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Decreasing trends of atmospheric sulphur — Indian and global

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सार — 1978 से 1982 की अवधि के भारतीय स्टेशनों के आंकड़ों का उपयोग करते हुए वायुमंडल में सल्फर डाइ आक्साइड सांद्रता की प्रवृत्तिया का अध्ययन किया गया जिससे पता चलता है कि देश में 1.7800 ± 0.7207 माइक्रोग्राम$^{-3}$/वर्ष की दर से प्रवृत्ति में कमी हो रही है। इस गिरती हुई प्रवृत्ति का प्रमुख कारण उद्योगों, रेलवे, घरों में कोक के स्थान पर पेट्रोलियम पदार्थों (जो कि कम गन्धक छोड़ते हैं) का अत्यधिक प्रयोग हो सकता है। वायुमंडल में गन्धक का निर्धारण करने के लिए 1975 से 1984 की अवधि में वर्षा के जल में सल्फेट—गन्धक की सांद्रता का भी अध्ययन किया गया, ये भी प्रवृत्तियों की कमी को बताते हैं। विश्व मौसम संगठन द्वारा प्रदत्त विश्व बपमोन आंकड़ों का प्रयोग करते हुए इसी प्रकार के किए गए अध्ययन वायुमंडलीय गंधक बजट में लगभग 24 प्रतिशत की कमी बताते हैं।

ABSTRACT. Trends of SO_2 concentration in the atmosphere have been studied using the data of Indian stations from the period 1978 to 1982 which reveal that the trend in the country is decreasing at the rate of 1.7800 ± 0.7207 μgm^{-3}/year. The main cause behind this downwards trend may be excessive use of petroleum products (which emit less sulphur) as substitute for coke by the industries, railways and household. The concentration of sulphate—sulphur in the rainwater has also been studied from the period 1975 to 1984 to assess the sulphur in the atmosphere which also exhibits decreasing trends. A similar study using the global BAPMoN data supplied by WMO reveals about 24 per cent deficiency in the atmospheric sulphur budget.

1. Introduction

The atmospheric sulphur budget have been studied by many workers such as Eriksson (1960, 1962), Jung (1963), Robinson and Robins (1970), Kellogg *et al.* (1972), Friend (1973), Granat *et al.* (1976), Rodhe (1978) and many others, over different regions of the world and given theoretical atmospheric input estimates using different models based on the production and consumption of fossil fuel, petroleum products, biogenic and agricultural activity, population statistics and sea-spray etc over a region. These estimates had wide variations, region to region and worker to worker, depending upon the basic model adopted by the author. However, due to paucity of available observational data, these theoretical estimates could not be confirmed with the available observational data. As of today, the data bank in the country has sufficiently been strengthened than what it was about a decade back. Many research institutions in the country have taken up the study in the environmental chemistry and consequently, it has become possible now to compare the theoretical models with the one obtained from the observational data set. An attempt has, therefore, been made in the present study to examine the existing atmospheric sulphur trends in India using the observational data recorded in the country and then to compare it with the existing global trends.

2. Temporal trends of sulphur dioxide (1978-82)

The data of SO_2 concentration from 1978 to 1982 recorded by National Environmental Engineering Research Institute (NEERI), Nagpur from ten of its Indian stations (Fig. 1) has been utilised for the present study. The methodology adopted by NEERI for monitoring SO_2 has been given in its report on air quality (NEERI 1980, 1982). The mean level of SO_2 concentration over India has been worked out and plotted. It reveals (Fig.1 inset) that the trend is decreasing continuously at the rate of 1.7800 ± 0.7207 μgm^{-3} per year. The percentage decrease from 1978 to 1982 has been observed as 26 per cent as given in Table 1. SO_2 is very soluble in water and oceans are generally considered as sink for SO_2. Many of the earlier measurements of SO_2 concentration have been reviewed by Jung (1963) who reported worldwide concentration at ground level between 0 and 20 $\mu g/m^3$. Recent measurements in tropical air in Panama (Lodge *et al.* 1966) yielded values between 1 and 5 $\mu g/m^3$. Cadle *et al.* (1968) found SO_2 concentration in Antarctic air as between 1 and 3.2 $\mu g/m^3$. More recently Georgii (1970) has obtained values between 1 & 4 $\mu g/m^3$ over Atlantic Ocean and between 0.5 and 2 $\mu g/m^3$ over Colorado. The study done by the above workers reveals that with time the concentration of SO_2 is decreasing continuously at different places

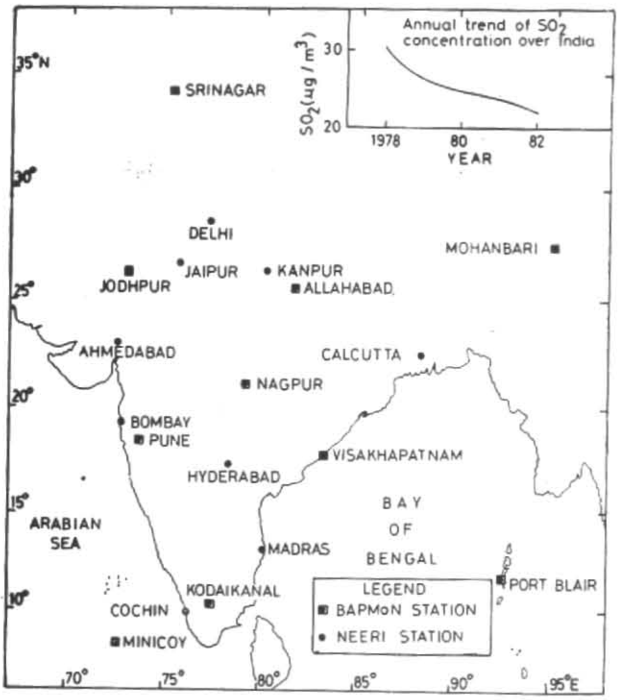

Fig. 1. Locations of BAPMoN and NEERI stations and annual trend of SO_2 concentration over India (inset)

TABLE 1

Trend of sulphur dioxide emissions over India from 1978 to 1982

Details	1978	1979	1980	1981	1982
Number of reporting stations	9	9	10	10	12
Trend (%)	100	85	82	80	74
Minimum value ($\mu g/m^3$)	5.5	11.0	8.3	6.3	5.7
Maximum value ($\mu g/m^3$)	51.3	45.0	44.7	85.3	63.7

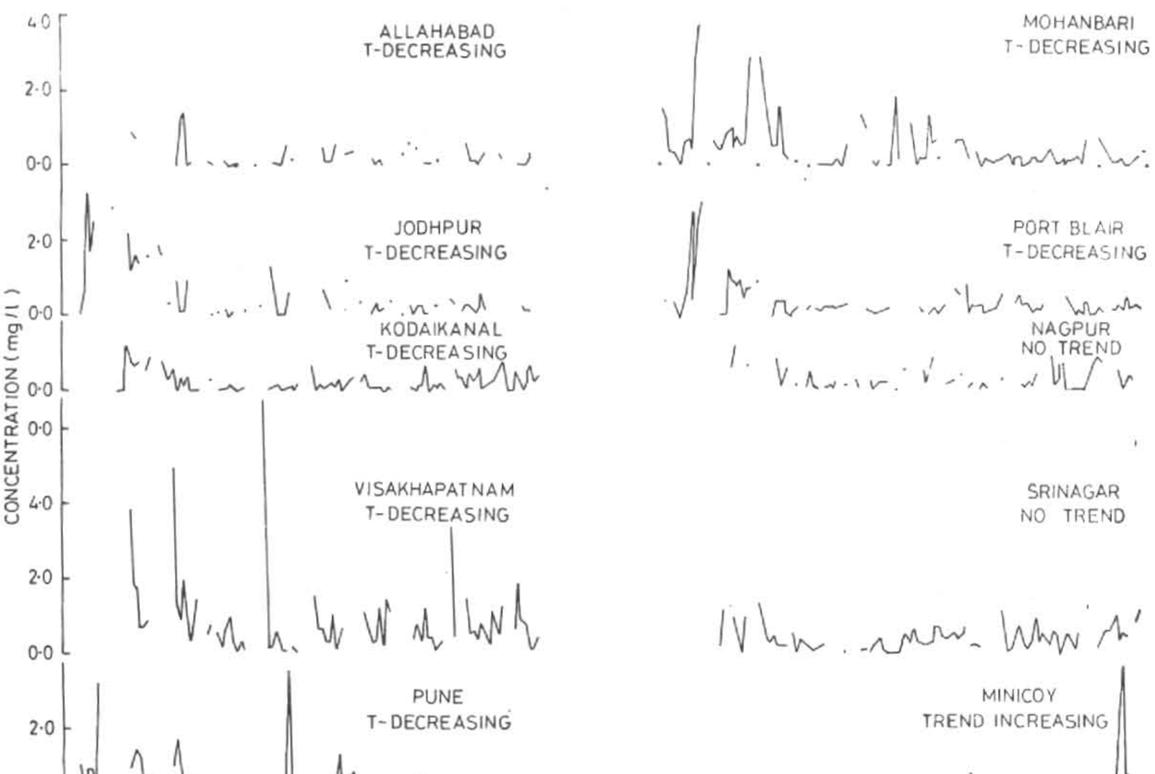

Fig. 2. Temporal trends of sulphate — sulphur over India (1975 -1984)

TABLE 2

Trend of sulpate—sulphur recorded by BAPMoN stations over India from 1975 to 1984

Details	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
No. of reporting stations	4	9	10	10	10	10	10	10	10	10
Trend (%)	100	95	62	15	10	36	26	20	25	30
Min. value (mg/l)	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Max. value (mg/l)	3.81	3.87	4.94	0.83	6.68	1.30	1.39	1.19	3.36	3.79

TABLE 3

Global trend of sulphate—sulphur recorded by BAPMoN stations all over the world from 1975 to 1984

Details	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
No. of reporting stations	49	54	73	74	77	76	73	70	64	44
Trend (%)	100	98	92	85	87	88	79	82	79	76
Min. value (mg/l)	0.34	0.24	0.20	0.05	0.05	0.12	0.06	0.09	0.07	0.12
Max. value (mg/l)	3.77	3.89	3.61	3.45	3.22	2.54	2.97	2.97	3.40	3.31

probably due to the change of mode of consumption of energy fuel, *i.e.*, from raw coal burning to other conventional sources of energy, *i.e.*, natural gas which is a very clean fuel, since sulphur content in it does not usually rise above 5 ppm (Medice 1974) and almost all of it is removed before use. The combustion of coal and petroleum accounts 90 per cent of the total sulphur emitted by man which is above 40 per cent of all atmospheric sulphur emissions (Cullis and Hirschler 1980).

3. Temporal trends of sulphate—sulphur (1975-84)

When the sulphur containing gases (SO_2, H_2S) emitted by the anthropogenic, biogenic and agricultural processes reach the atmosphere, which is a sink to all such gases, are oxidised in the atmosphere into sulphates under certain conditions. According to Robinson and Robbins (1968), out of the total sulphur in the atmosphere, about 70 per cent is in the form of sulphate aerosols. Sulphate ions in precipitation water thus originate from both dissolution of particulate sulphate and absorption of SO_2 with subsequent oxidation. So about 20-50 per cent SO_2 oxidises in the atmosphere to sulphur in this way. The sulphate species formed near the ground surface are easily removed by dry deposition over land, sea and trees, while those formed or transported at high levels remain there suspended as nuclii till they are trapped by the air mass or washed out by rains, and these rain samples have thus been collected and analysed in the laboratory under the instructions from the World Meteorological Organization (W.M.O.). Monthly concentrations of SO_4 in respect of Indian BAPMoN stations have been plotted for each station from 1975 to 1984 (Fig. 2) which exhibit decreasing trends at most of the stations. Similarly annual concentration of 'sulphate' species using rainfall weighted averages reveal that the trend is decreasing at a rate of 0.0681 $\pm$0.0071 mgl^{-1}/year (Fig. 3b) as detailed in Table 2. This trend has been compared with the global trend studied by WMO (WMO *Newsletter* No. 2) plotted here side by side (Fig. 3a) having the data of a number of global BAPMoN stations. The global trend based on the observational data also exhibit a decreasing trend at the rate of 0.0338$\pm$0.0032 mgl^{-1}/year as shown in Table 3 and about 24 per cent decrease from 1975 to 1984 has been observed which is quite comparable with the existing trend in Indian sub-continent. In order to see whether this global trend has any impact on its regional values, a correlative study has been done (Fig. 4) between global sulphate concentration and the corresponding concentrations as recorded at Indian stations (both BAPMoN data) revealing about 85 per cent correlation between the above two variables. This suggests that the global atmospheric sulphur has a profound effect on its regional values and the sulphur deficiency in the atmosphere, which has recently been witnessed in the country, is a part of the global phenomena.

4. Discussions

There is a growing pressure now for industrialised countries to limit the increase in sulphur emissions by the conservation of energy and increased installation of sulphur removal technologies, as a result of which in many parts of the world the sulphur trends have either decreased or its growth has considerably been arrested. Also the control strategies have become more and more effective now-a-days in reducing the sulphur pollution in the atmosphere due to the terror of acid rain phenomena in the coming century. According to Yanaglsawa (1973) concentration of SO_2 in Tokyo had increased continuously until 1966 and reached to its peak value but then started decreasing rapidly each year. Garnett (1980) observed a marked decrease in the levels of SO_2 concentration since 1970 in Sheffield

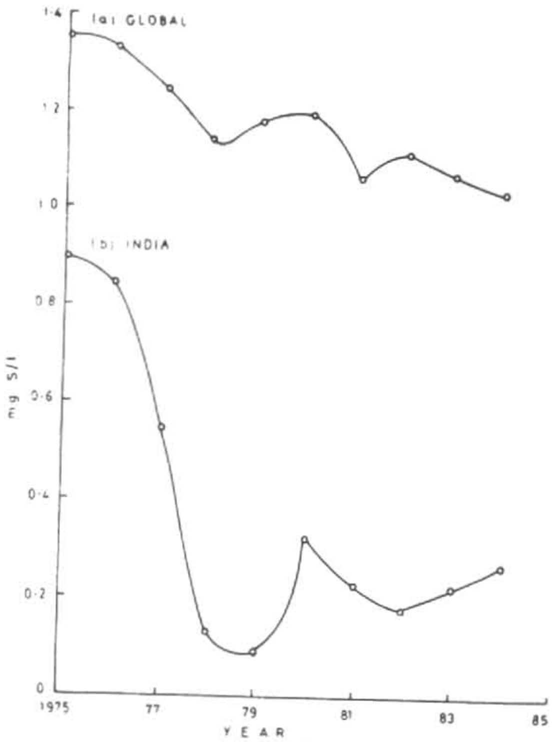

Fig. 3. Trends of sulphate—sulphur over (a) Global & (b) India

region of England which he claims to be due to substantial increase in the use of sulphur-free fuel (natural gas and purified coke-oven gas) in industries. Similarly, Weatherly (1979) reported that sulphur emissions in U.K. have not increased over last ten years or so.

In Canada (National report, 1984) the average annual sulphur dioxide concentration decreased by approximately 30 per cent between 1974 and 1981.

Similarly, according to Sequeira (1982) the trend in SO_4^{2-} ion concentration at United States over the last 20 years has not increased. But according to Harry (1987) there was a general nationwide decline in SO_2 emissions in United States between 1975 and 1984. The most notable emission decreases were recorded in Arizona (—62%), Kentucky (—54%) and California (—49%) whereas the largest increases occurred in Oklahoma (+171%) and Georgia (+74%). Thus, he observed statistically significant downward trends in 32 States, upward trends in 10 stations and no significant trend in 6 States of U.S.A.

Buishand *et al.* (1988) found a significant negative trend at 1 per cent level for SO_4^{2-} concentrations and depositions in Netherlands. The trend for deposition was $-3.5\%\ a^{-1}$.

Similarly, Berge (1988) observed decreasing trends of sulphate—sulphur in precipitation in Norway from 1972 to 1982.

According to Rodhe and Granat (1984) the decrease in sulphate concentration observed at most of the Scandinavian stations between the early 1970s and the early 1980s (on the average about 20 per cent) is, by and large, consistent with the estimated decrease in emissions in several of the countries that are known to contribute significantly to the deposition in the Scandinavian countries, *i.e.*, mainly the Scandinavian countries themselves, the U.K. and West Germany.

According to the W. M. O. BAPMoN *Newsletter* (1987), sulphur emissions for the period 1974-78 and for 1980 show a decrease by 19 per cent in Europe and the sulphur content in petroleum indicates a decrease by about 10 per cent from 1979 to 1984.

According to Hirsehler (1980), the amount of sulphur emitted per tonne of petroleum consumed has decreased considerably after reaching a maxima in 1965 and the sulphur content of the different petroleum products contributing to emissions was considerably lower in 1974 than, for example, in 1965. In India, Dave (1986) while reviewing the work done by NEERI (1978, 1982) observed that the average annual concentration of SO_2 has increasing trends only in one city in India,

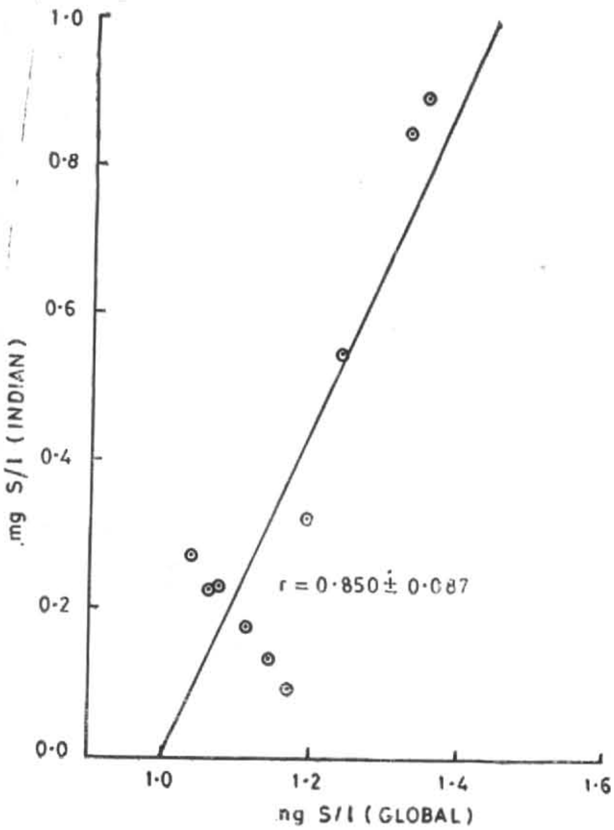

Fig. 4. Global *vs* Indian sulphur concentration (1975-1984)

viz., Calcutta and decreasing trends in Ahmedabad, Bombay, Hyderabad, Jaipur, Kanpur and Madras while no definite trend was observed in Delhi and Nagpur. Even in remote oceanic areas where the sulphur is predominantly available due to sea-spray, the trend of sulphur is observed to be decreasing. Varma (1986) observed decreasing sulphur trends over Port Blair which is situated in the midst of the Bay of Bengal.

5. Conclusions

From the present study it appears that the sulphur emission control strategies yielded tangible results all over the world and the petroleum products contributing to emissions have also registered decreasing sulphur content, as a result of which in many parts of the world the sulphur trends have surprisingly declined inspite of the heavy industrialisation. This is so, specially, in Indian sub-continent, Japan, United States, Canada, United Kingdom, Germany, Netherlands, Scandinavian countries and many other countries of the world where the sulphur trends have been successfully studied.

The global sulphur content in the atmosphere has, thus, been decreased considerably since last one and a half decade, which will definitely minimise the chances of acid rains (H_2SO_4) in many parts of the world specially in Europe and America where its chances are pretty high. Apart from this, the severity of certain respiratory and eye diseases will also be reduced with the decrease in the sulphur content in the atmosphere.

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