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Association of major earthquakes (magnitude ≥ 6 Richter scale) with geomagnetic activity index K_P during the period 2001-2007

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सार – इस शोध पत्र में 2001–2007 तक की अवधि के भूचूम्बकीय गतिविधि सूचकांक Kp की विविधता की विवेचना की गई है और बड़े भूकंपों (रिक्टर पैमाने पर ≥ 6 के परिमाण के) के साथ इसके निकट संबंधों का अध्ययन किया गया है। सांख्यिकीय विश्लेषण से यह पुष्टि होती है कि जब Kp 0 अथवा 0+ मानों तक पहुँच जाता है तब 48 घंटे के अंदर बड़े भूकंप आते हैं। इस शोध पत्र में पृथ्वी के बाहरी क्रोड में पिघली हुई धातु की गति के बारे में भी व्याख्या की गई है।

ABSTRACT. A critical study of variation of geomagnetic activity index Kp for the period 2001-2007 have been made and its close association with major earthquakes (magnitude ≥ 6 Richter scale) is presented. From statistical analysis it is confirmed that when Kp touches 0 or 0+ values, major earthquakes take place within 48 hours. This is also explained considering the motion of the molten metal inside the outer core of earth.

Key words – Kp index, Earthquakes.

1. Introduction

Earthquake is a complicated, nonlinear and irregular geophysical phenomenon. Dynamic relations between different parameters related to earthquake result in high uncertainties in their prediction. Sharma *et al.*, (1999), established a frequency-magnitude relationship in order to arrive at some estimates of seismic hazards for frequent earthquake struck regions. Liu *et al.*, (2000) reported that the plasma frequency of the ionospheric F-layer (foF2) shows variations and act as a precursor prior to major earthquakes (magnitude ≥ 6.0 Richter scale) for the period 1994-1999. Chuo *et al.*, (2002) observed that the electron density (plasma frequency) of the ionospheric E-layer (foEs) showed perturbations and anomaly during sunrise and sunset five days prior to major earthquake. Yanben *et al.*, (2004) proposed that great earthquakes (magnitude ≥ 8.0 Richter scale) in China, might be triggered due to solar activity. They proposed a relationship between major earthquake occurrence and sunspot numbers. Pulinets (2004) proposed a model on seismo-ionospheric coupling with the precursors of earthquake; he also proposed the mechanism by which the ionospheric layers and precursors are affected during earthquake. Chakraborty *et al.*, (2005) reported from the observation of very low frequency (VLF) signal from the roof of Indian Centre for Space Science, Kolkata that sun-set time extended towards nighttime before one or two days from the on-set of major earthquakes. They concluded that VLF monitoring could be a useful tool for major earthquake prediction. Cervone *et al.*, (2006) reported that the anomalous variations of the Surface Latent Heat Flux (SLHF) and the nighttime LF (low frequency) signals are found prior to earthquake. Thus they proposed that these two parameters can prove to be potential in providing early warning information of the impending earthquake. Hayakawa *et al.*, (2007) made a remarkable discovery - ULF (ultra-low frequency, below 10Hz) emissions from the crust prior to major earthquakes can play an important earthquake signature in earthquake prediction. Mukherjee (2008) in his paper revealed an interesting fact–the cosmic

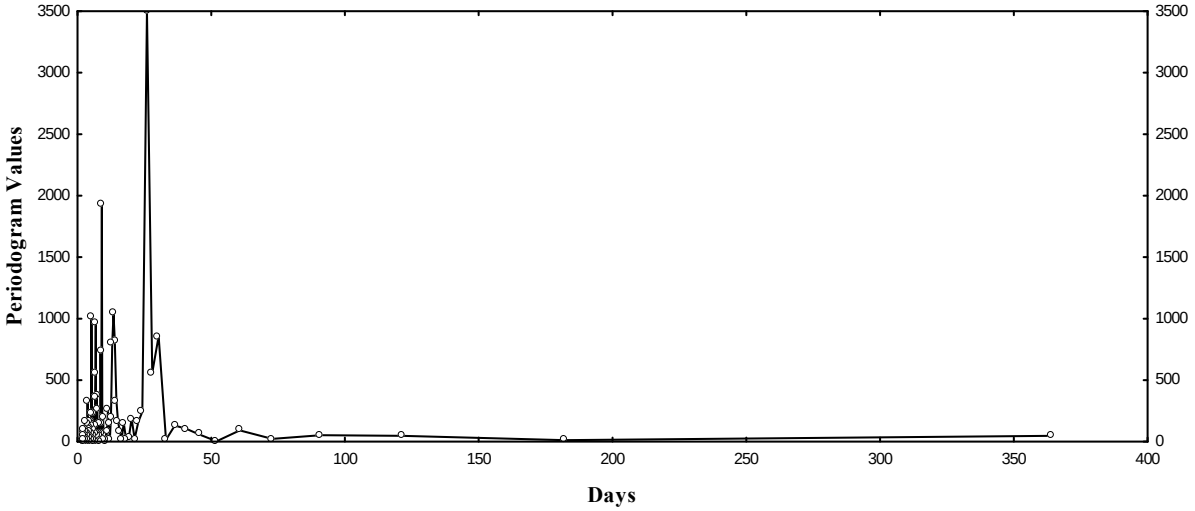

Fig. 1. Periodogram of geomagnetic activity index Kp

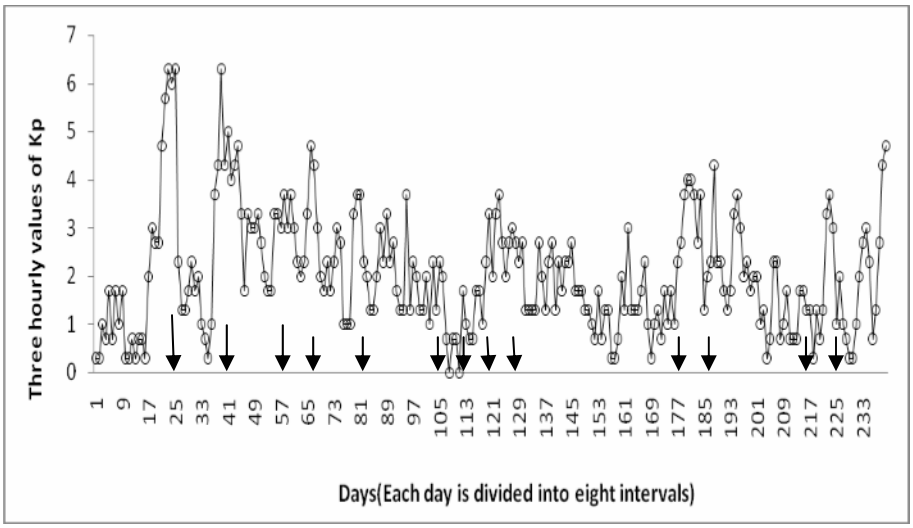

Fig. 2. Variation of geomagnetic activity index Kp for the month of April, 2004

influence on Sun and the Sun-Earth environment. He had shown that a correlation exists between cosmic influence on Sun-Earth environment in predicting earthquakes and sudden abnormal atmospheric changes. Gousheva *et al.*, (2009) in their paper showed the ionospheric quassi-electric field anomalies before and after moderate and major earthquakes. Moderate low depth earthquakes showed fewer fluctuations while it increases in case of major quakes. They also showed that the electric field has a vertical component E_z, which varies in accordance to latitude change. Akhoondzadeh *et al.*, (2010) observed the electron and ion density variation and fluctuation or anomalies in the ionosphere prior to strong earthquakes around the epicenter using the IAP (plasma analyzer) and ISL (Langmuir probe) experiments onboard DEMETER satellite and GPS network. Akhoondzadeh *et al.*, (2010) observed the anomalous behaviour of VLF and HF signals prior to strong earthquakes. Mukherjee and Mukherjee (2002) reported that some solar parameters can perturb the geomagnetic field, earths magnetosphere, geosphere etc. Anomalous changes in the geomagnetic activity index Kp and electron flux due to earth might be a precursor of the earthquakes (Mukherjee and Ma, 2007). So, it is necessary to study the precursory phenomena through the geomagnetic activity index Kp. The paper presents the nature of variation of Kp index during 2001 to 2007 and it's close association with major earthquakes (magnitude $\geq$ 6 Richter scale).

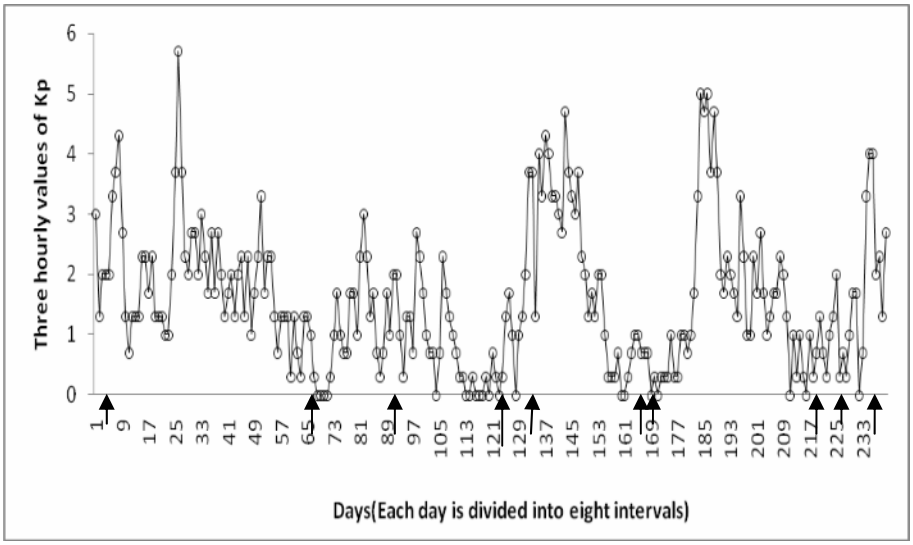

Fig. 3. Variation of geomagnetic activity index Kp for the month of September, 2006

2. Data Source

The website http://earthquake.usgs.gov/earthquakes/eqarchives/epic/epic_global.php is used to collect major earthquake data (magnitude ≥ 6 Richter scale). Kp index is taken from Solar Geophysical Data, National Oceanic and Atmospheric Administration, Boulder, Colorado. Kp is the three hourly mean standardized k-index from 13 observatories between geomagnetic latitudes 47 and 63 degrees. The scale of Kp index varies from 0 to 9 and expressed in thirds of a unit. 0 is considered for very quiet period and 9 is for extremely disturbed period. So O+ means 1/3.

3. Methods

Graphical presentation of Kp index with major earthquakes throughout the world is done. Nature of motion of highly viscous liquid of outer core is studied. Physical explanation considering the motion of liquid in the outer core is also presented. Test for equality of two population proportions and chi-square test are used to draw our conclusion.

4. Results and discussion

Periodogram of geomagnetic activity index Kp for the year 2007 is shown in Fig. 1. From the periodogram, it may be concluded that there is a significant periodicity of 26 days in geomagnetic activity index Kp. A few observations of variation of Kp index are shown in Fig. 2 & in Fig. 3. Arrow mark shows the time of occurrence of major earthquakes. We have obtained almost same type of observations during the period 2001-2007. In most cases we observed that major earthquakes occur within 48 hours after the occurrence of Kp minimum (0 or 0+).There are also some unexpected occurrence of earthquakes as shown in Fig. 2 & Fig. 3. The internal structure of earth consists of four distinct layers: the crust, the mantle, the outer core and the inner core. The earth magnetic field is believed to be generated due to spinning movement of molten metals inside the outer core of earth. The inner core is solid. The outer core is mostly liquid iron along with nickel. The fluid of the outer core can be considered as highly viscous fluid at higher temperature. The temperature of outer core close to mantle is about 4000 °C. This fluid rotates with high velocity with the rotation of earth. We know in a viscous fluid rotation, the Reynold's number R for the liquid near the mantle is given by

$$R = \rho d v_c/\eta \quad (1)$$

where, v_c = velocity = $2\pi r/T$,

r = Thickness of outer core = 2253 km (approx.)

d = radius of boundary between outer core & mantle = 3480 km (approx.)

T = Time of rotation of earth = 24 × 3600 sec.

ρ = 7.23 x 10^3 kg/m^3, for molten iron.

η for molten iron is taken 1 × 10^{-3} kg/ m sec.

[since, η for aluminium at 800° C 1.4 × 10^{-3} kg/m sec
η for Pb at 844 °C 1.18 × 10^{-3} kg/m sec
η for Tin at 600 °C 1.05 × 10^{-3} kg/m sec] (Koshkin and Shirkevich, 1977)

TABLE 1

Occurrence of major earthquakes on expected and unexpected days (monthwise)

Month and year	Expected days	Occurrence	Unexpected days	Occurrence
Jan(2001)	12	7	7	1
Feb	8	4	12	4
Mar	5	1	21	6
Apr	3	2	24	7
May	4	1	23	7
Jun	4	2	22	7
Jul	5	3	21	7
Aug	4	1	23	6
Sep	6	3	18	3
Oct	5	5	21	5
Nov	7	5	16	4
Dec	5	4	21	5
Jan(2004)	2	1	27	8
Feb	4	3	21	6
Mar	4	2	23	6
Apr	6	5	18	8
May	5	3	21	4
Jun	5	2	20	5
Jul	5	3	21	6
Aug	9	1	13	3
Sep	9	6	12	5
Oct	9	5	13	3
Nov	5	5	20	8
Dec	6	3	19	7
Jan(2005)	4	3	23	16
Feb	7	5	14	7
Mar	8	5	15	5
Apr	7	4	16	2
May	6	3	19	5
Jun	4	1	22	8
Jul	4	2	23	6
Aug	5	4	21	5
Sep	4	2	22	4
Oct	10	4	11	0
Nov	8	4	14	4
Dec	7	3	17	8
Jan(2006)	9	4	13	3
Feb	10	6	8	2
Mar	11	7	9	0
Apr	9	9	12	1
May	10	6	11	2
Jun	7	6	16	4
Jul	11	5	9	1
Aug	8	4	15	1
Sep	8	6	14	1
Oct	9	6	13	5
Nov	9	5	12	3
Dec	8	3	15	4
Jan(2007)	8	4	15	5
Feb	9	4	10	2
Mar	9	4	13	5
Apr	9	6	12	8
May	10	6	11	0
Jun	8	4	14	3
Jul	9	4	13	7
Aug	9	5	13	9
Sep	7	5	16	9
Oct	10	7	11	2
Nov	9	4	12	7
Dec	10	5	11	5
Total	427	242	972	290

Therefore, R (Reynold's number) = $2\pi\rho dr / \eta$.

Thus considering molten iron as main fluid of the outer core we get

$R = 4.13 \times 10^{15}$.

Due to very high value of Reynold's number (R), the motion of the highly viscous fluid of the outer core is turbulent. As a result the mantle in contact with the outer core vibrates continuously. When this vibration propagates through the mantle, the amplitude is attenuated, but it can vibrate the tectonic plates continuously causing earthquakes in large numbers with smaller magnitude.

The major earthquakes may be linked to the disturbances inside the outer core with large magnitudes. Other than the turbulent motion as mentioned above, there is a velocity gradient of the molten metal inside the outer core. The layer in contact of the mantle of the outer core moves at a greater velocity with respect to the layer in contact with the inner core. Due to the high viscous nature of material of the outer core, the layer in contact with the mantle will be dragged to some extend and then will break down causing a shear wave flowing towards the inner core. High frequencies of such waves propagate and superimposes with one another producing beats. Thus there will be some stages where the disturbances are minimum and then grow to a large magnitude. It is well known that magnetic field observed on the surface of the earth has two components, one internal part and other external part. The internal part arises within the outer fluid core of the earth. The silent duration can be linked with Kp having minimum value. Therefore one can expect that right after Kp having minimum value, the disturbances inside earth's core starts to grow to a larger values. We have studied the phenomenon of major earthquake occurrence within 48 hours after Kp being 0 and 0+.

Observed data is shown in Table 1 and analysis is given in Tables 2(a) & 2(b). Here we use a word pooled which is necessary to satisfy the condition of chi-square test. For Chi-square test the expected frequency in each cell should be greater than equal to 5. Otherwise we can't do this. So, we have to pool the expected frequencies of the consecutive cells to make it greater than equal to 5 and same treatment is done for the corresponding other cells.

Analysis : Test for equality of two population proportions:-

Let X_1 be the number of major earthquakes which occurred on the expected days and X_1 follows bin (n_1, P_1) and X_2 be the number of major earthquakes which occurred on the unexpected days and follows bin (n_2, P_2). Two populations are independent. Now, $n_1 = 427$ & $n_2 = 972$. $X_1 = 242$ & $X_2 = 290$. Sample proportions are $\hat{P}_1 = \frac{242}{427} = 0.56674$ & $\hat{P}_2 = \frac{290}{972} = 0.29835$.

Here, we want to test the hypothesis $H_0 : P_1 = P_2$ against the alternative hypothesis H_1: $P_1 > P_2$.

Here, we use the test statistic $\tau = \dfrac{\hat{P}_1 - \hat{P}_2}{\sqrt{\dfrac{\hat{P}(1-\hat{P})}{n_1} + \dfrac{\hat{P}(1-\hat{P})}{n_2}}}$

which follows under H_0, asymptotic N (0,1).

$$\hat{P} = \frac{n_1\hat{P}_1 + n_2\hat{P}_2}{n_1 + n_2} = 0.38027 \text{ \& } 1 - \hat{P} = 0.61973.$$

$$\tau = \frac{0.56674 - 0.29835}{\sqrt{\dfrac{0.38027 * 0.61973}{427} + \dfrac{0.38027 * 0.61973}{972}}}$$

$$= \frac{0.26839}{0.02818} = 9.5241$$

Tabulated $\tau_{0.05} = 1.645$. Since, calculated τ is greater than tabulated τ at the 5% level of significance, so, we can conclude, on the basis of the given data that H_0 is rejected, *i.e.*, the probability of the occurrence of the earthquake on the expected days is greater than the occurrence on the unexpected days.

Using the Chi-square test we also conclude the same result which is obtained in the above. All calculations are shown in Tables 1, 2(a) & 2(b).

From Table 2(a) we can conclude that there is no significant difference between the observed and expected no. of earthquakes, since here the calculated Chi square (= 14.17114) is less than the tabulated $\chi^2_{0.05,36}$ (= 50.9646).

Now, from Table 2(b), we can conclude that there is no significant difference between the observed and expected no. of earthquakes, since calculated Chi square (= 54.53164) less than the tabulated $\chi^2_{0.05,40}$ (=55.759).

Since, for expected days, calculated Chi square is less than the unexpected days, so, we can conclude that the probability of the occurrence of major earthquakes in the expected days is greater than the unexpected days. It shows that the probability of occurrence of expected major earthquakes (occur within 48 hours after the occurrence Kp minimum) is 56.67 per cent [Table 2(a)] where as the probability of occurrence of unexpected major earthquakes is only 29.84 per cent [Table 2(b)]. In

TABLE 2(a)

Calculation of Chi-square for expected days

Pooled Expected Days (ED)	Pooled observed no. of earthquakes (O)	Pooled expected no. of earthquakes (E = ED * 282/406)	$\chi^2 = \frac{(O-E)^2}{E}$
12	7	6.800936768	0.005827
13	5	7.367681499	0.760879
11	5	6.234192037	0.244335
15	7	8.50117096	0.265083
12	10	6.800936768	1.504794
11	8	6.234192037	0.500157
10	7	5.667447307	0.313315
10	5	5.667447307	0.078604
14	4	7.93442623	1.950955
9	6	5.100702576	0.158554
9	5	5.100702576	0.001988
11	8	6.234192037	0.500157
11	8	6.234192037	0.500157
15	9	8.50117096	0.02927
10	4	5.667447307	0.490588
9	6	5.100702576	0.158554
14	6	7.93442623	0.471616
15	7	8.50117096	0.265083
9	4	5.100702576	0.237525
10	6	5.667447307	0.019513
11	7	6.234192037	0.094072
9	9	5.100702576	2.980868
10	6	5.667447307	0.019513
18	11	10.20140515	0.062516
16	10	9.067915691	0.095808
9	6	5.100702576	0.158554
9	5	5.100702576	0.001988
16	7	9.067915691	0.471583
9	4	5.100702576	0.237525
9	4	5.100702576	0.237525
9	6	5.100702576	0.158554
10	6	5.667447307	0.019513
17	8	9.634660422	0.277344
9	5	5.100702576	0.001988
17	12	9.634660422	0.580698
9	4	5.100702576	0.237525
10	5	5.667447307	0.078604
Total = 427	Total = 242	Total = 242	Total = 14.17114

TABLE 2(b)

Calculation of Chi-square for unexpected days

Pooled Unexpected Days (UD)	Pooled observed no. of earthquakes (O)	Pooled expected no. of earthquakes (E = UD*195/950)	$\chi^2 = \frac{(O-E)^2}{E}$
19	5	5.66872428	0.078888
21	6	6.265432099	0.011245
24	7	7.160493827	0.003597
23	7	6.862139918	0.00277
22	7	6.563786008	0.02899
21	7	6.265432099	0.086122
23	6	6.862139918	0.108317
18	3	5.37037037	1.046232
21	5	6.265432099	0.25558
37	9	11.03909465	0.376653
27	8	8.055555556	0.000383
21	6	6.265432099	0.011245
23	6	6.862139918	0.108317
18	8	5.37037037	1.287612
21	4	6.265432099	0.819127
20	5	5.967078189	0.156733
21	6	6.265432099	0.011245
25	8	7.458847737	0.039262
33	11	9.845679012	0.135334
19	7	5.66872428	0.312644
23	16	6.862139918	12.16829
29	12	8.652263374	1.295307
35	7	10.44238683	1.134801
22	8	6.563786008	0.314256
23	6	6.862139918	0.108317
21	5	6.265432099	0.25558
22	4	6.563786008	1.001404
25	4	7.458847737	1.603951
17	8	5.072016461	1.690272
21	5	6.265432099	0.25558
21	1	6.265432099	4.425038
27	6	8.055555556	0.524521
24	2	7.160493827	3.719115
27	6	8.055555556	0.524521
27	7	8.055555556	0.138314
25	7	7.458847737	0.028227
25	13	7.458847737	4.116503
25	3	7.458847737	2.665468
26	16	7.757201646	8.758793
27	11	8.055555556	1.076245
23	12	6.862139918	3.846848
Total = 972	Total = 290	Total = 290	Total = 54.53164

our calculation we have not considered the data of 2002 and 2003 as they are in the period of solar maximum. It is expected that solar magnetic field during this period is not normal. As a result Kp value will be affected and the results will be disturbed. It is believed that the motion of the outer core (which is partially ionized state) is the origin of earth's magnetic field. The magnetic index, Kp depends on the earth's magnetic field and also on extraterrestrial events. A large value of Kp therefore not necessarily mean that there is a disturbance in earth's magnetic field. However, the major earthquakes, as we observed is also present which are not right after Kp being minimum and that may be attributed to the fact that there is a large disturbance in the outer core due to some

extraterrestrial events. We have also observed a few events where Kp touches minimum value and each quakes of magnitude mentioned did not occur within 48 hours. It may be due to decrease of the strength of seismic stress inside the core for some reasons. As a result strength of earthquake becomes less than 6 Richter scale. As we have considered the earthquakes of magnitude greater than 6 Richter scale those quakes are not considered.

5. Conclusion

The surface of the earth is always moving with the rotation of the earth. The plates in contact with the outer crust of our earth are also in motion constantly. Whenever there is a differential movement between plates, there is bound to be a certain disturbance in the lithosphere and as a result earthquakes take place. Due to high Reynold's number (nearly equal to 10^{15}) the motion of highly viscous liquid of outer core is always turbulent. As a result, vibration is created in the mantle. This is highly attenuated when it reaches to the lithosphere of our earth. The amplitude of these vibrations is minimum and not significant. This is the source of production of earthquakes of smaller amplitude which are occurring in large numbers. The velocity of the highly viscous liquid layer in contact with the mantle is greater than the layer in contact with the inner core. As a result the highly viscous liquid is dragged to some extent and then breaks down. This produces shear waves and it moves towards the inner core. Beats are formed due to the superimposition of such waves of high frequency. When beats are formed, the amplitudes of vibration become large and major earthquakes take place. Minimum disturbance of the molten magnetic material of the outer core produces minimum variation of magnetic index Kp which is equivalent to 0 or 0+. Just after this minimum value, maximum disturbances take place due to formation of beat. As a result, major earthquakes occur. This agrees fairly well with our observations as presented in this paper.

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