

Long -Term Relations of Cosmic ray Intensity with Sunspot Numbers and Geomagnetic Activity Parameters During the Period of 2013-2024



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Abstract

Yearly average of cosmic ray intensity (CRI) observed at Oulu super neutron monitor (NM) has been studied with yearly average of corresponding sunspot number (SSN) and also yearly average of corresponding geomagnetic activity parameter Ap, Kp Index during the period of 2013 to 2024. It is seen that yearly average of cosmic ray intensity is inversely correlated with yearly average of corresponding sunspot number (SSN), geomagnetic activity parameter Ap, Kp Index. We have found high negative correlation with correlation coefficient -0.96 between yearly average of cosmic ray intensity (CRI) and yearly average of sunspot number (SSN). High negative correlation with correlation coefficient -0.76 has been determined between yearly average of cosmic ray intensity (CRI) and geomagnetic activity parameter Ap Index and -0.58 between yearly average of cosmic ray intensity and geomagnetic activity parameter Kp index.

1. Introduction

Galactic cosmic rays (GCRs), which are omnipresent, charged and energetic particles coming from outside of the heliosphere, are affected by the heliospheric magnetic flux as they propagate inward from the heliospheric boundary at about 120 AU [9]. Galactic cosmic ray flux can be altered in the form of Forbush decreases [5] due to transient heliospheric structures with more turbulent and intensive magnetic fields such as interplanetary coronal mass ejections [2] and stream interaction regions [18]. As galactic cosmic rays can interact with Earth's atmosphere via ionization processes, such disturbed galactic cosmic ray variations have also been argued to be the connection of Sun-climate correlations [15] via changing the global electric circuit and modifying cloud properties [8;11;10]. In the long term of a few years, the galactic cosmic ray flux was first observed to anti-correlate with sunspot variations [6] since the transport of galactic cosmic rays is modulated by heliospheric field strength and irregularities that evolve following the quasi-11-year solar cycle [14;16]. Specifically, enhanced magnetic flux is more efficient in preventing charged galactic cosmic ray particles from deeply penetrating into the heliosphere, causing decrease of galactic cosmic ray fluxes towards solar maxima. The variation of galactic cosmic ray fluxes at Earth has been correlated with various solar and heliospheric parameters, such as the Sunspot Number (SSN), the strength and turbulence level of heliospheric magnetic field (HMF), the heliospheric current sheet (HCS) tilt angle, the open solar magnetic flux, the solar polarity, and so on [23;3;20;1;16], and empirical functions describing the galactic cosmic ray dependence on different solar cycle parameters have been proposed [4;2,4,7]. Several studies have demonstrated that there is lag between cosmic ray intensity variation and solar activity parameters and lag between GCR and solar-activity proxies is approximately zero (i.e. no lag) during even solar cycles, and that there exists a lag of around a year or more during odd solar cycles [23;12;22]. It has long been established that there exists an anti-correlation between GCR intensity and the level of solar activity over a cyclic 11-year period, with perhaps some time lag [6;14;23;24;25]. A recent study [19] has shown that during Cycle 24, GCR-SSN lag is about 4 months which is slightly longer than those during preceding even-numbered cycles which were 1-2 months, although not as long as those observed in previous odd-numbered cycles which were longer than a year. Sham Singh et al [21] have studied cosmic ray intensity with solar and geophysical parameters during the solar cycle 22 to 25. They observed that the geomagnetic activity index shows a clear modulation corresponding to the 11-year sunspot cycle. However, the 27-day averages of geomagnetic activity do not maximize at the time of sunspot maximum. During solar cycle 22 to 25 both the parameters V and B are correlated with geomagnetic indices Ap and Kp are showing the similar trend of variation during the maximum phase of solar cycle. Onuchukwu, C., & Edwin, D. [13] investigated the modulation of cosmic ray (CR) intensity in response to solar and heliospheric variability across the ascending (ASC) and descending (DSC) phases of Solar Cycles (SCs) 23 and 24. Using daily averaged data, they analyzed sunspot number (SSN) as a proxy for solar activity, solar wind parameters interplanetary magnetic field (IMF), solar wind plasma density (SWPD), speed (SWS), temperature (SWT) and geomagnetic indices (Kp, Dst, ap). Geomagnetic storms were categorized by intensity based on Dst index thresholds. Distribution analyses revealed broadly consistent trends for SSN, IMF, SWPD, SWS, and geomagnetic indices across both SC phases. However, CR intensity and SWT exhibited significant phase dependent discrepancies, with CR fluxes more suppressed during ASC phases, perhaps due to increased solar magnetic complexity and related solar activities. Average parameter values also diverge across storm intensity levels, indicating the modulation role of transient solar phenomena. Correlation coefficient analyses indicate stronger positive and negative associations between CR intensity and solar wind parameters during DSC phases compared to ASC phases, suggesting enhanced coupling between heliospheric conditions and CR flux during the declining solar activity. In this investigation cosmic ray intensity (CRI) observed at Oulu super neutron monitor (NM) during the period of 2013 to 2024 has been studied with solar activity parameter sunspot number (SSN) and geomagnetic parameter Ap and Kp index to see the trends of cosmic ray intensity with these parameters.

2. Experimental Data

In this work yearly data of sunspot number (SSN), Scalar B, geomagnetic activity Ap, Kp index and cosmic ray intensity (CRI) count rates over the period of 2013 to 2024 have been used to determine relation between cosmic ray intensity (CRI) variations and these parameters. For this investigation yearly, average data of Oulu super neutron monitors have been used. The data of yearly sunspot number, scalar B, geomagnetic activity Ap, Kp Index has also been used and these data are taken from omni web data (<http://omniweb.gsfc.nasa.gov/form/dxi.html>).

3.0. Data Analysis and Results

3.1. Cosmic Ray Intensity Variation in Relation with Sun Spot Number (SSN)

In this part of the study we analyzed yearly average values of cosmic ray intensity (CRI) observed at Oulu super neutron monitor (NM) with yearly average values of sunspot numbers (SSN) and performed correlative analysis between yearly average values of cosmic ray intensity (CRI) variation and yearly average values of solar sun spot numbers (SSN), for the period of 2013 to 2024. We have plotted a liner graph and a bar graph between

yearly average values of cosmic rays intensity (CRI) variation and yearly average values of solar sun spot numbers (SSN) shown in fig. [1, 2,]. From the figures it is clear that there is inverse correlation between yearly average values of cosmic ray intensity (CRI) variation and yearly average value of sunspot numbers (SSN) for the period of 2013 to 2024. We have also calculated correlation coefficient by statistical methods and high negative correlation with correlation coefficient -0.96 has been found between yearly average of cosmic ray intensity variation and yearly average of sunspot number during 2013-2024.

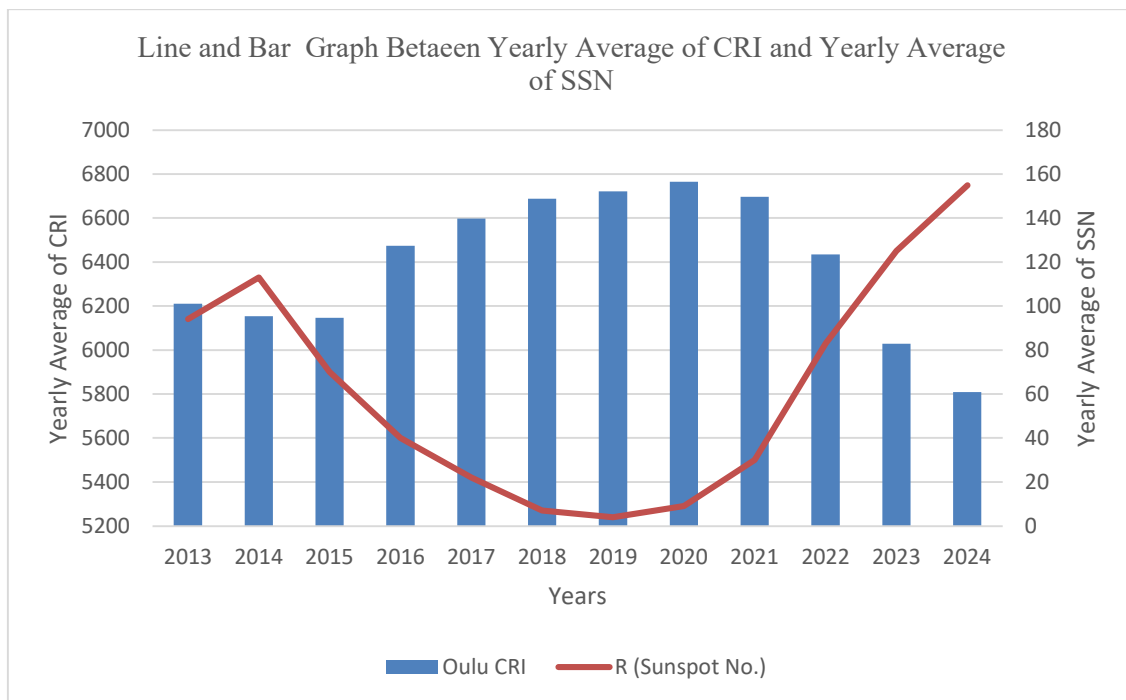


Fig.1 Shows the relationship between yearly average value of CRI (Oulu) and SSN, for the period of 2013-2024.

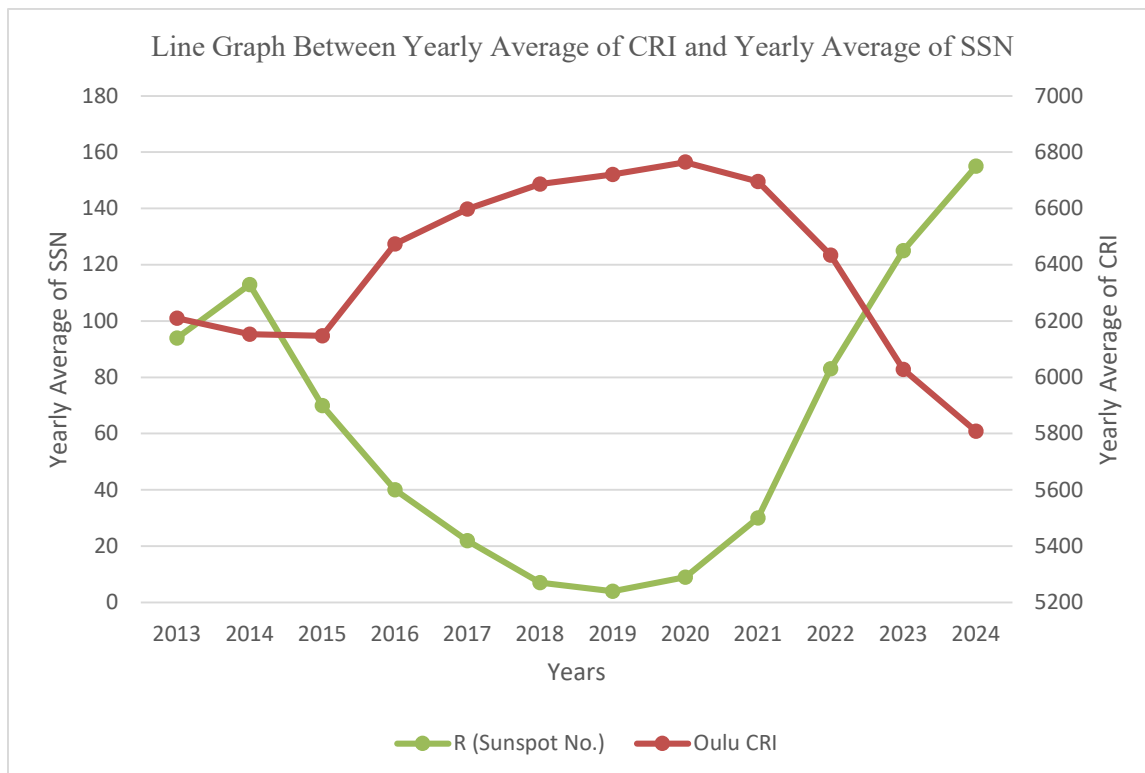


Fig.2 Shows the relationship between yearly average value of CRI (Oulu) and SSN, for the period of 2013-2024.

3.2. Cosmic Ray Intensity Variation in Relation with Geomagnetic Activity Parameter Ap index

In this section the data of yearly average of cosmic ray intensity observed at Oulu super neutron monitor is analyzed with yearly average values of geomagnetic activity parameter Ap index. A correlative analysis has been performed of these two parameters for the period of 2013 to 2024. We have plotted a liner and bar graph between yearly average values of cosmic rays' intensity (CRI) variation and yearly average values of geomagnetic activity parameter Ap index shown in fig. [3, 4.]. It is seen in the figure that these two parameters are anticorrelated for the period of 2013-2024. Large negative correlation with correlation coefficient -0.76 has been found between yearly average of cosmic ray intensity variation and yearly average of geomagnetic activity Ap index during the period of 2013-2024.

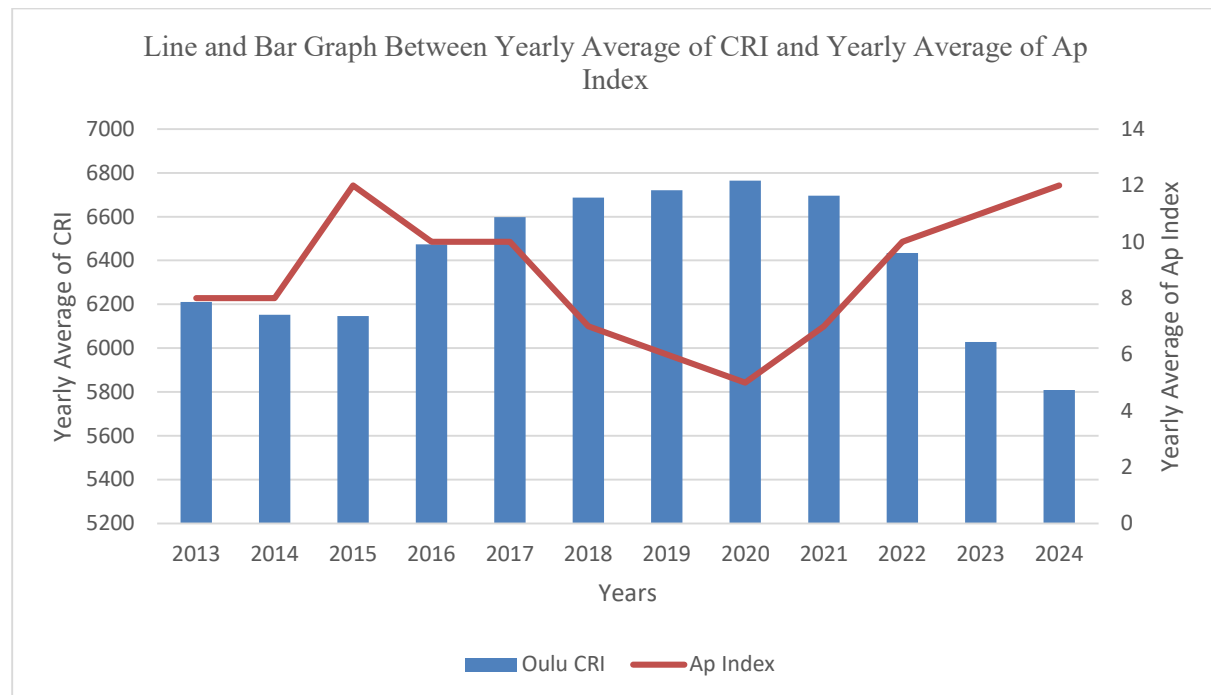


Fig.3 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of geomagnetic activity parameter Ap index, for the period of 2013-2024.

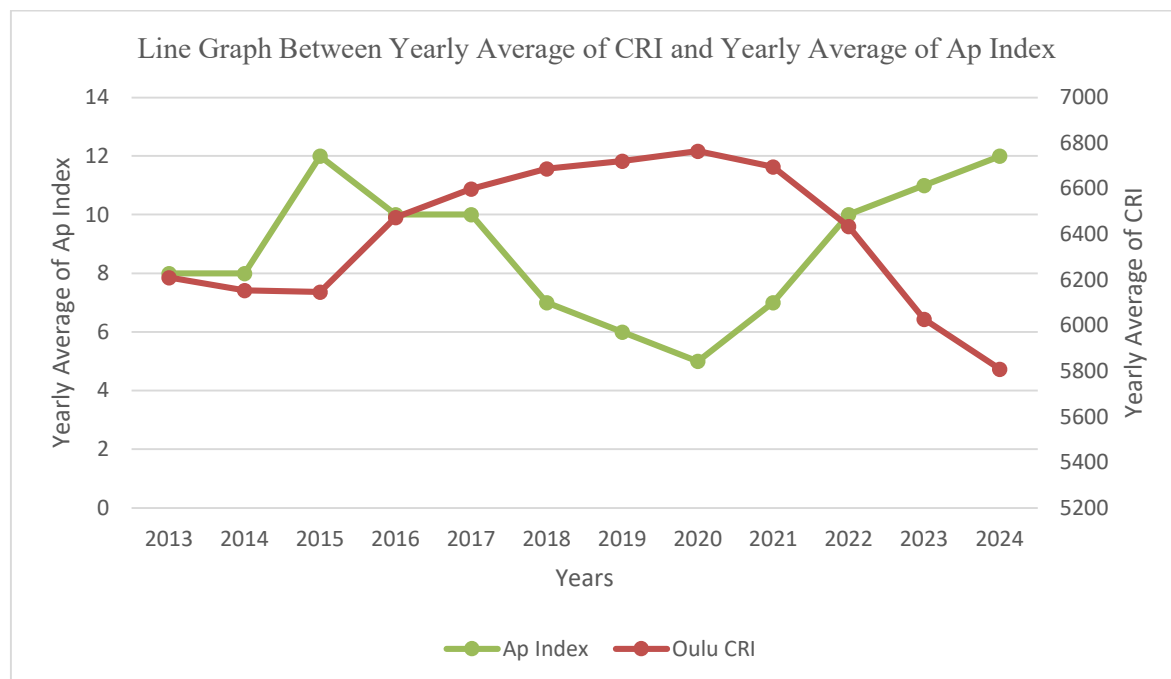


Fig.4 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of geomagnetic activity parameter Ap index, for the period of 2013-2024.

3.3. Cosmic Ray Intensity Variation in Relation with Geomagnetic Activity Parameter Kp Index

In this part of the study, we have analyzed cosmic ray intensity (CRI) variation with geomagnetic activity parameters Kp index. We have adopted correlative analysis between yearly average values of cosmic ray intensity (CRI) variation and yearly average values of geomagnetic activity parameter Kp index for the period of 2013-2024. We have plotted a liner graph and a bar graph between yearly average values of cosmic rays intensity (CRI) variation and yearly average values of geomagnetic activity parameter Kp index shown in fig. [5, 6]. From the figures it is observed that inverse correlation has been found between yearly average values of cosmic ray intensity (CRI) variation and yearly average value of geomagnetic activity parameter Kp index for the period of 2013-2024. Using mathematical formula of the correlation we have calculated correlation coefficient between them and large negative correlation with correlation coefficient -0.58 has been found between yearly average of cosmic ray intensity (CRI) variation and yearly average of geomagnetic activity Kp index.

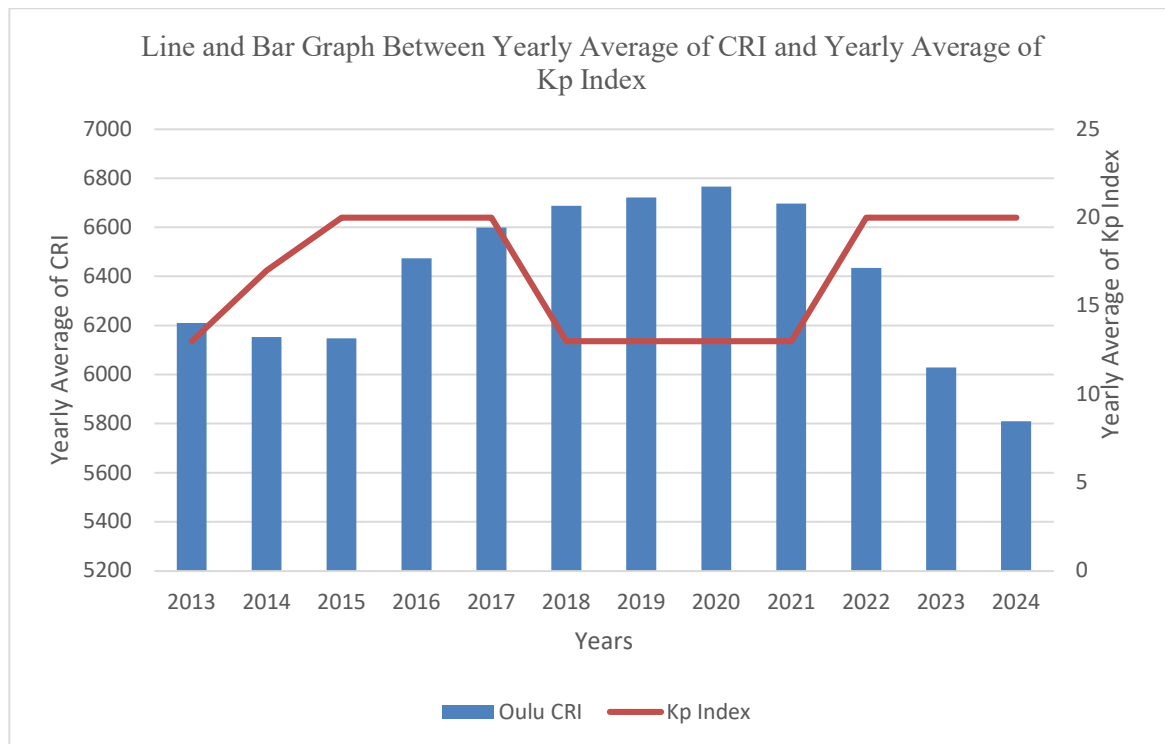


Fig.5 Shows the relationship between yearly average value of CRI and yearly average of geomagnetic activity parameter Kp index, for the period of 2013-2024.

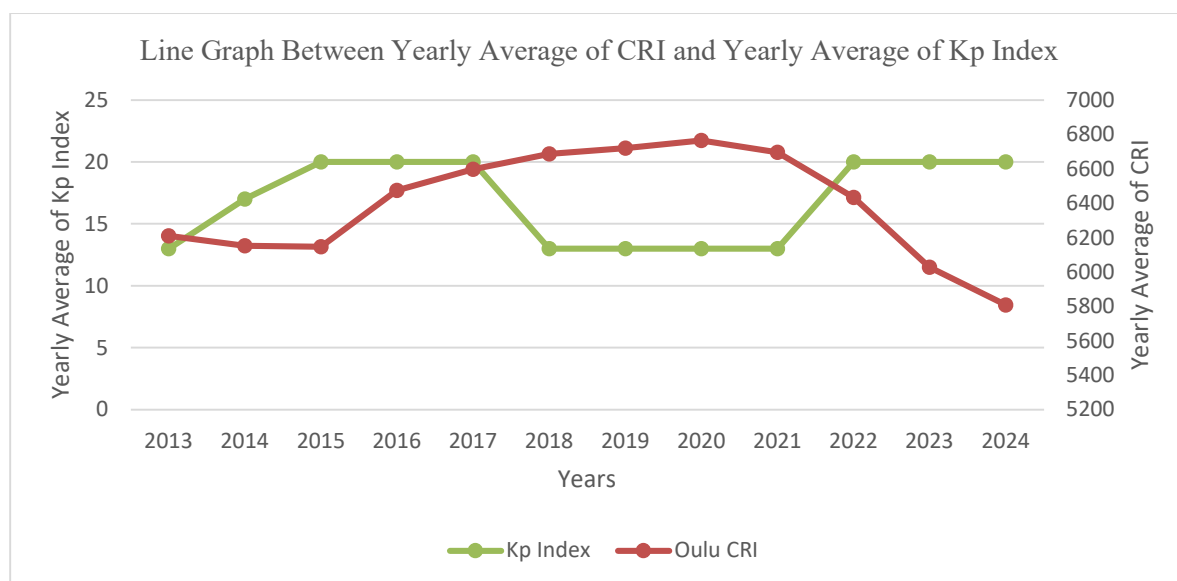


Fig.6 Shows the relationship between yearly average value of CRI and yearly average of geomagnetic activity parameter Kp index, for the period of 2013-2024.

4. Conclusions

From the results obtained in this investigation it is concluded that that CRI undergoes 11-year solar cycle within the heliosphere, which is greatly influenced mainly by solar activity parameters including sunspot numbers.

1-The study confirms that the yearly average of sunspot numbers and yearly average of cosmic ray intensity (CRI) are negatively correlated and anticorrelations observed are highly significant. As the correlation coefficient -0.96 has been found between yearly average of cosmic ray intensity variation and yearly average of sunspot number during the period of 2013-2024.

2-The study also confirms that the yearly average of cosmic ray intensity (CRI) and geomagnetic activity parameters Ap and Kp index is anti-correlated as the correlation coefficient -0.76 has been found between yearly average of cosmic ray intensity variation and yearly average of Ap index and -0.58 are determined between yearly average of cosmic ray intensity and yearly average of geomagnetic activity parameter Kp index during the period of 2013-2024. From these results it is concluded that cosmic ray intensity variations are closely related with solar activity parameter sunspot number (SSN) and geomagnetic activity parameter Ap and Kp index.

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Conflict of Interest

We have no conflicts of interest to disclose.

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