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Studies of the dust and nuclei content of the air near the ground and their effect on atmospheric electricity parameters*

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ABSTRACT. Regular measurements of the dust and nuclei content of the air near the ground at Poona were made during 1967-69 to study the characteristic elements of natural pollution near the ground, its origin and its variation with time, seasons and altitude. The electrical field strength, the positive and negative conductivity of the air and the number of positively and negatively charged small ions in the atmosphere near the ground were also measured at the same time. These observations were repeated at two mountain stations during February and June 1969. The dust content and the electric field show seasonal and diurnal variations opposite to those of the small ion density and electrical conductivity. Thus, while the electric field is a maximum in winter, the conductivity and small ion content is a maximum during the monsoon months and the dust content a maximum in the pre-monsoon summer months. A marked increase in the electric field and the dust and condensation nuclei content is observed since similar measurements were last made in 1933-1937 at Poona, with a corresponding decrease in small ion count and conductivity. These large variations are associated with the increased industrialisation and urbanisation of the regions around Poona during the last thirty years.

1. Introduction

Aerosols have been long recognized as a significant atmospheric constituent and a knowledge of their properties and their spatial and temporal distribution is fundamental to our understanding of the heat balance of the earth-atmosphere system and the weather processes occurring in the atmosphere. The abundance or scarcity of condensation nuclei and particulate matter in the air is of great importance to the physics of precipitation and studies of air pollution. With the recent explosive growth in human population and industrial activity there has been an equally large increase in the particulate matter injected into the atmosphere. An attempt has been made in the present study to make quantitative measurements of the aerosol content near the ground, to study their relationship with atmospheric electricity parameters and to assess the causes for the secular changes observed during the last thirty years.

2. Observations

Poona is situated on the Deccan Plateau, on the eastern side of the Western Ghats at a height above mean sea level of 600 m (18°3.0′ N, 73°51′E). During the last 30 years, since Sil (1938) first made systematic measurements of the dust and nuclei content of the air and its electrical conductivity at Poona, there has been a marked change in the surroundings of the observatory. The meteorological office, which was then on the western edge of the city, is now more or less in the centre of the greater Poona complex, with a population of over one million, with the observatory forming a small green oasis in a stone jungle of residential and office buildings and factories.

The measurements at Poona, the results of which are presented in the paper, include :

(1) Dust content using a Bausch and Lomb dust counter,

(2) Condensation nuclei content with an Aitken-Ludling nuclei counter,

(3) Small ion density, positive and negative using an Ebert's ion counter,

(4) Electrical conductivity of air, positive and negative, using a Gerdian conductivity apparatus and

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TABLE 1

Monthly averages of dust and condensation nuclei content, small ion density, electric field and conductivity at Poona
(Figures in brackets indicate the number of observations)

Month	Potential gradient F		Polar conductivity				Total conductivity		No. small ions per cc n				No. Aitken nuclei per cc Z		Coarse dust particles per cc	
	1935-37 (Volt/metre)	1964-65 (Volt/metre)	1935-37 (e.su × 10^{-4})		1967-69 (e.su × 10^{-4})		1935-37 (esu × 10^{-4})	1967-69 (esu × 10^{-4})	1935-37		1967-69		1935-37	1967-69	1935-37	1967-69
			$\lambda+$	λ^-	$\lambda+$	λ^-	λ	λ	$n+$	n^-	$n+$	n^-				
Jan	135 (32)	145 (58)	0·98	0·95	0·27	0·58	1·94 (24)	0·85 (30)	720	707 (15)	457	272 (30)	7,390 (19)	—	21 (22)	37 (30)
Feb	119 (34)	90 (42)	1·07	1·05	0·51	0·24	2·12 (18)	0·72 (8)	740	690 (18)	731	261 (8)	6,440 (25)	—	18 (21)	48 (8)
Mar	83 (30)	75 (60)	1·06	0·96	0·81	0·47	2·02 (20)	1·27 (39)	743	690 (14)	716	581 (39)	5,299 (30)	—	24 (16)	62 (39)
Apr	66 (30)	42 (61)	1·52	1·50	0·76	0·68	3·02 (19)	1·38 (35)	796	755 (15)	566	457 (35)	4,640 (26)	—	15 (15)	72 (36)
May	62 (30)	43 (54)	1·75	1·67	0·61	0·60	3·42 (20)	1·21 (42)	874	842 (15)	777	682 (42)	4,840 (32)	—	12 (19)	74 (42)
Jun	64 (30)	37 (58)	1·82	1·73	0·45	0·43	3·55 (21)	1·07 (6)	1,066	1,054 (11)	1,728	1,623 (70)	4,780 (27)	35,880 (10)	11 (15)	75 (70)
Jul	57 (26)	60 (50)	1·93	1·86	—	—	3·79 (17)	—	1,011	999 (12)	1,215	1,458 (30)	4,780 (29)	41,940 (22)	3 (12)	37 (30)
Aug	61 (32)	70 (52)	1·82	1·75	—	—	3·57 (27)	—	1,066	1,026 (15)	434	508 (68)	4,980 (34)	—	2 (13)	13 (68)
Sep	62 (37)	57 (58)	1·67	1·63	—	—	3·30 (17)	—	957	906 (9)	911	830 (4)	5,170 (24)	35,614 (17)	2 (12)	32 (4)
Oct	95 (26)	95 (54)	1·13	1·13	—	—	2·26 (18)	—	897	858 (8)	923	722 (20)	5,760 (19)	—	10 (17)	19 (20)
Nov	124 (33)	154 (58)	1·09	0·96	—	—	2·05 (15)	—	790	753 (13)	574	446 (24)	7,590 (19)	28,158 (22)	15 (19)	19 (24)
Dec	149 (30)	175 (60)	0·88	0·87	0·47	0·83	1·75 (14)	1·13 (20)	756	720 (10)	561	491 (20)	7,420 (18)	38,956 (20)	17 (26)	25 (22)
Mean	89	89	1·40	1·35	0·54	0·53	2·73	1·12	860	758	769	769	5,841	34,909	12	43

(5) electrical field by means of a Cambridge electrograph.

Simultaneous measurements of surface wind speed and direction, temperature and humidity were also made. Vertical profiles of the electrical field and conductivity of air in the atmosphere were obtained on a weekly or fortnightly basis with special balloon-borne sondes.

The readings were repeated at Sinhagad 11 km from Poona, 1500 metres above sea level on 14 February and on 18 March 1969 and at Gulmarg (34°N, 74°E) in Kashmir 3000 metres above sea level, from 11 to 18 June 1969·

2.1. *Electrical fields*

Continuous records of the earth's electric field have been made at Poona since September 1930 with a Cambridge electrograph (Sil and Agarwala 1940, Choudhuri and Gopinath 1968). The collector is exposed on the fourth floor of the Meteorological Office tower 20 m above and the recorded field values are corrected by an exposure factor which is determined periodically.

2.2. *Electrical Conductivity*

Electrical conductivity was determined by means of a Gerdien condenser and Wulf electrometer. The central rod of the condenser is alternately charged to +100 and —100 volts and the positive and negative values of conductivity calculated using standard formulae.

2.3. *Small ion count*

The number of positive and negative small ions per cm^3 was counted with an Ebert's ion counter. The inner electrode of the instrument is raised to a potential of 100 volts and about 250 cm^3 of air are drawn through the apparatus before an electrometer reading is taken. The Wulf electrometer is calibrated and tested periodically for surface leakage.

The observations were made on the roof of the Instruments Division building 10 m above ground and on the tower 40 m above ground. The positive and negative ion counts n^+ and n^- were calculated using the usual formula. Allowance has been made for the errors inherent in the measurement of small ion counts with an Ebert't ion counter (Israel 1970).

2.4. *Condensation nuclei count*

Hygroscopic dust particles were precipitated by drawing in samples of air in an Aitken-Ludling nuclei counter and the number of condensed nuclei on both first and second expansions were counted. The mean of three observations were recorded.

Observations were taken thrice a day at 1030, 1430 and 1700 IST on the roof of the Meteorological Office tower 40 m above ground. Each set of observations took 40 minutes.

2.5. *Dust count*

A Bausch and Lomb dust counter, combining in one unit both the necessary air sampling device and a dark field microscope was used to obtain the dust count. The air sampling mechanism consists of a moistening chamber through which the air is drawn by means of an accurately calibrated hand pump of 160 cc capacity and an impinging device which deposits the dust particles suspended in the air on a circular glass plate within the instrument. Twelve samples can be collected on one slide and viewed and counted without removing the slide from the counter. The viewing and counting apparatus consists of a built-in compound microscope of 200 × magnification with a special dark field illumination system. The microscope is fitted with a special hyperplane eyepiece in which there is a micrometer disc ruled in 30 micron square. These squares are used in counting the total number of dust particles.

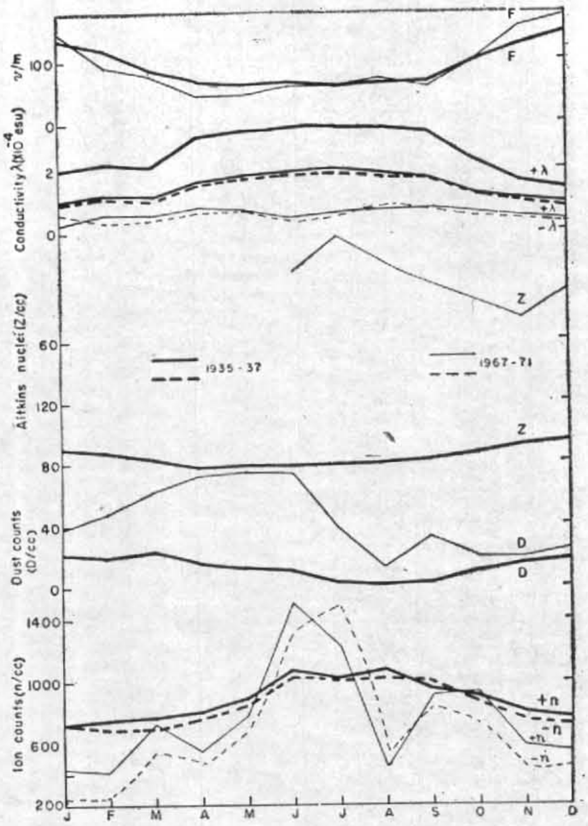

Fig. 1. Average monthly values of atmospheric electric field conductivity, nuclei content, small ion count and dust content at Poona (all data are for 1967-69 except for the field which is for 1964-65)

3. Results

The mean monthly values of the number of dust particles per cc (D) Aitken condensation nuclei cc (Z) and the positive and negative small ions per cc (n^+ and n^-) near the ground obtained daily four times a day from June 1967 to November 1967 and daily twice a day from December 1968 to May 1969 at Poona are given in Table 1. The small ion count values were corrected by reducing the observed number to 60 per cent of its value (Israel 1970). The values of positive and negative conductivity measured daily from December 1968 to May 1969 are included, as well as the values of the electric field strength E obtained during the IQSY (1964-65). Corresponding values of all these parameters obtained by Sil (1938) during 1933-1937 are given in the same table for comparison.

Fig. 1 shows the monthly mean averages of (*a*) polar and total conductivities λ^+, λ^- and λ, (*b*) positive, negative and total small ion concentration n^+, n^- and n, (*c*) condensation nuclei content Z and (*d*) the dust content D. Table 2 summarizes the seasonal and annual averages of D, Z, λ^+, λ^-, λ, n^+ n^-, n and E. All data

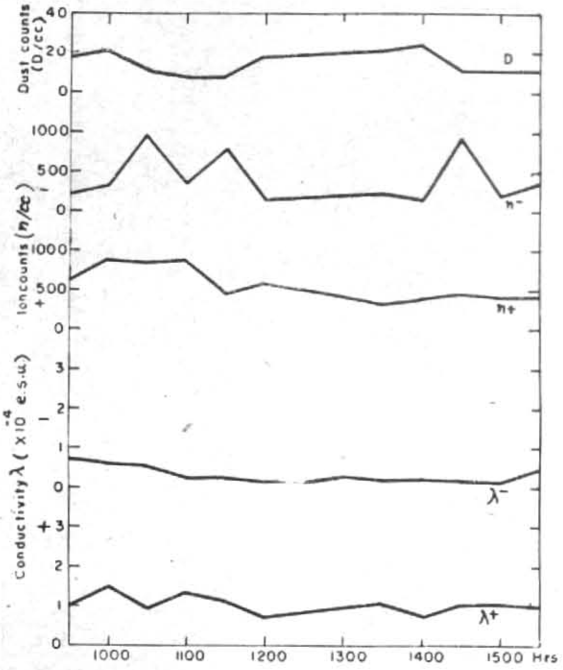

Fig. 2. Hourly values of the dust content, small ion density and polar conductivity at Sinhagad on 14 February and 18 March 1969

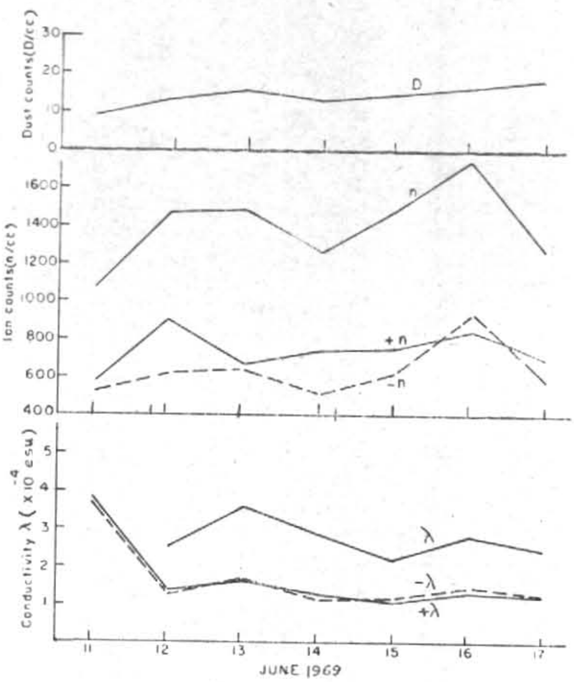

Fig. 3. Hourly values of the dust and nuclei content, small ion density and polar conductivity at Gulmarg from 11 to 18 June 1969

TABLE 2

Seasonal and annual averages of dust and condensation nuclei, small ion density, electrical conductivity and field at Poona (1967-1969)

Dust counts D per cc	Aitkens nuclei Z per cc	Conductivity (10^{-4} sec esu) $\lambda+$	λ^-	λ	Ion count per cc $n+$	n^-	n	Field v/m (1964-65) E
		Winter (Nov-Feb)						
33	30,555	0·46	0·48	0·94	459	321	780	137
		Summer (Mar-Jun)						
71	—	0·76	0·56	1·32	701	573	1,274	53
		Monsoon (Jul-Oct)						
25	37,811	0·45	0·43	0·88	1097	1079	2176	59
		Annual Mean (1967-69)						
48	34,185	0·56	0·49	1·05	752	658	1410	83
		Annual mean (1935-37)						
13	5,840	1·39	1·34	2·72	869	833	1720	89·7

are for 1967-69 except for the field which is for *1964-65.*

The variations hour by hour of the dust count, positive and negative small ion concentration, positive and negative conductivity and Aitken nuclei count at Sinhagad on 14 February 1969 and 18 March 1969 are shown in Fig. 2. Fig. 3 shows similar curves for the 6 days of observation at Gulmarg.

4. Discussion of results

4.1. *Dust count*

It will be seen from Tables 1 and 2 and Fig. 1 that the number of dust particles D is a maximum in the pre-monsoon summer months, March to June, when there are as many as 75 coarse dust particles per cm³ in the air. This number falls to 13 per cm³ in August with the establishment of the monsoon, when the dust content is a minimum. With the setting in of winter and the occurrence of low level temperature inversions, the dust count again increases to 25 to 48 per cm³.

A comparison of the figures in the last two columns of Table 1 shows that the dust content during the winter months has almost doubled since 1935-37. During the summer months, there has been a four to seven fold increase since 1935-37. The seasonal variations are generally similar during both periods with high values in summer and low values during the monsoon, when the atmosphere is washed clean by precipitation.

A study of the diurnal variations of the dust content shows that the dust count is a maximum during the early morning hours when temperature inversions form near the ground, particularly during the winter months. In the afternoon with heating and small scale turbulence, the dust particles are dispersed to higher levels and the dust content shows a decrease near the ground. The visibility also improves with the day. During the monsoon months the diurnal variation is practically non-existent with uniformly low values throughout the day.

The decrease in dust content with altitude is illustrated by measurements at the two mountain stations Sinhagad, 1500 m above sea level and Gulmarg, 3000 metres above sea level. The dust content is 7-21 per cm^3 at Sinhagad in February and at Gulmarg in June, in contrast to 37-75 per cm^3 at Poona in the same months. The 1935-37 values at Poona, when industrialisation, urbanization and traffic had not raised the dust content to the present high values, are of the same order of magnitude as the dust count at the two mountain stations during 1967-69.

At all three stations the dust content is very much a function of wind, showing rapid increases whenever there are gusts of wind which serves to mix the air at lower levels. The dust count shows a marked increase whenever there is haze. With light haze the count rises to 30-40 and with thick haze to 80 to 90 per cm^3.

Individual values are more interesting and more revealing. A rapid fall in dust count is invariably noticed after rain, as on 13 June 1967 when it fell from 166 at 1200 hours 67 particle per cc at 2000 hours and on 19 June 1967 when it fell from 179 at 1210 hours to 23 at 2000 hours. Rainout within clouds should be fairly efficient for aerosols, since cloud droplets will contain most of the aerosol mass present either as dissolved or undissolved material.

4.2. *Condensation nuclei*

The number of Aitken condensation nuclei Z were measured only during 5 months at Poona during 1967-68. The most important feature is the five to ten-fold increase in the condensation nuclei content since 1935-37. The nuclei content is also higher during the monsoon months in contrast to Sil's (1938) finding that the nuclei content is highest in winter and lowest during the monsoon months.

The condensation nuclei count shows a decrease with height, being only 7000 to 21000 per cm^3 at Gulmarg in June. This is about half to one fifth the corresponding values at Poona in the same month.

The average value of the nuclei content for a large city has been given as 147,000 per cm^3 at the centre of the city and 34,000 per cm^3 for the edge of the city (Israel 1970). This value drops to 9500 over land away from cities and on islands and to 950 on mountains 2000 metres above sea level and over the oceans. The 1935-37 Poona values of nuclei content represent a rural location, while the present nuclei content corresponds to those of an urban location. Gulmarg although a high mountain station 3000 metres above sea level is affected by the dense dust pall that lies over north and central India during summer and is as polluted as a sea level location, not very far from industrial pollution sources.

4.3. *Small ion density*

The number of small ions in the air normally is of the order of a few hundred per cc, the concentration of positive ions being about 20 per cent higher than that of the negative ions (Israel 1970). It is usually reduced from 3-500 cc to one tenth of its value in polluted atmosphere. Meteorological factors also have an appreciable influence on the small ion concentration of the atmosphere and the small ion count varies with wind strength, wind direction and aerosol content (This is clear from the Table 1 and Fig. 1 which shows the monthly variations of the small ion density). It is lowest in the winter and summer months, when the air is polluted, highest in the monsoon months, when the air is cleansed by precipitation.

The small ion concentration increases on an average with altitude, the values at Sinhagad being twice that at Poona.

It will also be seen from Table 1 that the small ion count at Poona is less in 1967-69 than in 1935-37. Much significance cannot, however, be attached to the actual values, considering the inaccuracies involved in the actual measurements of small ion density with the Ebert's ion counter.

The ratio $n+/n-$ is about 1.3, and agrees with the normal value of 1.1 to 1.3 on land. Sil (1938) obtained an annual average of 1.04 for $n+/n-$ and Agarwala an (1951) annual average of 1.07 for the ratio of the mobilities. At Sinhagad it is higher, as expected being 1.97. Gulmarg values are not considered because of disturbed conditions.

The $n+/n-$ seems to pass through small but systematic variations during the day and year

TABLE 3

Mean annual values of polar conductivities and small ion counts of 7 stations

Unit λ : ($\times 10^{-4}$/sec. esu)

Station	Year	$\lambda+$	λ^-	$n+$	n^-
				(cm^{-3})	
Seewalchen	1904	1·57	1·33	944	797
Davos	1910	1·47	1·30	1240	1010
Fribourg	1913	1·30	1·22	1013	908
Seeham	1912	1·00	0·90	650	626
Argentina	1911	0·51	0·49	566	545
Amazon	1911	0·40	0·30	375	354
Poona	1935-37	1·40	1·35	842	841
Poona	1967-68	0·56	0·49	752	658

showing a correlation with the electric field. It is highest in the winter and summer months and least during the monsoon. It is reasonable to assume an 'electrode effect' varying with the field near the ground.

As expected, the diurnal variation of the small ion concentration largely corresponds to that of conductivity (Figs. 2 and 3). This variation consists generally of a simple fluctuation with a peak in the early morning hours and low value in the day time. Table 3 lists the values of the small ion counts and polar conductivities at a number of representative stations in the world (Israel 1970) with Poona values for 1935-37 and 1967-69.

4.4. *Electrical conductivity*

The conductivity of the atmosphere is a direct consequence of its ion content and although atmospheric conductivity is almost exclusively due to the small ions, it is the large ions and neutral particles of corresponding size and type which largely govern the half life of the small ions and therefore the conductivity.

We must therefore expect a parallel behaviour between conductivity and small ion density and an opposite behaviour between these and the number of large ions and uncharged suspensions on the other (Israel 1953, 1970, 1933). This is evident from Table 1 and Figs. 1, 2 and 3 where the positive and negative conductivities and small ion counts are tabulated. The conductivity is highest in the monsoon months and lowest in the winter months as expected. It also shows an increase in value with altitude.

Table 3 gives similar values for a number of stations in the world with values obtained at Poona in 1935-37 and 1967-69. An examination of the Poona values shows that both the positive and negative conductivity decreased almost to one third the earlier value in the three decades between 1937 and 1967, indicating that the balance of the mechanisms of particle injection and removal is already being modified.

The positive conductivity is throughout more than the negative conductivity because of the 'electrode effect near the ground'.

4.5. *Electrical potential gradient*

The diurnal variations of surface potential gradient during the different months at Poona during 1964-65 are shown in Fig. 4 (Choudhuri and Gopinath 1968). The continental type double oscillation is very prominent in the winter and post monsoon months and is almost absent during the monsoon months. The field is also highest during the hot dry dusty summer months and lowest during the cool moist monsoon months.

The field also shows a marked increase in value since 1935 associated with the increase in dust content and decrease in electrical conductivity. Similar increases have also been observed at Bombay (Choudhuri and Gopinath 1968).

4.6. *Measurements in free atmosphere*

Measurements of electrical potential gradient and conductivity have been made in the free atmosphere over Poona using balloon radiosondes (Mani and Huddar 1965). While the mean values of the electrical potential gradient, air earth current and conductivity agree with the generally accepted theoretical picture of fine weather atmospheric electricity parameter, significant diurnal and seasonal variations are observed, particularly in the austausch or exchange layer.

The exchange layer extends to about 1-3 km in winter and 6 km in summer above the ground. Within this layer large diurnal variations occur, the potential gradient being a minimum and almost constant with height in the afternoon and showing a large increase early in the morning and at night. These are obviously associated with the local charges in the number and type of condensation nuclei in the lower layers of the atmosphere.

The mean conductivity of air shows a steady increase with height but appreciable variations are present both in the exchange layer and above.

5. Effects of air pollution

The local variations in atmospheric electrical parameters, which were earlier considered to be an unwelcome noise are now known to give information on the meteorological conditions in the lower layers of the atmosphere, particularly of its particulate content. Muhleisen (1956) showed by actual measurements that the diurnal variations of potential gradient near towns are caused mainly by positive space charges produced chiefly by urbanization, industry and traffic. Haze, which is the collective name of atmospheric suspensions is mainly confined to the lower layers of the atmosphere. Whipple (1929) found that the daily variations of atmospheric pollution and potential gradient at Kew are very similar, both showing a closely parallel 12 hours oscillation and explained the double fluctuations at Kew as a joint result of production and vertical transport of pollution particles.

Electrical conductivity even over the oceans as measured during the cruises of Carnegie from 1915 to 1929 showed a gradual decrease which was attributed to a gradual increase in the particulate content in the lower layers of the oceanic air (Wait 1946). At land stations all over the world, wherever more or less continuous records of atmospheric electrical conductivity or potential gradient have been kept, a diminution appears in conductivity and an increase in potential gradient.

Mukherjee and Pillai (1940) observed the effect of dust on potential gradient at Bombay and reported that with the occurrence of dust raising winds the air becomes visibly charged and the field shows a sharp reversal. The values of the potential gradient were seen to fluctuate violently from a few to several hundred volts, depending on the strength and direction of the winds. They found that on no less than 95 per cent of the days when the potential gradient was negative; this was due to dust in the air.

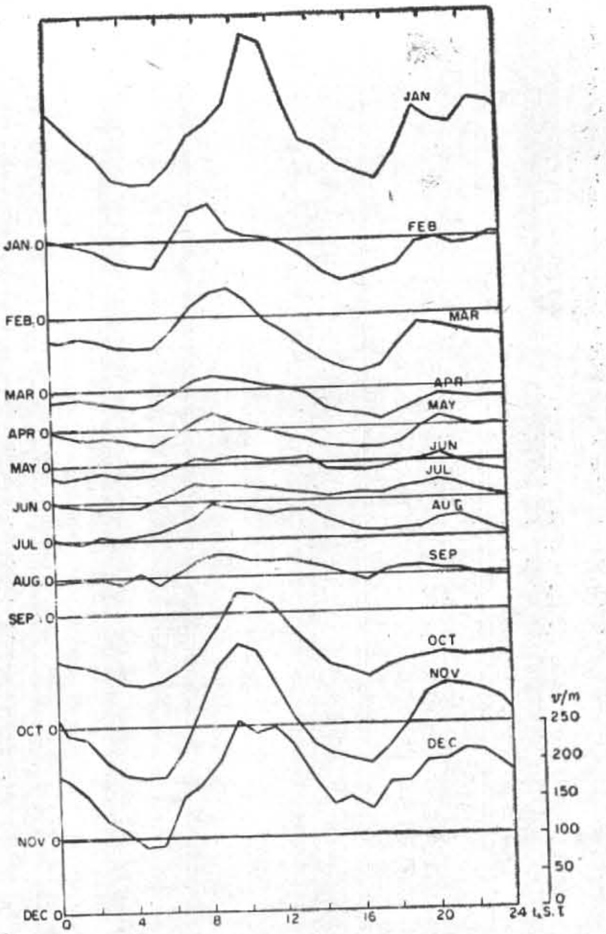

Fig. 4. Monthly values of electric field at Poona

6. Conclusion

The mean values of the electric field at Poona for the period 1933-37 and 1964-65 show a marked increase in the electric field during the last thirty years. A corresponding decrease in the electrical conductivity and small ion density is observed. The increase in the dust content since 1935-37 over Poona is spectacular. Measurements of the atmospheric turbidity coefficients at Poona since 1957 have shown a similar marked rise during the last fifteen years. Atmospheric electricity conditions are strongly anthropogenic and the increased atmospheric pollution at Poona during the last thirty years, associated with the increased industrialization, urbanization and traffic should be held responsible for the observed secular variations in the aerosol content and the atmospheric electricity parameters at Poona.

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