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Street Level Modeling of Pollutants for Residential Areas

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ABSTRACT:
An effort has been done here to model the pollutants concentration using a software i.e., COPERT STREET LEVEL. This software is a Microsoft windows based software and calculates emission on street basis. Working of this model is limited to calculation of pollutants up to street level only. Area under consideration is taken from streets of Jodhpur city which are basically residential areas. Six residential areas have been considered. Pollutants are modelled considering Indian environmental conditions and compared with the actual possible data of streets. Overall analysis shows the slight variations in pollutant concentration from actual conditions. It may be due to dust storms and heating effects which are highly prevalent due to geographical conditions of Jodhpur. Pollution estimations are represented in their standard units which are further converted into Air Quality Index. This Air Quality Index is calculated from the year 2016 to 2025 in alternate year. Pollutants which are calculated using this model are carbon monoxide, oxides of nitrogen and particulate matters. This model doesn't differentiate between PM_{10} and $PM_{2.5}$. Model results shows that pollutant concentrations are increasing if number of vehicles keeps on increasing and other street characteristics remains unchanged. Most dominating pollutant was observed to be carbon monoxide.
Key words: modeling of pollutants, COPERT STREET LEVEL, air quality index, residential area pollutant estimation, carbon monoxide, oxides of nitrogen, particulate matters.

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I. INTRODUCTION

Jodhpur, popularly known as Blue City of Rajasthan is the second largest city of state. Climate of Jodhpur is generally very hot due to its nearby desert areas. Temperature variations may occur from 45^0C in summer to 0^0C in winter. Hence it faces extreme weather conditions. This geographical condition changes the environmental nature of this city. As it is fastest upcoming state of Rajasthan, it is now witnessing the large number of human population and also enormous increase in vehicular numbers. It has led to increase in vehicular pollution to a very large extent. As per the latest WHO report, Jodhpur is the most polluted city of Rajasthan and grabbed 30th position in global ranking. It is followed by Jaipur at 33rd, Kota at 58th and Udaipur at 59th position. Such a high level of pollution is not only limited to industrial or commercial areas but also it can be found in residential areas also. Air pollution modeling is a method of determining the concentration of different air pollutants at different locations and different time period mathematically either manually or with the help of some software based on certain mathematical formulae.To calculate the level of pollution in the streets of such areas, COPERT STREET LEVEL model has been used. It is a standalone MS Windows software designed to calculate emissions on a street basis. It is structured in such a way as to work alongside traffic analysis tools. It is assumed during uses of this model that environmental conditions of India have been taken nearest to matching country. But do not correspond to exact environmental conditions of Jodhpur city as this city comprises lots of dust storms and heat waves. All these values were calculated at all monitoring stations of Jodhpur.

II. MATERIAL AND METHODOLOGY

This model uses the all characteristics of streets i.e., street length, time, number and type of vehicles, average speed of vehicles, emission and geographical characteristics and passenger car equivalents etc. pollutants estimated for measurement of quality of ambient air are carbon monoxide, oxides of nitrogen and particulate matters. These pollutants can help to predict future Air Quality Index of monitored streets. These values are inserted in an excel sheet first as shown in fig. 3.1and then uploaded in this software. After uploading, an input is given for passenger car unit (PCU). PCU's of different vehicles are given in table 3.1. As this model is country specific hence, in this case, country chosen was Turkey among the entire possible available list of COPERT STREET LEVEL as India was not in its list. This step will provide us current data. For subsequent pollutant concentration calculation, it is assumed that vehicular growth in India is at the rate of 41 percent as per 2013-14 data provided by government of India. An estimated growth in number of vehicles as per this annual increment is given in table 3.2. Using this, AQI have been calculated for the year of 2016, 2018, 2019, 2021, 2023 and 2025 as per the directions given by Central Pollution Control Board (India). A street survey was conducted during the peak hour in the residential areas of Chaupasani Housing Board, Shastri Nagar, Nehru Park, Jalori Gate area, Saraswati NagarAir Force Area, Golf course. In this survey, number and type of vehicles were calculated for a length of road from monitoring station until it bends in any other direction. These observations are listed in the table 3.3 as given below.On the basis of type and number of vehicles, street length of residential areas, passenger car unit and assuming emission rates, pollutional level of different pollutant i.e., CO, particulate matters and oxides of nitrogen are calculated for the assessment year of 2016, 2018, 2019, 2021, 2023 and 2025. Emission rate and average speed of vehicle has been assumed to be constant throughout of the assessment years. The percentage of different types of vehicles as per vehicular types in the total fleet has been considered for the purpose of precise result. Their concentration values are given in different tables 3.4 to 3.9. These pollutant concentrations were further used to calculate the AQI for those streets as shown in table 3.10 to 3.15.

Model evaluation is also done on the basis of one of the field data as discuss in this section.For the purpose of evaluation of model, we pick the emission of CO concentration from the monitoring station of Chaupasani Housing Board, Sector-21 for the date of 02/03/2016 during the sampling hour of 08:00-16:00 hrs. Emission value of CO measured during this period was 0.18 mg/m^3.Estimated CO produced for the year of 2016 as COPERT Street Level model is 11881.11 gm, while for 2018 this value is 20582.32 gm. So net increase in CO production during the period of 2016-18 is 8701.21 gm. Street length of this monitoring station was measured as 44 m. We applied Grid approach for calculation of emission in this area. We considered a grid of 44 m x 44 m for this monitoring station and dispersion height is taken for the pollutant dispersion in vertically upward direction as 20 m. Then the volume of this imaginary grid will be for that one day as.

$$44 \times 44 \times 20 = 38720 \text{ m}^3$$

Hence, for the whole year volume becomes 38720 x 365 = 14132800 m^3.

This is the total volume in which dispersion of CO has taken place for the period of 1 year.

Now, the volume for 2 year becomes 14132800 x 2 = 28265600 m^3.

Amount of CO produced during these two years is, 20582.32 – 11881.11 = 8701.21 gm.

Hence rate of production CO will be:

$$\frac{8701.21}{28265600} \times 1000 = 0.31 \text{ mg/m}^3.$$

Now, as we have measured CO at monitoring station as 0.18 mg/m^3, we can multiply this value twice with 1.41 for estimating the rate at the end of second year. Multiplication value 1.41 accounts for growth rate of vehicle of 41%.

On multiplication: 0.18 x 1.41 x 1.41 = 0.35 mg/m^3.

We can see CO emission value calculated using COPERT Street Level Model is somewhat close to our field data. Keeping in mind that it will be limited to a grid of 44 m. Difference in these two values may be attributed to different assumptions involved for the use of this model. Hence, this model can be used for approximate calculation of different pollutants. But there will be number of factors will be involved like wind speed, wind direction, growth rate of different types of vehicles, construction of building and plantation etc.

III. FIGURE AND TABLES

E19

	A	B	C	D	E	F	G
1							
2							
3							
4							
5	link no	length	volumeper hr	avg speed	hour	link type	
6	1	44	29	34	09:00	1	
7	2	78	46	38	09:00	1	
8	3	36	71	30	09:00	1	
9	4	178	68	42	09:00	1	
10	5	77	142	31	09:00	1	
11	6	48	152	30	09:00	1	
12							

Figure 3.1: Input used for model in excel sheet

In the figure 3.1, column A, B, C, D, E and F contains the link id of a specific road segment,the length of the link, number of vehicles driving through, vehicle speed, the hour this activity refers to and the type of link (e.g. one way, road with two lanes etc.) respectively. Columns A, B, C, and E are the minimum required for the calculations to be performed..

Table3.1: PCU for different vehicles

S.N.	Vehicle type	Passenger Car Equivalency
1.	Motor cycle or scooter	0.50
2.	Passenger car, pickup van, auto rickshaw	1.00
3.	Agricultural vehicle, Light Commercial Vehicle	1.50
4.	Truck or Bus	3.00
5.	Truck trailer, Agricultural Tractor trailer	4.50
6.	Bicycle	0.50

Table3.2: Estimated growth in number of vehicles

S.N.	Year	Link ID					
		1	2	3	4	5	6
		Number of vehicles					
1.	2016	34	45	65	91	141	150
2.	2018	68	90	130	181	281	299
3.	2019	96	128	183	257	396	422
4.	2021	191	255	364	511	788	839
5.	2023	380	507	724	1016	1567	1668
6.	2025	756	1008	1440	2020	3116	3317

Table3.3: Number and type of vehicles on monitoring stations

Location	Link ID	Length of street	Date	Time	Bike	Cars	LCV	Total number of vehicles	Average speed of vehicles
Chaupasani Housing Board	1	44	04/03/2016	7 to 8 pm	24	10	0	34	34
Shastri Nagar, Sector-G	2	78	10/03/2016	7 to 8 pm	31	14	0	45	38
Saraswati Nagar	3	56	16/03/2016	7 to 8 pm	44	21	0	65	30
Air Force Area, Golf Course	4	178	29/03/2016	7 to 8 pm	63	28	0	91	42
Nehru Park, Sardarpura	5	97	08/04/2016	7 to 8 pm	83	51	7	141	31
Jalori Gate area	6	78	13/04/2016	7 to 8 pm	94	56	0	150	30

Table 3.4: Pollutant concentration (in gram) for the year of 2016

S.N.	Link ID	Pollutants		
		CO	NO_x	PM
1.	1	11881.1118477796	453.678536533265	49.4158506585339
2.	2	27073.6353447184	1080.83979098539	115.74277414194
3.	3	19463.0114975399	703.410661290732	77.4512975883577
4.	4	123108.942866903	5090.6547312842	533.358688548284
5.	5	89112.0997917314	3268.5483090388	359.161855447677
6.	6	59886.1892231996	2164.34049627918	238.311684887255

Table 3.5: Pollutant concentration (in gm) for the year of 2018

S.N.	Link ID	Pollutants		
		CO	NO_x	PM
1.	1	20582.3234684169	782.581384308214	88.0365335401526

2.	2	46904.6307619861	1861.80495286518	206.25942006699
3.	3	33733.0248224779	1216.12282519298	137.937097782658
4.	4	212253.164876893	8715.14111427694	945.469893156158
5.	5	153874.463703502	5627.24166777353	637.437725849023
6.	6	103447.942788932	3729.44333059181	423.007099866817

Table 3.6: Pollutant concentration (in gm) for the year of 2019

S.N.	Link ID	Pollutants		
		CO	NO_x	PM
1.	1	27099.7012121583	1029.16097968087	117.28755054199
2.	2	62212.4416721812	2465.04405133338	276.851212146341
3.	3	44300.6106849135	1596.40776998824	183.21819969747
4.	4	281140.832101321	11517.4350448685	1267.06122244285
5.	5	202281.745531812	7392.75344254639	847.65457704761
6.	6	136210.25653212	4908.4450195631	563.33756118275

Table 3.7: Pollutant concentration (in gm) for the year of 2021

S.N.	Link ID	Pollutants		
		CO	NO_x	PM
1.	1	47028.494935077	1797.01218108283	207.120577858937
2.	2	108073.610834517	4304.82792135003	489.589934262926
3.	3	76928.2256858884	2792.50785923796	323.423506525936
4.	4	487636.236328631	20066.9119655556	2236.54335660961
5.	5	351311.981254701	12929.291971384	1496.9855846286
6.	6	236420.444507181	8582.10290806098	993.964549359927

Table 3.8: Pollutant concentration (in gram) for the year of 2023

S.N.	Link ID	Pollutants		
		CO	NO_x	PM
1.	1	83045.4262471576	3211.56059615511	367.296772909763
2.	2	190635.564182221	7681.91464447548	867.694944250296
3.	3	135947.292268899	4997.48607094713	573.355405548537
4.	4	860358.9835042	35803.4361525849	3964.00278996289
5.	5	620513.619704286	23122.1213850138	2653.28008928965
6.	6	417606.046969656	15351.3936765006	1761.24643914357

Table 3.9: Pollutant concentration (in gram) for the year of 2025

S.N.	Link ID	Pollutants		
		CO	NO_x	PM
1.	1	149632.090730751	5891.69973440461	655.138071129966
2.	2	343097.280327007	14074.5156314901	1546.68384295882
3.	3	245129.77615144	9176.90983886002	1022.39558460769
4.	4	1548579.22874811	65591.4972877884	7066.02220782382
5.	5	1118292.42732928	42434.357189636	4730.25331557264
6.	6	752866.173605858	28185.0091995358	3140.07977235529

Table:3.10Predicted AQI for the year 2018

Link Id	Sub-Index for Pollutants			AQI
	CO	NOx	PM	
1	15	15	2	15
2	11	35	2	35
3	16	7	2	16
4	10	10	1	10
5	24	21	3	24
6	25	22	3	25

Table:3.11Predicted AQI for the year 2019

Link Id	Sub-Index for Pollutants			AQI
	CO	NOx	PM	
1	23	22	3	23
2	17	17	3	17
3	23	21	3	23
4	15	15	2	15
5	36	32	5	36
6	37	33	5	37

Table3.12: Predicted AQI for the year 2021

Link Id	Sub-Index for Pollutants			AQI
	CO	NOx	PM	
1	36	34	5	36
2	26	26	4	26
3	36	33	5	36
4	23	23	3	23
5	54	50	8	54
6	57	52	8	57

Table 3.13: Predicted AQI for the year of 2023

Link Id	Sub-Index for Pollutants			AQI
	CO	NOx	PM	
1	64	63	9	64
2	47	48	7	48
3	64	60	9	64
4	40	43	6	43
5	98	93	14	98
6	101	95	14	101

Table 3.14: Predicted AQI for the year of 2025

Link Id	Sub-Index for Pollutants			AQI
	CO	NOx	PM	
1	105	115	17	115
2	86	90	13	90
3	105	111	16	111
4	74	81	11	81
5	120	161	25	161
6	122	64	26	122

IV. CONCLUSION

Modeling analysis shows that prime pollutant responsible in the streets of all locations is oxides of nitrogen, followed by carbon monoxide and particulate matters. Simple reason behind this pattern is that model is purely considering vehicular characteristic and emission standards. It is not considering local environmental conditions of Jodhpur city. Also, in the streets considered, the mobility of vehicle was limited to only two wheelers and four wheelers which contribute more towards the emission of oxides of nitrogen and carbon monoxide. Particulate matters were observed to very low as there was no movement of heavy vehicles. But in reality, particulate matters were present in very high concentration due to dust storms etc. as compared to the value reported by this model. Evaluation of model has also been performed based upon the field data to check compatibility of model which is showing slight variation from field study. If all parameters are adequately applied, this model can provide us approximate pollutant concentration if local environmental conditions do not dominate very high.

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