Interestingly, cool pools have developed over the western sector of the city, due to the favourable topographic setting of the area. The area is bounded by hill ranges (> 700 m ASL) on the western margin and by Pauna and Mutha rivers to the north and south respectively. Drainage of cold air from these hill ranges might have been responsible for the formation of cool pools in the foothill zone. The lowest minimum temperature of 5.8°C was recorded near Pashan lake (C1) located in a natural depression surrounded by hills. At this site, the relative relief is more than 100 m and this might have resulted in stagnation of cold air leading to lower temperature. The other cool pools namely C2, C3 and C4 were observed near Aundh and N.C.L. in the western sector, and at Warje in the southwestern sector respectively. In comparison with other cool pockets, C1 exhibits remarkably low temperature values. This difference can be possibly attributed to the lower relative relief in the vicinity of other cool pocket sites. In view of the above discussion the occurrence of H3 pocket in the west is anomalous. This can be attributed to the overwhelming effect of the process of intense urbanization over the effect of terrain characteristics on the formation of temperature fields.

The preceding discussion leads one to conclude that urban influences on the temperature distribution within Pune city are very pronounced. It is well-reflected in the rapid cooling at the outskirts than in the built-up areas in the city. The major heat island was observed over the densely populated old core of the city where the magnitude of temperature difference is about 3.5°C. It is interesting to note that the centre of heat island identified in 1978 has shifted towards northeast. The study further demonstrates that the industrial area to the north continues to be a warm pocket. The development of two additional warm pockets (H2, H3) can be associated with rapid urbanization, in the last decade. Three cool pools detected during the survey owe their existence to the hilly terrain in the western sector. The lowest temperature of 5.8°C, as expected, was observed near Pashan lake. The anomalously high temperature giving rise to the heat pocket (H3) can be explained in terms of the overwhelming influence of development over topography in the Kothrud area.

In this context, it can be suggested that to reduce the intensity and adverse effects of heat islands, the planning of urban complexes should include green parks and open spaces. Such green pockets are not only important as recreational areas but will also contribute in amelioration of the undesirable features of city climate.

---

1 Oke, T. R., in *Science and the Future Encyclopedia Britannica*, Chicago, 1977, pp 116-131

2 Henderson-Sellers, A and Robinson, P J, *Contem Climatol*, 1988, 285

3 Landsberg, H. E., Technical Note, WMO, 1968, 108/1

4 Nkmdrın, L. C., *J Appl Meteorol*, 1976, **15**, 818

5 Oke, T. R and Maxuel, G B., *Atmos Environ*, 1975, 191

6. Padmanabhmurthy, B and Hirt, M S., *Water, Air Soil Pollut*, 1974, **3**, 81

7. Bahl, H. D and Padmanabhmurthy, B, Prepublished Scientific Report, India Met Dept., 1977, 0077/6

8 Krishna Nand and Maske, S J, Prepublished Scientific Report, India Met Dept, 1978, 113

9 Philips, N M, Daniel, C E. and Krishnamurthy, K, Proc Symp on Environ. Poll, CPHERI, Nagpur, 1974, pp. 308–317

10. Maske, S J, Krishna Nand, Behere, P G. and Kachare, S D, Prepublished Scientific Report, India Met Dept, 1978, 78112

11 World Meteorological Organization, Technical Note, 1968, No 108

ACKNOWLEDGEMENTS We gratefully acknowledge the assistance received from the Department of Geography and School of Environmental Sciences, Univ of Poona during this survey and thank Dr V S Kale, Head, Department of Geography for constructive suggestions in the manuscript We also acknowledge the facilities provided and the valuable suggestions of Dr H S Shrivastava, the Additional Director General of Meteorology, IMD, Pune

Received 24 November 1993, accepted 2 December 1993

---

# Diurnal and seasonal variations in air pollutant concentrations in a seasonally dry tropical urban environment

**J. Pandey and M. Agrawal**

Centre of Advanced Study in Botany, Banaras Hindu University
Varanasi 221 005, India

**Air quality monitoring of Varanasi city indicates a logarithmic normal distribution pattern of 2-h mean concentrations of $SO_2$, $NO_2$ and $O_3$. Ozone concentrations peaked from late morning to afternoon of summer and those of $SO_2$ and $NO_2$ during early morning and late evening of winter months. The coincidence in the timing of $SO_2$ and $NO_2$ peaks appears interesting from the biological perspectives.**

AIR quality monitoring is important for understanding the air pollution effects on living systems Air quality data have been used to establish relationships between pollutants[1], between source and sink[2] and between plant and pollutants[3]. Recent studies have emphasized the importance of peak exposure in eliciting adverse effects on plants[4,5]. Peak concentration of $SO_2$ affects vegetation more adversely than prolonged exposure to low concentrations[6,7]. Further, the combination of $SO_2$ and $NO_2$ has been shown to cause visible injury at considerably lower concentrations than those required for either gas alone[8]. Thus data regarding peak concentration of pollutants and their co-occurrence pattern are important for assessing vegetation damage due to air pollutants. In India, $SO_2$ and $NO_2$ have been found to be the phytotoxic components of urban air[9-13]. There are, however, no published data on peaks of these pollutants and the co-occurrence patterns of different pollutant pairs that may be encountered in different conditions in the urban industrial areas. The objective of this study was to characterize the timing of peak occurrence and patterns of co-occurrence of important gaseous pollutants ($SO_2$, $NO_2$ and $O_3$) in a seasonally dry tropical urban area.

Varanasi city (latitude 25°18'N, longitude 80°1'E) is located about 76.19 m above the mean sea level (Figure 1). It has a tropical climate with marked monsoonal effect. The average annual rainfall exceeds 1000 mm, more than 90% of which occurs during the rainy season (late June to mid-October). November to February is cool and dry (winter) and March to mid-June is hot and dry (summer). The mean maximum monthly temperature varies from 22°C in January to 42°C in May and the mean minimum monthly temperature from 6°C in January to 25°C in June. Wind direction shifted from predominantly westerly and north-westerly in October through April to easterly and north-westerly in the remaining months.

The present data are for two years at fifteen urban sites of Varanasi city. The city was divided into five zones (I to V) and three microsites were selected in each zone on the basis of pollution sources and structure of build-up areas (Table 1). Air quality was monitored at each sampling site by using high volume samplers located at 2.5 m above the ground level. Pollutants such as $SO_2$, $NO_2$ and $O_3$ were scrubbed separately in tetrachloromercurate, NaOH (0.1 N) + 1% sodium arsenite, and buffered KI (0.1 N) respectively as described by Pandey *et al.*[13] These absorbing solutions were analysed colorimetrically for sulphur dioxide[14], nitrogen dioxide[15] and ozone[16] at 10-day interval at each microsite. For the diurnal cycle, data were collected at 2-h intervals.

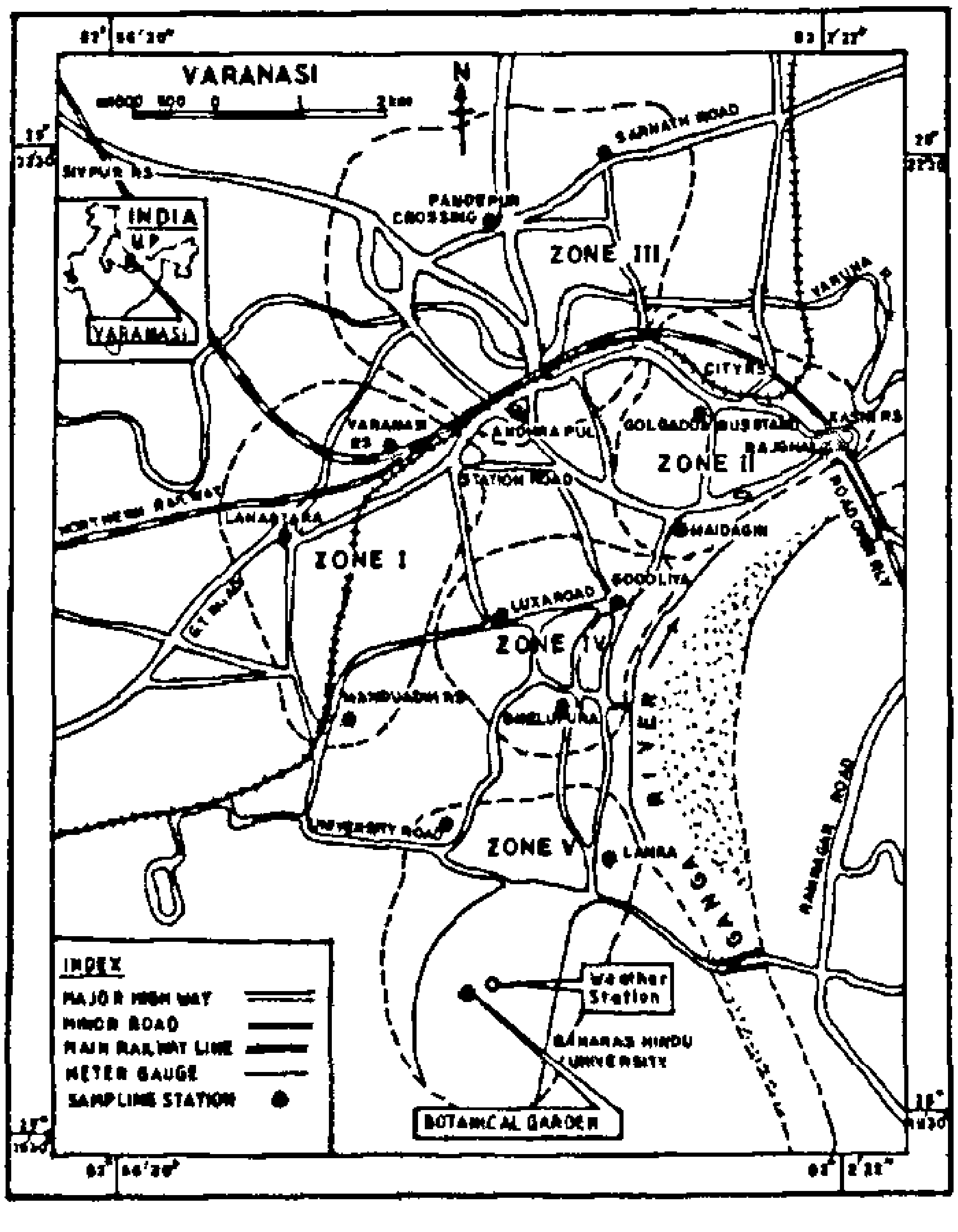

Figure 1. Index map of the sampling sites

**Table 1.** Characterization of monitoring sites

| Site | Site type | Site no. | Comments |
|---|---|---|---|
| Lahartara<br>Rajghat | West zone<br>East zone | I<br>II | Occupied the areas along major highways and railway stations. These zones are also characterized by a number of transport vehicle stops, motor workshops and small industries. |
| Pendepur | North zone | III | This zone includes the entire area of Andhrapul, Shivapur to Sarnath The zone is characterized by a network of major and minor roads with moderate traffic congestion |
| Godolia | Central zone | IV | A highly congested shopping and residential complex characterized by high building and narrow streets. The zone is particularly exposed to the emission from light vehicles. |
| Banaras Hindu University | South zone | V | This zone is primarily a residential locality mainly with official buildings, gardens and cultivated lands |

Figures 2 to 6 show seasonal and diurnal variations in the concentrations of $SO_2$, $NO_2$ and $O_3$ at different zones. On the basis of air quality data, the urban area of Varanasi can be ranked from maximum pollution load to a minimum as I > II > III > IV > V. Zone V, situated at the south-west of the city, is typically a residential locality with official buildings, gardens and cultivated land. Since the predominant wind direction of the area is westerly, this zone received minimum pollution input. Sitewise variations in pollutant concentrations were significant. However yearwise variations in pollutant concentrations were not significant. Highest concentrations of ozone occurred in summer, while that of $SO_2$ and $NO_2$ during the winter season. In a diurnal cycle, peak concentrations of $O_3$ at all sites were recorded during early and late afternoon in winter and summer seasons respectively. However, $SO_2$ and $NO_2$ peaks were observed at evening hours. Additional peaks of $SO_2$ and $NO_2$ occurred during the morning hours.

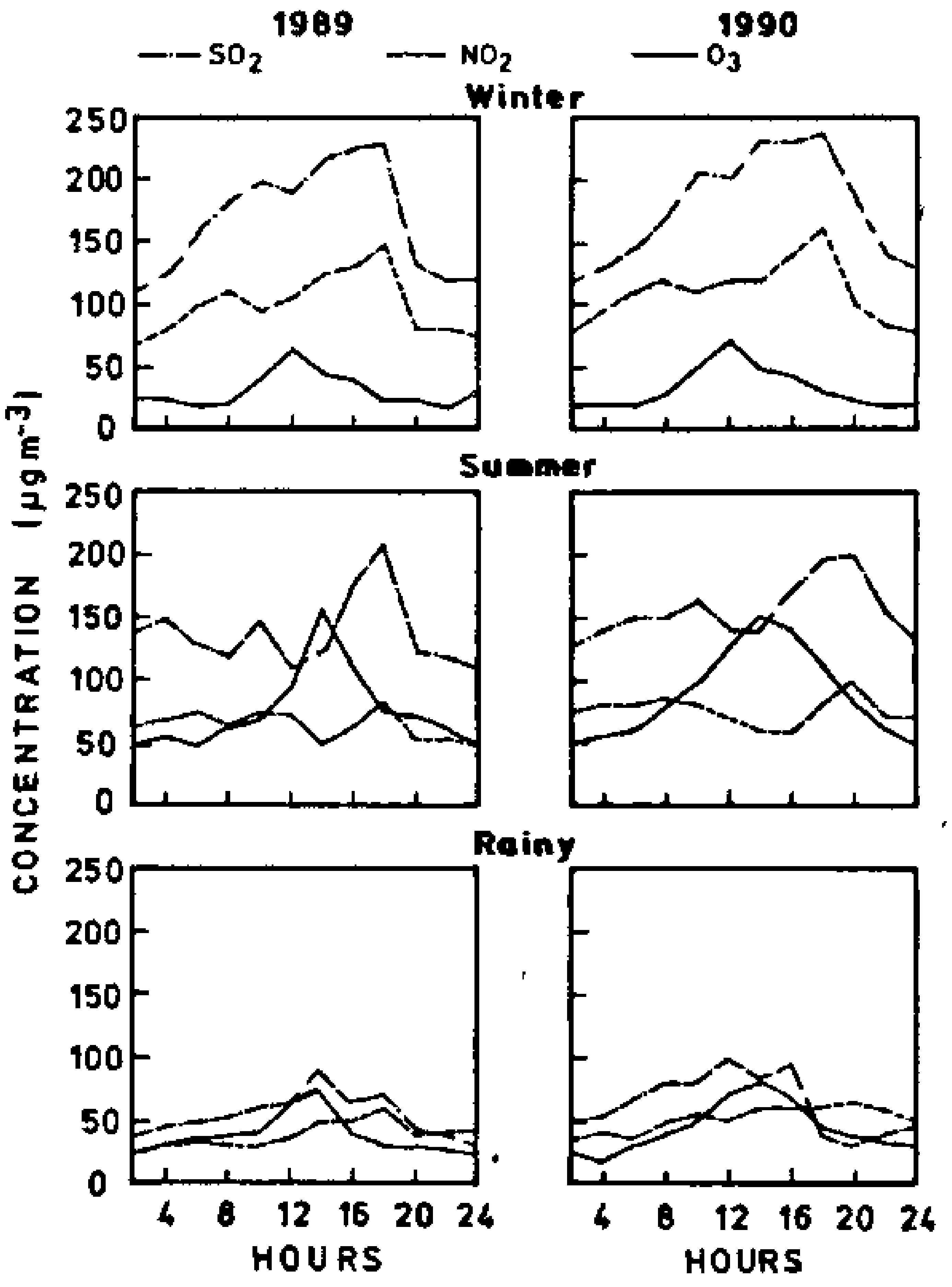

Figure 2. Seasonal and diurnal trends in pollutants concentration at zone I

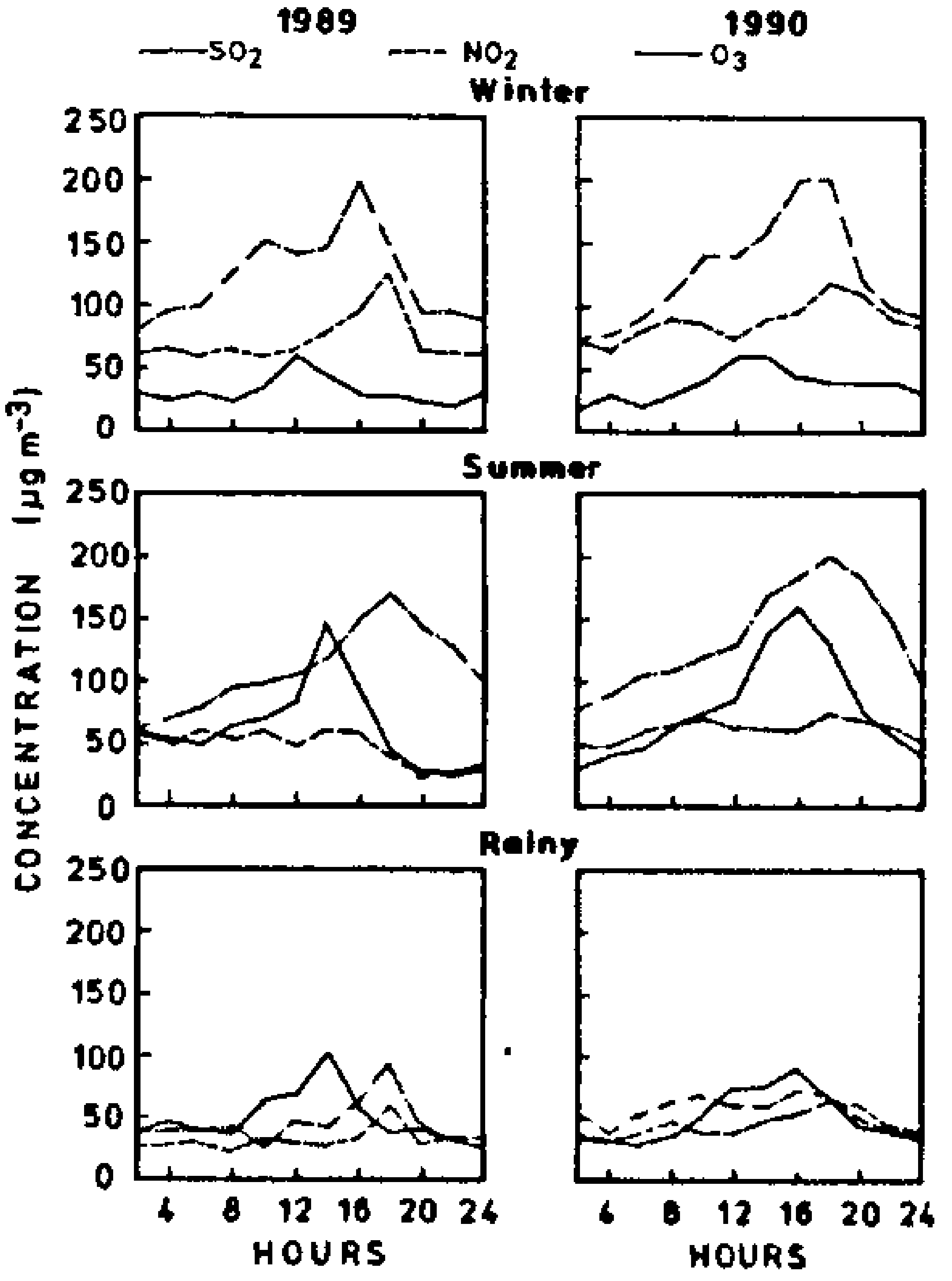

Figure 3. Seasonal and diurnal trends in pollutants concentration at zone II

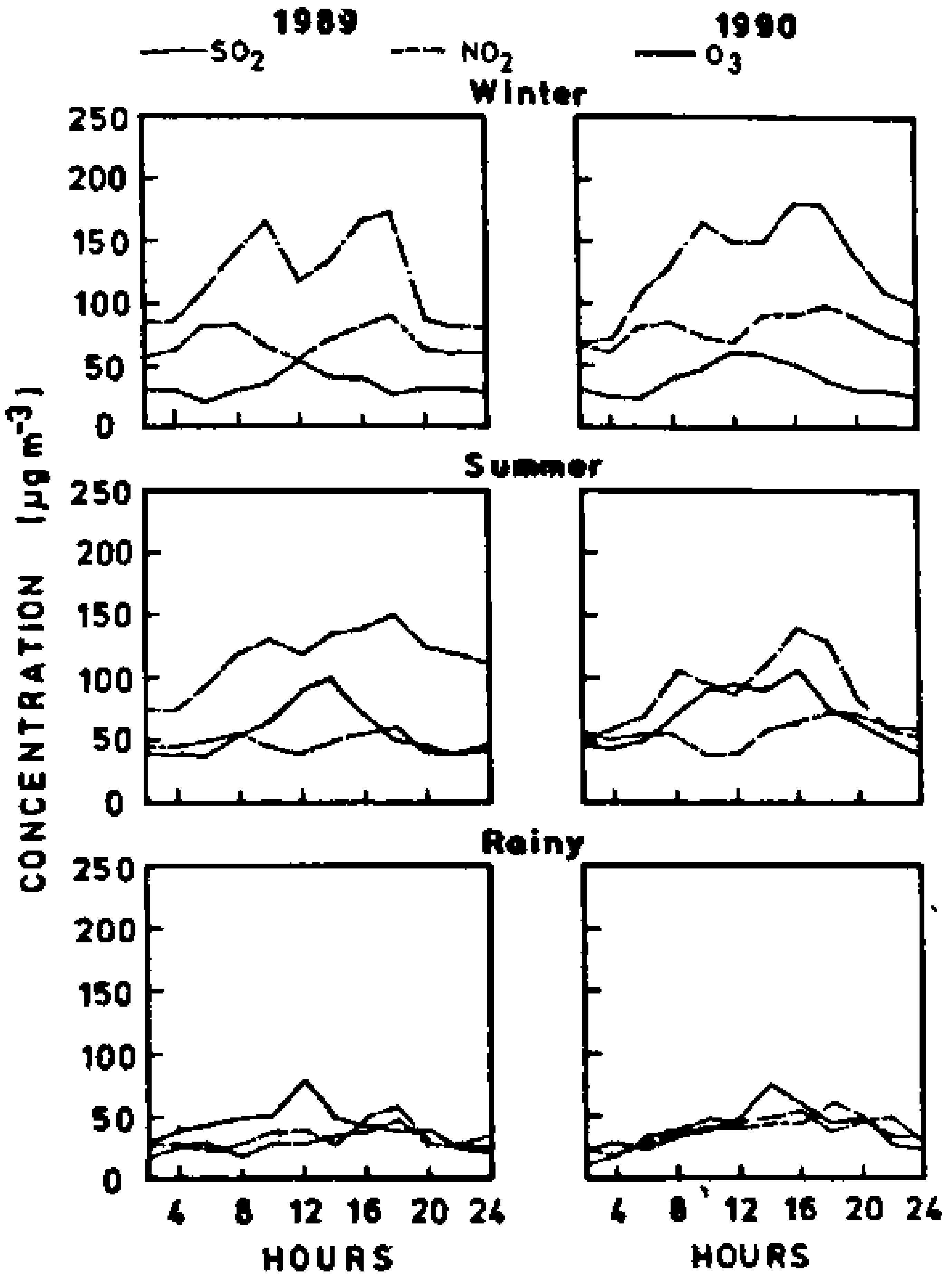

Figure 4. Seasonal and diurnal trends in pollutants concentration at zone III.

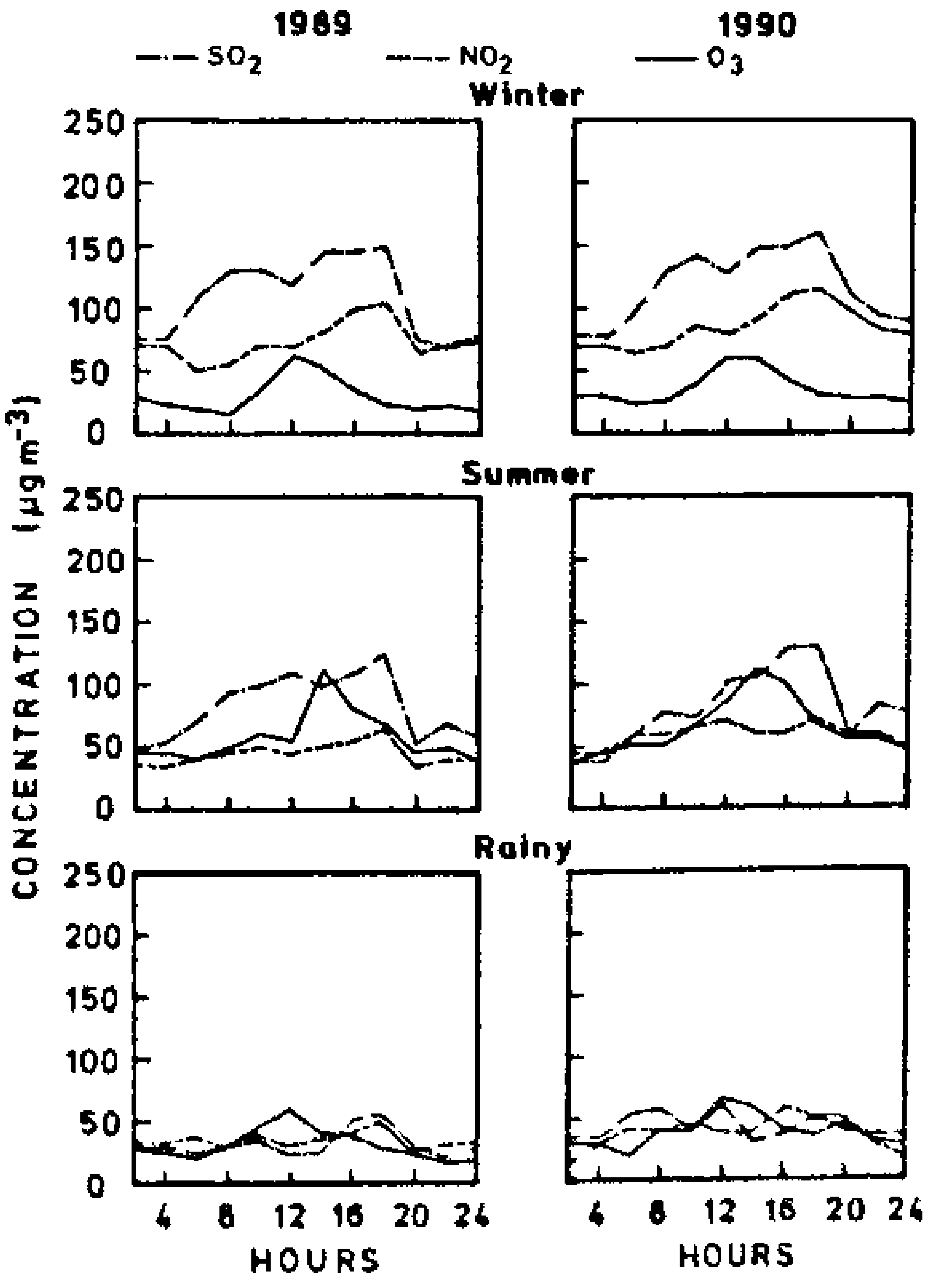

Figure 5. Seasonal and diurnal trends in pollutants concentration at zone IV

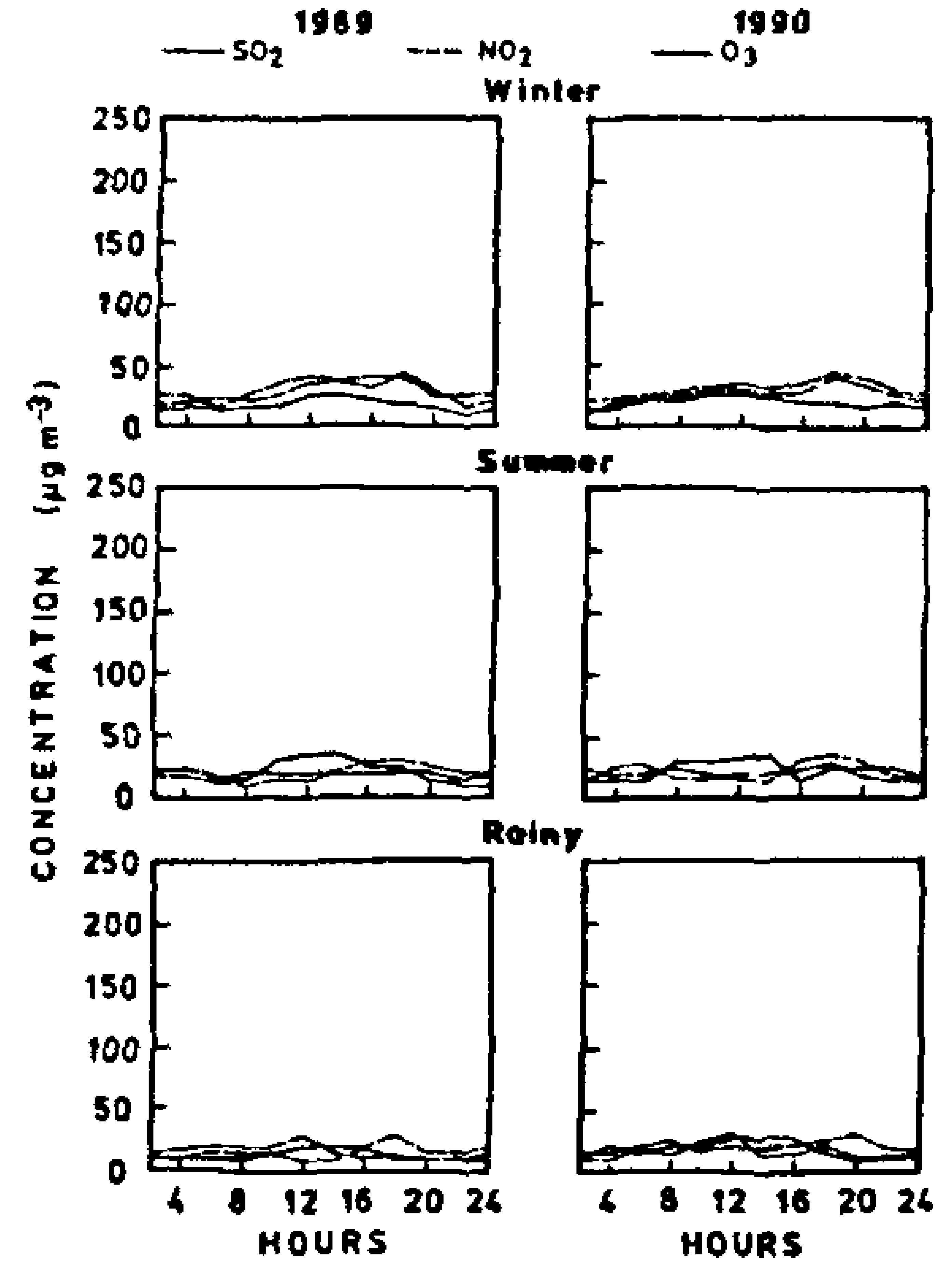

Figure 6. Seasonal and diurnal trends in pollutants concentration at zone V

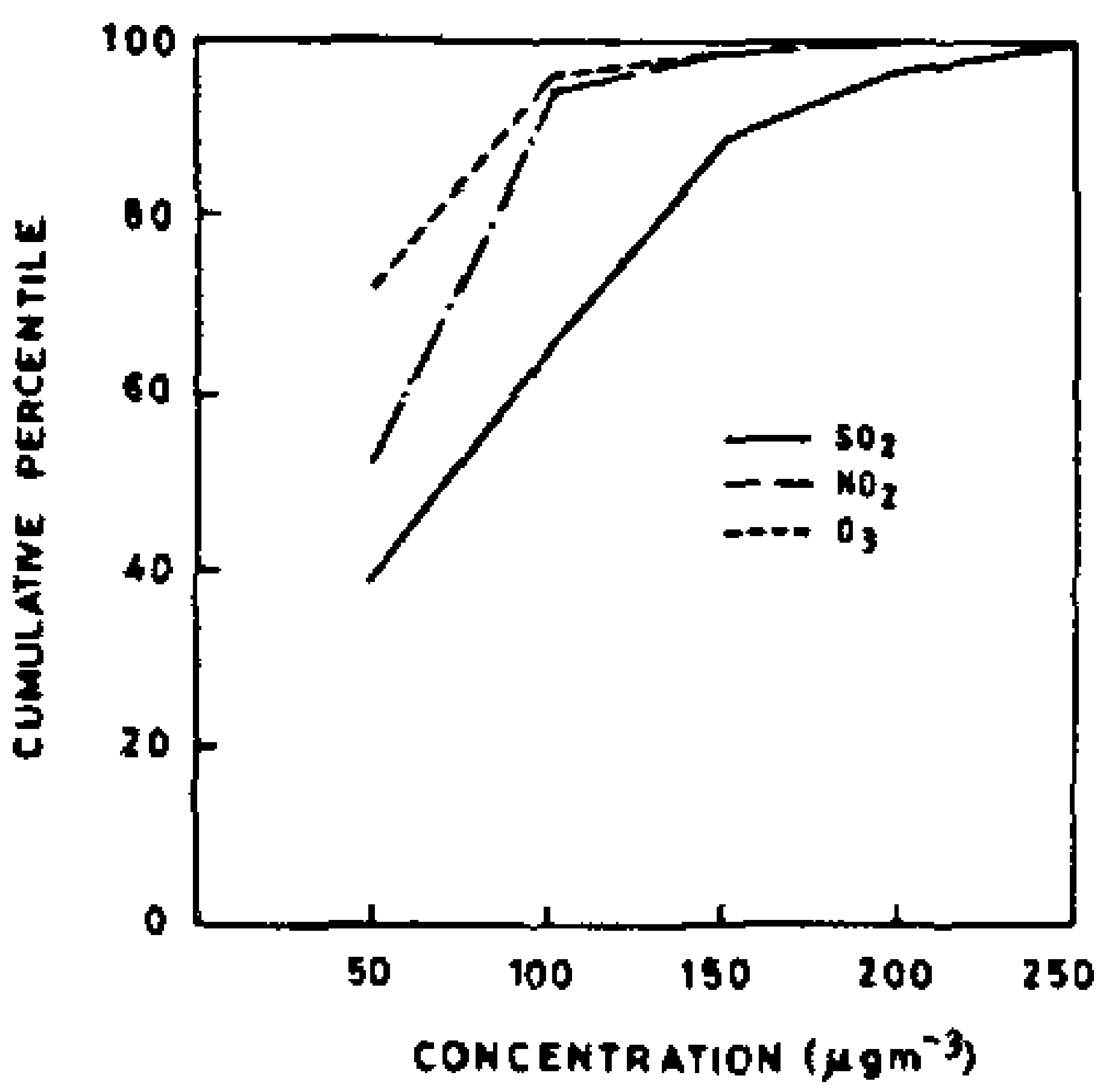

*Figure 7.* Cumulative frequency distribution of pollutants concentration in Varanasi city (all sites combined)

Figure 7 shows the percentile distribution of 2-h mean $SO_2$, $NO_2$ and $O_3$ concentrations. About 40%, 50% and 70% of 2-h mean concentrations of $SO_2$, $NO_2$ and $O_3$ respectively, were less than 50 µg$^{-3}$. For $NO_2$ approximately 6% and for $O_3$ only 4% of 2-h mean concentrations exceeded 100 µg$^{-3}$.

Except for zone V, most monitoring stations experienced 16 to 35% of simultaneous co-occurrence of $SO_2/NO_2$ concentrations ($\geqslant 0.05$ ppm $SO_2$ and $\geqslant 0.03$ ppm $NO_2$) in winter months (Table 2). Daily occurrence of $O_3$ with 2-h mean concentrations $> 0.03$ ppm (60 mg$^{-3}$) was frequent in summer. At all sites, the number of air samples with $SO_2$ and $NO_2$ concentrations $\geqslant 0.05$ and $\geqslant 0.03$ ppm respectively, was very small when $O_3$ was$\geqslant 0.03$ ppm.

**Table 2.** Air samples (%) showing co-occurrence at minimum concentrations ($\geqslant$ 0 03 ppm for $NO_2$ and $O_3$ and $\geqslant$ 0 05 ppm for $SO_2$) during 1989–90

| Pollutant pairs | Co-occurrence* Winter | Summer | Rainy |
|---|---|---|---|
| $SO_2/NO_2$ | 28 (16–35) | 21 (15–30) | 0 (0) |
| $SO_2/O_3$ | 4 (0–10) | 26 (15–35) | 0 (0) |
| $NO_2/O_3$ | 6 (4–12) | 37 (22–45) | 7 (0–16) |

*Values in paranthesis represent range of percentage

Seasonal and diurnal variations in pollutant concentrations can be attributed to the meteorological variations and partially to the role of emission sources. Low temperature and calm weather during winter contribute to the elevated levels of $SO_2$ and $NO_2$. Significant negative correlations were observed between monthly average concentrations of $SO_2$ and $NO_2$ and mean monthly temperature (Table 3). Concurrent formation of inversion layer further maximizes the peak overlap of these two pollutants during morning and evening hours. Two peak periods of $SO_2$ and $NO_2$, one during early morning and a second during late evening have been reported from Fontana and California air monitoring stations of United States[6]. Asynchrony in the peaks of $NO_2$ and $O_3$ ensures the atmospheric transformation of the former into the latter. Further, ozone being a secondary pollutant is very much dependent on the intensity of solar radiation and air temperature. Significant positive correlations between mean monthly temperature and monthly average concentrations of ozone (Table 3) indicate temperature-dependent oxidant formation resulting in ozone maxima during afternoon. This agrees with the results of Bruckman and Lagensiepen[17].

In the present study, most air samples were in the low concentration range, indicating a logarithmic normal distribution pattern (Figure 7). Similar patterns were observed by Lefohn and Jones[7] for hourly $O_3$ and $SO_2$ concentrations in the areas influenced by local urban sources, and by Lefohn *et al.*[3] for $SO_2$ and $NO_2$ at rural and remote areas in USA. However, the distribution patterns for ozone in remote areas were skewed[3]. This suggests that ozone concentrations follow the logarithmic normal distribution pattern only at source-oriented sites.

Our study, although limited, encompassed a range of conditions (temperature, rainfall, humidity, etc.) that are representative of seasonally dry tropical belt of Indian

**Table 3.** Correlation matrix of pollutants concentration and meteorological variables

| | $O_3$ | $NO_2$ | $SO_2$ | $T_{max}$ | $T_{min}$ | Rainfall | $R_H$ | Wind speed |
|---|---|---|---|---|---|---|---|---|
| $O_3$ | 1.0 | $-0.48^{*}$ | $0.05^{NS}$ | $0.80^{**}$ | $0.43^{**}$ | $-0.27^{NS}$ | $-0.81^{**}$ | $0.76^{**}$ |
| $NO_2$ | | 1.0 | $0.84^{**}$ | $-0.76^{**}$ | $-0.95^{**}$ | $-0.55^{**}$ | $-0.04^{NS}$ | $-0.59^{**}$ |
| $SO_2$ | | | 1.0 | $-0.48^{*}$ | $-0.85^{**}$ | $-0.73^{**}$ | $-0.38^{NS}$ | $-0.30^{NS}$ |
| $T_{max}$ | | | | 1.0 | $0.82^{**}$ | $0.27^{NS}$ | $0.49^{*}$ | $0.75^{**}$ |
| $T_{min}$ | | | | | 1.0 | $0.52^{**}$ | $0.04^{NS}$ | $0.63^{**}$ |
| Rainfall | | | | | | 1.0 | $0.52^{**}$ | $0.19^{NS}$ |
| $R_H$ | | | | | | | 1.0 | $0.11^{NS}$ |
| Wind speed | | | | | | | | 1.0 |

$T_{max}$ maximum temperature, $T_{min}$ minimum temperature, $R_H$ relative humidity
$^{*}p < 0.05$, $^{**}p < 0.01$, NS not significant

subcontinent. Because no single pollutant can be identified as being responsible for causing potential vegetation damage under field conditions, precise data are needed regarding the levels of major phytotoxic air pollutants and the timing of multipollutant exposure. This is specially important in seasonally dry tropical areas where frequent temporal variations in the concentration of phytotoxic air pollutants occur due to frequent climatic variations. Ozone concentrations peaked during dry summer days when it is known to be less toxic to plants[18, 19]. The concentrations of $NO_2$ were below those that produce visible injury or growth suppression in plants[20]. However, the magnitude of the effects observed in the field studies was highly significant[21]. It is suggested that as there is normally a coincidence in the timing of $SO_2$ and $NO_2$ peaks, their combined rather than individual effects need to be considered while assessing vegetation damage, especially in winter months. However, in summer, ozone can have a greater impact. The results have implications in defining pollutant exposure regimes and to set the receptor-based air quality standards.

1 Wark, K and Warner, C F, *Industrial Environmental Pollution*, Donnelley Publisher, New York, 1976, pp 401–405
2 Cochran, L S, Pielke, R A and Kovacs, E, *J Air Waste Manage Assoc.*, 1992, **42**, 1567–1572
3 Lefohn, A S, Davis, C. E., Jones, C K, Tingey, D T and Hogsett, W E, *Atmos Environ*, 1987, **21**, 2435–2444
4 Lefohn, A S and Runeckles, V C, *Atmos Environ*, 1987, **21**, 561–568
5 Lefohn, A S, Runeckles, V C, Krupa, S V and Shadwick, D S, *J APCA*, 1989, **39**, 1039–1045
6 Lefohn, A S and Tingey, D T, *Atmos Environ*, 1984, **18**, 2521–2526
7 Lefohn, A S and Jones C K, *J. APCA*, 1986, **36**, 1123–1129
8 Wellburn, A R, Higginson, C, Robinson, D. and Walmsley, C, *New Phytol*, 1981, **88**, 223–237
9 NEERI, Annual Report on National Air Quality Monitoring Network (1980–81) Vols I & II, Air Pollution Division, NEERI, Nagpur
10 Dave, J M, *Proc 7th Clean Air Cong*, 1986, **86**, 410–421
11 Mathur, H B, *Proc 7th Clean Air Cong*, 1986, **4**, 353–362
12 Goyal, P and Singh, M P, *Atmos Environ*, 1990, **B24**, 407–411
13 Pandey, J, Agrawal, M, Khanam, N, Narayan, D and Rao, D N, *Atmos Environ*, 1992, **B26**, 91–98
14 West, P W and Gaeke, G C, *Anal Chem*, 1956, **28**, 1816–1819
15 Merryman, E L, Spicer, C W and Levy, A, *Environ. Sci Technol*, 1973, **7**, 1056–1059
16 Byers, H D and Saltzman, B E, *J Am Ind Hyg Ass*, 1958, **19**, 251–257
17 Bruckman, P and Lagensiepen, E W, *Staub-Reinhault Luff*, 1981, **41**, 79–85
18 Showman, R E, *J Air Waste Manage Assoc*, 1991, **41**, 63–64
19 Pandey, J and Agrawal, M, *Encology*, 1991, **6**, 8–18
20 Mansfield, T A and Freer-Smith, P H, *Biol Rev*, 1981, **56**, 343–368
21 Pandey, J and Agrawal, M, Proc 2nd IUAPPA Regional Conference on Air Pollution, Seoul, Korea, 1991, vol 1, pp 317–320

ACKNOWLEDGEMENT We are grateful to UGC, New Delhi for financial assistance

Received 15 April 1993, revised accepted 18 December 1993

---

# Energy-dispersive X-ray fluorescence analysis of Kushan period coins

**C. K. Bhat, B. R. Singh and C. L. Bhat**

Nuclear Research Laboratory, Bhabha Atomic Research Centre, C-7, Shastri Nagar, Jammu 180 004, India

**Kushan period coins (78 AD), recovered from the Handwara region of South Kashmir (India) were subjected to non-destructive energy-dispersive X-ray fluorescence analysis to determine their elemental composition. Based on the observation and the uniformity of composition, it is concluded that the process of extraction of metals from their ores and techniques for the production of alloys was well known to the craftsman of that era.**

The Department of Archives, Archaeology and Museums of the Jammu and Kashmir state (*India*) has