Chapter

Air Pollution Dispersion Using Coupled AERMOD-WRF Modeling System and Generation of Gridded Emission Inventory of NO_X Over Nagpur

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Abstract

This study, a work used to distinguish the dispersion patterns of air pollutants, is designs particularly NO_X because of vehicular and modern sources over a quickly creating metropolitan city, Nagpur (21.15° N, 79.09° E), India, during winter and summer representative months, that is, January and April respectively in 2009. Utilizing the emission variables of industry and various vehicles, 1 km x 1 km high-resolution Gridded Emission Inventory (GEI) has produced over Nagpur city. Here, two PBL schemes form WRF model *viz.*, local (MYJ) and non-local (YSU) schemes considered for obtaining the PBL as well as meteorological parameters. Both the schemes MYJ and YSU representing the boundary layer parameters are reasonably well and measured for generating the input parameter for AERMOD model. During the winter and summer month's fundamentally unique scattering patterns of NO_X have been observed. After carefully examining the NO_X concentration from the AERMOD model, the reasonable well-by integrated YSU schemes of WRF were found to be superior to the other schemes. The current review advocates the utility of the created GEI of NO_X with coupled AERMOD-WRF offline model for air quality appraisal over Nagpur.

Keywords: gridded emission inventory, air quality, AERMOD, PBL schemes, WRF model

1. Introduction

Air pollution is a not unserious risk to the climate influencing human's health [1–3], and horticulture and normal biological systems [4]. There are many wellsprings of air pollution, *viz.*, usual sources, transportation, horticultural, and generation of power and industrial industries. According to World Health Organization (WHO) standards, among many Indian urban communities with populace of over a million,

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air contamination levels surpassed the edge. It is revealed by WHO [5] that nearly 500,000 premature deaths are in India due to only indoor air pollution. Mesoscale atmospheric flows play significant character in dispersion of air pollutants, local air quality problems, and transference [6–12]. Emission estimates and trends during 1990 to 2000 and its implications over Delhi have been reported [13]. AERMOD [14–16], a Gaussian plume air dispersion model with explicit representation of PBL processes, is widely being used for the assessment of air pollution dispersion of various pollutants and estimation of ground-level concentrations (GLC) as well. WRF-AERMOD coupling is employed for the methodology to study the dispersion patterns of PM_{10} over Pune [17]. Gurjar et al. [18] have evaluated emission and air quality in selected megacities of different countries. Mohan et al. [19] implemented AERMOD dispersion model in standalone mode for the exposure assessment of particulate matter pollution over Delhi. Goyal et al. [20] have developed grid-based mobile source emission inventory over Delhi using IVE modeling tool. It is appraised the enactment of WRF, for the situation usage as the meteorological pre-processor aimed at investigative modeling of air quality using AERMOD over Cuba [21]. A sensitivity study of different PBL schemes of parameterization schemes of WRF model coupled with AERMOD NO_X dispersion over a shoreline city of Visakhapatnam [22] and over Gurugram [23] was conducted.

The good activist resolution of various parameters such as upper air meteorological and surface parameters in standalone mode is required by AERMOD model. In maximum Indian cities, this type of the PBL data is absent and over Nagpur such data are not available. The high resolution (3 km) has been utilized for integrating the meteorological variables from WRF model, which is required in air quality simulation. The result obtained is used with offline coupler [22]. The presented coupler in the present work originates the PBL and surface meteorological parameters over Nagpur and generates required input variables for the integration of AERMOD. It is obviously true that PBL processes assume a significant part in the scattering of air toxins and is crucial for utilizing reasonable PBL plot in WRF-ARW model. It has been reported that YSU followed by MYJ has shown better simulation PBL processes after validating it with available observations over Nagpur region [22, 23].

In this study, AERMOD [24, 25] and a Mesoscale weather prediction model WRF-ARW [26, 27] with YSU and MYJ schemes are employed for calculation of NO_X dispersion and estimation of ground-level concentrations (GLC), due to vehicular traffic during two contrast seasons such as winter and summer during the year 2009 over Nagpur city. January has been chosen as a representative month of winter and April as summer month following the criteria of India Meteorological Department, India. In this study, GEI with high resolution (1 km $\times$ 1 km) using emission factors of different types of vehicular traffic over the study area has been developed. An additional NO_X emission from a thermal power plant (TPP) located in the north direction which is 11 km away from Nagpur city has also been considered. The model-simulated NO_X concentrations are validated using the monitored observations by CPCB to assess the presentation of the displaying framework with two distinct PBL plans during summer and winter.

2. Study area

Nagpur (21.15° N, 79.09° E) is the biggest city in focal of India and the second capital of the territory of Maharashtra. Nagpur is the quickly developing city and third most crowded city after Mumbai and Pune in Maharashtra. Additionally, it is the Center for advancement, industrialization, urbanization, and business action (**Figure 1**). The main sources of air pollution are vehicular, and industrial and domestic sources. Over Nagpur city, according to the National Ambient Air Quality Standards (NAAQS)—2008, suspended particulate matter (SPM), and respirable suspended particulate matter (RSPM) fundamentally high, the degree of nitrogen dioxide (NO_2) is moderate [28]. NO_X is of specific worry as it is radiated from industrial and vehicle cycles that consume non-renewable energy sources. NO_X draws consideration as it responds with volatile organic compounds (VOCs) to shape ground-level ozone and it likewise responds with different constituents in air to frame nitrates and corrosive vapor sprayers. Nitrogen dioxide disturbs the nose and throat, and it seems to build vulnerability to respiratory diseases separated from nearby wellsprings of air contamination. Territorial and metropolitan air quality peculiarities are affected by a few different factors like the local meteorology.

According to climate classification by Köppen, the dry climate and tropical wet climate with dry conditions found for throughout year over Nagpur. Nagpur is situated at a height of 312.42 meters above sea level. Over Nagpur region, the winter season lies from late November to January and the temperature can goes below 10°C. Summer lies from late March to June and it is extremely hot and May being the hottest month over Nagpur region. On May 22, 2013, highest temperature (47.9°C) was recorded in Nagpur city.

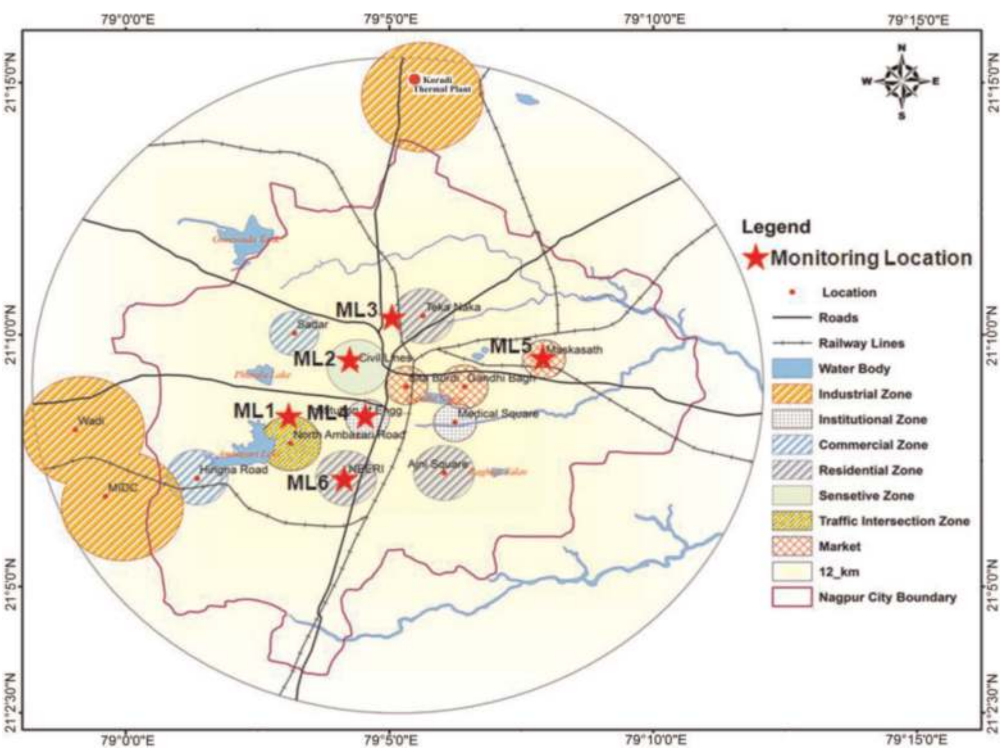

Figure 1.
Study area (30 km × 30 km) over Nagpur [monitoring locations (ML1 = .MIDC industrial area, ML2 = MIDC office, ML3 = Govt. polytechnic college, ML4 = Institute of Engineering, ML5 = Maskasath, and ML6 = NEERI lab)].

3. Data and methodology

The data required for running WRF-ARMOD coupled modeling system and methodology of emission inventory and prediction of pollutant concentrations over Nagpur city using integrated WRF-ARMOD coupler are described in the following sections.

3.1 Data

In the present section, the mandatory data for offline coupled modeling system, gridded data of emission inventory from area and point sources over Nagpur, and ambient air quality monitored by CPCB are described in detail.

3.1.1 Data required for WRF-ARW model

In the current review, here accessible 6-h global final analysis (FNL) utilized with 1.0° × 1.0° grid resolution produced by the National Center for Environmental Prediction (NCEP's) global forecast system (GFS) as initial conditions, during study period in January and April 2009.

3.1.2 Emission data

In this study, two types of emission data have been used. One is the vehicular data along with exhaust emissions considered as an area emission and the other is thermal power plant (TPP) data considered as point source over the Nagpur city. The CPCB has six monitored stations over Nagpur city. They are MIDC industrial area, MIDC office, Government Polytechnic College, Institute of Engineering, Maskasath, and NEERI Lab. The NO_X-monitored data are accessible as 24 h average from CPCB, designed for all above six monitoring locations.

The data are not uniform w. r. to time at all monitoring locations; that is, the monitored data at each location are available on different days. Hence, in the current study, the comparison of observed and predicted concentrations has been done at those monitoring locations where data are available for the days, the concentrations are estimated.

3.1.3 Estimating number and types of vehicles pursuing over Nagpur

In this study, a number of vehicles plying in Nagpur city are calculated using RTO (Regional Transport Office) report for Maharashtra state [30]. Based on this report, there is an increase in the number of vehicles registered at the rate of 7.21% per year. Accordingly, we have estimated the number of vehicles at Nagpur city from the base year 2011. The yearly vehicular growth during the last 16 years is shown in **Figure 2**. According RTO, vehicles registered before 15 years from the current year will not be allowed to play on the road.

We considered this as assumption that the vehicles registered in 1994 were not plying on the roads in 2009. For year 2009 (base year), diverse types of vehicles with pollutant emission factor for NO_X obtained from Automotive Research Association of India (ARAI) are shown in **Table 1** [31]. The TPP located at Koradi area of Nagpur is 11 km away from Nagpur city zero miles, which is considered as point source.

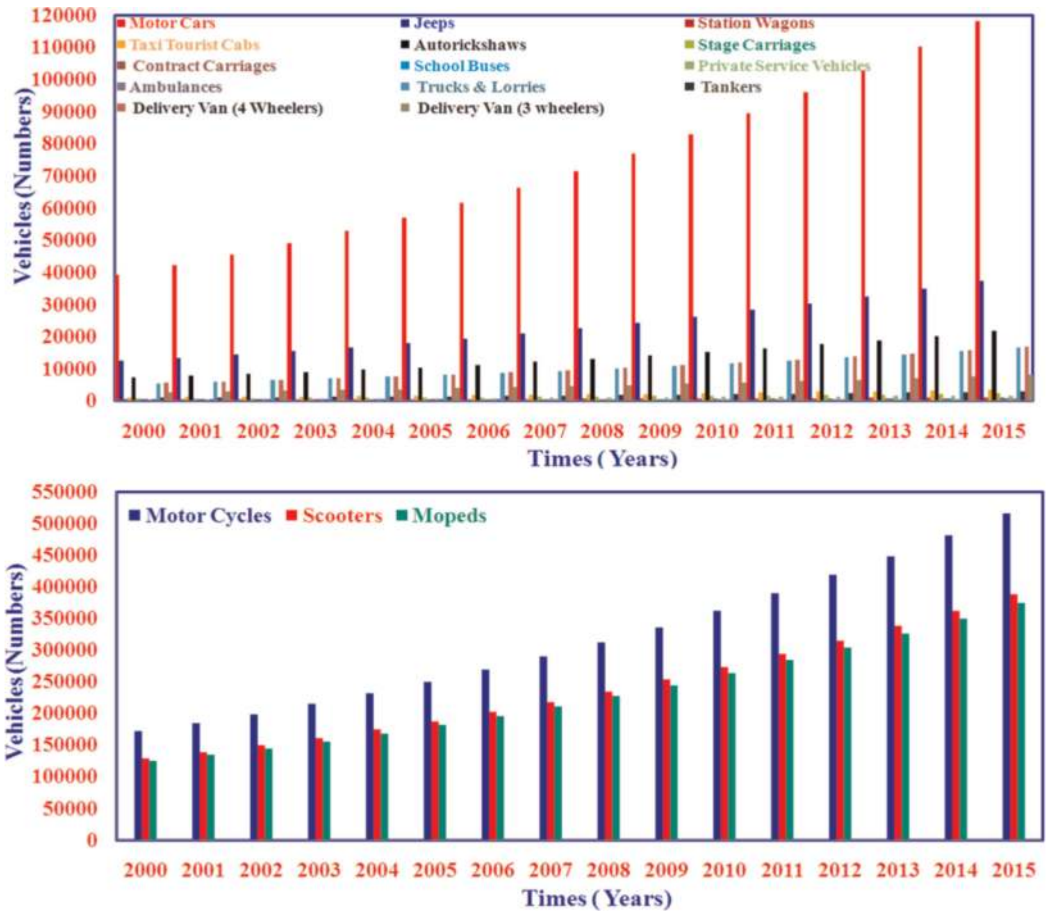

Figure 2.
Yearly vehicle growth for the past 16 years over Nagpur city.

For the calculation of NO_X emissions from the area sources, the Nagpur city (9 km × 8 km) area of 72 km^2 has been considered with 1 km × 1 km grid resolution. The selected area covers all six monitoring stations of CPCB, where urban activities take place due to different sources, and predominantly vehicular exhaust is the main source of air pollution in Nagpur city. Considering this criterion, emissions from 64 grid cells were used as input into the model.

The calculation of emissions from vehicles is based on the emission factors for different types of vehicles according to ARAI 2007, vehicles explicit kind [30], the distance went by a specific vehicle, and their appropriation in light of the sort of the fuel utilized. The methodology to obtain emission from vehicular estimates was based on an earlier work [13, 19, 32];

$$E_i = \sum \left(Veh_j \times D_j \right) \times E_{i;j;km}$$

The emission of the compound (i) is denoted by E_i, per type of vehicles numbers denoted by Veh_j and different vehicle type (j) traveled distance defined by D_j in a grid box. This study has assumed based on the previous study according to ARAI, Ei;j; km the emission factor (g km^{-1}) of different vehicles of compound (i) and vehicle type (j) per driven kilometer. The GEI of NO_X over Nagpur city is shown in **Figure 3**. Based on the previous study, this study assumed only 50% vehicles are moving on

Vehicle type	Number of vehicles	Fraction	Emission factor (gkm^{-1})
Motor Cycles (Petrol)	226,558	113,279	0.15
Scooters (Petrol)	170,702	85,351	0.14
Mopeds (Petrol)	164,827	82,413	0.02
Personal Cars (Petrol)	52,266	26,133	0.09
Multi Utility Vehicles (Diesel)	16,892	8446	0.67
Personal Cars (Diesel)	1545	773	0.28
Three Wheelers (Petrol)	9534	4767	0.16
Three Wheelers (Diesel)	3578	1789	0.51
Busses (Diesel)	1772	886	6.53
Heavy Commercial Vehicles (Diesel)	8672	4336	9.3
Light Commercial Vehicles (Diesel)	8238	4119	2.12

Table 1.
Different types of vehicles based on ARAI-2007 and emission factor over Nagpur city in 2009.

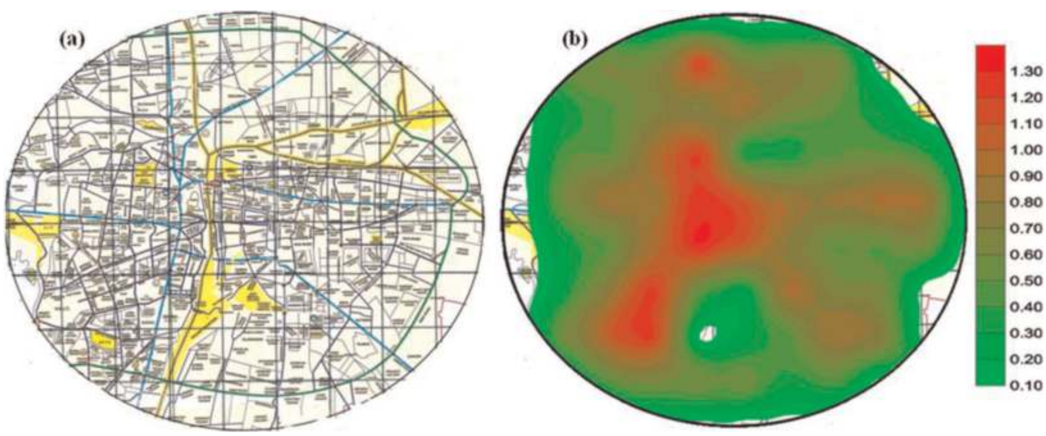

Figure 3.
(a) Nagpur city map (9 km × 8 km) and (b) emission inventory (gs^{-1} m^{-2}) over Nagpur city.

road in per grid box. According of ARAI emission factors, vehicular emissions of NO_X are designed for different types of the vehicles in each 1 km × 1 km grid box.

3.2 Methodology

3.2.1 Air pollution dispersion model

AERMOD [14] is a consistent state Gaussian plume model valuable for the calculation of contamination scattering relevant to metropolitan and provincial region and several sources (volume, point and area) of emissions [14–16].

AERMOD expects the likelihood circulation work for the toxin concentration to be Gaussian in the both horizontal and vertical steady boundary layers. Then, at that point, in present instance of the convective boundary layer, while the flat scattering is Gaussian, the upward dissemination is addressed by a bi-Gaussian likelihood conveyance function.

In light of perceptions of meteorological predictions using a similarity connection, the rising profiles of the essential components, such as wind and temperature, are constructed.

AERMOD represents the vertical in-homogeneity of the PBL in its scattering estimation by averaging the boundaries of real PBL into successful boundaries of an identical homogeneous PBL. The AERMOD meteorological preprocessor, recognized as AERMET, calculates the PBL boundaries, *viz*., friction velocity, temperature scale, Monin-Obukhov length, surface heat flux, convective speed scale, blending tallness by involving nearby surface attributes as unpleasantness of surface, and Bowen proportion in mix with the standard meteorological perceptions [22, 33]. AERMOD is an analytic model and uses limit layer boundaries alongside routine meteorological information as contribution for assessing the contamination focuses. The overproduction of concentrations of pollutants is because of the lower reversal/blending stature under solid stable circumstances anticipated by WRF.

For predicting 24 hourly normal NO_X concentration utilizing metropolitan scattering choice, the model has been utilized in this study. In this work, two different domains were chosen: Domain-1 with 30 km $\times$ 30 km with 1-km grid resolution considering the entire city including TPP and Domain-2 a finer 12 km $\times$ 12 km with 1-km grid resolution without considering TPP emissions. This exercise has been conducted so as to assess whether TPP emission does have any influence in the concentration of NO_X over Nagpur. The consequences of the integrated concentration of NO_X are approved against CPCB information on 24-h noticed concentration of NO_X over Nagpur.

3.2.2 Weather research and forecast model

WRF version 3.6 mesoscale model established by the National Center for Atmospheric Research (NCAR) is utilized in the existing study [26, 27, 29]. This model contains the bother amounts of tension, scalars (cloud water, water vapor mixing ratio etc.), turbulent kinetic energy, surface pressure, geo-potential, three-dimensional wind, and potential temperature and includes the prognostic variables. WRF is also completely squeezable with non-hydrostatic equations. From the literature, one can say that PBL cycles and land surface affect the incorporation of winds, choppiness, and other state factors in the lower atmosphere.

The two PBL schemes YSU and MYJ both have shown better performance than the other schemes of WRF-ARW chosen based on the works over the Nagpur region and three nested domains used in study (**Figure 4**) [22, 25]. The complete model over view consists of model domain; different parameterizations used are presented in **Table 2**.

3.2.3 Offline coupler of WRF and AERMOD models

Hourly meteorological observations of surface and upper air remain mandatory to AERMOD. The model acknowledges a solitary station information and expects that the condition of the weather is evenly homogenous over the whole study region. In any case, the sort of meteorological information, which is fundamental to process the necessary boundary layer variables that can fill in as contribution to AERMOD, is not sweeping the study region. Subsequently, in the current work, we have utilized the offline coupler to incorporate the weather research forecast and AERMOD models.

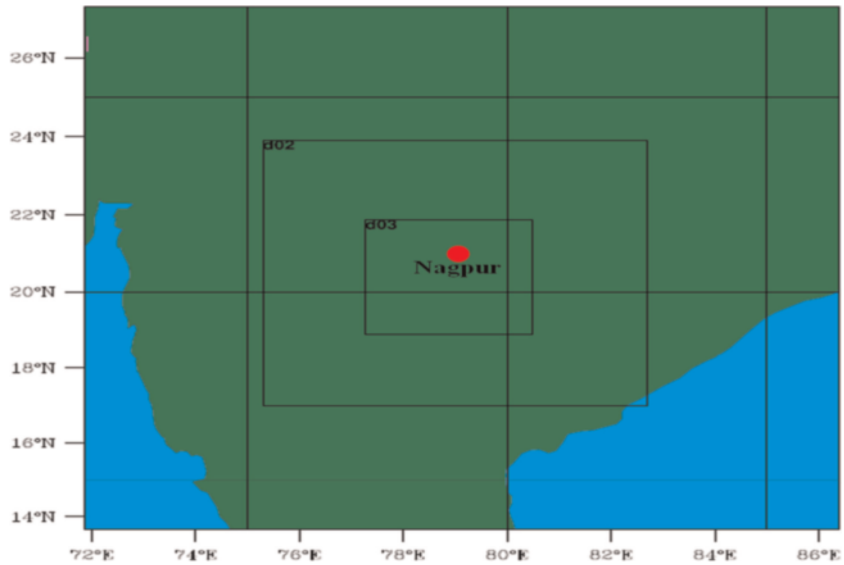

Figure 4.
WRF-ARW model domain used over Nagpur.

PBL scheme	1) YSU [34] 2) MYJ [35, 36]
Vertical coordinates	Terrain-following hydrostatic pressure vertical coordinate with 27 vertical levels
Covered area	13.8°-27.4° N and 71.9°-86.2° E
Interval	6 hrs
Spatial differencing scheme	6th order center differencing
Microphysics	Eta microphysics [37]
Horizontal grid system	Arakawa-C grid
Map projection	Mercator
Surface layer parameterization	Noah land Surface Scheme
Integration time step	90 sec
Data	NCEP FNL
Time integration scheme	3rd-order Runga-Kutta Scheme
Long-wave radiation	RRTM scheme radiation [38]
Short-wave radiation	Dudhia scheme [39]
Dynamics	Non-hydrostatic
Resolution	Domain1: 27 km $\times$ 27 km Domain2: 9 km $\times$ 9 km Domain3: 3 km $\times$ 3 km
Grid size	Domain1: (60$\times$ 60) $\times$ 27 Domain2: (91$\times$ 91) $\times$ 27 Domain3: (112$\times$ 112) $\times$ 27
Cumulus parameterization	Kain-Fritsch scheme [40]

Table 2.
Overview of the WRF-ARW modeling system.

Presented coupler directly generates meteorological input files mandatory in AERMOD model [22] from the surface and PBL parameters over Nagpur from the output of WRF model.

4. Results and discussion

The current section approval of GLCs and scattering patterns of NO_X acquired by utilizing the coordinated coupler of WRF-AERMOD are examined.

4.1 Simulation and dispersion of NO_X

In segment, the coupled WRF-AERMOD displaying framework reenacted dispersion patterns and GLCs of NO_X utilizing the different information (presented in Section 3) and Emission Inventory (EI); approval practices utilizing the accessible checked perceptions from factual investigation are introduced. The meteorological information obtained from WRF-ARW by utilizing PBL plans YSU (consequently alluded to as Model-1) and MYJ (hereafter alluded to as Model-2) are utilized in the coupled modeling framework for foreseeing NO_X concentrations over the review area. The exhibition assessments of integrated NO_X concentrations by Model-1 and Model-2 are learned through the accessible perceptions. The investigation and approval of the obtained GLC of NOX subsequent to coordinating the modeling framework more than two chosen domains (Domain-1 and Domain-2) of Nagpur city are presented in Section 3.2.1 with the accessible observations (given in Section 3.1.3).

4.2 Validation and GLCs of NO_X

For the model combination, we utilized EI of area sources over Nagpur (without TPP in Domain-2) for integrating the concentrations of NO_X pollutant. Concentrations of NOX pollutant in January and April 2009 anticipated by Model-1 and Model-2 with the accessible CPCB checked information are portrayed in **Figures 5 and 6**, individually.

The convergence of NO_X anticipated by Model-1 shifts 52 to 110 μgm^{-3}, though by Model-2 fluctuates between 53 and 180 μgm^{-3}, while the noticed focus differs from 28

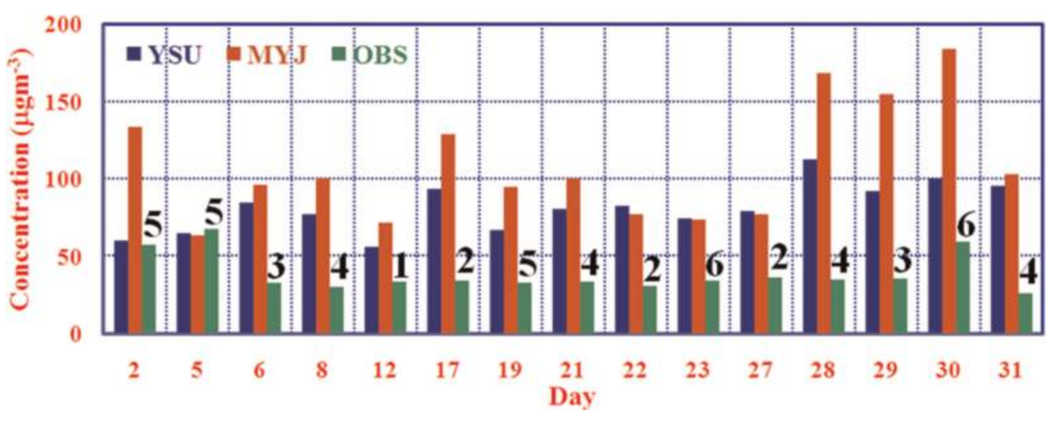

Figure 5.
*Validation of model predicted 24-hour NO_X concentration (μgm^{-3}) with CPCB observation in January 2009 over Nagpur (with the monitoring location number given in **Figure 1**).*

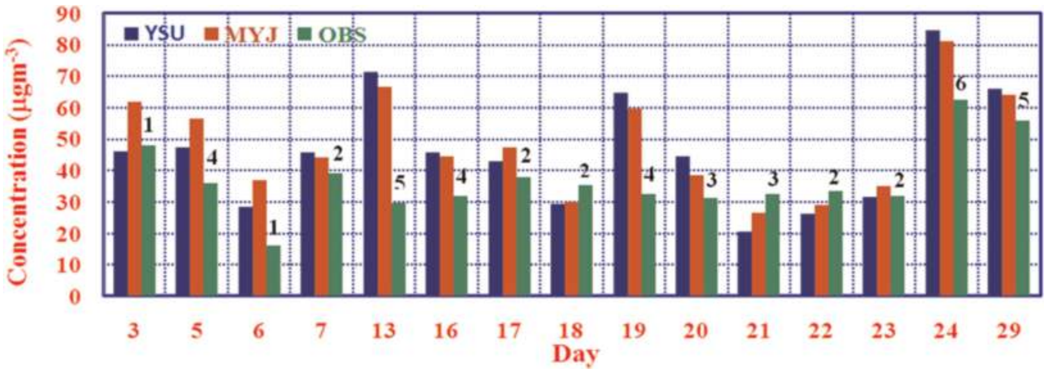

Figure 6.
*Validation of model predicted 24-hour NO_X concentration (μgm-3) with CPCB observation in April 2009 over Nagpur (with the monitoring location number given in **Figure 1**).*

to 54 μgm^{-3} during winter. On the correlation with the observed qualities, over-forecast of re-enacted convergence of NO_X by both Model-1 and Model-2 is seen (**Figure 5**). This might be credited to that reality the more grounded stable soundness conditions and low breezes reproduced by the WRF-ARW model prompting more catching of contamination interface of NO_X.

During summer month, the anticipated fixation by Model-1 and Model-2 shifts between 20 to 85 μgm^{-3} and 28 to 80 μgm^{-3} separately. During same month, CPCB perception of NO_X fixations fluctuates somewhere in the range of 18 and 61 μgm^{-3}. On the nearby assessment of the outcomes presented in **Figure 6** uncovers, the scope of fixations by the Model-1 and Model-2 is practically identical with the perceptions, with generally better execution by Model-1. The primary explanation of the over expectation of the NO_X focus could be because of the exclusion of metropolitan geology in the current review since this sort of information getting is extremely intense in India. The metropolitan regions would adjust the thermo-dynamical design of the barometrical limit layer and changes the strength definition. Because of the avoidance of metropolitan elements, there are potential outcomes of over assessment of stable circumstances by the models and prompts more catching of NO_X results in over forecast more. To find out the best execution of the models, factual examination is directed as given in the accompanying section.

4.3 Statistical analysis

The model presentation was assessed utilizing classical statistical [41] parameters such as geometric variance (VG), normalized root mean square error (NMSE), fractional bias (FB), mean absolute error (MAE), correlation coefficient (CC), root mean square error (RMSE), and fraction of two (FAC2) (prediction and observations). The results for the performance of statistical indicators have been shown in **Table 3**.

It is found from these results that the RMSE and MAE of Model-1 are less as compared to Model-2 during winter month and summer month, as reported in previous studies [19, 23, 42, 43]. The statistical parameters, for example, FB and NMSE would give the necessary dependability rules in the model execution assessment. Chang and Hanna [43] examined the correlation of execution north of five field tests for three models specifically AERMOD, AMDS, and ISC-3. Hanna et al. [44] contemplated and observed and getting error VG and FAC2 separately 2.9 and 0.46 from

Parameter (ideal value)	January 2009 (Winter)		April 2009 (Summer)	
	YSU scheme	MYJ scheme	YSU scheme	MYJ scheme
MAE (0)	48.61	77.38	18.52	21.85
RMSE (0)	54.34	87.90	24.73	28.92
CC (1)	0.12	0.36	0.55	0.50
NMSE (0)	0.99	1.94	0.35	0.44
FB (0)	0.80	1.03	0.34	0.42
FAC2 (1)	0.43	0.32	0.71	0.66
VG(1)	2.02	3.23	1.07	1.22

Table 3.
Statistical analysis of NO_X concentrations during winter and summer months over Nagpur city.

AERMOD. This is comparable to model-1 error for both of the month as compared to model-2.

The performance of AERMOD model is examined over Delhi [19]. They observed that RMSE error is higher for each of the seven stations, and the scope of the error lies between 90.05 and 245.66. In the current work, RMSE error is sensibly well in contrast to the past review and this is given affirmation that model-1 is given better performance in contrast to the model-2.

Less values of FB and NMSE indicate that the overall deviation is less by Model-1 compared to Model-2. These boundaries uncover that exhibition of Model-1 is superior to the Model-2 during winter and summer months. FB demonstrates how well the calculation creates the normal qualities around the normal upsides of observed factors. The ideal value is zero of FB, but it can range from −2 to 2. An absolute value of 0.67 corresponds to a prediction inside an influence of two of observation [45]. Interestingly, correlation coefficient of Model-2 is to found better as compared to Model-1 for during winter and summer months. Yet, in light of the in general factual assessment, the presentation of expectation of NO_X concentrations utilizing the meteorological factors integrated from Model-1 is superior to Model-2. Large values of MAE, RMSE, NMSE, FB, and VG1 indicate overprediction of concentrations by both models due to low wind conditions.

4.4 Spatial dispersion of GLC NO_X concentrations

In the current segment, spatial scattering examples of GLC NO_X concentrations are obtained from WRF-AERMOD modeling system utilizing two definition plans; specifically, YSU and MYJ are introduced over Domain-1 and Domain-2 over Nagpur city (as presented in Section 3.2.1). The coupled demonstrating framework has been incorporated for the entire long periods of winter and summer months over the picked spaces at whatever point the CPCB monitoring of GLC perceptions is accessible during winter- and summer-represented months. In this chapter, the aftereffects of 1 day each from these 2 months, January 8 and April 21, 2009 are just introduced.

The dispersion of 24-hourly averaged NO_X concentrations for 30 km × 30 km domain on January 8 by utilizing PBL schemes of YSU and MYJ is represented in **Figure 7a–e** along with wind roses. On January 8, 2009, the most extreme GLCs are anticipated by MYJ plot (**Figure 7b**) contrasted with the YSU (**Figure 7a**), in light of the fact that MYJ (**Figure 7d**) re-enacted low breezes than that of YSU as displayed in **Figure 7c**. The extent of winds obtained from MYJ is lesser as compared with YSU.

This clearly shows that the winds stay improved arrested by YSU upon an evaluation by the observations (**Figure 7e**) with MYJ. Maximum concentrations of NO_X by using both schemes (YSU and MYJ) inside the city stay only due to vehicular emission. From the concentration patterns, it is clearly seen that nearby is nope influence of TPP-generated NOX over Nagpur as seen in **Figure 7a** and **b**.

The NO_X concentrations of April 21, 2009 are depicted in **Figure 8a**–**e** along with wind roses. The similar patterns of the wind roses are shown by both schemes YSU and MYJ, respectively (as seen in **Figure 8c** and **d**) as shown in observations (**Figure 8e**). The wind simulations of MYJ scheme are showing the low winds in comparison with YSU scheme but are in better arrangement with the observation. The GLCs of NO_X predicted by both schemes YSU and MYJ are presented in **Figure 8a** and **b**, respectively. MYJ predicted higher concentration compared to YSU, because MYJ simulated low wind compared with YSU. This is on the grounds that the impact of wind speed is contrarily corresponding to the centralizations of the pollutants [46, 47].

In comparison to the winter day, there is significantly less NO_X emission from TPP over Nagpur during this summer day. Comparative sort of results is seen during every one of the times of the both study months. Henceforth, we can infer that the impact of the power plant emissions of NO_X concentrations is negligible over Nagpur city for both winter and summer months. Based on this result, a fine resolution of 12 km × 12 km domain was selected for predicting the GLCs of NO_X over the Nagpur city for these two contrasting months and results during January 8, 2009 and April 21, 2009 are presented.

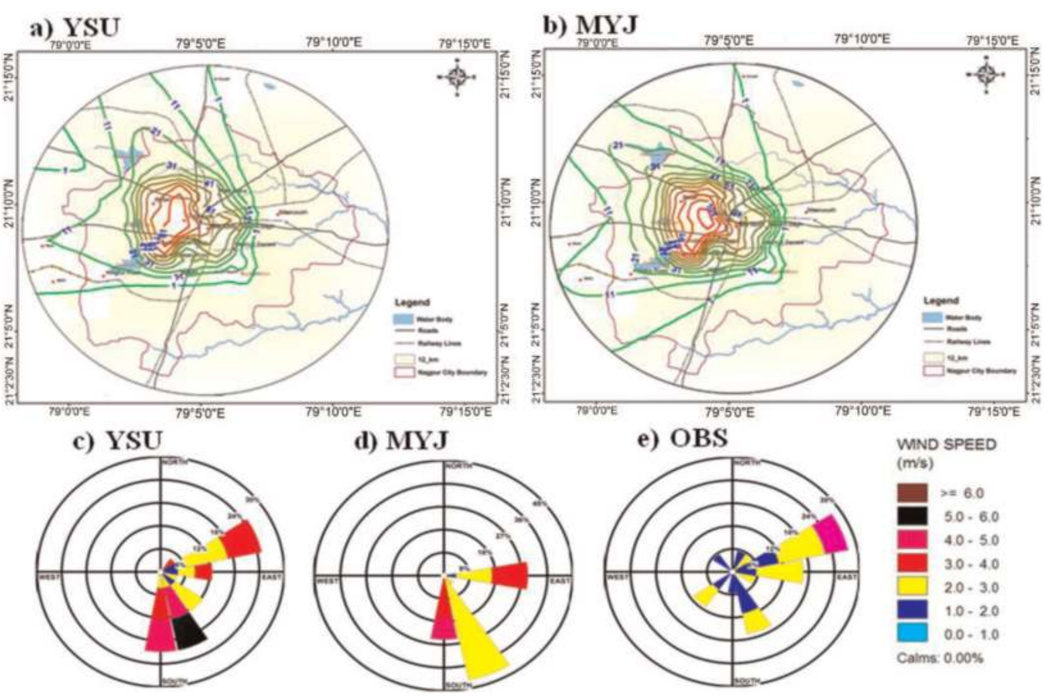

Figure 7.
Spatial distribution of 24-hour predicted NO_X GLCs (μgm^{-3}) (a) YSU, (b) MYJ (c) wind roses of YSU (d) wind roses of MYJ and (e) OBS wind roses on January 8, 2009, over Nagpur by using 30 km ×30 km domain.

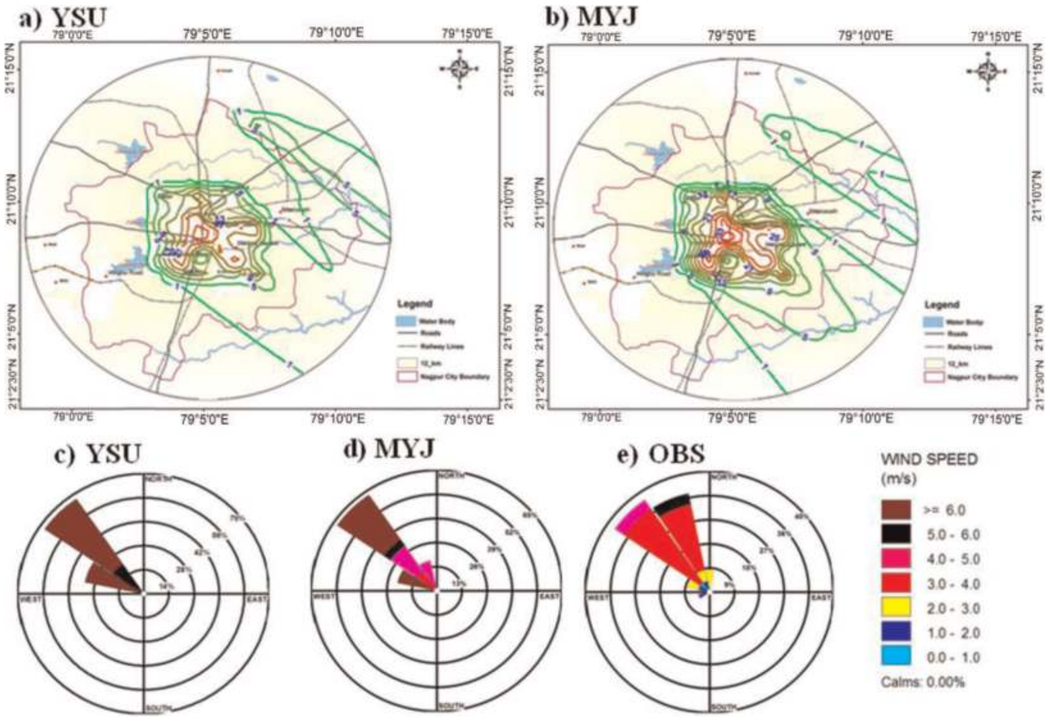

Figure 8.
Spatial distribution of 24-hour predicted NO_X GLCs (μgm^{-3}) (a) YSU, (b) MYJ (c) wind roses of YSU (d) wind roses of MYJ, and (e) OBS wind roses on April 21, 2009 over Nagpur by using 30 km ×30 km domain.

The forecasted concentration on January 8, 2009 from both (YSU and MYJ) schemes along with wind roses is presented in **Figure 9**. The determined NO_X concentration forecasted by PBL schemes YSU and MYJ (**Figure 9a** and **b** respectively) on January 8 is mostly in western part of the city, because the predominant wind directions are east northeasterly and southeasterly (**Figure 9c** and **d**). The predicted concentration of NO_X by both (YSU scheme and MYJ scheme) the schemes on April 21, 2009 is presented in **Figure 10**. The predominant wind direction is northwesterly (**Figure 10c** and **d**) and the results (the maximum concentration of the NO_X) predicted by YSU (**Figure 10a**) and MYJ (**Figure 10b**) schemes are in southeastern quadrant of the Nagpur city.

Similar kind of signatures of maximum concentrations is noticed during study period of these two contrasting months. These varieties of scattering of concentrations of NO_X are critical during these two differentiating months' outcomes in particular unique air quality over Nagpur. In light of the model inferred most extreme NO_X concentrations, not many spots of the Nagpur city are distinguished as area of interest areas meaning decayed air quality and are displayed in **Table 4**.

The recognized hotspot sites are Sita Buldi, Central bazaar road, North Ambazari road, Anjumna square, Liberty square, Low College square, Katol road, police commissioner office, and Sankar Niger square located in the western part to Nagpur city. These locations have high concentrations in January month and low concentrations in April month. Other locations such as medical chowk, Baidwanath chowk, Great nag road, NMC office Mahal, Sakkardara road, and Rajendra nagar are in north and southeastern part of the Nagpur city. These locations have higher concentrations of NO_X in January and low concentrations in April 2009. These changes in concentrations in the different locations of the Nagpur city during these two representative

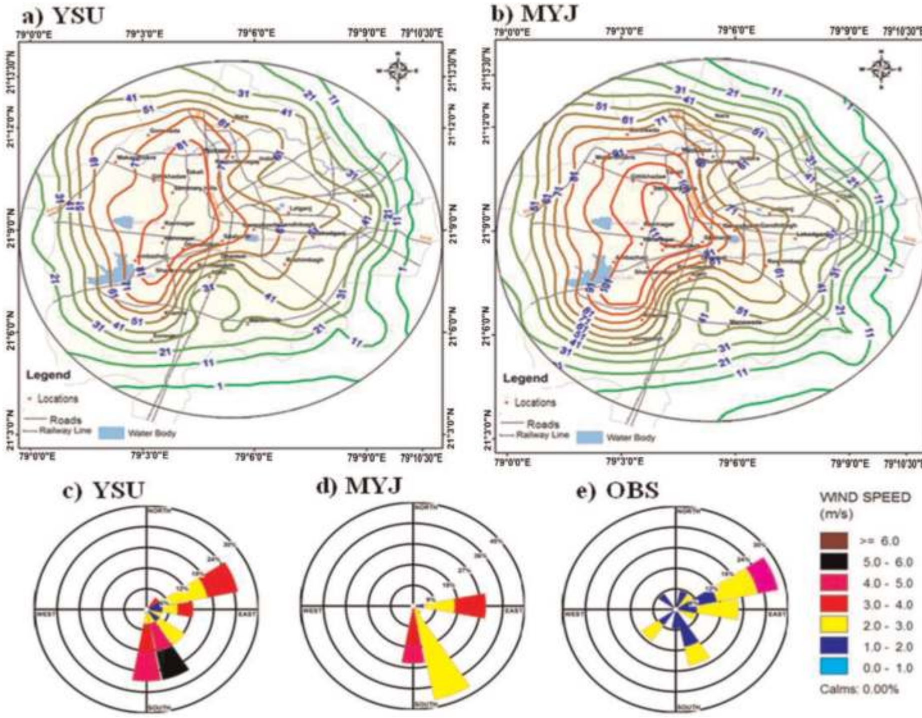

Figure 9.
Spatial distribution of 24-hour predicted NO_X GLCs (μgm^{-3}) (a) YSU, (b) MYJ (c) wind roses of YSU (d) wind roses of MYJ and (e) OBS wind roses on January 8, 2009 over Nagpur by using 12 km × 12 km domain.

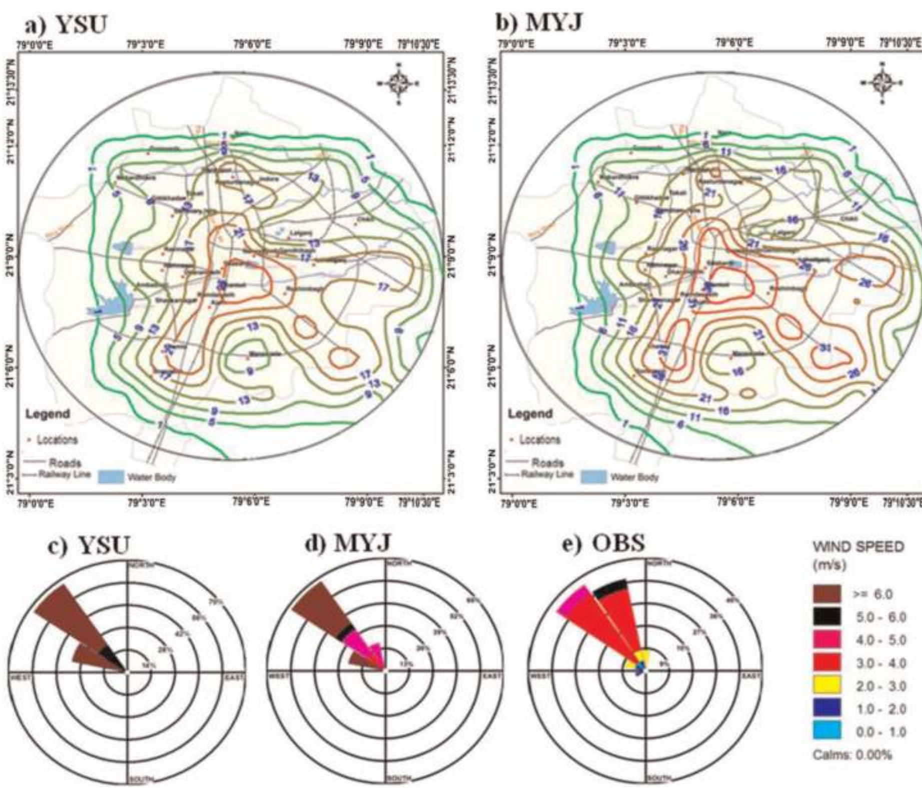

Figure 10.
Spatial distribution of 24-hour predicted NO_X GLCs (μgm^{-3}) (a) YSU, (b) MYJ (c) wind roses of YSU (d) wind roses of MYJ and (e) OBS wind roses on April 21, 2009 over Nagpur by using 12 km ×12 km domain.

Hotspot locations over Nagpur City based on higher NO_X concentrations	Average NO_X Concentration (μgm^{-3}) of January 2009 (Winter)		Average NO_X Concentration (μgm^{-3}) of April 2009 (Summer)	
	YSU	MYJ	YSU	MYJ
Sita Buldi	92	105	41	44
Central Bazar Road	80	90	38	25
North Ambazari Road	65	87	32	28
Anjuman Square	78	96	30	24
Liberty Square	62	84	29	26
Sankar Nagar Square	78	98	34	28
Low College Square	75	84	37	23
Katol Road	65	75	28	22
Police Com. Office	73	96	35	26
Medical Chowk	48	52	34	36
Baidwanath Chowk	35	48	29	34
Great Nag Road	54	62	33	35
NMC Office Mahal	62	67	38	29
Sakkardara Chowk	38	43	30	31
Rajendra Nagar	29	35	21	29

Table 4.
Identified deteriorated air quality (hotspot) locations over Nagpur City.

months of summer and winter season have discovered the monthly variability of deteriorated air quality locations in relations to extreme concentrations of NO_X.

5. Conclusions

WRF-ARW model is combined with AERMOD for processing GLCs of NO_X over Nagpur city. Scattering of NO_X by utilizing YSU and MYJ planetary limit layer plans of WRF-ARW model over Nagpur has been assessed.

Accurate assessment of the air pollution dispersion as well as air quality issues requires high-resolution emission inventory and air pollution dispersion models with better representation of the PBL parameters. One of the contributions emanated from this study is the preparation of gridded emission inventory using the vehicular traffic data over Nagpur city with 1-km resolution. The offline coupled modeling system of WRF-AERMOD reasonably simulated GLCs concentrations of NO_X during both representative months of winter and summer seasons over Nagpur city.

The coarse resolution of the (30 km $\times$ 30 km) has shown negligible impact of NO_X emission released from Thermal Power Plant in both the contrasting. The GLCs obtained from the finer resolution (12 km $\times$ 12 km) over of the Nagpur city has revealed significant dispersion patterns during the 2 months. Deteriorated air quality locations referred to as hotspot locations, based on the maximum NO_X concentrations, are identified for Nagpur. Significant variations in the concentrations are noticed during these two seasons. This study advocates the better representation of air pollution dispersion has shown by offline coupled modeling system of WRF-AERMOD and given confidence for its utility in the air quality assessment.

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