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Investigating volatile organic compounds and modeling their dispersion from agriculture and industry in Dabal Khazaei, Ahvaz, Iran

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Abstract

Background: The present study was conducted to investigate the type, concentration, and modeling of the emission of odorous volatile organic compounds (VOCs) caused by the industry in Dabal Khazai with AERMOD software to determine whether the activity of this industry affected the residential community or not.

Methods: In this study, volatile compounds were collected in Tedlar bags and analyzed by gas chromatography-mass spectrometry (GC-MS). The emission rate of pollutants from sources is calculated using a combination of different equations. This calculation method is suitable for industrial sources that do not have primary data to calculate the amount of pollutant emissions.

Results: The results analysis identified 59 VOC_s and determined that ketene and methane are the most important pollutants in industrial source samples. The highest release rate is 3460 g/s of ketene gas for vinasse ponds, and the lowest one is for methane gas from the primary processing unit of the sugarcane plant in the sugarcane factory. The dispersion model showed that the emission radius of concentrations higher than the standard level is only at a distance of 10 km compared to industrial sources.

Conclusion: The investigated industrial sources are not the origin of the bad smell in Ahvaz city. As a result, more research is needed to determine the bad smell in the city.

Keywords: Environmental pollutants, Smell, Ketene, Gas chromatography-mass spectrometry, Saccharum

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Introduction

Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical, or biological agent that modifies the natural characteristics of the atmosphere (1). Air pollution can cause various diseases, allergies, and even death in humans, as well as harm to other living organisms and the environment (1). Some of the major sources of air pollution include household combustion devices, motor vehicles, industrial facilities, and forest fires (2). Air pollutants are usually a mixture of dangerous and non-hazardous compounds. One of the air pollutants is volatile organic compounds (VOCs) (3). VOCs are emitted by a wide range of products numbering in the thousands, including building materials, home and personal care products, activities such as tobacco smoke and arts and crafts products, and outdoor sources such as gasoline, diesel emissions, and industrial emissions (4). Sugarcane and alcohol industries are one of the sources of volatile organic pollutants (5,6). Due to the importance of the issue, many research has been conducted in this field. According to research by Rodríguez-Félix et al the main source of odorous compounds and VOCs was reported to be "vinasse" wastewater, the most important of which are furanic compounds (7). In the study of Chen et al the VOCs obtained from alcoholic beverages were investigated, and various compounds were identified

(6). Moreover, the major VOCs of alcoholic beverages are aldehydes such as acetaldehyde, low-molecular-weight alcohols such as methanol, and higher alcohols (8,9). Also, VOCs may be produced from other wastes of the sugarcane industry, such as bagasse; in research by Laranja et al pollutants such as ketone compounds and other VOCs, including phenols, carboxylic acids, and sterols, were identified (10). Weather conditions can significantly affect the release of pollutants, making it important to investigate the method of pollutant release in different weather conditions for proper management (11,12). Many studies have also investigated the impact of meteorological conditions on the distribution of industrial pollutants (13,14). The AMS/EPA Regulatory Model (AERMOD) is a modern, steady-state Gaussian air dispersion model based on planetary boundary layer theory (15). This model can be used to determine the concentration of different pollutants in urban and non-urban areas, flat and non-flat settings, surface diffusion and height, from point areas, volume, and different types of surface sources (16). AERMOD is a steady-state plume model aimed at short-range dispersion from stationary industrial-type sources, including flat and complex terrain, urban and rural conditions, and elevated and surface releases with and without building wake effects (17). It is also suitable for simulating the dispersion of pollutants up to distances of 50 kilometers (11). Rangel et al studied the release of VOCs from the burning of sugarcane bagasse using AERMOD software and found less pollution in farms where burning was done in small sections compared to cases where burning was done in a larger section and a large mass of pollution was formed (18). In the study conducted by Chanana et al, the release of VOCs from sugarcane burning, including pre-harvest burning, was modeled using AERMOD (19). According to the study of Rangel et al, the risk assessment of pollutants from the sugarcane industry in the rural areas of northern Brazil was investigated using AETMOD. The results showed that the highest trend of pollutant dispersion was in February, while the highest concentration was observed in April (18). All studies that modeled air pollution using AERMOD required source emission rate values. In the mentioned studies, most of the basic data required for air modeling have been available. Due to the lack of basic information, including the rate of emission of pollutants from industries, research on air pollution in Iran and countries with similar conditions is limited in this field (20).

The sugarcane industry is an important industry in Iran that makes a significant contribution to the production and agricultural economy of the country (21). Cultivation and industry of Dabal Khazai is one of the important industries of Iran, which is located in Khuzestan province and 25 km south of Ahwaz city. During the operation of the units of this company, such as the vinasse evaporation ponds, chipboard factory, the primary processing unit in the sugarcane factory, and the company's purification factory, volatile and some aromatic compounds are produced (Figure 1). Industrial units such as sugarcane production, alcohol production, and chipboard factory are active in the cultivation and industry of Dabal Khazai. This research was conducted to determine the type and concentration of VOCs released from the sources using device analysis and pollutant release modeling using AERMOD software to determine whether the investigated industrial sources have an effect on creating bad odors in Ahvaz or not. In this research, by combining the results of the PID detector, gas chromatography-mass spectrometry (GC-MS), and weather information, the pollutant emission rate from industrial sources was estimated. Therefore, this method can be useful in calculating the pollutant emission rate of industrial sources. Also, by combining GC-MS results and modeling using AERMOD software, the evaluation of the environment was done in sugarcane cultivation and industry.

Materials and Methods

Sample collection and identification of VOC

First, the low-flow SKC sampling pump was calibrated by a rotameter with a volume of 0.1 L/min. In the next step, the output part of the pump was connected to the input part of the one-liter Tedlar bag by a pipe. After closing the circuit, 80% of the volume of the one-liter bag was filled with air in about 8 minutes (EPA 0040) (21). Sampling of the pond was done at a height of one meter and in the direction of the wind around the pond. Sampling was done on days with almost the same weather conditions and at a certain time. Also, to ensure the results, the samples were replicated three times. After the operation was completed, the sample was transferred to the laboratory within an hour. The samples were analyzed using a gas chromatography-mass spectrometer equipped with a DB-5J and w column. Helium was used as a carrier gas at a rate of 1 mL/min, and the detection and injector temperatures were set to 220 and 240 degrees, respectively. Then, 2 µL of the sample were removed by a 2500 µL Gazteite gas syringe and injected into the device (22). In this regard, the electron impact energy was considered for 30 minutes at 70 eV and fragments from 40 to 650 m/z. The oven temperature of the device was set to range from 60 to 246 degrees at a speed of 3 degrees per minute and was kept at this temperature. Then, the NIST library of the device was used to identify the compounds and their properties.

Estimation of the pollution rate

This step was done after the results of sampling and analysis of the samples were determined in the GC-MS machine. It was necessary to determine the release rate for each of the identified pollutants. The results of GC-MS analysis showed that more than 99% of the released

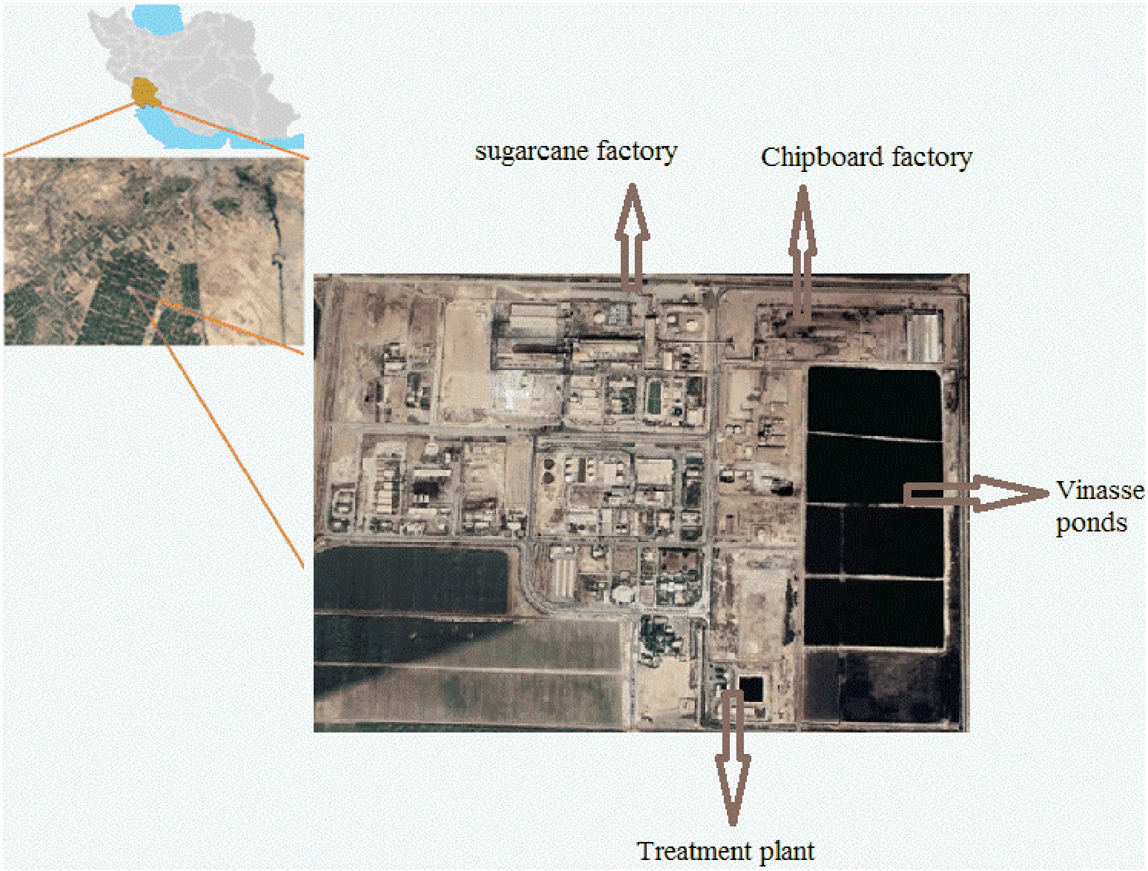

Figure 1. Location of resources in the study area

pollutants are from methane and ketene gas sources. Therefore, all the vapors emitted from industrial sources are methane and ketene gas. To ensure that the vapors emitted from the sources are the same VOC, in addition to the GC-MS results, the pollutants emitted from the sources were checked instantly using a BW Gas Alert Micro5 Series portable gas meter with a PID detector. The PID sensor in the detector can detect a wide range of VOCs and other gases (22). After the calibration process, the device was ready to be used for gas detection and measurement. The type and concentration of pollutants released from the target sources were read twice using a BW Gas Alert Micro5 series portable gas meter with a PID detector. Its results are shown in Table 1. Based on the results of the PID detector, only VOCs are being released from the sources. The findings from the PID detector are consistent with the results obtained from the GC-MS analysis. Based on the results obtained from the GC-MS analysis and the PID detector, it can be confidently concluded that the vapors emitted from the sources are the same VOCs. The results of the PID detector in the industrial environment determined that the only pollutant in the environment is VOCs. On the other hand, the results of the GC-MS device showed that more than 90% of the samples are related to methane and methane compounds. Based on this, by determining the rate of evaporation, the rate of emission of VOC pollutants is determined. At this stage, the average temperature, humidity, and average wind speed values were prepared from the Dabal Khazai meteorological station to calculate the evaporation rate. The Penman equation was used to determine the rate of evaporation according to the type of pollutant in the source.

$$Ea = 0.35 \times (ea - ed) \times (1 + u \div 10) \quad (1)$$

Where E_a is the pollutant evaporation rate in mm/day, e_a is the saturated vapor pressure of the pollutant at the average air temperature in mmHg, e_d is the actual vapor pressure in the environment in mmHg, and u is the average wind speed in miles per day.

To calculate the required parameters of the Penman equation, in the first step, the available temperature, humidity, and wind speed data were used to calculate the saturated vapor pressure of the pollutant and the actual vapor pressure.

According to the available search results, it was confirmed that the emitted pollutants are mainly hydrocarbons. This confirmation was done through GC-MS analysis and field measurements. Therefore, Antoine's equation was used to estimate the vapor pressure of each of the produced hydrocarbons (23). Equation (2) is given below.

Table 1. Volatile organic compounds in industry and its surroundings

Area%	RT	Odor	Material	Number
VOCs of the vinasse pond sample				
99.78	0.741		Ketene	1
0.02	5.846	-	Cyclotrisiloxane, hexamethyl	2
0.02	9.503	-	Cyclotetrasiloxane, octamethyl	3
0.03	14.657	-	Cyclohexasiloxane, dodecamethyl	4
0.06	17.071	-	Benzoic acid, 5-methyl-2-trimethylsilyloxy-, trimethylsilyl ester	5
0.05	19.727	-	D-Mannitol, hexaacetate	6
0.01	23.335	-	1,4-Bis benzene	7
0.01	23.384	-	Gibberellin A3	8
0.01	23.456	-	1,1,3,3,5,5-hexamethyl-cyclohexasiloxane	9
VOCs sample of the Dabal Khazai treatment plant unit				
0.29	1.210	-	1-Butanamine, N-methyl	10
55.38	1.427		Ketene	11
37.38	1.584	-	Methane	12
0.25	10.684	-	Cyclopentasiloxane, decamethyl	13
0.17	14.462	-	Cyclopentasiloxane, decamethyl	14
0.25	14.691	-	Cyclopentasiloxane, decamethyl	15
VOCs sample of chipboard factory				
0.56	0.926	-	Ammonia	16
36.74	1.264	-	Methane	17
62.70	1.409		Ketene	18
VOCs sample of the sugarcane factory				
100	1.308	-	Methane	19
VOCs sampled from 8 km East				
6.16	6.054	-	Benzo[h]quinoline, 2,4-dimethyl	20
7.49	7.695	-	N-Methylglycine	21
4.32	8.057	-	3-Ethoxy-1,2-propanediol	23
4.82	9.542	-	Cyclotetrasiloxane, octamethyl	24
2.79	12.113	-	1-(2-Adamantylidene)semicarbazide	25
8.04	14.623	-	Cyclohexasiloxane, dodecamethyl	26
30.98	16.953	-	Hexasiloxane, 1,1,3,3,5,5,7,7,9,9, 11,11-dodecamethyl-	27
22.78	19.282	-	Silane,bis(oxy)]bis[trimethyl	28
12.64	22.082	-	1H-Indole-2-carboxylic acid, 6-ethoxyphenyl	29
VOCs sampled from 8 km northeast				
99.49	0.668	-	Methane	30
0.01	9.503	-	Cyclotetrasiloxane, octamethyl	31
0.01	14.633	-	Cyclohexasiloxane, dodecamethyl	32
0.02	15.683	-	2H-1-Benzopyran-2-one, 3,4-dihydro	33
0.08	16.468	-	2H-1-Benzopyran-2-one	34
0.01	16.673	-	4-Aminobenzo-1,2,3-triazine	35
0.02	16.999	-	Cycloheptasiloxane, tetradecamethyl	36
0.01	19.437	-	2-Pyridine carboxylic acid, methyl ester	37
VOCs sampled from 16 km northeast				
0.16	1.011		Ketene	38
99.14	1.349	-	Methane	39
0.01	5.972	-	Cyclotrisiloxane, hexamethyl	40
0.02	6.081	-	Cyclotrisiloxane, hexamethyl	41

Table 1. Continued.

Area%	RT	Odor	Material	Number
0.01	9.533	-	Benzoic acid, 4-methyl-2-trimethylsilyloxy-, trimethylsilyl ester	42
0.01	12.103	-	Heptasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13-tetradecamethyl	43
0.07	14.638	-	Cyclohexasiloxane, dodecamethyl	44
0.20	17.004	-	Cycloheptasiloxane, tetradecamethyl	45
0.01	18.187	-	Cyclopropene, 3-methyl-3-vinyl	46
0.19	19.490	-	Silane, [[4-[1,2-bis[(trimethylsilyl)oxy]ethyl]	47
0.05	22.664	-	1H-Indole-2-carboxylic acid,	48
0.07	22.725	-	Tetrasiloxane, decamethyl	49
VOCs sampled from 16 km west				
0.06	1.112	-	Carbon dioxide	50
99.84	1.305	-	Methane	51
0.01	6.061	-	Benzo[h]quinoline, 2,4-dimethyl	52
0.01	14.317	-	Hydrazide cyclopropene, 3-methyl-3-vinyl	53
0.01	14.667	-	Cyclohexasiloxane, dodecamethyl	54
0.00	15.717	-	Bicyclo[3.1.0]hexane, 6-methylene	55
0.01	16.513	-	2H-1-Benzopyran-2-one	56
0.01	16.755	-	Bicyclo[3.1.0]hexane, 6-methylene	57
0.03	17.129	-	Pentasiloxane, dodecamethyl	58
0.01	19.929	-	Cyclopentyl acetylene	59
VOCs sampled from 8 km northwest				
0.05	1.072	-	Nitrous Oxide	60
99.83	1.241	-	Methane	61
0.01	6.044	-	Cyclotrisiloxane, hexamethyl	62
0.01	9.520	-	Cyclotetrasiloxane, octamethyl	63
0.02	14.674	-	Cyclohexasiloxane, dodecamethyl	64
0.01	15.736	-	1,3-Propanediamine, N-methyl	65
0.04	17.136	-	Pentasiloxane, dodecamethyl	66
0.01	18.597	-	2,3-Hexadiene, 4-diethylboryl-2-methyl	67
0.02	19.961	-	Cyclopropene, 3-methyl-3-vinyl	68
VOCs sampled from 16 km northwest				
99.83	1.262	-	Methane	69
0.00	1.769	-	1-Propanamine, N,2-dimethyl	70
0.02	14.647	-	Cyclohexasiloxane, dodecamethyl	71
0.01	16.518	-	2H-1-Benzopyran-2-one	72
0.07	17.025	-	Ethylphosphonic acid, bis ester	73
0.05	19.548	-	Silane, [[4-[1,2-bis oxy]ethyl]	74
0.01	22.831	-	N-Methyl-1-adamantaneacetamide	75
0.00	23.941	-	Cyclotrisiloxane, hexamethyl	76
VOCs of the control sample				
100	1.523	-	Methane	77

RT: retention time; VOCs, volatile organic compounds.
Area%: Percentage of area under the curve.

$$ea = p = A - (B \div (T + C))\ (2)$$

In this equation, *ea* is the saturated vapor pressure of the pollutant, *T* is the temperature of the substance, and *A*, *B*, and *C* are the Antoine coefficients for each of the hydrocarbons, which can be easily extracted from the relevant handbooks.

Calculation of the actual vapor pressure

Equation (3) is used to calculate the actual pressure (24).

$$ed = 0.6108 \times \exp\ (17.27 \times Td \div Td + 237.3)\ (3)$$

where e_d is the actual vapor pressure in mmHg and T_d is the temperature at the dew point in degrees Celsius.

Also, the following equation was used to calculate the temperature at the dew point (25).

$$Td = T - (100 - RH \div 5) \quad (4)$$

where T_d is the temperature at the dew point in degrees Celsius and RH is the humidity percentage.

According to the equations and meteorological data, the parameters necessary to calculate the emission rate were determined. After calculating the necessary parameters, the emission rate of pollutants in each of the sources was obtained in millimeters per day. After unit conversion, these values were multiplied by the area of each relevant industrial source, and the evaporation rate was obtained in meters per second per square meter. Finally, by multiplying the resulting values by the density of pollutant-producing materials in the sources (as an influencing factor in evaporation), the value of the evaporation rate was obtained in grams per second. According to the reasons mentioned above, the evaporation rate was considered equal to the emission rate. Then, the final value obtained was used in the modeling.

Modeling with AERMOD

AERMOD version 8.3 was used for modeling. For this purpose, raw meteorological data were prepared for the three months from September to December. The lower atmospheric data were obtained from the Ahwaz meteorological station, while the upper atmospheric data were acquired from the NOAA website for the same station. Then, boundary layer files and meteorological parameters required for modeling were prepared in the AERMET preprocessor for three successive months. In addition, the input for the topography module, which is a 90-meter DEM map, was prepared using WebGIS facilities. As a result, by entering two boundary layer files and meteorological parameters, the DEM file was processed, the emission rate and source characteristics were entered into the AERMOD pre-processor, and the average time interval of 8 hours was selected for the pollutant sources (26).

Results

Identified VOC

The results of the analysis of gaseous waste samples showed 59 different VOC compounds. These compounds include aromatic, aliphatic, esters, and alcohol compounds. Table 1 shows the type and level under the curve of each compound in all samples. The results showed that only in the sample 16 km northeast of the smelly polluting industry, the sources are similar.

The emission rate of pollutants

According to the working method, the BW portable device was used for the field measurement of pollutants. The results of this device are shown in Table 1. Based on the results obtained from the GC-MS analysis and the PID detector, it can be confidently concluded that the vapors emitted from the sources are the same VOC compounds. Based on this, the evaporation rate was used to determine the emission rate of pollutants. The pollutant emission rate was calculated based on the environmental data and equations. Table 2 shows the emission rate of the main pollutants from industrial sources. According to the results, the highest emission rate of ketene gas is from vinasse ponds.

AERMET module

The resulting forecast (Figure 2) showed that the winds from the north mostly have low speeds while the eastward and westward winds have higher speeds. Also, winds from the south have a significant speed. In addition, as Figure 3 displays, it is evident that 34% of the winds in this area have a speed between 2-3.60 m/s, but the fastest winds account for only 2%.

Pollutant emission model for the vinasse pond

As it turned out, the main pollutant of this unit is odorous ketene gas, which is released into the atmosphere at a rate of 4360 g/s. There is currently an internal standard of 8 hours for this pollutant. Therefore, the 8-hour emission model is drawn for this source and shown in Figure 4. The modeling results indicate that the highest pollutant concentration is at the source, and the greater the distance from the source, the lower the pollutant concentration. Based on the search results, no concentration of ketene gas has been detected near the beginning of the Ahwaz suburbs. Additionally, an increase in the concentration has been observed in some rural areas, indicating pollutant diffusion towards the north.

Pollutant emission model for the chipboard factory

In the chipboard factory, bagasse is used to produce wood in the Dabal Khazai industry. Since the production of bagasse does not persist throughout the year, the artisans are required to maintain it on a regular basis. A significant advantage of bagasse is its rich nutrients and high humidity. Therefore, it is a suitable environment for the growth of microorganisms, especially yeasts. Therefore, various impurities may be produced during the fermentation process. According to the results of the CG-MS device, the main emissions of this unit are ketene and methane gas. Based on the available search results, the emission rate of ketene from this source is 100 g/s. The results of checking the emissions from this source with the AERMOD model are presented in the four figures. The emission radius of ketene odorant gas from the bagasse storage of the chipboard plant is shorter than that of the previous unit. Concentrations higher than the

Table 2. Emission distances of pollutants from four industrial sources

Source Name	Emission rate of pollutant(g/s)	Pollutant-free air standard	Distance of the pollutant
Vinasse pond	4360 g/s ketene	0.05 ppm (8h)	The concentration in the source is 1 to 0.05 ppm up to a distance of 10 km.
Chipboard factory	100 g/s ketene and methane	0.05 ppm 10 ppm (1 h)	The concentration in the source is 0.1 to 0.05 ppm up to a distance of 5 km.
Treatment plant	60 g/s ketene 100g/s Methane	0.05 ppm 10 ppm (1 h)	The concentration of ketene gas in the source is 0.1 to 0.05 ppm up to a distance of 5 km.
Sugarcane factory	0.25 g/s Methane	10 ppm	Pollutant concentration in the source 6.3 E-02

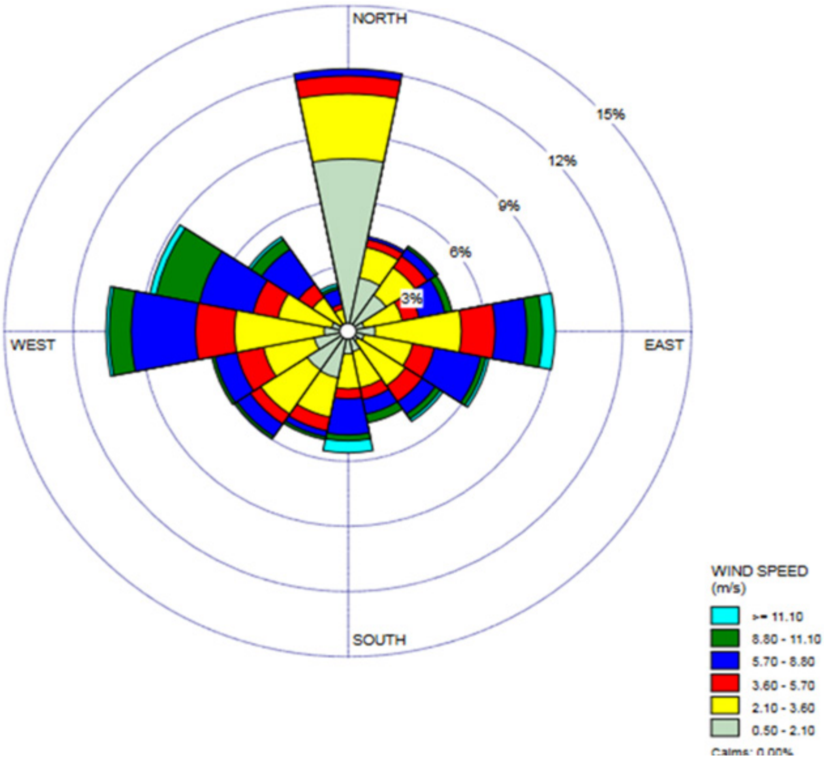

Figure 2. Wind pattern is drawn for the months of October-September and December 2020

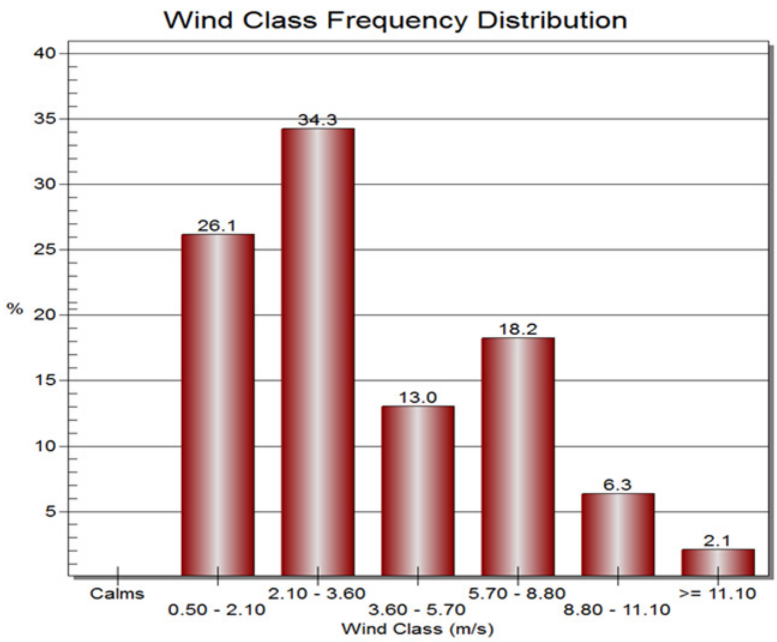

Figure 3. The percentage of wind speed classes for the months October-September and December 2022

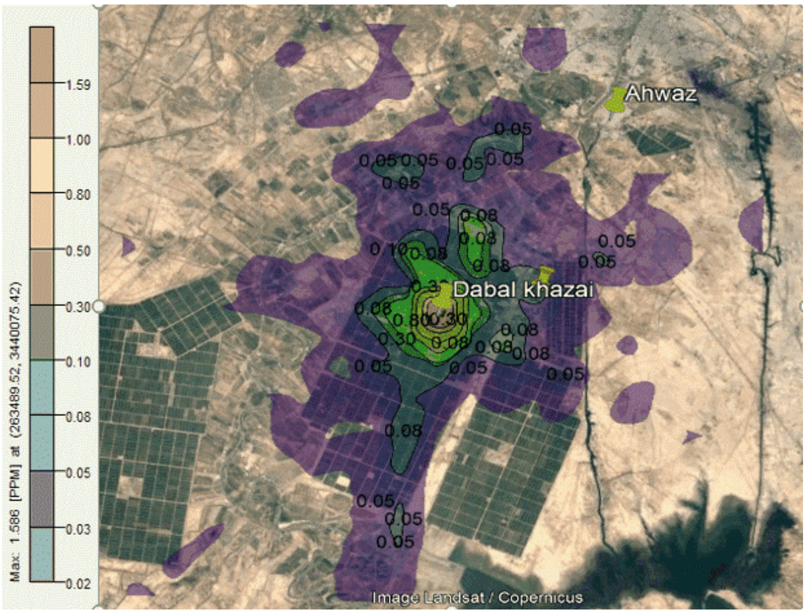

Figure 4. 8-hour ketene gas emission model for vinasse ponds

permissible limit of 0.05 ppm are only within the limits of the company itself (Figure 5).

Pollutant emission model for the treatment plant

Instrumental analysis of samples of VOC compounds from this source revealed that the main odorant of this source was ketene gas and methane. According to the search results, the emission rates of ketene gas and methane gas from this source are 60 and 100 g/s, respectively. The ketene emission model for this source is shown in Figure 6.

Pollutant emission model for the sugarcane factory

In the sugarcane factory and specifically in the sugarcane mill unit, when the sugarcane is received from the reed carrying baskets, some of the sugarcane stalks may remain on the ground, and over time, due to their special properties, fermentation reactions are expected to take place and lead to the release of gaseous compounds into the air. The mechanical analysis of the samples from this source showed that only methane gas is produced during the factory's peak activity, with a production rate of 0.25 g/s. According to the emission models (Figure 7), it is clear that the emission radius of this unit is significantly shorter than the other units, and the concentration detected for this source is also much lower than the standard limit.

Discussion

In this research, the type and concentration of VOCs were examined in vinasse evaporation ponds at Razi Alcohol and Khimmayeh Company, Chipboard Factory, Sugarcane Factory and Treatment Plant in Dabal Khazai Cultivation and Industry of Ahwaz. In addition, pollutant emissions were investigated through modeling. The instrumental analysis of the samples identified 59 different compounds of VOCs. Ketene gas and methane gas are the main compounds identified in the investigated sources. Ketene gas is a highly reactive, oxygenated, and VOC (27,28). It is a colorless gas with a penetrating odor and reacts violently with water (29). Ketene gas fumes are highly irritating and can have immediate health effects, including respiratory irritation, shortness of breath, eye and skin irritation, and central nervous system disturbances (30). Therefore, considering that the concentration of ketene gas inside the industry is high, people working in the said industry are exposed to these health problems. Although the second pollutant, methane, is emitted at a lower level than the standard, it is important because exposure to low levels of methane can also lead to lasting health problems, such as cardiovascular problems, respiratory problems, neurological disorders, memory loss, and depression (31). These findings have similarities and differences with the results of the study by Laranja et al. Based on their search results, in addition to ketone compounds, other VOCs such as phenols, carboxylic acids, and sterols have also been identified. Also, one of the reasons for its difference from the findings of the present research is the use of a different analysis method because the resulting compounds were obtained by implementing the hydrothermal ionization carbon method (10). Also, another reason for the difference between the findings of the present research and the study of Laranja et al is that the present research examined the pollutants released from the combined vinasse. The vinasse investigated in this study is the vinasse resulting from a combination of the alcohol-making unit and the yeast-making unit. While in the studies of Laranja et al, only the vinasse obtained from the alcohol-making unit was examined. Rodríguez-Félix et al also obtained different results from those of the present research.

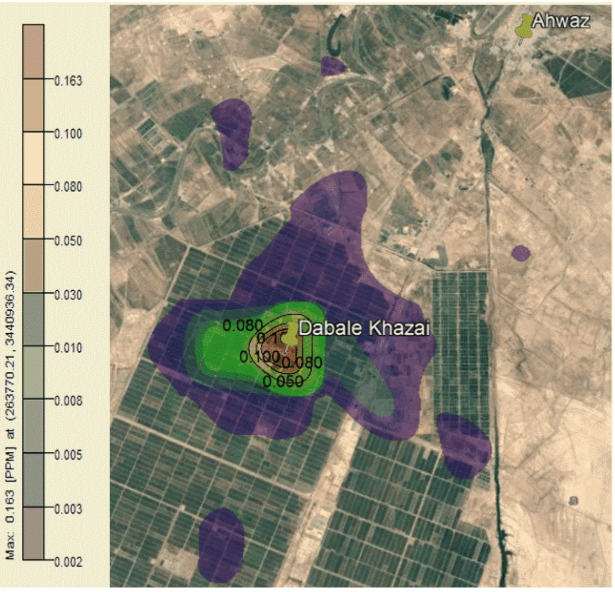

Figure 5. 8-hour ketene gas emission model for the chipboard factory

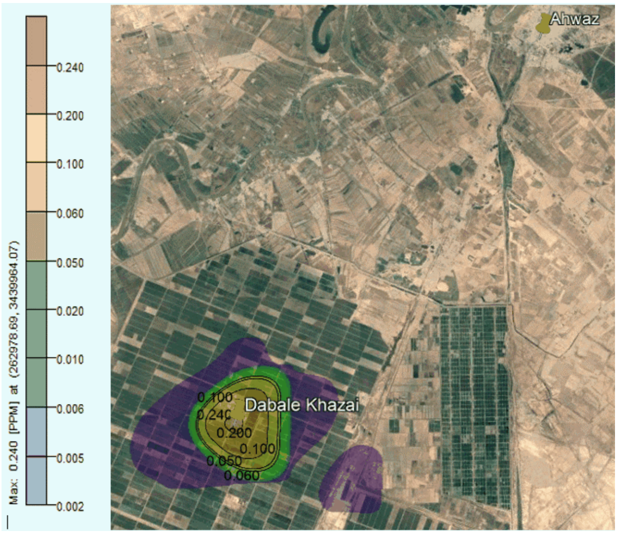

Figure 6. 8-hour ketene gas emission model for the treatment plant

Rodríguez investigated the volatile compounds obtained from vinasse wastewater using an extraction method and GC-MS, and concluded that most of the resulting compounds included furanic compounds such as furfural and organic acids such as acetic acid (7). Also, the nature of the investigated vinasses is another reason for the difference in the results. Because Rodríguez-Félix et al like Laranja et al, only investigated the vinasses of the alcohol-making unit. The findings of the present research differ from the results of Chen et al regarding the VOCs in sugarcane vinegar. Chen et al investigated the phenolic and volatile compounds in the production of sugarcane vinegar using UPLC-MS and solid phase microextraction coupled with GC-MS (6). They found that the major VOC emitted in sugarcane vinegar was benzoic acid. Monitoring the concentration of pollutants, especially those of industrial origin, is crucial for determining the level of occupational exposure of people in industrial environments (32,33). Based on the presented search results, the investigation of greenhouse gas emissions from the four investigated sources shows that the emission of ketene gas from vinasse ponds and bagasse storage in the chipboard factory in the environment of the Dabal Khazai industry is excessive. This situation requires the implementation of management measures to address this issue. The emission of VOCs from any source can be strongly affected by atmospheric conditions. AERMOD is an atmospheric dispersion modeling system that is used for environmental assessment (34). One of the advantages of the current study is the environmental assessment of industrial VOCs with AERMOD software. The findings of the study by Rangel, which analyzed the pollutant release model and its risk with AERMOD, and concluded that the highest trend of pollutant dispersion was observed in February, and the highest concentration was observed in April, which is different from the present study (18). The difference in the results of the two research studies, in addition to the characteristics of the sources, is the time of the meteorological information used in the modeling. The modeling results indicate that almost all the pollutants released from the four investigated sources in the 3 and 8-hour time frame have emission radii outside the industry. However, their concentration in these areas is lower than the set limit. The modeling results indicate that the concentration of ketene gas released from vinasse ponds is higher than from other sources. Based on the instrumental analysis of the samples inside and outside the industry, it was determined that there is no ketene gas in the sample 8 km northeast, while a very small amount of the gas was found in the sample 16 km away. The low wind speed in the region can be a reason for the appearance of ketene gas in the 16 km northeast sample. The low wind speed in the region reduces the pollutant transport, and, due to the weight of ketene gas compared to air, the pollutant is condensed, causing this gas to appear in the sample 16 km northeast. The piles of bagasse deposited in the rural areas of the region can be another reason for the presence of ketene gas in the 16 km northeast sample. According to the analysis of a sample taken inside the city of Ahwaz, there are no odorous pollutants similar to those emitted from the sources located in the cultivation and industry of Dabal Khazai. Therefore, the findings of the device analysis and the modeling results in this research are consistent because both sampling results and modeling results confirmed that the concentration of ketene gas in the source is higher than the standard. The analysis of the device showed that the samples taken 16 km northeast contained some ketene gas, indicating the presence of pollutants in that area. On the other hand, the modeling results indicated an increase in the pollutant concentration in the same area. The findings of the device analysis for the control sample collected in the city are consistent with

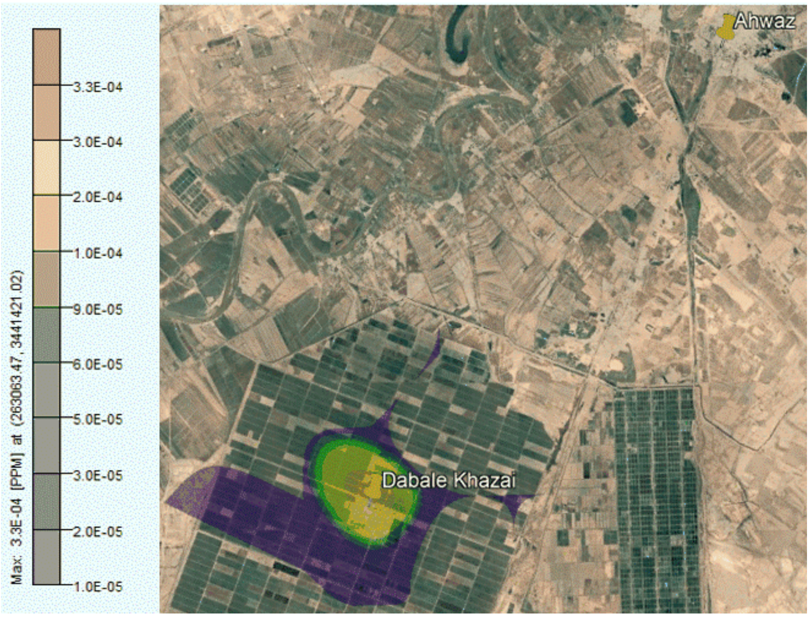

Figure 7. 8-hour Methane gas emission model for the sugarcane factory

the findings of the modeling results. The device analysis revealed that the control sample contained no odorous pollutants similar to those from industrial sources, which aligns with the modeling results that did not detect any pollutants in that range. The results indicate that vinasse ponds, chipboard factories, and sewage treatment plants are important sources of odorous pollutants. While the primary processing unit in the sugarcane factory does not appear to be a source of odorous and non-odorous pollutant production. Because it only produces odorless methane gas with a much lower concentration than the standard, and with a very limited diffusion radius. According to the search results, vinasse ponds are a significant source of foul-smelling pollutants. The emission rate of vinasse ponds is higher than that of other units, and as a result, it creates a larger emission radius for the emission of odorous pollutants than other units. However, it is important to note that the illegal concentration of pollutants released from vinasse ponds is detected only up to a distance of 10 km from the source of dispersion. Therefore, other sources with a lower emission rate than vinasse ponds will have a smaller contribution to odor production in the industry and its surroundings. Therefore, it can be concluded that the odorous pollutants resulting from the cultivation and industry of Dabal Khazai cannot be a source of odor production in Ahwaz City. Because the emission radius of the maximum concentration of this pollutant does not reach Ahwaz in the period of 3 to 8 hours. Also, the concentration of the mentioned pollutant at distances greater than 10 kilometers from the industry is less than the permissible limit. One of the limitations of the research is the absence of the desired standard sample inside and outside the country. Therefore, the standard curve laboratory method cannot be used to determine the concentration of ketene gas, as it may provide a more accurate estimate of the concentration compared to the method used in this study. Additionally, surface meteorological data for one year were not fully recorded.

Conclusion

According to the results, the main pollutants of agriculture and industry in Dabal Khazai are cotton and methane, among which vinasse evaporation ponds have the highest amount of cotton gas emission. The processing unit in the sugarcane factory was identified as the source with the lowest emissions of pollutants. Also, the pollutant distribution model results indicated that the pollutant concentration was the highest at the source and then gradually decreased. Additionally, only at a distance of 16 kilometers in the north and northeast directions, due to the low dilution of the pollutant and the presence of bagasse warehouses in rural areas, the amount of pollutant has increased slightly. Moreover, near the city, the concentration has decreased drastically. Based on this, it is concluded that the pollutants of this industry have not been confirmed as the source of the unpleasant smell of Ahvaz city. According to the results, an increase in pollutant concentration was observed in rural areas with bagasse warehouses. As a result, there is a possibility that the presence of a bagasse warehouse in the city may lead to unpleasant odors. Therefore, research should be conducted in this field in the city. Additionally, there are currently no control measures in the mentioned industry to prevent the release of pollutants, particularly in ponds. Therefore, it is recommended that the most suitable solution in this field be examined and presented scientifically.

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Competing interests

The authors declare that there are no competing interests.

Ethical issues

All ethical principles have been observed in this research (ethical code: IR.SSU.SPH.REC.1400.200.)

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