Poll Res. 41 (4) : 1220-1225 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2022.v41i04.012

FUTURE PROJECTION OF SO_2 CONCENTRATION LEVELS OVER TAMIL NADU, INDIA USING A HIGH-RESOLUTION REGIONAL CLIMATE MODEL, PRECIS

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(Received 22 April, 2022; Accepted 8 June, 2022)

ABSTRACT

Due to rapid economic growth, industrialization and urbanization, sulfur dioxide (SO_2) from coal-fired power plants in India has increased notably in the past decades. The present paper estimates and predicts the future sulphur dioxide (SO_2) concentrations in Tamil Nadu, India by using PRECIS, a Regional Climate Model (RCM) developed by Hadley Centre –UK Met office. The model is run with 25 km × 25 km resolution using different baseline Lateral Boundary Conditions (LBCs) from the Global Climate Model (GCM) - HadCM3Q at the emission rate of SRES A1B scenarios. Results show that SO_2 emissions in major industrial cities in Tamil Nadu increased dramatically by 40% during 2000–2012. It is estimated that, with current expectations on future economic development and with the present air quality legislation, anthropogenic emissions of SO_2 for the whole Tamil Nadu would increase more between 2010 and 2030 and then may decrease by end of the century due to various pollution control measures are implemented. For Tamil Nadu as a whole, the projection shows a decrease of 33% by the end of the century with respect to baseline period (1970-2000). Further, a long term trend in the sulphur emissions for all the districts of Tamil Nadu including Cudddalore, Kancheepuram and Chennai districts having major industrial areas are projected for the period 2020s, 2050s and 2080s. Such important results by using a high resolution regional climate model may be useful for various impact and vulnerability assessments studies in the state.

KEY WORDS : Air pollution, SO_2 emission, Climate Change, Regional Climate Model, PRECIS

INTRODUCTION

In India, the problem of air pollution has assumed serious proportions in most of the major metropolitan cities, where vehicular emissions contributed about 72% and industrial emissions about 20% to the ambient air pollution (Garg *et al.*, 2001). Uncontrolled use of fossil fuels in industries and transport sectors has led to the increase in concentrations of gaseous pollutants such as SO2, NOx, etc. Industrial sources, thermal power plants and transport sectors are identified as sole contributors for SO_2 emissions. According to the RAINS estimates, the world emissions of SO_2 in 1990 were about 120 million tons, while in 2000, the emissions were about 20% lower than 1990 level. Current energy and air pollution control policies cause a further 5% decrease till 2010-2020 (Cofala *et al.*, 2007). SO_2 emissions have reduced in most of the developed and developing countries due to stringent pollution control measures. Increase in SO_2 emissions are also linked with increase in motor vehicle population (Gurjar *et al.*, 2004). The Indian SO_2 emissions have grown from 2.39 Tg in 1985 to 4.8 Tg in 2005. The analysis of National Environmental Engineering Research Institute (NEERI), India air quality data in 1990 for annual average of SO_2 concentrations reveals a trend for increasing concentrations (from 3.8 to 15.2 ppb) in most of the parts of northern region, except for a few cities including Delhi, that had mean annual SO_2 concentration above 22.8 ppb after 1985 (Agarwal *et al.,* 1999). Many of the metropolitan cities in India are ranked amongst the top few cities of the world for air pollutants concentrations and for SO_2, the strictest values for annual means are 15 µg/m^3 for sensitive areas in India (Baldasano *et al.,* 2003). A study from Zifeng Lu *et al*. (2013) shows that during 2005–2012, SO_2 emissions increased rapidly by 71% in India from 3354 to 5738 Gg, with an annual average growth rate (AAGR) of 8.0% and Uttar Pradesh, Orissa, Gujarat, Chhattisgarh, Maharashtra, and Tamil Nadu are the six states with power-plant emissions >500 Gg SO_2 in 2012, and together, they accounted for 60% of total emissions, According to Zifeng Lu *et al.* (2013) the major source for SO_2 emission is from various coal-fired power plants. In Tamil Nadu, thermal power plants and other industrial sources are responsible for most of the SO_2 emissions. The top polluters from Tamil Nadu included Vellore, Cuddalore, Manali, Coimbatore, Tirupur, Mettur and Erode (TNPCB Report, 2011). In this paper, we present the results of RCM simulations using PRECIS (Providing Regional Climates for Impacts Studies) for Tamil Nadu state of India based on the second generation Hadley Centre regional climate model known as PRECIS by keeping in view the information that urban air pollution may be a serious threat to health and agricultural productivity in areas around urban centers. We explore on the trend of emissions and concentrations of SO_2.

METHODOLOGY

PRECIS is an atmospheric and land surface model of high resolution (up to 25 km) and limited area which can run with boundary data of HADCM3Q from 1950 to 2100 continuously. A more complete description of PRECIS is provided by Jones *et al.* (2004). HadCM3Q is used in this study to force the PRECIS simulations over a large domain which covers India. The Met Office Hadley centre is now able to provide boundary data from 17-member perturbed-physics ensemble (HadCM3Q0-Q16, known as 'QUMP') for use with PRECIS in order to allow users to generate an ensemble of high-resolution regional simulations. The detailed descriptions about the QUMP ensembles members are carried out by Mc Sweeney *et al.,* 2012 and Murphy *et al*., 2009. These boundary data have been derived from ERA40 [ECMWF (European Centre for Medium-Range Weather Forecasting] (Simmons *et al*., 2007). This reanalysis data set was produced with an improved GCM compared to that used in the construction of ERA15. HadCM3Q uses flux adjustments to ensure that the SSTs remain close to climatological values during a control period, while allowing SSTs to vary from natural variability and from atmospheric forcings such as CO_2 (Simon *et al*., 2004). The external forcing is from SRES (Special Report on Emission Scenarios) A1B emission scenario. Detailed description about various scenarios prepared under IPCC coordination have been described in SRES Report, 2010, Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all formulated, while the boundary conditions at the limits of the model's domain are required to be specified. The model simulations include sulphur cycle, to understand the role of regional patterns of sulphate aerosols in climate change. However, the effect of black carbon has not been included in the simulation experiments. The calibration is considered for Tamil Nadu which has boundaries at 08° 05′ N to 13° 35′ N and 76° 15′ E to 80° 20′E as depicted in Fig. 1. The detail about the PRECIS model simulation over the Tamil Nadu state is provided in one of our earlier publications (Prasanta Kumar Bal *et al.,* 2016). The model data is validated with Tamil Nadu Pollution Control Board data (TNPCB) by using 10 years air quality monitoring data (2003-2013) for the district Chennai. The GIS technology has been used in this study to better understand the spatial distributions at a regional scale. All the maps have been developed by using ArcGIS tool with spatial interpolation methods. The model data have been considered for SO_2 MASS MIXING RATIO. As the name says, this is mass mixing ratio, so would need to multiply it by air density to convert to kg/m^3 (and then to µg/m^3). As with all sulphur-cycle variables, this one is mass mixing ratio of S in SO_2, i.e. only the mass of the sulphur atom is considered. Since the observations are of the mass of SO_2 , then as well as multiplying by air density, the model data is multiplied by the ratio of the atomic weights of SO_2 and S (which, conveniently enough, in this case is just a multiplication by 2: S=32, O=16, so SO_2/S = (32+16+16)/32 = 2). The performance of change in future SO_2 emission is calculated by taking the difference of future and observed values from the model divided by observed values from the model in percentage.

RESULTS AND DISCUSSION

The simulated mass mixing ratio of SO_2 emission data during the baseline period (1970-2000) averaged over the whole Tamil Nadu from the model is shown in the Figure 1. The spatial distribution shows, there is high concentration of sulpher over the northern part of Tamil Nadu including the districts Kancheepuram, Villupuaram, Cuddalore, Vellore, Dharmapuri, Salem, Namakkal etc. Since, major industrial towns and municipalities are located in northern part of Tamil Nadu, these areas show high emission compared to other part of the state. Future concentration for Tamil Nadu by end of the century (2080s) in terms of % change is shown in Figure 2. Three major districts of Tamil Nadu (Cuddalore, Kancheepuram and Chennai) have been considered as the major contributors for SO_2 emission as most of the coal-based thermal power plants are established at these areas. Therefore the high concentrations are widespread over Northern part of Tamil Nadu. The concentration in northern part would intensify more by 2010-2040 in the range of 20 μg/m^3 to 78 μg/m^3 including the districts Chennai, Cuddalore, Kancheepuram, Dharmapuri, Erode, Perambalur, Pudukotai, Tirupur etc. (Table 1). The future emission for Chennai district shows a trend for increasing concentrations (from 15 to 27 μg/m^3) by 2030 and then a decreasing concentration to 6 μg/m^3 by end of the century. This is due to the major

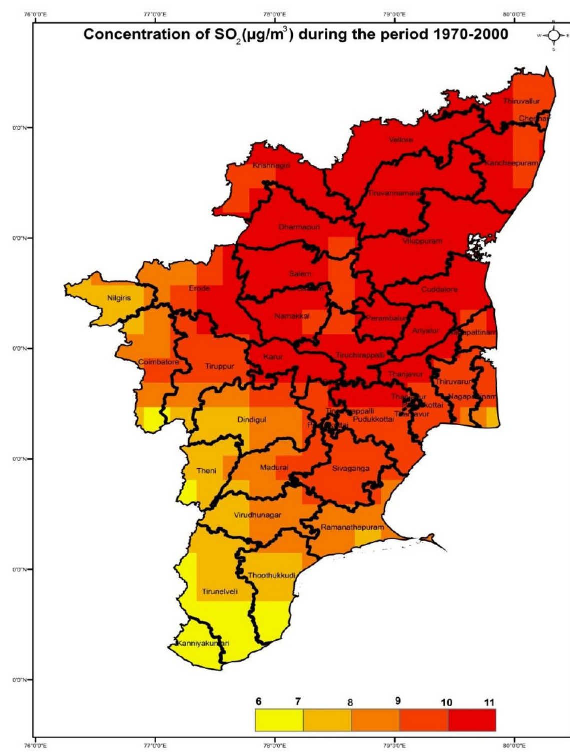

Fig. 2. Concentration of SO_2 (μg/m^3) during the baseline period over the whole Tamil Nadu

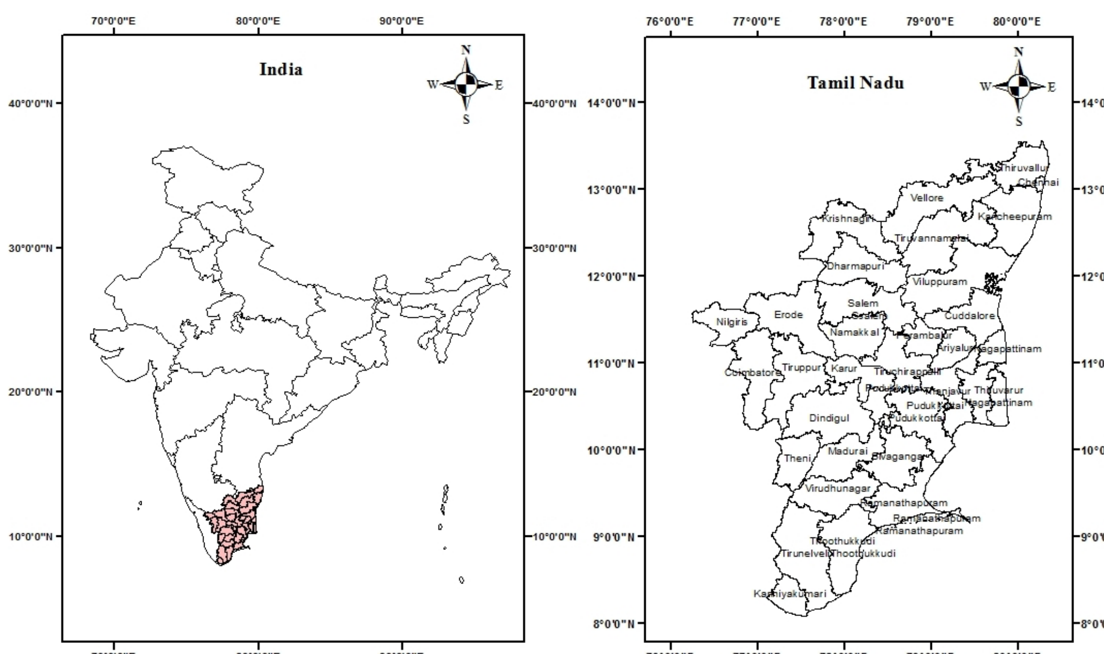

Fig. 1. Study Area

Table 1. Observed ambient air quality data (TNPCB) and model generated data (PRECIS) for the Chennai district for the period 2000–2013

Year	Model data-PRECIS ($\mu g/m^3$)	Observed-TNPCB ($\mu g/m^3$)
2000	17	14
2001	15	12
2002	15	12
2003	17	15
2004	16	15
2005	17	15
2006	18	16
2007	18	16
2008	17	18
2009	20	20
2010	19	20
2011	20	20
2012	21	24
2013	20	24

industrial area Manali, being situated at the northern part of Chennai. Chennai Petroleum Corporation Limited (CPCL) is the largest company in Manali and SIPCOT are the major sources for SO_2 concentration in Chennai. Similarly for Kancheepuram and Cuddalore, the projection shows an decrease in concentration from 24 $\mu g/m^3$ to 9 $\mu g/m^3$ and then a decrease up to 6 $\mu g/m^3$ by end of the century (Figure 3). SIPCOT industrial complex, Cuddalore is the major source for SO_2 concentration. The brief industrial profile has been described in MSME Report, 2012. Government of India contributed some recent policy decisions to reduce SO_2 emissions in future. These include a new automobile fuel policy for India, sulfur content reduction in petroleum oil products, and mandatory washing of coal that is used 700 km away from the mine mouth (Mashelkar *et al.,* 2002). A directive of the Supreme Court of India has resulted in conversion of more than 40,000 diesel vehicles (including buses, taxis and three-wheelers) to CNG in the national capital Delhi by 31 January 2003. This forced fuel switching has resulted in considerable reduction in particulate and SO_2 emissions in Delhi. Such initiatives are also underway in some of the major cities in Tamil Nadu. However, the sulfur content in the diesel oil supplied to the entire country has been decreased and the maximum sulfur content in gasoline has also been reduced from the entire country during 2000 and 2001(Garg *et al.,* 2006). These have resulted in an appreciable decrease in SO_2 emissions from the transport sector. Policy dynamics to mitigate local pollution is

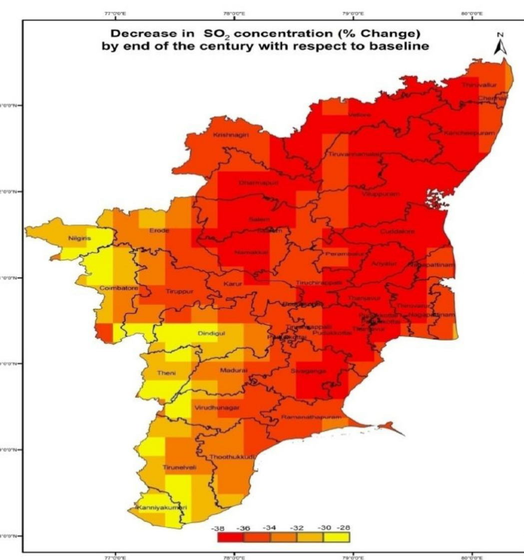

Fig. 4. Future projection of the concentration of SO_2 in % change by the end of the century

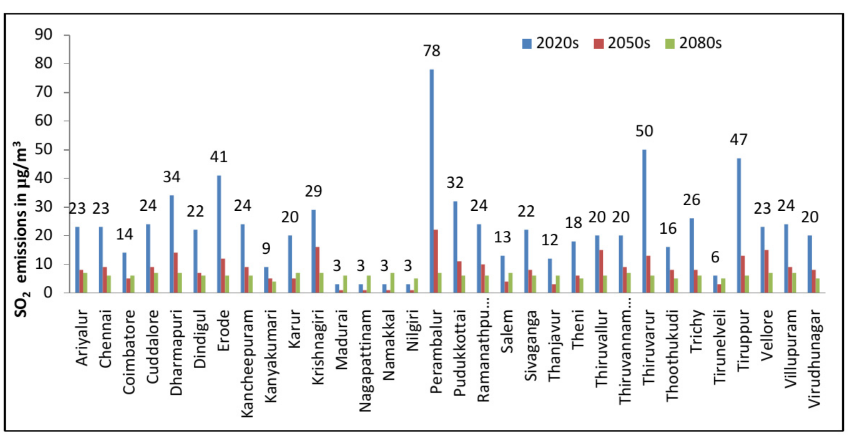

Fig. 3. Future projection of the concentration of SO_2 ($\mu g/m^3$) for the Tamil Nadu (District wise) for the periods 2020s, 2050s and 2080s

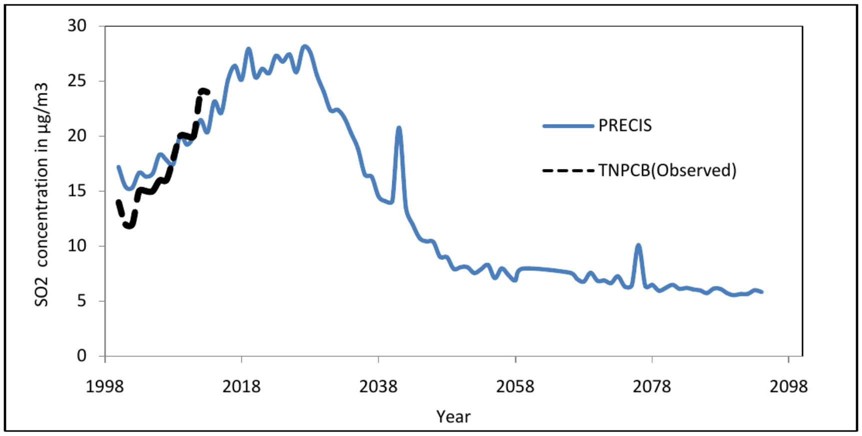

Fig. 5. Model evaluation and projection of SO_2 concentration (µg/m^3) over Chennai district of Tamil Nadu with TNPCB observation

projected to manifest in a reduction in SO_2 emissions in future even though the absolute energy consumption, and therefore CO_2 emissions, would continue to rise (Garg *et al*., 2003; Kapshe *et al*., 2003). The national mean of SO_2 levels reported by the Indian Government shows a decreasing trend, which is explained by recent policy measures such as a reduction of the sulfur content of diesel, the use of cleaner fuels in metropolitan areas, a change in domestic fuel from coal to liquefied petroleum gas (LPG) etc. (CPCB 2010). These may be the key factors which have been taken into consideration while developing regional climate models and predicting future SO_2 concentrations over India under A1B Scenarios.

CONCLUSION

PRECIS generated SO_2 emission scenarios are evaluated with ground-based observed data during 2003-2013 for the most polluted cities in Tamil Nadu. In this work, future projections for SO_2 emission for Tamil Nadu with district wise distributions have been performed for 2020s, 2050s and 2080s. Model Simulations using PRECIS shows more realistic results and performs well by representing the future SO_2 emission of Tamil Nadu. The current state of air quality indicates that SO_2 maintains a downward tendency throughout Tamil Nadu by end of the century, High emission is observed over northern part of Tamil Nadu including the districts Chennai, Cuddalore and Kancheepuram, Perambalur, Erode. Tirupur etc. No significant change is seen from the baseline by the end of the century over the rest of the parts of Tamil Nadu. Such information is highly desirable for the state like Tamil Nadu to plan for , adapt to and mitigate future impacts of climate change.

ACKNOWLEDGMENT

We are grateful to the scientists from modelling group, Hadley Centre for Climate Prediction and Research, UK Meteorological Office, for making available the PRECIS and the LBC data for the simulations used in this study. We are thankful to the Director of Centre for Climate Change and Disaster Management for initiating the climate change research and encouraging such unique piece of research at the center. This work was carried out when the second author (PKB) was employed there.

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