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An Investigation of SO_2 and PM10 Emissions Sourced from Residential Areas by Using Different Models of Distribution in Körfez District

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ABSTRACT

In this study, the behaviours of SO_2 and PM10 emissions emitted from the settlements located in the Körfez district in Kocaeli Province into the atmosphere was studied with the use of different distribution models. This study area is one of the most intense points in Kocaeli province in terms of industry. Therefore, the increases of region's population and residential areas have been observed in recent years. According to the obtained data from Körfez Municipality, 15 villages, 11 districts, 865 streets, 14150 buildings and 29128 housings locate in this study area. In the county, occupied area of housing buildings was found as 5,31 km^2 with the help of Google Earth program and the area of housings was divided into four different areas while modelling. In the study, firstly, the fuels and their amounts used by housings for heating were determined according to the data obtained from Kocaeli Province Environmental Status Report and then the emissions rates were calculated with the use of mass - based emission factors of US Environmental Protection Agency (EPA) and with the help of obtained data. These rates were divided into occupied spaces of residential areas and were obtained the data in g/m^2. The obtained data were entered into AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model), ISCST-3 (Industrial Source Complex Short Term) and CALPUFF VIEW (California Puff Model) programs in order to make modelling. As a result of the modelling work, daily and annual distribution maps were obtained. Analyzing maps, the obtained daily high concentrations for SO_2 were calculated as 41,13 $\mu g/m^3$ (AERMOD), 14,10 $\mu g/m^3$ (ISCST-3), 35,16 $\mu g/m^3$ (CALPUFF) and the obtained annually concentrations were calculated as 6,52 $\mu g/m^3$ (AERMOD) 4,33 $\mu g/m^3$ (ISCST-3) 10,18 $\mu g/m^3$ (CALPUFF). The estimated highly daily concentrations for PM10 emissions were calculated as 86.70 $\mu g/m^3$ (AERMOD), 69,47 $\mu g/m^3$ (ISCST-3), 92,21 $\mu g/m^3$ (CALPUFF) and annually concentrations for PM10 emissions were calculated as 17,10 $\mu g/m^3$ (AERMOD), 11,51 $\mu g/m^3$ (ISCST-3), 26,7 $\mu g/m^3$ (CALPUFF). Analyzing of distribution maps created with the use of all programs, it was seen that, according to both daily and annual time options for both pollutants, the area where the most intensity of pollution located in residential areas. When the results of dispersion model program were examined, it was revealed that the results of each program different from each other. The causes of this situation were supported by literature research and these causes were reviewed.

Keywords: Area source, AERMOD, CALPUFF, ISCST-3, Körfez District.

1. INTRODUCTION

Air pollution is defined as the presence of undesirable impurities had some detrimental effects in the atmosphere. These foreign substances can cause to damage on human health, vegetation and buildings. In addition to, they may cause to objectionable odours and fogs. These harmful substances escape into the atmosphere outside of human control. However, when viewed at a global scale, especially in the industrialized cities, the main sources of these pollutants are human activities [1]. The problem of air pollution occurred by human effects has been viewed since the ancient Roman and medieval ages according to old inscriptions. The industrial revolution in 19th century made the effects of air pollution worse and it grew and air pollution has ceased to be a local problem [2]. Nowadays, air pollution caused by human impacts consists of some reasons such as heating of housings, transportation sustaining all kinds of motorized transport, particularly energy production using fossil fuels and industrial activities [3]. Air pollution problems associated with urbanization have continued through the centuries in a way increasingly and these problems have emerged as a result of mixing of vapour to atmosphere and/or combustion of fuel such as coal, wood, natural gas, diesel and so on [4]. Air pollution consisting of human resources is emitted into the atmosphere from a variety of sources. One of these resources is the spatial source. Pollutants are dispersed into the atmosphere from a two-dimensional resource. By definition, these sources are the places community emitting less than 10 tons hazardous air pollutants or less than 25 tons conventional pollutant per year. Facilities storing raw materials or products in outdoor within any geographic area and open flaming fires and facilities storing solid waste are given as example [5]. In addition, the emissions resulting for heating purposes in buildings are defined as the spatial resources [6].

SO_2, which is one of the pollutants examined in this study, disperses into the atmosphere from many sources. The most important of these sources forms with the combustion of fossil fuels containing sulphur. SO_2 is a gas which is soluble in water and substantially in body fluids. The most important effect of SO_2 is to injury the walls of the upper respiratory and is to reduce the resistance to air flow. The effect of SO_2 forms as acute rather than chronic [7]. The other pollutant is PM10 examined in this study. In the light of current information, particulate matters consist of solid or liquid mixtures of organic matter, mineral powder, secondary inorganic pollutants and trace metals.

These pollutants are released into the atmosphere from all natural and artificial sources and they consist of heat generation plants used fossil fuels as energy, residential areas (warming-induced fuel burned) and vehicles [8]. As regards the effect of particulate matters on people, it is observed that they often lead to chronic lung disease. The majority of airborne particles cause lung inflammation and asthma and they increase the risk of pulmonary failure. When particulate matters are inhaled, some of them are caught with the help of hairs and mucus in the nose and are thrown out of here. However, remaining portions of them generally reach the lungs [9]. The deposition sites of particulates in respiratory organs and their residence times especially depend on the size of particles and some physical factors [7]. According to The World Health Organization (WHO) estimates, people lose their lives worldwide each year due to exposure to airborne particulate matter concentrations [10].

When we talk about air quality dispersion models, mathematical estimation of emissions in the atmosphere carried along is understood [11]. Convection term is the term as reaching of the pollutants to the receptor points after the come from any source of pollutants [12]. The information about dispersion of pollutants, transports and chemical transformation of them and removal of them can be obtained with the help of air quality modelling systems [13]. In this study, AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model), ISCST-3 (Industrial Source Complex Short Term) and CALPUFF VIEW (California Puff Model) programs which modelled the distribution of pollutants as mathematically were used.

As a region, Körfez district, where characterized industrialization-related air pollution, in Kocaeli Province were selected. This region is one of the most intense of counties of Kocaeli Province due to industry, urbanization density, ports and harbours, railway and highway.

2. MATERIAL AND METHODS

In this paper, the distribution maps of SO_2 and PM10 emissions sourced from fuels used for heating in buildings in Körfez district of Kocaeli Province were created with the help of AERMOD, ISCST-3 and CALPUFF distribution models. The study area is one of the most intense countries of Kocaeli in terms of industry. Therefore, the population and residential areas in the region has increased considerably in recent years. According to the obtained data from Körfez Municipality, 15 villages, 11 districts, 865 streets, 14150 buildings and 29128 housings locate in this study area. In the county, occupied area of housing buildings was found as 5,31 km^2 with the help of Google Earth program and the area of housings was divided into four different areas while modelling. Satellite image of the study area and area sources are given in Figure 1.

Figure 1. Satellite image of the study area and area sources. [14]

2.1. Modelling Programs

The first program used for modeling of the study area is a version 6.5.0 of AERMOD VIEW. AERMOD is a smoke (in the steady–state) dispersion model for used determining the effects of pollutants emitted from different sources into the atmosphere to the air quality [15] and it bases on Gaussian smoke equality. This program consists of different algorithms and structures such as planetary boundary layer and it can evaluate the distribution of pollutants such as PM10, SO_2, VOC [16]. This program has some several options such as urban and rural, flat and complex terrain and multiple sources (point, spatial, linear and volumetric sources) [15]. In addition, this modeling program has two pre-processing program as AERMET using the superficial and upper air data and AERMAP processing the digital terrain elevation data [17]. Another modeling program used for modeling of the study area is ISCST-3 model which is in "AERMOD VIEW 6.5.0" version developed and recommended by the EPA. ISCST-3 is a steady-state Gaussian modeling using for evaluate to emissions emitted from local scale sources [18]. ISCST-3 model is a modeling approach, where a variety of sources of pollution are concerned and it can offer different options about modeling of the distribution of emissions belonged to these resources. This program is defined as a suitable model for the air quality [19]. Hourly surface meteorological data are used in the calculations of the smoke rise, transport and distribution in this program [20] and hourly stability class and hight of hourly mixing is calculated by a meteorological pre-processor program called as PCRAMMET [21]. The last program used in modeling is the version VIEW 5.8.0 of CALPUFF program. This program is a multi-layered, unsteady state puff dispersion modelling and it predicts the movements of pollutants in the air in different meteorological conditions [22]. Puff models refer the pollutants smokes emitted continuously into the atmosphere as a large number of pollutant clusters [23]. CALPUFF modeling system consists of three main components. The first of these is CALPUFF program, recommended by EPA and used for modeling of long-distance transport of pollutants, the second of these is CALMET, which is a meteorological model, used for modeling of hourly wind and temperature fields in three dimensional. The last program of these is CALPOST showing graphical output [24].

2.2. Input Data of the used models

The input data used in AERMOD, CALPUFF and ISCST-3 programs is presented in Table 1.

Table 1. The input data of distribution models used in the study.

Input Data	AERMOD	ISCST-3	CALPUFF
Land use	%40 rural, %60 urban	%40 rural, %60 urban	Calculated by CALPUFF
Receptor points	1250 uniform cartesian	1250 uniform cartesian	1250 uniform cartesian
Surface roughness	0,62	0,62	Calculated by CALPUFF
Albedo	0,2145	0,2145	Calculated by CALPUFF
Bowen ratio	1,89	1,89	Calculated by CALPUFF
Distribution coefficient	Urban	Urban	Calculated by CALPUFF
Stability ratio of land	Simple + complex	Simple + complex	Calculated by CALPUFF
Time interval	Daily and annual	Daily and annual	Daily and annual

When looking at meteorological data, AERMOD and ISCST-3 models use annual data on an hourly basis [25]. Hourly meteorological data, recorded by "Lakes Environmental Software", were used in modelling for the years 2005-2009. These data include of hourly temperature, wind speed, wind direction, pressure and daily cloud height and precipitation measurements. Unlike ISCST-3, the upper air meteorological data were used in AERMOD and CALPUFF models. The wind rose was prepared by WRLPLOT which was a sub-program of AERMOD 6.5.0 according to the meteorological data belonged to region and it is presented in Figure 2.

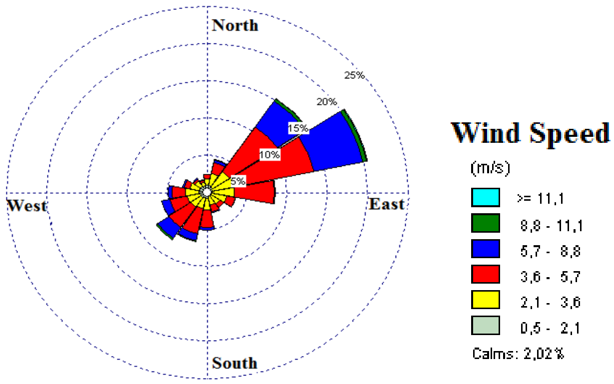


Figure 2. The wind rose belonging to the region for data of the year 2005-2009 [13].

The fuels and their amounts used by housings for heating were determined in Körfez District according to the data obtained from Kocaeli Province Environmental Status Report and then, the emissions rates were calculated. From the same report, the fuels used by housings for heating were identified as natural gas, fuel oil, wood and coal. Residential area was divided into four different areas on the map. Residential area no 1 was calculated as 1100121,7 m^2, residential area no 2 was calculated as 2206175,5 m^2, residential area no 3 was calculated as 893721,1 m^2 and residential area no 4 was calculated as 1118526 m^2 . These measurements were measured on the map approximately. The amounts of emissions of SO_2 and PM10 occurred in these sections were divided into the area of each section and finally data required for the programs was obtained as "g/s.m^2". In all residential areas, the height of spread of SO_2 emissions was considered as "20 m".

3. RESULTS AND DISCUSSION

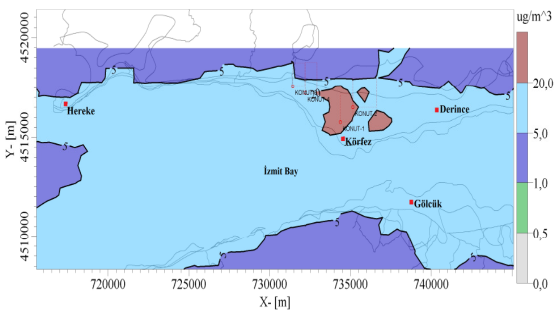
SO_2 and PM10 emissions emitted from housings (spatial area) in Körfez district of Kocaeli Province were modelled with the help of AERMOD, CALPUFF and ISCST-3 programs and the daily and annual distribution maps were created and the results are given below.

3.1. The Spatial Resource SO_2 Distributions

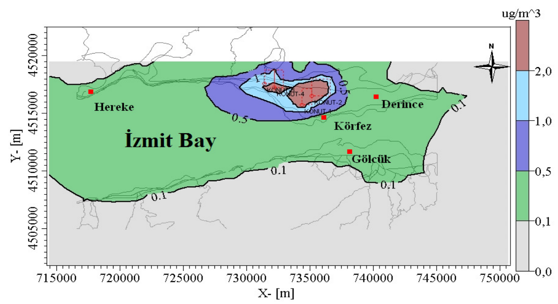
SO_2 and PM10 emissions emitted from housings (spatial area) in Körfez district of Kocaeli Province were modelled with the help of AERMOD, CALPUFF and ISCST-3 programs and the daily and annual distribution maps were created and the results are given below.

Table 2. The highest daily and annual concentrations of SO_2, obtained by modeling and their coordinates.

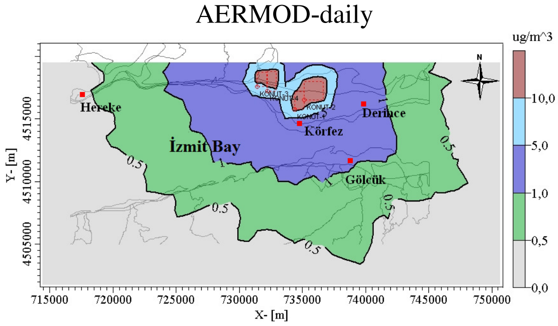
Program	Concentration (µg/m^3)	UTM Coordinates	Geographic Coordinates
	Daily		
AERMOD	41,13	x-734400,63, y-4516516,03	40° 45' 58,37" N, 29° 46' 37,78" E
ISCST-3	14,10	x-736620,63, y-4517996,00	40° 46' 44,02" N, 29° 48' 14,38" E
CALPUFF	35,16	x-732551,00, y-4517626,00	40° 46' 36,21" N, 29° 45' 20,47" E
	Annual		
AERMOD	6,52	x-734400,63, y-4516516,02	40° 45' 58,37" N, 29° 46' 37,31" E
ISCST-3	4,33	x-735140,63, y-4517256,00	40° 46' 21,58" N, 29° 47' 10,31" E
CALPUFF	10,18	x-732551,00, y-4517626,00	40° 46' 36,21" N, 29° 45' 20,47" E



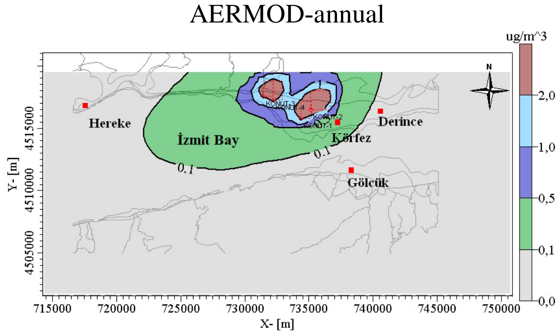
AERMOD-daily



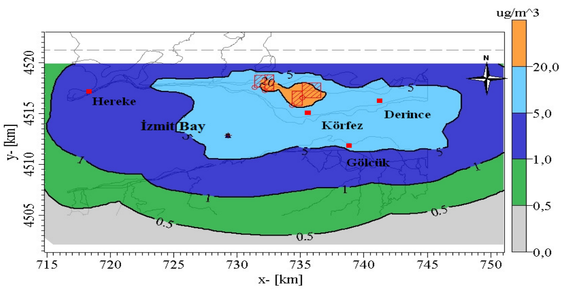
AERMOD-annual



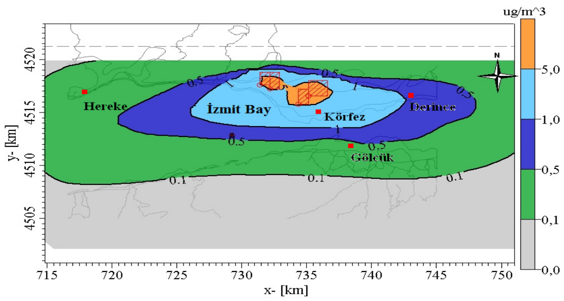
ISCST3- daily



ISCST3- annual



CALPUFF-daily



CALPUFF-annual

Figure 3. The daily and annual distribution maps obtained by modeling programs used.

It is understood that there are not much difference between the highest concentration quantities calculated by AERMOD and CALPUFF programs when the daily high concentrations are examined in Table 2. However, the daily highest concentration quantity calculated by ISCST-3 program is less from the quantities of other two programs. The concentration disparity between the programs decrease in annual option and the values approach each other.

The concentration is seen on settlement areas in district according to the program maps presented daily SO_2 distribution estimates sourced from housings and the receptor point calculated highest concentration locates on the settlement area in the town centre. Regarding the distribution directs, CALPUFF and ISCST-3 maps both distribution directions and in terms of the concentration amounts on these points close to each other. However, AERMOD distributions map created a different map. According to analyzing of annual distribution maps, the highest concentrations has occurred on the settlement areas in district as shown on daily distribution map. There is not much difference among three programs and distribution directions and levels of concentrations on these points are similar to each other according to the values of the highest concentrations.

3.2. Spatial Source PM10 Distributions

The highest concentration amounts as daily and annual obtained for PM10 emissions with the help of modeling and coordinates shown these concentrations are given Table 3 and distribution maps are given in Figure 4.

Table 3. The highest daily and annual concentrations of PM10, obtained by modeling and their coordinates.

Program	**Concentration ($\mu g/m^3$)**	**UTM Coordinates**	**Geographic Coordinates**
	Daily		
AERMOD	86,70	x-734400,63 y-4516516,03	40° 45' 58,37" N, 29° 46' 37,78" E
ISCST-3	69,47	x-736620,63 y-4516516,00	40° 46' 44,02" N, 29° 48' 14,38" E
CALPUFF	92,21	x-731551,00 y-4517626,00	40° 46' 36,21" N, 29° 45' 20,47" E
	Annual		
AERMOD	17,10	x-734400,63,y-4516516,03	40° 45' 58,37" N, 29° 46' 37,31" E
ISCST-3	11,51	x-735140,63,y-4517256,00	40° 46' 21,58" N, 29° 47' 10,31" E
CALPUFF	26,70	x-732551,00,y-4517626,00	40° 46' 36,21" N, 29° 45' 20,47" E

Even though the daily and annual concentrations of three programs are different, receptor points are close to each other according to Table 3. When considering on the basis of the concentration, the values of ISCST-3 are less than the other two programs. However, the maximum values belong to CALPUFF program.

According to Figure-4, on the map created as daily on AERMOD program, a concentration density on the residential areas in the district is seen. Moreover, the concentration density is seen on three areas on the ISCST-3 map and the receptor point calculated the highest concentration locates on the residential areas in district. When CALPUFF VIEW map is analyzed, a concentration is seen on residential area. The receptor point, the highest concentration occurs on, locates on about 2500 m on the west than the other points obtained from other two programs. Again, according to Figure 4, the map created as annual on AERMOD program, the density occurs on settlement areas in the district. The receptor point coordinates calculated by the highest concentration is same as the receptor point calculated by the daily highest concentration. In addition to, it is seen that the concentration density occurs on residential areas on two different regions. This density occurs on town centre according to CALPUFF annual distribution map. The highest concentration calculated annually, is located in the north west of the county.

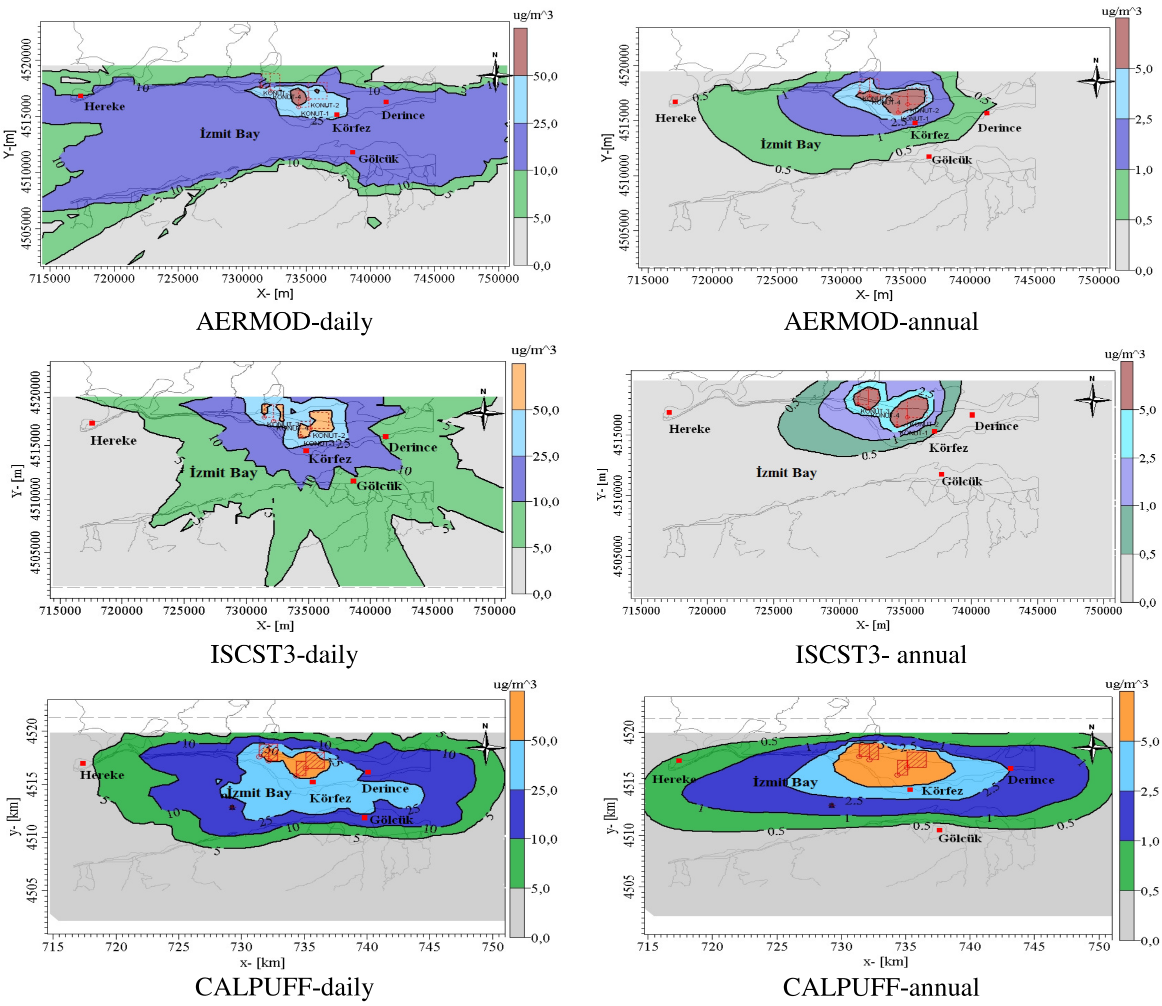


Figure 4. The daily and annual distribution maps obtained by modeling programs used.

4. CONCLUSION

The distributions of SO_2 and PM10 emissions emitted to the atmosphere from the spatial resources (residences) in Kocaeli district were examined by AERMOD, ISCST-3 and CALPUFF models and consequently the daily and annual distribution maps were created. Accordingly;

• Daily maximum concentration amounts with ranking AERMOD, ISCST-3, CALPUFF, for SO_2 41,13 µg/m^3, 14,10 µg/m^3, 35,16 µg/m^3 and annual maximum concentration quantities respectively 6,52 µg/m^3, 4,33 µg/m^3, 10,18 µg/m^3 .

- Daily maximum PM10 concentration amounts respectively 86,70 µg/m^3, 69,47 µg/m^3, 92,21 µg/m^3 and annual maximum concentration amounts in order of 17,10 µg/m3, 11,51 µg/m^3, 26,70 µg/m^3 .

When examining the results, it is observed that the programs gave different results from each other. However, both contaminant concentration magnitudes were determined by sequencing CALPUFF, AERMOD and ISCST-3. The reasons for this situation, based on information gathered from the literature, are summarized below.

AERMOD and ISCST-3

In conduction cases, when there is smoke on the centre of the mixture, ground-level concentration is considered as zero by ISCST-3 program. However, AERMOD program considered of three smoke constituents as direct smoke, advection of smoke toward the ground level and indirect smoke. Smoke rises but it is directed towards the ground again. Smoke penetrates into the mixture and dissipates on the stagnant layer slowly. AERMOD program cannot calculate the conditions which cannot be estimated the spread of smoke as calculated by ISCST-3 program and it bypasses the calculations in those conditions. This condition called as “all-or-none" on smoke distribution. Also, AERMOD program uses convective currents compared to ISCST-3. Thus, AERMOD program calculates higher estimates than ISCST-3 program [27]. Pollutant concentrations obtained by ISCST-3 and AERMOD models are also depended upon solar radiation. The effect of solar radiation in downstream concentration used by AERMOD program is different from that obtained by ISCST-3 program. In the absence of solar radiation, the estimates obtained by AERMOD program are % 55 more than the estimates obtained by ISCST-3 program. The performance of AERMOD program is within acceptable limits in conductive and neutral atmospheric conditions. However, the same condition cannot be said in stable atmospheric conditions. During the night hours (zero solar radiation) the concentration estimates of AERMOD program is higher than the estimates of ISCST-3 program. This condition indicates that the predictions made during the night hours might non- compliance [28].

The other deficiencies of ISCST-3 program are insufficient chemical conversion and the effects of surface structure calculations and characterizing the turbulence effect resulting from buildings. This also affects the estimation results. As indicated by the EPA, AERMOD program calculates more realistic the boundary layer parameters, convective distribution, complex surface structure and smoke formulations than ISCST-3 program [29]. Another factor in the emergence of different types of results may be resource type, terrain and time options. In a study carried out in a flat area covered with bushes, AERMOD program had difficulty in calculating of the distribution calculations of pollutant emissions emitted from the source [28].

CALPUFF

CALPUFF is another program which is used for modeling and it has been found more advantageous than AERMOD and ISCST-3 programs. CALMET which is used as a meteorological pre-processor program of CALPUFF program works three dimensional wind, temperature and pressure data. Therefore, CALMET needs many complex and sensitive data such as superficial and upper air layer. Besides, the region- specific parameters which is used for the calculation of mixing heights on AERMOD and ISCST-3 programs and usually entered manually such as surface roughness, albedo, land-use type (urban, rural, industrial), terrain (flat, complex, etc.) and vegetation are obtained by CALPUFF program from WEBLAKES database by giving the coordinates of the study area. Hence, the structure of study area can be illustrated in a manner closer to reality without any error. In addition, the study structure of CALPUFF program (especially, CALPUFF program is an unsteady state puff dispersion model) and algorithms are quite different than other two programs. This situation considerably increases the sensitivity of the results obtained. The disadvantage of CALPUFF program is to be quite a lot and more sensitive entries than the other two programs. Due to the sensitivity of data, the lack of data or errors which occurs program in execution process may lead to disruptions in the modelling process. This condition also causes to extend the working time and to attrition of program users. Another disadvantage of this program is long calculation time depending on used computer hardware. The computation time of the distribution of pollutants emitted from any source can be measured with days. In the case of power failure, computer failure, and so on during process, the accounts waste and the program should be run again.

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