterways	24.35	24.52	48.86	-0.17	48.69	0.07
Storage and industrial facilities and roads	22.56	23.15	45.72	-0.59	45.13	0.06
Industrial complexes and port	24.04	21.94	45.98	2.09	48.07	0.07
Urban core	25.41	25.97	51.38	-0.55	50.83	0.07
Schools	25.20	25.79	50.99	-0.59	50.39	0.07
Hospitals and nursing homes	23.22	25.79	49.01	-2.58	46.43	0.07
Population density	25.67	27.16	52.83	-1.49	51.34	0.07
Total					712.69	1.00

Source: Own elaboration

The influenced degree (R) and the degree of effect of population density, nitrogen dioxide and urban core are more than other factors of the system. The interplay of PM10, population density and urban core in the investigated system is greater than other factors, so they interact more with other factors of the system. Also, the incoming and outgoing effects of these factors are greater than other factors in the system. The cause variables in this system include industrial complexes and port, hydrogen sulfide, benzene, sulfur dioxide and PM10, and the effect variables in this system include carbon monoxide, ozone, hospitals and nursing homes, nitrogen dioxide, population density, PM2.5, schools, storage and industrial facilities and roads, urban core and natural zones, agriculture and waterways.

***Cause* group:**

PM10 ranks 1st ***D-R*** (5.6), highest ***D*** (29.6), 7th in R (23.94) and 1st ***D+R*** (53.5) in the system. PM10 has the highest ***D-R*** among causal agents. This means that this factor has an ***effect*** on enhancing air contamination risk in the industrial area more than any other factor. Therefore, PM10 is the first ***cause*** of air contamination risk in the industrial area and is the driving factor to deal with the problem of air contamination in the industrial area. PM10 has a very high influenced degree and moderate influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Sulfur dioxide ranks 2th in D-R (4.3), 9th in D (24.1), 14th in R (19.78) (lowest ***R*** value), and 13th in D+R (43.9) of the system. This means that this factor has a great ***effect*** on air contamination and sulfur dioxide is the second ***cause*** of air contamination risk in the industrial area, but it has a low influenced degree and very little influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Benzene ranks 3th in D-R (2.9), 2th in D (26.9), 6th in R (23.99) and 5th in D+R (50.87) of the system. Benzene is the third ***cause*** of air contamination risk in industrial area, it is the driving factor to deal with the problem of air contamination risk in an industrial area, and it has high influenced degree and moderate influenced degree compared to other factors involved in enhancing air contamination risk in industrial area. Hydrogen sulfide ranks 4th in D-R (2.6), 6th in D (24.7), 10th in R (22.1), and 9th in D+R (46.8) of the system. Hydrogen sulfide is the fourth ***cause*** of air contamination risk in the industrial area. It has a moderate influenced degree and a weak influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Hydrogen sulfide is an independent factor in the health air contamination risk and can affect only a few other factors. Industrial complexes and ports rank 5th in D-R (2.1), 10th in D (24.04), 12th in R (21.94), and 10th in D+R (46) of the system. Industrial complexes and ports are the fifth ***cause*** of air contamination risk in the industrial area. It has a weak influenced degree and influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Industrial complexes and ports are an independent factor in the occurrence of air contamination health risk and can affect only a few other factors.

***Effect* group:**

Natural zones, agriculture and watercourses are ranked 6th in ***D-R*** (-0.2), 8th in ***D*** (24.35), 5th in ***R*** (24.5) and 8th in ***D+R*** (48.9) of the system. Reducing the quality of natural zones, agriculture and waterways is the first ***effect*** of air contamination risk in the industrial area, in the sense that more than other factors, natural zones, agriculture and waterways are affected. It has a moderate influenced degree and influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. The urban core ranks seventh in ***D-***

R (-0.56), fourth in ***D*** (25.4), third in ***R*** (25.968) and third in ***D***+***R*** (51.4) in the system. The urban core is the second ***effect*** of air contamination risk in the industrial area. Therefore, the urban core is greatly affected by air contamination. The urban core is the main issue in planning to reduce air contamination that should be considered. However, the urban core is a feature of the ***effect*** type that cannot be improved directly. It has a great influencing degree and influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Storage and industrial facilities and roads are ranked 8th in ***D-R*** (-0.59), 12th in ***D*** (22.6), 8th in ***R*** (23.2) and 11th in ***D***+***R*** (45.72) of the system. Therefore, storage and industrial facilities and roads are independent and can only be affected by a few other features. Storage and industrial facilities and roads are the third ***effect*** of air contamination risk in the industrial area. Therefore, it is ranked third in terms of being affected by air contamination. It has low influencing degree and moderate influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Schools ranked ninth in ***D-R*** (-0.6), fifth in ***D*** (25.2), fourth in ***R*** (25.79) (the same ***R*** value as hospitals and nursing homes), and fourth in ***D***+***R*** (50.99) in the system. Schools are one of the main problems that must be solved. However, schools are features of the ***effect*** type that cannot be improved directly. Schools are the fourth ***effect*** of air contamination risk in the industrial area. Therefore, it ranks fourth in terms of being affected by air contamination. It has a high influencing degree and influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. PM2.5 ranks 10th in ***D-R*** (-1.26), 13th in ***D*** (21.5), 9th in ***R*** (22.72) and 12th in ***D***+***R*** (44.2) of the system. Therefore, PM2.5 is independent and can only be affected by a few other properties. PM2.5 is the fifth ***effect*** of air contamination risk in the industrial area. Therefore, it is ranked fifth in terms of being affected by air contamination. It has very low influencing degree and moderate influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. The population density ranks 11th in ***D-R*** (-1.5), third in ***D*** (25.7), first in ***R*** (27.2) and second in ***D***+***R*** (52.83) of the system. Population density is the main problem in the issue of air contamination in the industrial area that needs to be solved. However, it is a property of the ***effect*** type that cannot be improved directly. Population density is the sixth ***effect*** of air contamination risk in industrial area. Therefore, it ranks sixth in terms of being affected by air contamination. It has a great influencing degree and influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Nitrogen dioxide ranks 12th in D-R (-1.6), 7th in D (24.4), 2th in R (25.97) and 6th in D+R (50.33) of the system. Nitrogen dioxide is the main problem in the industrial area that needs to be solved. However, it is a property of the ***effect*** type that cannot be improved directly. Nitrogen dioxide is the seventh ***effect*** of air contamination risk in the industrial area. Therefore, it ranks seventh in terms of being affected by air contamination. It has a medium influencing degree and a very high influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Hospitals and nursing homes rank 13th in ***D-R*** (-2.6), 11th in ***D*** (23.2), 4th in ***R*** (25.79) (the same ***R*** value as schools), and 7th in ***D+R*** (49.01) in the system. The main problem is air contamination in the industrial area that needs to be solved. However, they are properties of the type of ***effect*** that cannot be improved directly. Hospitals and nursing homes are the eighth ***effect*** of air contamination risk in the industrial area. Therefore, it is ranked eighth in terms of being affected by air contamination. It has a low influencing degree and a high influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Ozone ranks 14th in ***D-R*** (-4.2), 15th in ***D*** (17.3) (lowest ***D*** value), 13th in ***R*** (21.5) and 15th in ***D+R*** (38.8) (lowest ***D+R***) of the system. Ozone is an independent factor and can only be affected by a few other properties. Ozone is the ninth ***effect*** of air contamination risk in the industrial area. Therefore, it is ranked ninth in terms of being affected by air contamination. It has very little influencing degree and influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Ozone has less interaction with other factors of air contamination system in industrial area. Carbon monoxide ranks 15th in ***D-R*** (-4.5), 14th in ***D*** (17.5), 11th in ***R*** (22.02) and 14th in ***D+R*** (39.56) of the system. Carbon monoxide is an independent factor and can only be affected by a few other properties. Carbon monoxide is the tenth ***effect*** of air contamination risk in the industrial area. Therefore, it is ranked 10th in terms of being affected by air contamination. It has a very low influencing degree and low influenced degree compared to other factors involved in enhancing air contamination risk in the industrial area. Figure 2 depicts the ***cause*** and ***effect*** relationship diagram of air contamination system factors.

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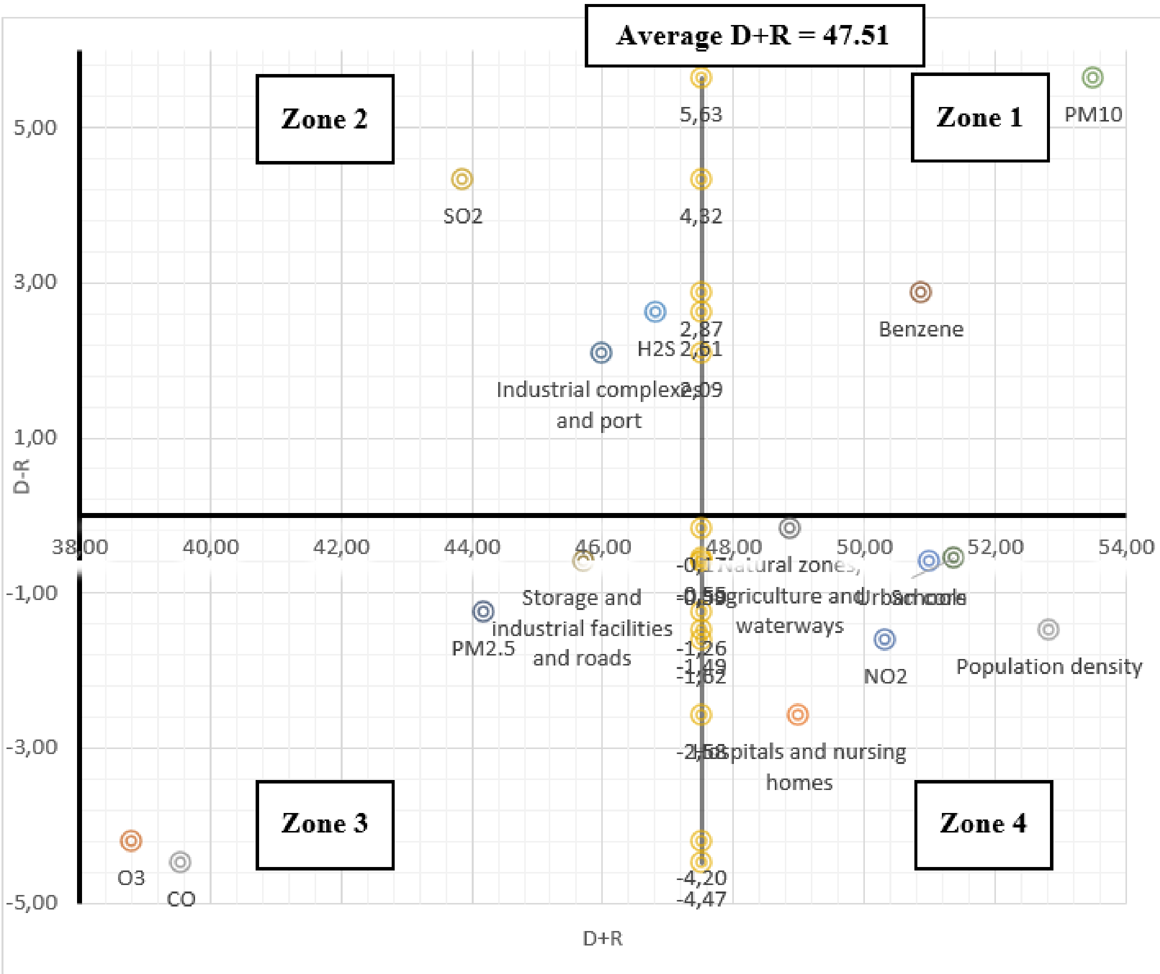

Figure 2. ***Cause*** and ***effect*** diagram of system factors

Source: Own elaboration

According to Figure 2, the variables of region 1 show the most important variables affecting air contamination risk and pollution in the industrial area. This area includes PM10 and benzene variables. Therefore, to improve the air quality in an industrial area, it is necessary to prioritize measures to improve these variables. In region 2, hydrogen sulfide, industrial complexes and port, and sulfur dioxide were variables that were less important than the first group (region 1). Therefore, to design the second line of corrective measures, these variables should be considered. In region 3, the variables were influenced by the variables in region 1 and region 2 while they influenced the variables in region 4. These variables included storage and industrial facilities and roads, PM2.5, carbon monoxide and ozone. It should be noted that the variables of this group were considered as independent variables and should be considered for the design of the third line of corrective measures. In the case of region 4, the ***effect*** variables were population density, schools, urban core, nitrogen dioxide, hospitals and nursing homes, and natural zones, agriculture, and waterways. Although these variables are important, they must be considered for the design of the last line of corrective measures and usually must be improved indirectly.

4. Discussion

All the following comparisons will be from the perspective of the health air contamination risk. No direct relationship was observed between nitrogen dioxide and ozone. According to the study of Han et al. (2011), due to the chemical coupling of O3 and NOx, the amount of O3 and NO2 are related. Therefore, the response to the reduction of NOx emissions is significantly non-linear (Photochemical Oxidants Review Group, 1997) and any decrease in the amount of NO2 is always gone along by an enhancement in the amount of O3. According to the study of Chan et al. (2021), nitrogen dioxide plays an important role in the formation of tropospheric ozone (Crutzen, 1970). In addition, high levels of NO2 may be toxic to humans. In conditions where the air quality is suitable, sunlight leads to the decomposition of nitrogen dioxide and ozone is formed, and after the reaction with nitric oxide, nitrogen dioxide is formed. When hydrocarbons from fuel combustion are released into the air, nitrogen dioxide is produced as a result of the reaction of hydrocarbons, which eventually forms more ozone. Finally, the amount of nitrogen dioxide and ozone increased, and smog may even form in summer (Reigate & Banstead, 2022). No relationship was observed between NO2 and CO. In the research of Kovač et al. (2013), it was found that there is a strong correlation between CO and NO2. Because CO affects the oxidation of NO to NO2, CO and NO2 pollutants are significantly correlated with each other. Based on the results of this study, the relationship between nitrogen dioxide and sulfur dioxide is not observed in the direction of a one-way reaction of nitrogen dioxide with sulfur dioxide, but the relationship between sulfur dioxide and nitrogen dioxide was confirmed in the direction of a one-way reaction of sulfur dioxide with nitrogen dioxide. Nitrogen dioxide was identified as the ***effect*** and sulfur dioxide as the ***cause***. The ***effect*** of NO2 is greater than that of sulfur dioxide in the system. On the other hand, the influenced degree of nitrogen dioxide is more than sulfur dioxide. Also, the influencing degree of both pollutants in the system is moderate. In the study of Mallik & Lal (2012), a significant correlation between SO2 and NO2 in the industrial corridors of cities due to the emission of greenhouse gases from industries and power plants has been reported. According to the research results, hydrogen sulfide has a one-way relationship with nitrogen dioxide. In the study of Igin et al. (2010), considering the fact that H2S gas is a byproduct of oil refining with monoethanolamine in oil refineries, H2S gas mixtures may contain combined nitrogen (RNH2). Therefore, the contribution of nitric oxide formation during the burning of H2S feedstock may be very significant. Further, according to the studies of Arashidani et al. (1996) and Jarvis et al. (2010), after the rapid oxidation of nitric oxide in ambient air, oxidants such as oxygen, ozone and VOCs lead to the formation of nitrogen dioxide. Due to the high rate of oxidation, nitrogen dioxide is known as a primary pollutant. However, oxidation occurs much more slowly in the air of a closed environment. In this study, no relationship between PM2.5 and nitrogen dioxide was observed. Also, nitrogen dioxide has a two-way relationship with PM10. According to Chan et al. (2021) study, nitrogen dioxide plays an important role in the formation of aerosols (Jang & Kamens, 2001). In Y. Wang et al. (2021) study, industrial NOx emissions had a significant ***effect*** on PM2.5 concentrations. The relationship between nitrogen dioxide and benzene is two-way. In Cassar (2013) study, Pearson correlation was used to analyze the true relationship between benzene and nitrogen dioxide values. According to their study, there is a positive linear relationship between the concentration of benzene and nitrogen dioxide, showing that when the amount of nitrogen dioxide is high, benzene is high. The relationship between NO2 and natural zones, agriculture and waterways is two-way. According to the The United Nations Economic Commission for Europe (2021) report, high levels of nitrogen dioxide are harmful to vegetation; Damages foliage, slows growth, or reduces crop yield. SO2 and nitrogen oxides in water are deposited on vegetation and soil as "acid rain" and thus enhance their acidity and have adverse ***effect***s on plants and animals. The potential of ecosystems to provide ecosystem services is affected by acidification. According to the studies of Nowak et al. (2014) and Gourdji (2018), vegetation is effective in removing nitrogen dioxide through stomata simultaneously with carbon dioxide and oxygen or through water absorption in leaves. Therefore, this process is also done by potted plants and the amount of water in the plant and the growth environment have an effect on this process. Nitrogen dioxide has a two-way relationship with storage and industrial facilities and roads and a one-way relationship with industrial complexes and ports. According to the study of Gilbert et al. (2005), industrial use and the length of secondary roads had no relationship with NO2. The internal concentration of NO2 in cities and industries was significantly higher than in villages. The average concentration of NO2 inside and outside the house was not significantly different and these values were significantly more correlated. In addition, NO2 concentration values and meteorological factors were not significantly correlated, so the hypothesis that meteorological factors may have influenced the indoor NO2 concentration can be rejected. These findings clearly emphasize the relationship between NO2 concentration and local activity levels such as traffic intensity. NO2 emissions and indoor air quality change due to local activities. The results of Harrison et al. (2021) confirm that road traffic in Europe leads to the production of nitrogen dioxide and primary particulate matter. Maes et al. (2007) also noted in their study that the International Maritime Organization estimated that NOx emissions from ship activities account for about 7% of the total global emissions. Acid rain and problems related to the health of local areas such as ports due to the presence of nitrogen dioxide. The relationship between nitrogen dioxide and urban core is two-way. In fact, the urban core can ***cause*** more nitrogen dioxide emissions, and nitrogen dioxide also has an ***effect*** on the urban core and can ***cause*** problems in the city. According to the study of Mills et al. (2016), who examined 60 studies from different parts of the world, there is a significant relationship between short-term exposure to NO2 and mortality. Also, according to the study of Huang et al. (2021), long-term exposure to NO2 leads to a higher risk of mortality from all ***cause***s, cardiovascular and respiratory. The relationship between NO2 and schools is two-way. This means that schools can have an ***effect*** on the amount of nitrogen dioxide and nitrogen dioxide also has an ***effect*** on schools. According to the study of Gaffin et al. (2018), in children with asthma, the amount of NO2 inside the classroom can be associated with enhanced airflow obstruction. According to the study of Salonen et al. (2019), people's behavior is statistically significantly related to the amount of NO2 in the environment inside the school and office. Based on studies, the average NO2 concentration in schools was 30.1 μg/m3 and ranged between 6.00 μg/m3 (in Uppsala, Sweden, during spring/summer) (Smedje et al., 1997) and 68.5 μg/m3 (in Santiago, Chile, during winter) was variable (Rojas et al., 2002). The calculated average concentration (based on average reported concentrations) in school environments was 26.1 μg/m3, which was lower than the WHO guidelines (40 μg/m3 for NO2 as annual average concentration) (World Health Organization, 2010). However, according to studies by Annesi et al. (2012), Janssen et al. (2003), and Mi et al. (2006), exposure to higher concentrations of NO2 in school buildings (maximum values in the range of 40-262 μg/m3) is commonly observed. Al-Hemoud et al. (2017) and Annesi et al. (2012) mentioned that the average concentration of NO2 in several schools exceeded the permissible values of the World Health Organization (2010) in the context of long-term exposure (In a one-year period, an average of 40 milligrams per cubic meter). In a study conducted by Al-Hemoud et al. (2017), it was determined that the highest amount of NO2 (46.53 μg/m3) was formed in schools due to the use of HNO3 and Bunsen burners in laboratories. Also, gas heater without a NOx reducing chimney enhanced the concentration of NO2 and enhanced respiratory symptoms, especially in atopic children (Marks et al., 2010). The relationship between nitrogen dioxide and hospitals and nursing homes is two-way. According to the study of Lee et al. (2020), there is no significant difference in the concentration of NO2 in different departments of the hospital. However, the overall concentration of NO2 was higher in winter than in summer. Continuous use of heating systems in winter can explain this finding. Nitrogen dioxide has a two-way relationship with population density. Nitrogen dioxide is closely related to population density (Lamsal et al., 2013). Therefore, it is very important for urban areas from the point of view of the environment (Guerreiro et al., 2014; Hilboll et al., 2013; Liu & Zhu, 2013; Schneider et al., 2015; Schneider & van der A, 2012). NO2 emitted from industries, home heating devices and transportation is associated with reduced lung function and airway inflammation and related issues (World Health Organization, 2021). According to Chan et al. (2021) study, areas with higher population density have higher NO2 concentrations. Usually, the higher the level of pollution in the city, the higher the population density. No direct relationship was observed between ozone and PM2.5, and PM10 has a one-way relationship with ozone. Ozone and particle pollution can have adverse ***effect***s on people's health and are mainly the result of human activities. However, people should not assume that the two are the same. But in different ways, NOx and VOCs play a role in their formation. They are classified as precursors of particulate pollution, but not the direct source, while ozone is the result of their reaction to sunlight. In addition, its ***effect***s on people's health are also different and are not limited to asthma (Lafond, 2022). According to Li et al. (2021) findings, the large enhance in ozone in spring and summer in northern China is not related to the enhancement in emissions ***cause***d by PM reduction. In the present study, it was found that there is a one-way relationship between benzene and ozone, which is also confirmed by the study of Park et al. (2012). According to their study, oxygen species formed during ozone decomposition, oxidize benzene and produce oxygen-containing byproducts. With more ozone consumption, more benzene conversion occurs. There is no direct relationship between ozone and the urban core. Based on the results of Kang et al. (2019), the percentage of residential land use significantly affects ozone concentration. Therefore, communities with a higher percentage of residential use experience fewer days of excess ozone. In the air of cities with mixed land use and clustered and concentrated spatial patterns, it is more likely that there are fewer days with high amounts of ozone (above the health limit). This result shows that compact urban land use leads to a reduction in long-distance transportation and car driving and creates more favorable conditions for air cleanliness. Urban compaction affects transportation, energy and finally air quality. No direct relationship between ozone and population density was observed. In study of Carroll et al. (1997), the highest ozone concentrations were found in locations with relatively small populations of young children. This finding is consistent with the findings of Knowlton et al. (2004) study. Accordingly, the areas with relatively low population density correspond to the areas with the highest enhance in O3, while the areas with relatively high population density correspond to the counties where the O3 concentration reduces slightly. According to the study by Kang et al. (2019), the enhancement in population density is related to the intensification of ozone concentration, which is not consistent with the mentioned studies. Based on this, enhancing population density leads to poor air quality due to ozone concentration. Where the population density is high, the traffic is also high, and this leads to more traffic density, which ultimately leads to more pollution. As Newman & Kenworthy (1991) emphasized, modal splits, such as the percentage of trips made by public transportation, car, bicycle, or walking, are used to measure density. The total distance traveled by a car, air contamination and energy consumption are reduced by walking more and using public transport and cycling more. However, if private vehicles are used, the number of trips will enhance and this will contribute to the enhancement in air contamination. It seems that the positive relationship between population density and ozone concentration is consistent with Nam et al. (2012) argument that as population density enhances, the number

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of car trips also enhances. There is a one-way relationship between PM10 and carbon monoxide. The results of the study by Chamseddine et al. (2019) showed that while the amount of CO inside and outside the hospital was lower than the air quality standards/guidelines, the concentration of PM2.5 and PM10 measured in some places exceeded the standards by 2 to 3.5 times. Benzene has a one-way relationship with carbon monoxide. According to the study by Dalla (2017), the relationship between CO and benzene has been scientifically proven in homogeneous areas. There are many studies that detect similar concentration trends for these two pollutants in homogeneous areas. This correlation is due to the fact that the main source of emission of two pollutants is the same, among which we can mention vehicle traffic, wood burning and tobacco smoke. The lifetime of atmospheric benzene is another factor in the correlation between CO and benzene concentrations, which can last for several days. Therefore, carbon monoxide is removed from the air of the city as benzene is removed due to weathering processes. The urban core has a one-way relationship with carbon monoxide. The results of Saadi et al. (2021) showed that, regardless of the size, the amount of CO in the examined cities was low (much lower than the maximum accepted threshold standards) and the city residents were exposed to these concentrations for less than half of the hours of the day. In addition, larger cities do not have a higher concentration of CO than small cities. Exposure to high concentrations of CO in indoor air is rare and limited to some specific conditions such as proximity to CO emitting sources (Chaloulakou & Mavroidis, 2002). CO concentrations in indoor air typically do not exceed 30 ppm under normal conditions with adequate natural ventilation and air exchange rates (Agency for Toxic Substances and Disease Registry, 2009). The concentration of CO in indoor environments such as houses, schools and offices where there are no sources of CO gas emission is similar and is affected by the concentration of CO in the external environment (Fazlzadeh et al., 2015; Zhong et al., 2013). Population density has a one-way relationship with carbon monoxide. A study by Burke et al. (2015) found that population density in US cities enhanced by 30% between 1980 and 2004, while carbon emissions enhanced by 19% over the same time period. The report states that when more people live together, the number of vehicles reduces. Sulfur dioxide has a two-way relationship with PM10, but it does not have a direct relationship with PM2.5. SOx in the atmosphere can react with other compounds to form small particles. These particles pollute particulate matter. It is possible that small particles penetrate deeply into the lungs and affect people's health (U.S. Environmental Protection Agency, 2022). Sulfur dioxide has a one-way relationship with benzene. According to the study of Sinha et al. (2014), SO2 exists in the hot gas exiting the furnace in high concentration, if the optimal process conditions, such as temperature and residence time are maintained in the BTX degradation unit, it is possible for BTX to be oxidized by SO2. An experimental study was carried out by Levy & Ambrose (1959) in which the oxidation of benzene by SO2 was carried out in sealed Pyrex lamps at temperatures between 400-540°C. The reaction between them was shown at a temperature higher than 540 °C. Since the exhaust gas from the Klaus furnace is much higher than this temperature, the reaction between SO2 and BTX can take place. High temperature studies of SO2 addition to hydrocarbon flames (Cotton et al., 1971; Glarborg, 2007; Lawton, 1989) also show that SO2 reduces the concentration of aromatic hydrocarbons and soot through their oxidation. Sulfur dioxide has a one-way relationship with population density. According to Hien et al. (2014) study, no significant relationship was found between SO2 and population density, and according to Yang et al. (2017) study, population density did not have a significant long-term ***effect*** on SO2 concentration. Hydrogen sulfide has a one-way relationship with PM10 and PM2.5 and a two-way relationship with benzene. According to the study of Rolewicz et al. (2021), H2S can have negative ***effect***s on the biological treatment of other pollutants. Hydrogen sulfide has a one-way relationship with population density. People who work in certain industries may be exposed to higher amounts of hydrogen sulfide than the general population. These industries include the production of rayon textiles, pulp and paper factories, oil and natural gas drilling operations, and wastewater treatment plants. People who work in field fertilization are exposed to more hydrogen sulfide than other people. Activities such as wastewater treatment, oil and gas drilling, fertilizing, and animal husbandry can produce hydrogen sulfide beyond the normal limit. The route of exposure to this pollutant is through breathing (Agency for Toxic Substances and Disease Registry, 2016). PM10 has a two-way relationship with benzene. Based on the study of De Donno et al. (2018), the strong correlation between PM10 and benzene indicates the high contribution of vehicular traffic to urban pollution. PM10 and PM2.5 have a one-way relationship. According to the study of Chamseddine et al. (2019), the entry of particles from the outdoor environment into the indoor environment was evident with a high correlation between indoor and outdoor PM2.5

and PM10, especially during the hot season. The relationship between PM10 and natural zones, agriculture and waterways is two-way. PM can be produced naturally and its sources are dust, volcanoes, and forest fires (Nurkiewicz et al., 2010). One of the global environmental issues is the emission of suspended particles from agricultural sources. The main factors affecting PM10 emissions are the production of crops, the origin of particles, the physical and chemical properties of the soil, weather conditions, and the mechanical ***effect***s of farm operations. Several studies have been conducted to determine PM10 emission factors for tillage operations, but these emission factors vary depending on soil characteristics, especially soil texture and water content, and environmental conditions (such as relative humidity, and changes in wind speed and direction) (Péterfalvi et al., 2018). In the study of McDonald et al. (2007), it was found that enhancing tree cover reduces the initial PM10 concentration. Most river dust contains PM10 particles (Lin et al., 2016). Several factors can ***cause*** dust to be released from rivers, but one of the main ***cause***s is wind speed (Monn et al., 1995). The magnitude of wind speed often determines wind erosion rates and sediment movement patterns. After the wind erosion of the barren river bed, the fine sediment particles that were initially sitting on the river bed are removed by the wind and become the main source of PM10. So, higher wind speed may lead to higher PM10 (Lin, 2013; Yu, 2010). The effective factor on water vapor saturation and air convection is temperature and the effective factor on air currents caused by local differences in land cover, the increase and decrease of air flow and movement in sea and land gentle wind is the difference in temperature. These things indirectly affect the transmission of airborne particles. In addition, daily and seasonal temperature changes affect the water vapor saturation in the air. Higher temperatures ***cause*** more evaporation, which can create cracks in the river bed. Combined with sufficient wind speed, this can lead to wind erosion. Therefore, One of the factors that affect PM10 changes is temperature (Chan, 1996). Humidity depends on the amount of water vapor in the air. Although, the limiting factor of water vapor saturation pressure is temperature, but seasonal and regional changes or precipitation and other factors can change the amount of humidity and affect the transport of suspended particles. Therefore, one of the meteorological factors that affect the micropollen of the river is humidity (Smith et al., 2001). In addition to meteorological factors, other important factors are the moisture content of wasteland and soil. A larger area of barren riverbed indicates a greater amount of source material for riverine dust (Kim et al., 2013; Tegen et al., 2002). According to Lin et al. (2016) study, in early winter, there is a positive correlation between barren land area and PM10 concentration, but this relationship is not statistically significant in late winter. The main reason is that the coarse earth and sand particles of the wasteland create a protective armor that reduces the concentration of PM10. According to the study of Diener & Mudu (2021), plants may absorb PM through the stomata or cell membrane of its elements, especially their leaves. The relationship of PM10 with storage and industrial facilities and roads is one-way. According to the study of Fan & Lin (2011), PM particles with a size of 2.5 to 10 μm are mainly produced by mechanical processes such as suspended road dust, abrasive mechanical processes in industry and agriculture, as well as some bio-aerosols. PM10 has a two-way relationship with industrial complexes and the port. In the study of Clemente et al. (2021), port activities were the main human factor of high PM10 values. The relationship between PM10 and the urban core is two-way. A study by Kopar & Zengín (2009) on air contamination in Erzurum between 1990 and 2008 showed a reduce in SO2 and PM10 in the city center. PM10's relationship with schools is two-way. According to the study of Pegas et al. (2012), the daily value of PM10 in the classroom during the academic period was always higher than the value outside. This result is consistent with Oeder et al. (2012) findings, according to which the concentration of PM10 during teaching hours was 5.6 times higher than outdoors. The relationship between PM10 and hospitals and nursing homes is one-way. According to the study of El-Sharkawy & Noweir (2014), the highest amount of particles less than 10 microns (PM10) was present inside the hospital where there was more human activity. The relationship between PM10 and population density is two-way. An et al. (2013) study showed that an area with human settlements and fewer factories was the cleanest, followed by an area near the sea with fewer factories. However, annual PM10 concentrations were higher in more developed and densely populated areas. In addition, the area with less human inhabitants had higher PM10 concentration due to sand dust and low precipitation. The relationship between benzene and PM2.5 is one-way. The results of the study by Liu et al. (2019) showed that the effect of PM2.5 on the photodegradation of benzene in the atmosphere is known. This content was the first study that showed for the first time that based on long-term field observation data, the role of PM2.5 in the photochemical behavior of atmospheric benzene can be determined. In addition, the results showed that the regional transport of PM2.5 can seriously affect the geochemical cycle of some VOCs. The urban core has a one-way relationship with PM2.5. Population density has a two-way relationship with PM2.5. The main human and social factors include GDP per capita and urbanization rate (Wang & Fang, 2016), population density and public transportation intensity (Z. Wang et al., 2021), foreign direct investment (Z. Wang et al., 2021), and energy consumption (Wu et al., 2017) and geographic physical factors mainly including air pressure, temperature, relative humidity, wind speed, precipitation, duration of sunshine and gases such as SO2, NO2, CO and O3 (He & Lin, 2017) affect on PM2.5 concentration (Z. Wang et al., 2021). Based on the study of Z. Wang et al. (2021), population density had a significant positive ***effect*** on PM2.5 pollution in a certain area, but it had an opposite ***effect*** in nearby areas. Urbanization rate also had a negative ***effect*** on PM2.5 pollution in urban densities at the national level, but it had the opposite ***effect*** in regional and local urban densities. Benzene has a two-way relationship with natural zones, agriculture and waterways. Benzene can exist as a result of natural processes such as volcanic eruptions, the release of forest fire smoke into the atmosphere, and in some plants and animals. After rapid evaporation in the air, it is transferred to long distances. As benzene remains in the soil, it decomposes quickly and leads to groundwater pollution. By reacting with other chemical substances in the atmosphere, benzene can create smoke, which can be decomposed naturally, but by sticking to the rain and snow, it reaches the ground and leads to water and soil pollution, and poisoning of aquatic animals and as a result It prevents them from increasing. It affects their behavior, appearance and lifespan. Exposure of plants to benzene in the soil reduces their growth and in some cases they may die (National Pollutant Inventory, 2009). Some plants can absorb pollutants in the air such as carbon monoxide, benzene, formaldehyde and trichloroethylene. The relationship of benzene with storage and industrial facilities and roads is one-way. Oil refineries and petrochemical plants are the main sources of volatile aromatic hydrocarbons in the environment. Benzene is a major aromatic hydrocarbon emitted during oil refinery operations (Edokpolo et al., 2015). There is a two-way relationship between Benzene and industrial complexes and the port. According to the study of Kimmlingen (2003), Port Everglades is an important port in the state of Florida and the United States. It is located on the east coast of South Florida in the cities of Fort Lauderdale, Hollywood and Dania. The Department of Environmental Planning and Protection of Broward County has conducted research on the release of benzene in the air. With increasing activity in ports, the amount of benzene in this area increases and reaches nearby residential areas. Also, the values that were predicted in their study are against the allowed standards of air quality, their results are confirmed. Also, according to National Pollutant Inventory (2022), benzene is released into the air through industries that manufacture, use, or displace benzene, for example, in the chemical, petroleum, rubber and shoe manufacturing industries. Benzene has a two-way relationship with the urban core, hospitals, nursing homes, and schools. As the distance between the city center and the source of benzene emission enhances, the concentration of benzene also reduces (Strebel et al., 2013). The results of Mojarrad et al. (2020) showed that the BTEX concentration reduces with enhancing distance from the city center and industrial areas. On the other hand, the transportation sector is the main source of traffic pollution in the city center (Mohd & Mahmud, 2020). Pollutants produced by vehicle exhaust include hydrocarbons, CO, NO2, PM, SO2, and VOCs (The State of Queensland (Department of Transport and Main Roads), 2017). Therefore, the amount of these pollutants is high in the city centers. The relationship between benzene and population density is two-way. According to the research of Hien et al. (2014), the benzene concentration enhances with population density. The relationship between urban core and population density is two-way. Stewart (1947) and Clark (1951) stated that urban population density is a negative exponential function of distance from the city center (Cohen, 2021). There is a negative correlation between the distance to the city center and urban expansion, if non-urban lands are close to the city center, it is easier to transform into urban lands. The expansion of the city center and the surrounding environment leads to the gradual weakening of the effect of urban center density (Jin & Zhang, 2021). Storage and industrial facilities and roads have a two-way relationship with population density. According to Cooke & Behrens (2017), enhancing population density reduces the average distance to access the public transport network (which reduces trip length) and enhances personal movements along major corridors. Therefore, it improves the durability of the system. Higher density provides more potential riders for transit, which in turn can support more frequent transit service and more diverse routes. Industrial complexes and ports have a two-way relationship with population density. Population density shows the pressure of society on ports. The location variable is considered as an ordinal measure of the geographic concentration of the population and reflects the degree of urbanization of the region in which a port is located (Sornn et al., 2021).

5. Conclusion

Based on the results, the ***cause*** of the health air contamination risk in an industrial area is the activity of industrial complexes and the port and the presence of hydrogen sulfide, benzene, sulfur dioxide and PM10 and the ***effect***s of these factors will affect the amount of carbon monoxide, ozone, nitrogen dioxide and PM2.5, and hospitals and nursing homes, schools, storage and industrial facilities and roads, urban core and natural zones, agriculture and waterways receive ***effect***s from the ***cause*** factors. Population density is also affected by ***cause*** factors. Therefore, by controlling the activity of industrial complexes and ports and the amounts of hydrogen sulfide, benzene, sulfur dioxide and PM10 in the ambient air, the occurrence of ***effect***s can be prevented.

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