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Highway By-pass Alternatives for a City: A Digital Case Study from Air Pollution Dispersion Criterion

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Abstract Meteorology plays key role in the dispersion of air pollution. However the highway geometry is also an equally important aspect. In fact the combination of the two variables can significantly affect the air pollution accumulation on either side of the highway. Hence the geometry of the highways passing through cities should be judiciously selected keeping in view the meteorological aspect too. This will reduce the air pollution concentration along highways and consequently will protect the human health. The present work is a case study of city of Jalgaon. The AH no. 46 passes through the city. It has high traffic density. Hence the proposal for a bypass is under consideration of government authorities. The authors have developed a computer simulation model to analyze the air pollution dispersion taking into account the meteorological parameters and highway geometry. The analysis has revealed that due to the existing typical layout of highway and prevailing meteorology there is a drastic effect on the air pollution concentration over the city. The proposed bypass highway also has the same problem. Hence an alternative geometry for the highway has been proposed. The alternative geometry is able to significantly reduce the air pollution concentration.

Keywords Air pollution, Dispersion, Meteorological factors, Highway planning

1. Introduction

In India the awareness about air pollution is still at nascent stage. The first air pollution act came in existence in 1981 [1]. Later India's pollution control authorities had been prompt enough to recognize EURO norms and even to promulgate Bharat stage emission norms for vehicular air pollution control. Vehicles are the prime cause of air pollution in India [2]. With rapid industrialization and population growth, this problem is taking gigantic shape in India.

The air pollution coming out of a source is dispersed in certain volume of air and is diluted [3]. However, this dispersion and dilution is strongly influenced by the meteorological factors including wind velocity, solar radiation, humidity, atmospheric thermal gradient, etc. The researchers had begun to explore these variables as early as in 1947 [4-5]. Sutton has analyzed the micrometeorological parameters that influence the air pollution dispersion. The dispersion of air pollution is a complex phenomenon. The first models to describe the air pollution dispersion came into existence in 1960-70s [6-7]. The earlier models considered point sources which mathematically resemble to stacks. However, Turner (1969) considered a line source in his mathematical simulation [8]. The line sources resemble to a highway. Thus it became possible to analyze the dispersion of air pollution through a highway.

The authors have done an attempt to apply Turner model through computer simulation to study the air pollution dispersion over a city due to the highway passing through it. Presently the highway authorities are working for a bypass highway for the city to reduce the air pollution. The authors have extended their simulation study further to analyze the effect of bypass highway layout and have also proposed an alternative highway layout keeping in view the local meteorological conditions. The analysis shows that the alternative thus proposed shall greatly reduce the air pollution over the city.

2. The Software

Turner's model for dispersion of air pollution from line source is written as follows [8]:

$$C(x,0) = \frac{2q\, e^{\left(\frac{-H^2}{2\sigma_z^2}\right)}}{\sqrt{2\pi}\ \sigma_z u \sin\phi} \qquad (1)$$

Where,

C → Ground level concentration of air pollution at distance x along the wind direction.

q → rate of emission of air pollution

h → height of source

σ_z → standard deviation in z direction (a parameter that takes into account the effect of meteorology)

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u → wind velocity

ϕ → angle between wind direction and line source.

The equation (1) is solved numerically. A computer simulation software is developed using FORTRAN 77. The software is facilitated to use inputs like vehicular emission levels, wind velocity and other meteorological parameters. Hence the software can be used to analyze the effect of varying meteorological parameters on the air pollution dispersion. The equation (1) is applicable when $\phi < 45^0$. In case the $\phi > 45^0$, the wind velocity is divided into two components. The parallel component is ignored and the perpendicular component is considered. As the source length is sufficiently large, the uniform distribution in y direction is assumed, above-mentioned assumption of ignoring the parallel component is justified. The software is given in appendix 1.

Referring to the wind rose diagram of figure 3, it can be seen that the wind is quiet during January to March. From April to September it blows heavy in the direction W-E. in October to December there are mild winds from E-W directions. Hence the most significant wind direction can be considered as W-E, with the maximum velocity 2.36 m/sec. For the highway segments, as defined in Fig 1, it is parallel to segment 1-2 and 4-5. For segments 2-3 and 3-4, the wind direction is approximately 45^0. For segments 1-2 and 4-5, the wind velocity is considered to be at a nominal angle of 3^0 angle to the highway. It is resolved in two components 2.36cos3 and 2.36sin3. The later component is perpendicular to the highway and it is used as input to the software. The parallel component is ignored with the justification as given earlier.

3. Results and Discussion

The present work has used Turner's model and solved is numerically. A computer software is developed using this model. The software can be used to estimate air pollution dispersion due to any highway. In the present work, a case study is done for the city of Jalgaon (21.05N, 75.57E, at 250 m from mean sea level). AH46, also known as NH6, passes through the city. Fig 1 shows the city with highway layout. The highway is heavily loaded with the traffic. It creates lot of air pollution in the city. Considering the pollution aspect as well as the traffic congestion aspect, the government has decided to provide a bypass to the city. Fig 2 shows the bypass highway layout. The present work has used the software for air pollution dispersion studies. The software has been used to explore following aspects, using the vehicular emission data, vehicular density and meteorological parameters from the literature:

(i) Existing level of air pollution in the city: it is found to be significantly high.

(ii) Changes in the air pollution due to the proposed highway bypass, considering the prevailing meteorological conditions of the locality.

(iii) An alternative bypass layout that can significantly reduce the air pollution level. The alternative bypass is shown in Fig 3.

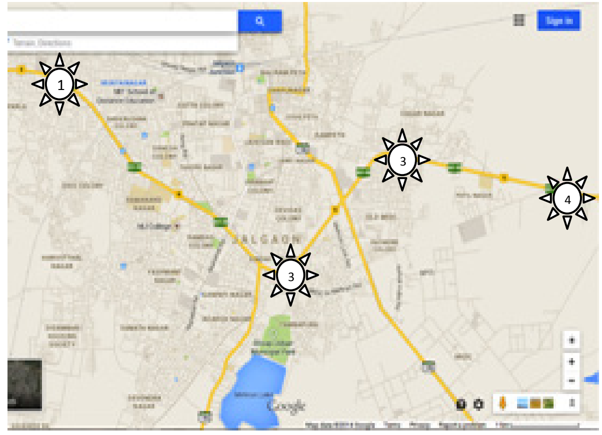

Figure 1. Road map of Jalgaon city. The NH6 (AH46) is shown in pink color. The stars are used to denote the segments of highway. Lengths of segments are as follows: 1-2: 4.5 km, 2-3: 4.8 km, 3-4: 3.7 km, 4-5: 5.3 km

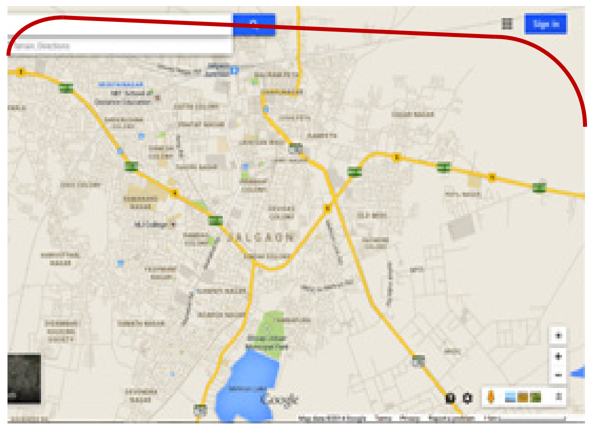

Figure 2. Bypass highway layout of Jalgaon. Bypass is shown in green color

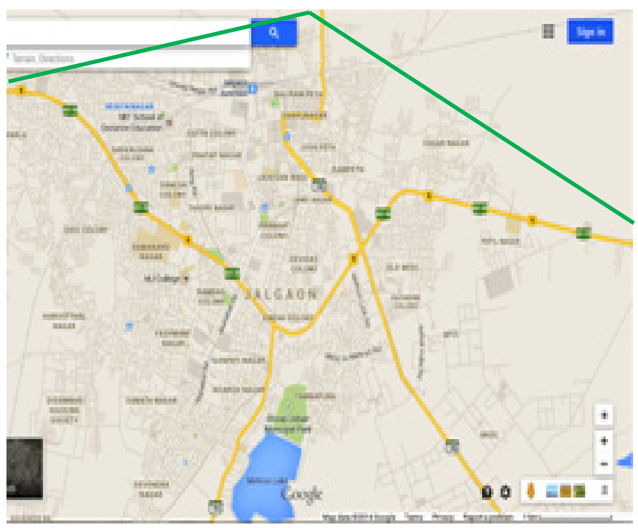

Figure 3. Proposed alternative bypass highway for Jalgaon. The proposed alternative is indicated in black

It is found that the selected location (the Jalgaon city) has a typical meteorology. The wind rose diagram (Fig 4) shows that the significant flow of wind air is approximately from West to East for most of the time in year. If we divide the existing highway in 4 segments, as shown in the figure 1, we find that the first and fourth segment are parallel to the wind direction while the second and third segments are at 45^0 to the wind direction.

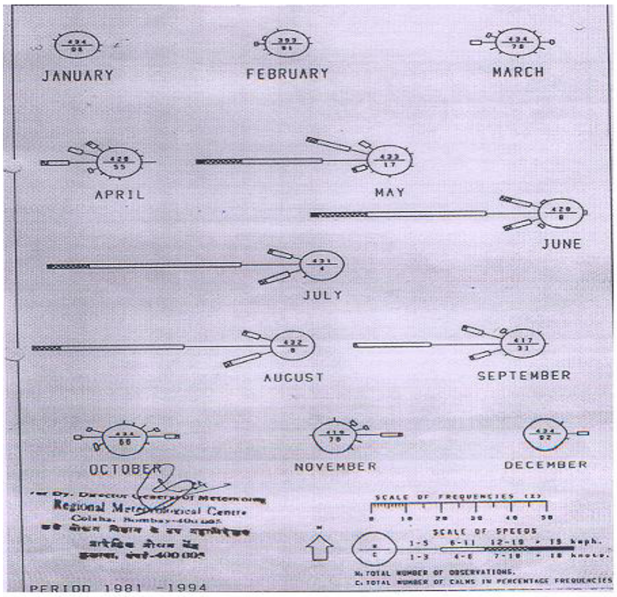

Figure 4. Wind rose diagram for Jalgaon city

The software analysis shows that when wind direction is approximately parallel, the dispersion of pollution is very less and localized accumulation is high. The proposed bypass highway is also parallel to the wind direction in its major part. The software analysis indicates that this will also result into build up of higher concentrations on both sides of the highway affecting the residential areas. Considering this critical situation arising due to the combination of highway geometry and meteorology, an alternative layout of the highway is proposed in fig 4. The alternative highway layout will significantly reduce the air pollution accumulation.

Using the software with the input data as described above, the dispersion of air pollution is estimated. The ground level air pollution is estimated at every 100 m distance, perpendicular to the highway, for 2 km distances on both the side of the highway. The vehicular density is considered to be 600 vehicles per hour with an average speed of 40 km/hour. The average emission rates of HC and CO are taken as 1200 ppm and 4000 ppm [9]. The software allows any combination of meteorological parameters. Here the following parameters are considered:

Time of day: day

Solar radiation: strong

Wind velocity: 2.36 m/sec

The results are summarized in table 1.

Results for the segment 3-4 and 4-5 will replicate respectively 2-3 and 1-2 due to symmetry in the layout of the highway.

Table 1. Ground level concentration of air pollution along NH6

Distance from highway in m	**Segment ID 1-2**		**Segment ID 2-3**	
	Concentration of HC, μg/m³	*Concentration of CO, μg/m³*	*Concentration of HC, μg/m³*	*Concentration of CO, μg/m³*
100	1161	3866	79	263
200	816	2717	41	136
300	424	1412	21	69
400	249	829	12	40
500	161	536	8	27
600	134	446	5	17
700	112	372	4	13
800	83	276	3	10
900	72	239	2	7
1000	63	209	2	7
1100	50	166	1.6	5
1200	40	133	1.3	4
1300	33	109	1.1	4
1400	27	90	0.9	3
1500	22	73	0.8	3
1600	19	63	0.7	2
1700	16	53	0.5	2
1800	14	46	0.5	1
1900	12	40	0.4	1
2000	11	36	0.3	0.9

The permissible limit of HC and CO pollution is given in table 2 [10]:

Table 2. Permissible level of air pollution as per American Public Health Association (APHA)

Pollutant	Permissible limit as per APHA
HC	Annual average =3.0 $\mu g/m^3$ Max 24 h concentration = 100 $\mu g/m^3$
CO	240 $\mu g/m^3$ Max 3 h concentration

It can be seen that in case of segment ID 1-2 (or 4-5) the concentration of HC air pollution is above permissible limits even after two km from the highway. However in case of ID 2-3 (or 3-4) the concentration reduces to permissible level just after 800 m. Similarly for CO pollution, for segment ID 1-2 (or 4-5) the permissible level is achieved after 900 m, while the same is achieved after 200 m in case of ID 2-3 (or 3-4). Hence the highway layout has significant influence on the air pollution dispersion. It is in accordance to the hypothesis adopted by the authors to propose the alternative layout of the highway.

If the authorities will go ahead with the proposed layout of bypass (case of figure 2) the higher concentration of air pollution will prevail around the highway. However if the alternative highway lay out (case of figure 4) is implemented, the concentration of air pollution around highway will be less significantly.

The present analysis is a sample analysis for the air pollution dispersion in month of May. The software is versatile and can be used for other months of the year and even for other locations also.

4. Conclusions

Dispersion of air pollution from a line source is a complex phenomenon. Its dependence upon meteorological parameters has been recognized by engineers. However its dependence upon combination of the line source layout and meteorology is a new concept. The concept has been first time proposed by the authors and has been justified by the digital simulation in the present work. The information is of great significance for town planners. Traditionally the town planners have worked on the plain fundamental concept that the highways should be away from the cities so as to minimize the air pollution. However the present work has linked the highway geometry with the local meteorology. It is in fact an emergence of new dimension in the domain of town planning as well as highway planning.

Appendix 1

```
C      PROGRAM FOR ESTIMATION OF AIR POLLUTION DISPERSION DUE TO LINE
C      SOURCE

c      ***************************************************************

C      THE LINE SOURCE IS CONSIDERED TO BE INFINITE IN LENGTH
C      THE CONCENTRATION IN Y DIRECTION IS SAME THROUGHOUT.
C
C      ***************************************************************
       DIMENSION CC(50)
       COMMON U,AX(50),SIGMAZ(50),SIGMAY(50)

C      WRITE(*,*)'ENTER AVERAGE CONCENTRATION OF AIR POLLUTION IN g/s_m
C      READ(*,*) Q
       Q=2.5E-3
C      WRITE(*,*)'ENTER HEIGHT OF SOURCE'
C      READ(*,*) H
       H=0.
C      WRITE(*,*) 'ENTER WIND VELOCITY IN m/S'
C      READ(*,*) U
       U=4.
C      WRITE(*,*) 'ENTER THE DIRECTION IN DEGREES OF WIND wrt LINE SOURCE'
C      READ(*,*) FI
       FI=90.

       AFI=FI*(3.14/180.)
       DO 15 I=1,40
```

```
       AX(I)=50.*FLOAT(I)
 15   CONTINUE

C     ESTIMATION OF STANDARD DEVIATION SIGMAZ AND SIGMAY
      CALL ASIGMA
      DO 25 K=1,40
       CC(K)=(2.*Q*(10.**6))/(((2.*3.14)**0.5)*U*SIGMAZ(K))
       CC(K)=CC(K)*EXP(-0.5*(H/SIGMAZ(K))**2)
       CC(K)=CC(K)/SIN(AFI)
       WRITE(1,*) AX(K), CC(K)
 25   CONTINUE
      STOP
      END


C     SUBROUTINE TO ESTIMATE SIGMAZ AND SIGMAY
      SUBROUTINE ASIGMA
      COMMON U,AX(50),SIGMAZ(50),SIGMAY(50)

C     WRITE(*,*) 'ENTER 1 FOR DAY AND 2 FOR NIGHT'
C     READ(*,*) I1
      I1=1


      IF(I1.EQ.1) THEN
C     READ(*,*)'ENTER 1 FOR STRONG,2 FOR MODERATE 3 FOR SLIGHT RADIATION'
C      READ(*,*) RAD
       RAD=2.
      ELSE
C      READ(*,*) 'ENTER 1 FOR MOSTLY OVERCAST AND 2 FOR MOSTLY CLEAR'
C      READ(*,*) RAD
       RAD=1.
      ENDIF
      IF(I1.EQ.1) THEN
       IF(U.LE.2.0.AND.RAD.EQ.1.) THEN
        STB=1.
        GOTO 10
       ENDIF
       IF(U.LE.2.0.AND.RAD.EQ.2.) THEN
        STB=1.
        GOTO 10
       ENDIF
       IF(U.LE.2.0.AND.RAD.EQ.3.) THEN
        STB=2.
        GOTO 10
       ENDIF
       IF(U.LE.3.0.AND.RAD.EQ.1.) THEN
        STB=1.
        GOTO 10
       ENDIF
       IF(U.LE.3.0.AND.RAD.EQ.2.) THEN
        STB=2.
```

```
  GOTO 10
 ENDIF
 IF(U.LE.3.0.AND.RAD.EQ.3.) THEN
  STB=3.
  GOTO 10
 ENDIF
 IF(U.LE.5.0.AND.RAD.EQ.1.) THEN
  STB=2.
  GOTO 10
 ENDIF
 IF(U.LE.5.0.AND.RAD.EQ.2.) THEN
  STB=2.
  GOTO 10
 ENDIF
 IF(U.LE.5.0.AND.RAD.EQ.3.) THEN
  STB=3.
  GOTO 10
 ENDIF
 IF(U.LE.6.0.AND.RAD.EQ.1.) THEN
  STB=3.
  GOTO 10
 ENDIF
 IF(U.LE.6.0.AND.RAD.EQ.2.) THEN
  STB=3.
  GOTO 10
 ENDIF
 IF(U.LE.6.0.AND.RAD.EQ.3.) THEN
  STB=4.
  GOTO 10
 ENDIF
 IF(U.GE.6.0.AND.RAD.EQ.1.) THEN
  STB=3.
  GOTO 10
 ENDIF
 IF(U.GE.6.0.AND.RAD.EQ.2.) THEN
  STB=4.
  GOTO 10
 ENDIF
 IF(U.GE.6.0.AND.RAD.EQ.3.) THEN
  STB=4.
  GOTO 10
 ENDIF
ELSE
 IF(U.LE.2.0.AND.RAD.EQ.1.) THEN
  STB=5.
  GOTO 10
 ENDIF
 IF(U.LE.2.0.AND.RAD.EQ.2.) THEN
  STB=6.
  GOTO 10
 ENDIF
 IF(U.LE.3.0.AND.RAD.EQ.1.) THEN
```

```
          STB=5.
          GOTO 10
         ENDIF
         IF(U.LE.3.0.AND.RAD.EQ.2.) THEN
          STB=6.
          GOTO 10
         ENDIF
         IF(U.LE.5.0.AND.RAD.EQ.1.) THEN
          STB=4.
          GOTO 10
         ENDIF
         IF(U.LE.5.0.AND.RAD.EQ.2.) THEN
          STB=5.
          GOTO 10
         ENDIF
         IF(U.LE.6.0.AND.RAD.EQ.1.) THEN
          STB=5.
          GOTO 10
         ENDIF
         IF(U.LE.6.0.AND.RAD.EQ.2.) THEN
          STB=5.
          GOTO 10
         ENDIF
         IF(U.GE.6.0.AND.RAD.EQ.1.) THEN
          STB=5.
          GOTO 10
         ENDIF

         IF(U.GE.6.0.AND.RAD.EQ.2.) THEN
          STB=5.
          GOTO 10
         ENDIF
        ENDIF
 10     WRITE(*,*)
C       CO-EFFICIENTS TO BE USED IN ESTIMATION OF SIGMAZ AND SIGMAY
        B=8.94
        DO 45 J=1,40
        IF(AX(J).GE.1000.) GOTO 20
        IF(STB.EQ.1.) THEN
          A=213.
          C=440.8
          D=1.941
          F=9.27
        ENDIF
        IF(STB.EQ.2.) THEN
          A=156.
          C=106.6
          D=1.149
          F=3.3
        ENDIF
        IF(STB.EQ.3.) THEN
          A=104.
```

```
          C=61.0
          D=0.911
          F=0.
        ENDIF
        IF(STB.EQ.4.) THEN
          A=68.
          C=33.2
          D=0.725
          F=-1.7
        ENDIF
        IF(STB.EQ.5.) THEN
          A=50.5
          C=22.8
          D=0.678
          F=-1.3
        ENDIF
        IF(STB.EQ.6.) THEN
          A=34.
          C=14.35
          D=0.74
          F=-0.35
        ENDIF
        GOTO 30
20      WRITE(*,*)
        IF(STB.EQ.1.) THEN
         A=213.
         C=459.7
         D=2.094
         F=-9.6
        ENDIF
        IF(STB.EQ.2.) THEN
         A=156.
         C=108.2
         D=1.098
         F=2.0
        ENDIF
        IF(STB.EQ.3.) THEN
         A=104.
         C=61.0
         D=0.911
         F=0.
        ENDIF
        IF(STB.EQ.4.) THEN
         A=68.
         C=44.5
         D=0.516
         F=-13.
        ENDIF
        IF(STB.EQ.5.) THEN
         A=50.5
         C=55.4
         D=0.305
```

```
         F=-34.
        ENDIF
        IF(STB.EQ.6.) THEN
         A=34.
         C=62.6
         D=0.180
         F=-48.6
        ENDIF
  30    WRITE(*,*)
        AX(J)=AX(J)/1000.
        SIGMAZ(J)=C*((AX(J))**D)+F
        SIGMAY(J)=A*((AX(J))**B)
  45    CONTINUE
        RETURN
       END
```

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