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A comparative study of *K*-indices at three Indian Magnetic stations

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ABSTRACT. Indices K of geomagnetic activity scaled from magnetograms of Alibag, Hyderabad and Sabhawala are mutually compared and individually with planetary index *Kp* to bring out the salient features of their occurrence frequencies. The main results of the analysis are :

(*a*) Distributions of occurrence frequency for the three stations differ from each other and from that of *Kp*, especially with respect to peak occurrence.

(*b*) $K = 0$ is reckoned least at Alibag.

(*c*) *K*—indices of Sabhawala do not confrm exactly to the expected pattern. This could be mainly due to improper elimination of regular variations.

(*d*) In relation to Alibag, $K \geqslant 2$ at Hyderabad are reckoned more often whereas at Sabhawala the bias is towards less frequency.

(*e*) Study of persistence of geomagnetic activity shows that a high value of K-index is not always followed by the same value. But adjacent values ($K \pm 1$) together indicate a significant probability of occurrence.

1. Introduction

The index *K* of geomagnetic activity is designed to measure irregular variations observed on a standard magnetogram at a station and is intended to be a measure of the solar corpuscular radiation based on the intensity of geomagnetic activity scaled as deviation from the regular daily variation within a three-hour interval. The form of the regular daily variation during any three hour period is usually presumed to correspond to *Sq* and *L* variations appropriate to the season and phase of the solar cycle. There will always exist certain ambiguity as well as difference from person to person in the elimination of the regular daily variation. Care and expertise are called for in assigning *K*-index from a magnetogram. Mayaud (1967) has given elaborate details for scaling *K*-indices. For a station, the index represents regional conditions and will include local features such as the systematic diurnal variation at its location (Lincoln 1967).

Among the many magnetic stations operational in India, regular scaling of *K*-indices is carried out at Hyderabad (Dipole Lat. 7.6°N), Alibag (Dipole Lat. 9.5°N) and Sabhawala (Dipole Lat. 20.8°N). Alibag is a coastal station wherea Hyderabad is at an inland location and Sabhawal is well separated from the other two and is close to the focal latitude of the northern *Sq* current system. In this communication, we attempt a comparative study of the *K*-indices at the three Indian stations. The planetary index *Kp* is also compared with the *K*-indices. The approach is broadly similar to that presented by Zawalick and Cage (1971) and Cage and Zawalick (1972), who used *Kp* for their analysis.

2. Data

K-indices for the period 1968 – 1975 were used in the analysis as data for previous years were not available for all the three stations. Missing values were interpolated by substituting the previous 3-hourly *K*-index. This process could introduce some uncertainty but the number of such occasions were so few that the main conclusions and features are not vitiated. Though there are 28 possible value of *Kp*, for purposes of comparison with the *K*-indices we have reduced this to a more coarse scale compatible with the *K*-indices (for *e.g.* $1-$, 1_0 and $1+$ are all considered as 1).

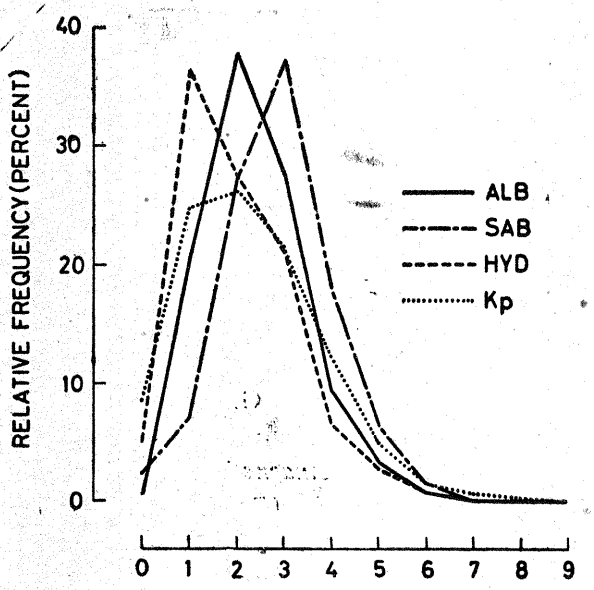

Fig. 1. Occurrence frequencies of different values of *K*-indices at Alibag (ALB), Hyderabad (HYD), Sabhawala (SAB) and the planetary index *Kp*

The frequency of occurrence of each value of *K* (0 to 9) was computed monthwise for each year and later combined for all the eight years. The distributions of occurrence frequency for the three Indian stations and for *Kp* are shown in Fig. 1. Similarly using the *K*-indices of ALB/HYD and ALB/SAB contingency tables were generated which provide the number of occasions when a particular combination of *K*-index occurred. Whenever the value *Ki* of *K*-index at Alibag has the corresponding value *Kj* at Hyderabad the $i-$th row, j th column is increaseed by one. For *e.g.* there were 187 occasions when $K=3$ at Alibag was reckoned as $K=4$ at Hyderabad. Tables 1 and 2 are the contingency tables for ALB/HYD and ALB/SAB combinations.

3. Results and discussion

(*i*) *Relative frequency of K*

For all the three Indian stations, the most common values of *K* appear to be 1, 2 or 3. However, the most frequent occurrence is sensibly different for the three stations with the peak occurrence corresponding to $K=1$ at Hyderabad, 2 at Alibag and 3 at Sabhawala. For comparison, frequency of occurrence of different values of *Kp* for the same period is also shown in Fig. 1. This frequency distribution depicts a broader maximum with occurrence of $Kp=1$, 2 or 3 being nearly equal, in contrast to the Indian stations' data, which exhibit sharp maximum for one of the *K* values 1, 2 or 3. As would be expected, the occurrence of $K \geqslant 6$ is rare. It can be seen from the figure that while frequency of $K=1$ is substantially lower at Sabhawala as compared to Hyderabad or Alibag, $K=3$ or 4 occurs more frequently at this station. It is quite likely hat at Sabhawala during the period of moderate magnetic disturbance threre tends to be an overestimate of index *K*. The sharp peak at $K=3$ at Sabhawala apparently is either due to such an overestimate or due to larger magnitude of the magnetic disturbance there. Another pertinent cause could be the inadequacy in approximating the regular diurnal variation, as Sabhawala is close to the focal latitude where range of diurnal variation is very small and day-to-day and seasonal variability in form of variation is large. Except for the location of the peak of the distribution, the change of relative frequency with increasing *K*-index at the three Indian stations is quite similar. The change in *Kp*, however, is not quite comparable. This difference can be attributed to the fact that *Kp* is derived from magnetograms of several stations located between 48° and 63° (dipole lat.) after a standardization procedure and is basically representative of the disturbance effects from equatorial ring current as well as auroral electrojet. Alibag and Hyderabad magnetograms on the other hand, should basically reflect changes representative of low latitudes. While $K \geqslant 7$ is recorded only on 29 occasions during the period 1968-75 at Alibag, the number is 80 for Hyderabad and 56 for Sabhawala. This implies that there is a bias towards under estimation at Alibag or overestimation at Hyderabad of the *K*-index when the magnitude of the disturbance is sufficiently large. The corresponding figure for *Kp* is as high as 156 indicating that much of the large-scale disturbances at high latitudes (50°-60°) is caused by substorm phenomena that do not register variations of corresponding magnitude at lower latitudes. It also implies that the relationship between DP field due to auroral electrojet and DR field due to ring current studied by several workers may not have a one-one correspondence though they can be correlated to varying degree.

(*ii*) *Alibag/Hyderabad comparison*

In Table 1 are given the number of occasions a particular combination of *K*-indices at Alibag and Hyderabad occurred during the period 1968-75. Ideally, in such a table, for two stations whose dipole latitudinal separation is only about 2° the diagonal elements should be very prominent and others must be close to zero. But in reality the following features are noticed :

(1) $K=0$ is recorded much more often at Hyderabad than at Alibag. The main reason for this appears to be the fact that the sensitivity of the Watson *H* magnetograph used in scaling *K*-indices at Alibag, was relatively low (about 45 *nT*/cm). This, coupled with thickness of the variation trace on photographic paper may preclude the chance of assigning $K=0$ for any 3-hour interval. With the change-over to IZMIRAN variometers with greater sensitivity and finer trace this discrepancy may vanish. But it is surprising that even $K=2$ at

Alibag corresponds to $K=0$ at Hyderabad on many occasions. $K=1$ at Hyderabad corresponds almost as often to $K=2$ at Alibag as to $K=1$. While this tendency is perceptible even for higher values of K (2 & 3) there is a definite reduction in magnitude and for $K=4$ it almost vanishes with only the diagonal element dominating. For $K=5$, the tendency is clearly reversed. In general the most probable value K*i* at Hyderabad corresponds to *Ki* or $(Ki+1)$ at Alibag for $K\leqslant 3$ and to *Ki* or $(Ki-1)$ for $K\geqslant 5$.

Since *K*-indices are derived for H records and the contribution of internal currents to *H* at Alibag and Hyderabad is known to be of the same order, deviation from diagonal in the ALB/HYD table should be small. Table 1 shows this to be generally true.

(*iii*) *Alibag / Sabhawala comparison*

Table 2 is a contingency table derived from comparison of the K-indices at Sabhawala and Alibag, similar to Table 1. The salient features of this table are :

(1) As at Hyderabad, the frequency of $K=0$ is more at Sabhawala than at Alibag but in comparison to Hyderabad, $K=0$ is reckoned less often at Sabhawala. Here again, strikingly on 104 occasions $K\geqslant 2$ at Alibag has a corresponding value of only 0 at Sabhawala. Also, corresponding to the occasions when Alibag recorded $K=0$, Sabhawala recorded any index between 0 and 5 (*vide* row 1, Table 2).

(2) In contrast to Table 1, there is no value of *K* for which only the diagonal element is dominant. In general, the most probable value *Ki* at Sabhawala corresponds to Ki or $(Ki+1)$ at Alibag for $K=0$ and 1 and to $(Ki-1)$ or *Ki* for others.

Apparently at least for those occasions when $K=0$ at Alibag corresponds to $K=4$ or 5 at Sabhawala, there seems a doubt about the scaled index specifically at Sabhawala as the Alibag/Hyderabad comparison does not indicate such a large discrepancy.

To check whether there is any seasonal dependence of the tendency for bias in estimating the *K*-index at a station, the contingency tables were recomputed separately for each month for the pairs ALB/HYD and ALB/SAB. It is found that the features of Tables 1 and 2 mentioned above are present in the tables for individual months and there is no apparent effect of the variability associated with the seasons, of the regular changes in magnetic field.

(*iv*) *Comparison with planetary index Kp*

In Tables 3, 4 and 5 are given the occurrence frequencies derived from comparison of three-hourly *Kp* with the *K*-indices of Alibag, Hyderabad and Sabhawala respectively. The main features can be summarised as follows :

(1) The magnitude of *K* at Alibag is the same as or one more when $Kp \leqslant 2$ whereas it is same as or one less when $Kp > 2$.

(2) The diagonal element is dominant only when the index has value 2 or 3.

(3) At Hyderabad, *K*-index has the same or a larger magnitude than *Kp*, when *Kp* is 0 or 1 and less magnitude otherwise.

(4) The diagonal element is never dominant.

(5) $Kp=0$ has corresponding value of even 3 at Sabhawala on several occasions. Similarly $Kp=1$ corresponds more often to $K=2$ or 3 at Sabhawala. The tendency for *Kp* to correspond with higher values of *K* persists almost till $Kp=4$ after which a reversal is noticed. At Sabhawala too, the diagonal element is never dominant.

Similar tables generated separately for each month indicate that all the above features are not seasonal.

(*v*) *Seasonal variation of occurrence frequency in Quiet and Disturbed periods*

In Fig. 2 are depicted the seasonal variation in occurrence frequency of *K* for quiet ($K=0$, 1 and 2 combined) and for moderately disturbed ($K=3$, 4 & 5 combined) conditions separately for the three stations. The anticipated equinoctial maximum and minimum in occurrence frequency for the moderately disturbed and quieter intervals respectively is noticed in Alibag and Hyderabad indices. It is however not seen in the frequencies for Sabhawala, particularly for the lower *K*-indices. The autumnal equinoctial peak occurs a month earlier in comparison to other two stations and the frequency of occurrence in January also appears different. In quiet intervals, there is a secondary maximum in October not so clearly seen at the other two stations. A feature of interest in all the cases is that whereas the actual frequencies differ substantially, the amplitudes of the seasonal variation are uniformly same at all the stations. It suggests that the bias, if any, in the estimation of the *K*-indices at a station is independent of season, a conclusion derived also from the contingency tables discussed earlier.

(*vi*) *Linear relationship between the* K*-indices of Alibag/Hyderabad and Alibag/Sabhawala, for quiet interval*

The monthly occurrence frequencies of K-indices ($K\leqslant 2$) at the three stations were used in the study of the linear relationship. The correlation coefficients and the regression lines were computed

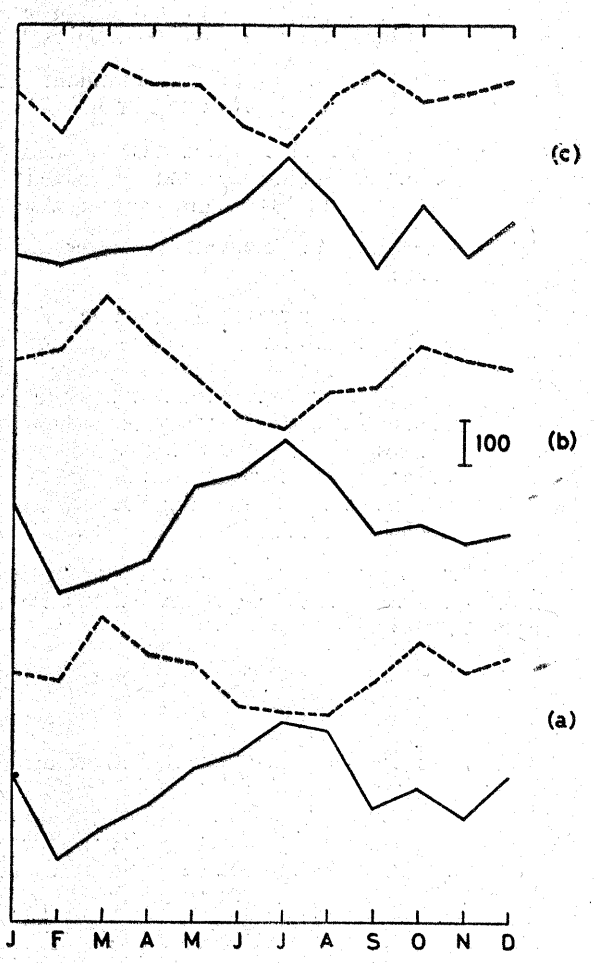

Fig. 2. Seasonal variation of occurrence frequency of K-indices during quiet (0, 1 & 2) and moderately disturbed (3, 4 & 5) intervals or the three Indian stations (*a*) Alibag (*b*) Hyderabad (*c*) Sabhawala. Continuous line pertains to quiet intervals and broken line pertains to disturbed intervals

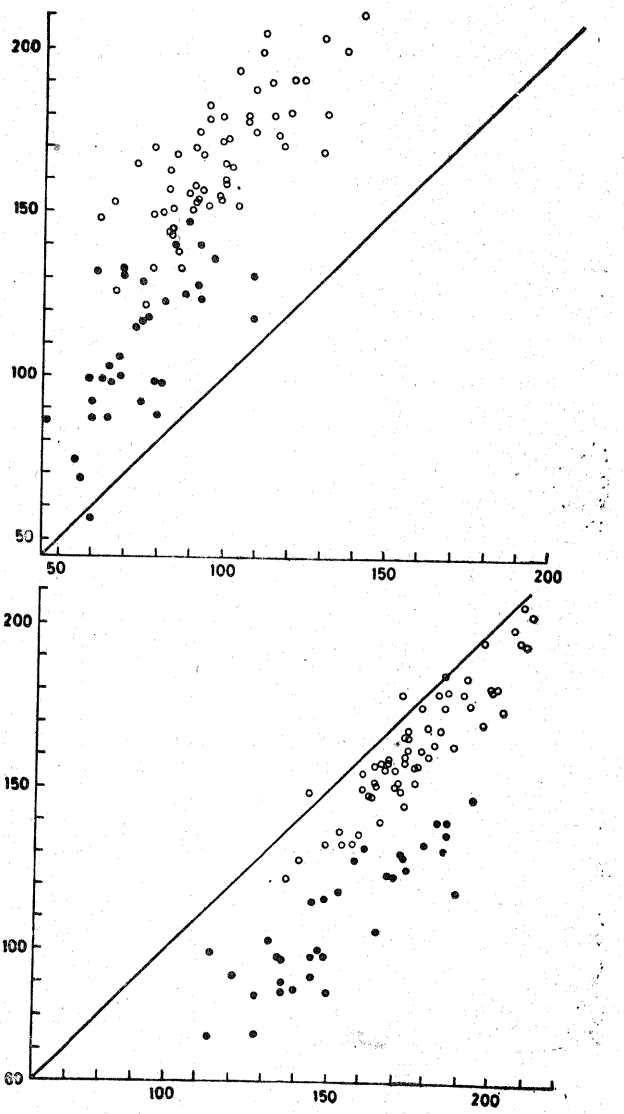

Fig. 3. Scatter plots of monthly occurrence frequencies of $K \leqslant 2$ at Alibag/ Hyderabad (bottom) and Alibag/Sabhawala (top). Ordinates are frequencies of K at Alibag. The straight lines in the diagram indicate equal frequencies at two stations. Data for 1968-1972 are shown as open circles and for 1973-1975 are shown as closed circles

for the pairs of K-indices at the two stations ALB/HYD and ALB/SAB using :

(*a*) all the years' data (96 pairs)

(*b*) for first 5 years' and latter 3 years' data separately (60 and 36 pairs) and

(*c*) individual years' data (12 pairs)

The values of *CC* and the slopes of the lines of regression are given in Table 6. Fig. 3 is the scatter plot of the K-indices ($K \leqslant 2$) for the two pairs of stations. For the ALB/HYD combination, a change in trend is seen after the year 1973. Because of this feature only, the correlations were computed for two separate segments as indicated above. The diagonal line in Fig. 3 indicates equal values at the two stations. It is immediately apparent that at Hyderabad lower values of K ($\leqslant 2$) is slightly over-estimated in relation to Alibag whereas at Sabhawala the bias is towards underestimation. Also the distinct shift after 1973 in the linear relation noticed between ALB/HYD is not seen in ALB/SAB data. It is possible that there is some change in the manner of scaling the K-index at Hyderabd. A study of table 6 indicates ALB/HYD CCs are more consistent and have larger magnitudes than ALB/SAB.

As ΣK (K=0, 5) is nearly the same at all the three stations, similar study for K=3, 4 & 5 leads to result which can be, otherwise, inferred from the same Fig. 3.

TABLE 1

Frequency of all *K*-indices at Hyderabad that occurred corresponding to given values of *K* at Alibag 1968-75

ALB/HYD	0	1	2	3	4	5	6	7	8	9
0	51	8	1	0	0	0	0	0	0	0
1	964	3386	183	11	0	0	2	0	0	0
2	165	4484	4005	383	8	0	4	0	0	0
3	9	602	2074	3667	187	17	4	0	0	0
4	1	29	107	787	1135	121	23	4	0	0
5	0	3	3	25	197	469	49	15	2	0
6	0	0	0	0	2	26	87	25	5	0
7	0	0	0	0	0	0	2	16	6	0
8	0	0	0	0	0	0	0	1	4	2
9	0	0	0	0	0	0	0	0	0	0

TABLE 2

Frequency of all *K*-indices at Sabhawala that occurred corresponding to given values of *K* at Alibag 1968-1975

ALB/SAB	0	1	2	3	4	5	6	7	8	9
0	25	26	41	29	15	5	0	0	0	0
1	367	1040	1954	1194	257	40	9	0	0	0
2	91	504	3628	3806	725	78	16	1	0	0
3	11	58	632	3484	2063	152	10	1	0	0
4	2	19	72	200	1112	734	22	1	0	0
5	0	8	26	28	46	454	201	1	0	0
6	0	0	15	1	3	7	99	27	0	1
7	0	0	1	1	0	0	6	15	1	0
8	0	0	0	1	0	0	1	1	3	1
9	0	0	0	0	0	0	0	0	1	2

TABLE 3

Frequency of all *Kp*-indices that occurred corresponding to a given value of *K* at Alibag

ALB/Kp	0	1	2	3	4	5	6	7	8	9
0	46	13	1	0	0	0	0	0	0	0
1	1379	2222	798	138	13	1	0	0	0	0
2	515	3102	3416	1641	333	43	4	0	0	0
3	36	430	1779	2583	1367	319	47	4	0	0
4	1	10	98	579	910	472	118	18	1	0
5	0	0	1	54	203	296	158	42	8	1
6	0	0	0	1	12	31	44	35	22	0
7	0	0	0	0	0	0	6	8	8	2
8	0	0	0	0	0	0	0	1	4	2
9	0	0	0	0	0	0	0	0	0	0

TABLE 4

Frequency of All *Kp*-indices that occurred corresponding to a given value of *K* at Hyderabad

HYD/Kp	0	1	2	3	4	5	6	7	8	9
0	719	403	62	6	2	0	0	0	0	0
1	1189	4030	2434	740	112	12	1	0	0	0
2	67	1217	2559	1883	555	92	6	0	0	0
3	2	123	997	2004	1305	380	59	4	0	0
4	0	1	36	327	686	361	101	17	0	0
5	0	0	3	31	166	265	137	26	5	0
6	0	3	2	5	12	46	55	36	12	0
7	0	0	0	0	0	6	18	22	14	1
8	0	0	0	0	0	0	0	3	12	2
9	0	0	0	0	0	0	0	0	0	2

TABLE 5

Frequency of all *Kp*-indices that occurred corresponding to a given value of *K* at Sabhawala

SAB/Kp	0	1	2	3	4	5	6	7	8	9
0	230	196	57	9	3	1	0	0	0	0
1	523	865	197	43	5	0	4	1	0	0
2	741	2747	2095	630	94	12	2	0	0	0
3	410	1690	3068	2599	854	136	12	1	0	0
4	71	268	641	1518	1295	390	75	12	1	0
5	2	11	34	193	553	490	169	26	5	0
6	0	0	1	4	37	130	104	52	19	1
7	0	0	0	0	1	3	11	15	13	2
8	0	0	0	0	0	0	0	1	4	0
9	0	0	0	0	0	0	0	0	1	2

TABLE 6

Correlation Coefficient and slope of the line of regression between *K* (0, 1 & 2) at (*a*) Alibag & Hyderabad and (*b*) Alibag & Sabhawala

Year	Corr. Coeff.		Slope (m) of Regression line		$\tan^{-1} m$	
	ALB/HYD	ALB/SAB	ALB/HYD	ALB/SAB	ALB/HYD	ALB/SAB
1968-75	0.870	0.817	1.265	1.393	51°20′	54°40′
1968-72	0.916	0.770	0.967	0.870	44°03′	41°01′
1973-75	0.876	0.680	0.857	0.996	40°35′	44°45′
1968	0.957	0.707	0.856	0.778	40°34′	37°53′
1969	0.977	0.787	1.137	0.879	48°20′	41°19′
1970	0.876	0.875	0.804	1.233	38°48′	50°57′
1971	0.905	0.700	1.048	0.639	46°40′	32°35′
1972	0.812	0.801	0.800	0.740	38°40′	36°30′
1973	0.956	0.554	0.636	0.791	32°28′	43°43′
1974	0.806	0.486	0.670	0.538	33°50′	28°17′
1975	0.943	0.705	1.102	1.174	47°16′	49°26′

TABLE 7

Frequency distribution (percentage) of all *K*-indices at a station that occurred in the 3-hour interval following that of a given value of *K* for two samples 1968-1971 and 1972-1975

	0	1	2	3	4	5
			ALIBAG			
0	80(6)	13(5)	5(1)	1(1)	0	0
1	1(0)	50(4)	40(2)	8(3)	1(0)	0
2	0	20(3)	50(1)	25(3)	5(0)	1(0)
3	0	7(3)	35(3)	42(2)	13(1)	3(1)
4	0	2(1)	17(3)	43(3)	25(2)	11(1)
5	0	1(0)	8(1)	31(1)	30(2)	23(2)
			HYDERABAD			
0	31(5)	55(7)	7(1)	2(1)	0	0
1	7(2)	60(2)	24(0)	7(1)	1(0)	0
2	2(1)	31(1)	39(1)	24(1)	3(1)	1(0)
3	1(0)	15(2)	29(0)	39(0)	12(2)	3(1)
4	0	4(1)	18(0)	37(1)	26(0)	12(2)
5	0	2(0)	7(0)	29(1)	27 (0)	25(0)
			SABHAWALA			
0	20(4)	20(1)	28(6)	25(2)	5(2)	1(1)
1	7(0)	25(0)	37(0)	26(1)	6(0)	1(0)
2	2(0)	10(1)	41(1)	34(2)	9(1)	1(0)
3	1(0)	5(1)	26(1)	46(0)	17(1)	4(0)
4	1(0)	2(1)	16(2)	36(1)	31(2)	11(2)
5	1(0)	1(0)	4(0)	28(4)	33(4)	24(2)

Persistence at *ALB* for 1st interval
Persistence at *HYD* for 1st interval
Persistence at SAB for 1st interval

(*vii*) *Persistence of geomagnetic activity*

Persistence is one of the main features of geomagnetic activity. In general a high value of *Kp* will be followed by a high *Kp* and similarly a low value of *Kp* will be followed by a low *Kp* (Cage and Zawalick 1972). Following the technique of analysis of Cage and Zawalick (1972), we computed tables which indicate the persistent nature of low latitude *K*-indices. Though the tables were computed over 3-hour, 6-hour, 9-hour - - - and 24-hour time intervals, only that corresponding to the immediately next value (3-hour apart) are shown in Table 7, for Alibag, Hyderabad and Sabhawala. Instead of actual frequencies, the table indicates conditional probability (percent) derived by dividing the elements of any row by the sum of the elements in that row (Cage and Zawalick, 1972).

In order to ascertain whether the persistence pattern is preserved, the tables were computed in two batches 1968-1971 and 1972-1975 of 4 years each. Table 7 gives the mean conditional probability and the figures in the bracket denote the deviation of the two values from the mean. Since the actual frequencies when $K>5$ are themselves small the percentage figures are unreliable and hence are not included in the table. It is immediately apparent that the deviations are small compared to the percentage especially for the diagonal and adjacent elements indicating the stable character of the persistence. Except for the quiet intervals $K=0$ or 1 when the percentage for the three stations differ significantly, the other intervals show nearly the same order of probability. It is remarkable that the probability is never very large for the diagonal element (<50 per cent) indicating that a high value of K is not always followed by the same value of K. However the diagonal and adjacent values on either side together add upto a high probability value. Similar tables for intervals separated by 6 hours, 9 hours etc. show that the percentage probability is more evenly spread in all columns except for that value of K which indicated a peak in the distribution in Fig. 1.

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References

Cage, A. L. and Zawalick, E. J., 1972, AFCRL-72-0693 Massachussetts 07130.

Lincoln, J.V., 1967, *Physics of Geomagnetic Phenomena*, I, Academic Press, New York, p. 67.

Mayaud, P. N., 1967, IAGA Bulletin No. 21.

Zawalick, E. J. and Cage, A. L., 1971, *J. Geophys. Res.*, **76**, 7009.