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Statistical Study of the Factors Affecting Outdoor Gamma Dose Rate and Impact of Season

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ABSTRACT

The objective of the study was to find the significant impact of season on the outdoor gamma dose rate including statistical analysis. Outdoor gamma dose rates were studied for 52 locations of the Balod district, Chhattisgarh, India, in summer and winter. Statistical analysis confirmed that there was no significant difference in dose rate between summer and winter. Geology of the area was the most important factor, and meteorological parameters had less influence; consequently, in this investigation, the impact of these parameters were checked through linear regression, cluster, principal component and factor analysis.

INTRODUCTION

Human beings are always exposed to natural background radiation because of terrestrial and cosmic sources (Tripathi et al. 2011; Rafique et al. 2014). Each location has a different cosmic radiation level and it depends strongly on the altitude of areas above sea level and less on the latitude (UNSCEAR 2000). The variation in terrestrial radiation is higher than that of cosmic radiation, and the former makes a higher contribution to the total background radiation (Karunakara et al. 2014). The United Nations Scientific Commission on the Effects of Atomic Radiation (UNSCEAR) reported an external terrestrial radiation dose of 59 nSv/h and cosmic radiation dose at sea level of 32 nSv/h (UNSCEAR 2000, 2008; Rafique et al. 2014). Gamma rays penetrate the body and may cause damage at a cellular level and cause of stochastic health risk, which is based on the probability of genetic damage and cancer induction. Radiation may pass through the cell without doing any damage, or this may damage the cell, but the body has self-repair phenomena, and it may repair the damaged cell. Many studies have been carried out in the field of natural radiation detection, but only a few of them studied seasonal variations of terrestrial gamma radiation (Al-Ghorabie 2005; Hassan 2006; Inomata et al. 2007; Negi et al. 2009; Dhawal et al. 2014; Ramasamy et al. 2013; Karunakara et al. 2014; Kaur et al. 2018). The magnitude depends on geology and is mostly associated with the local lithological formation (Negi et al. 2009). Radiation due to natural radioactive materials like rocks, soils that are widely spread in the environmental air. It is mainly due to gamma radiation, which comes from ^{238}U, ^{232}Th series, and ^{40}K ions (Hazrati et al. 2012; Ononugbo et al. 2016). Few studies have been carried out for meteorological impact on the gamma dose rate (Baciu 2006). Researchers also studied the seasonal variation in values of indoor and outdoor gamma dose rate. However, these studied confirmed that the indoor gamma dose rate values were higher in winter than in summer but no significant evidence available about outdoor gamma dose rate (Al-Ghorabie 2005; Negi et al. 2009; Mrdakovic et al. 2012; Dhawal et al. 2014; Karunakara et al. 2014). The main objectives of the present study are: (a) To find the impact of summer and winter season on outdoor gamma dose rate by statistical analysis. (b) To check the impact of geology and meteorological parameters on gamma dose rate through various modelings such as linear regression analysis, principal component analysis, and factor analysis.

MATERIAL AND METHODOLOGY

Selection of the Study Area

The Balod district is densely populated and situated at the bank of river Tandula in the central part of Chhattisgarh state, covering an area of 3527 km^2 from latitude 20°35.826' (Marram Kheda) to 21°01.978' N (Khursuni), and longitude 81°00.811' (Sanjari) to 81°29.323' E (Miri Tola). The gamma dose rates measured from 52 locations of Balod district, Chhattisgarh India, and a previous study reported radiation risk for this region. Still, seasonal variation and impact of various factors analyzed in this study (Jindal et al. 2018), the total population of the study region is 0.79 lakh (approx.). Six square kilometer grids were selected for study locations.

Geology of the Study Area

The study region has water and mineral-rich resources. Mineral deposit of Balod district includes iron ore, limestone, sandstone, flagstone, quartzite, sand, murum, laterite and soil.

Geologically, the area has the following lithological units, namely (a) Chandi Formation (1.92 %) with stromatolite limestone which is purple to grey, fine-grained, hard and compact, calcareous rock showing stromatolitic structure. (b) Gunderdehi Formation (19.23 %) has purple calcareous shale, which is fine-grained, friable with intercalations of stromatolitic limestone. (c) Charmuria Formation (38.46 %) contains grey bedded/flaggy limestone which is dark grey, hard compact flaggy/bedded and pyritiferous. (d) Chandarpur Group (28.85 %) comprises of sandstone with shale and siltstone, intercalations, and conglomerate which are medium-grained, compact, glaucreonitic, peblly at places (viz, conglomerate, arenite). (e) Dongargarh granite (5.77 %) has granite gneisses with enclaves of quartzite, quartz-mica schist and amphibolite. (f) Bastar gneissess (1.92 %), hard, compact, banded iron formation (BIF) and shale/phyllite. (g) Bijli Rhyolite (3.85 %) (District survey report 2019).

Measurement Techniques

Polimaster PM-1405 gadget was used for measurement of gamma dose rate, which included terrestrial and cosmic radiation. The measurement range of this device is 0.05 to 3 MeV, and the detection range is 0.01 μSv/h to 100 mSv/h (Monica et al. 2017; Jindal

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et al. 2018). The latitude (N) and longitude (E) of all locations were deduced by using the GPS coordination device model GARMIN OREGON 650. ArcGIS version 10.7 software was used for the preparation of radiation maps for study areas in summer and winter seasons.

The climate of the Balod district is of tropical type. All meteorological parameters like temperature, relative humidity, pressure, and wind speed were determined from the National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center model data (Model- Version 2 data).

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) version 23 was utilized for the investigation of information about season variation and the impact of geology and meteorological parameters on the outdoor gamma dose rate. In this study, paired t-test, correlation, histogram, and linear regression analysis, principal component analysis, cluster analysis were used for estimation of the impact of season on gamma dose rate incorporating geology, altitude, and meteorological parameters of the study area.

RESULTS AND DISCUSSION

In recent decades, studies from many researchers confirmed that indoor gamma radiation always found higher in the winter season; however, the outdoor gamma radiation level still not confirmed; it varied for different locations. Hence, this study included statistical aspects to evaluate the season variation on the outdoor gamma dose rate. This study involved 52 locations data for evaluation of seasonal variation as well as factors (geology and meteorology) affecting the gamma dose rate. The maximum and minimum values of the outdoor gamma dose rate in summer and winter seasons were 271 nSv/h, 201 nSv/h and 110 nSv/h, 103 nSv/h, respectively with standard deviation range between summer and winter season were 161 and 98 nSv/h respectively. The mean value of the outdoor gamma dose rate found 150.35 nSv/h with a standard deviation of 26.36 nSv/h and 143.62 nSv/h with a standard deviation of 22.12 nSv/h in the summer and winter season respectively. The higher value of the outdoor gamma dose rate in the summer season seems to be similar, as reported from Al-Hada village, At-Taif city, and Ash-Shafa village from the region of Kingdom, Saudi-Arabia and three locations from Norway (Al-Ghorabie 2005; Mrdakovic et al. 2012). Radiation maps for outdoor gamma dose rate of study areas in the summer and winter season are shown in Fig.1. In the summer season, 3.85% locations indicated outdoor gamma dose rate more than 200 nSv/h, and only 1.92 % locations indicated the outdoor gamma dose rate more than 200 nSv/h in the winter season. However, all areas show higher values of gamma dose rate as compared to world populated average value (UNSCEAR 2000).

From Table 1 (a), the significance value for paired samples for correlation between values of outdoor gamma dose rate in summer and winter season was 0.001 which was less than the 0.05 indicates there is a relationship between outdoor gamma dose rate in summer and winter season. Correlation value for outdoor gamma dose rate in summer and winter season was 0.44, which indicates positive correlation. The significance value of paired sample t-Test from Table 1 (b) of the outdoor gamma dose rate in summer and winter season was 0.066, which indicates that the null hypothesis was accepted. Based on individual correlation analysis, there was no strong correlation between these factors (altitude, geology, and meteorological parameters) with the outdoor gamma dose rate. Only the correlation value for outdoor gamma dose rate in the summer season with temperature was found positive and significant.

Statistical Modelling

Histograms for outdoor gamma dose rate in summer and winter season are shown in Fig.2 which indicates that the data was normally distributed and same was also confirmed with significant values of normality test as mentioned in Table 2, however, the data in winter season is fairly symmetrical as compared to the summer season based on skewness value. The distribution of overall data is shown in Fig.3 by using a scatter plot for both seasons.

Histograms for standardized regression residual for outdoor gamma dose rate with other factors in summer and winter season are shown in Fig.4. The histogram for regression standardized residual measures the strength of the difference between the observed and expected values, which clearly indicate that the data set follows normality with other factors. The normal P-P plots of regression standardized residual for outdoor gamma dose rate in the summer

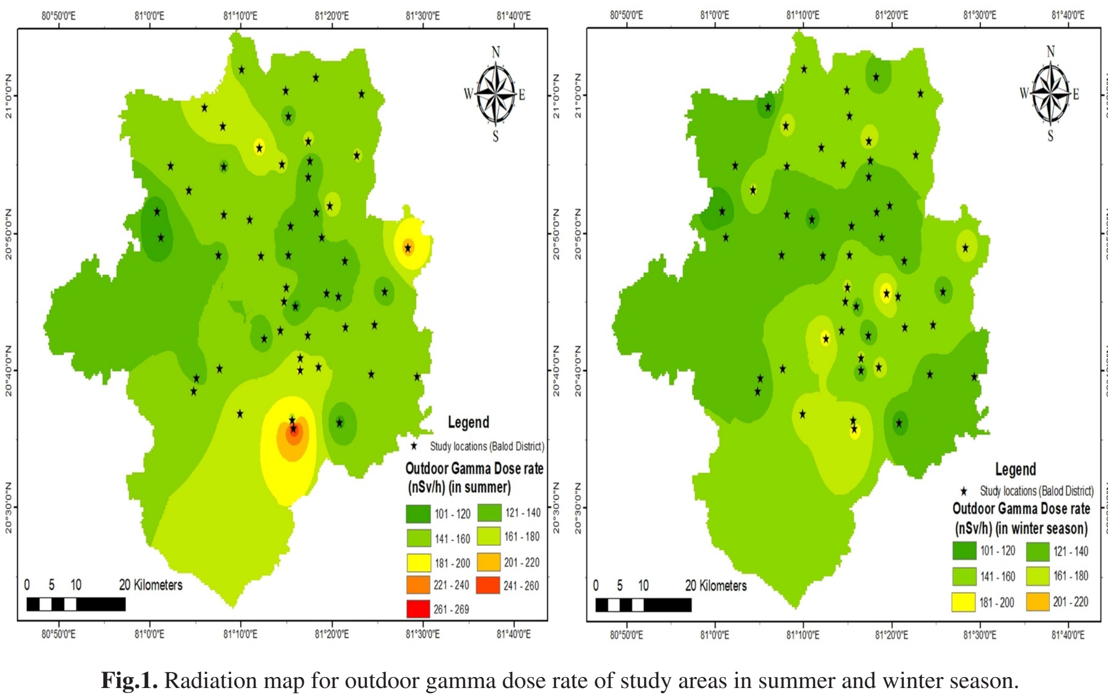

Fig.1. Radiation map for outdoor gamma dose rate of study areas in summer and winter season.

Table 1. Statistical data of pair t-test for the outdoor gamma dose ate in summer and winter seasonfrom Balod district, Chhattisgarh: (a) Paired sample correlation statistics, (b) Paired sample t-test

(a) Paired Samples Statistics							
		Mean	N	Std. Deviation	Std. Error Mean	Correlation	Sig.
Pair 1	Outdoor Gamma Dose Rate (in summer season)	150.35	52	26.36	3.65	0.44	0.001
	Outdoor Gamma Dose Rate (in winter season)	143.62	52	22.12	3.07		

(a) Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Outdoor Gamma Dose Rate (in summer season) - Outdoor Dose Rate Gamma (in winter season)	6.73	25.82	3.58	-0.46	13.92	1.9	51	0.066

Table 2. Test of Normality for outdoor gamma dose rate data.

	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Outdoor Gamma Dose Rate (in summer season)	0.116	52	0.078
Outdoor Gamma Dose Rate (in winter season)	0.113	52	0.094

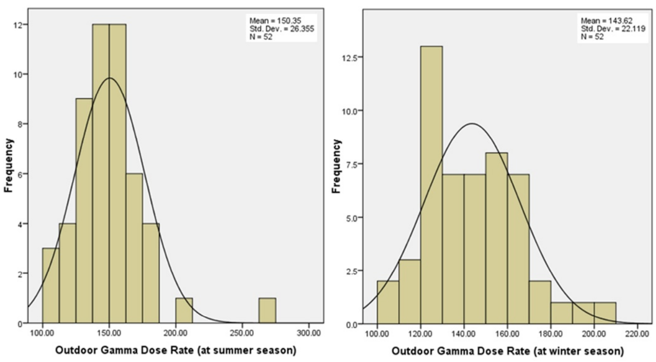

Fig.2. Histogram of outdoor gamma dose ratein summer and winter season.

and winter season shown in Fig.5. P-P plots are used for judging the distribution of the data set.

Regression state in Table 3, the R values in summer (model-1), and winter (model-2) season for outdoor gamma dose rate are 0.533 and 0.414, which illustrates that there are positive relations for outdoor gamma dose rate with other factors. The R-value shows that the strong relationship of outdoor gamma dose rate with other factors in the summer season as compared to the winter season and positive values indicate that there are no changes of multicollinearity. From Table 3(b), the significant value of ANOVA was 0.016, which was less than 0.05 means that the outdoor gamma dose rate value would depend on geology, temperature, pressure, wind speed, relative humidity, and altitude in the summer season. The significant value of coefficients from Table 3(c) shows that the outdoor gamma dose rate was significant with respect to geology in the summer season.

Principal Component Analysis

Principal component analysis was done by SPSS software using varimax rotation with the Kaiser normalization method, which is given in Table 4 and 5. Screen plot of eigenvalue in summer and winter season is shown in Fig.6, which indicated two factors that have Eigenvalue more than one that can be outdoor gamma dose rate and geology of the areas. Varimax rotated factor plot from Fig.7 for both seasons shows the rotation factor loading outdoor gamma dose rate in summer and winter season. Table 4 and 5 shows the eigenvalues for two-factor analysis in variance, which indicate two factors in summer and winter have percent variance values 76.48 % (in summer) and 71.65 % (in winter) that reflect the good quality of the data set. (Shivakumar et al. 2014).

Statistical Analysis of Outdoor Gamma Dose Rate with Geology

Automatic linear modeling through SPSS software is shown in

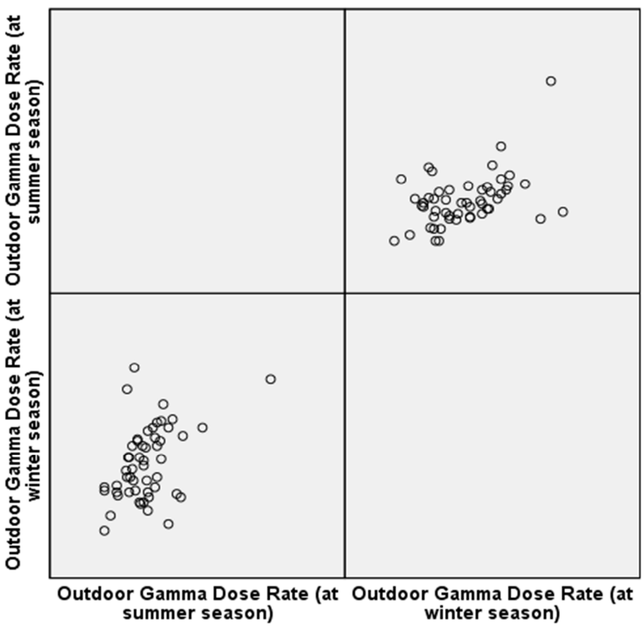

Fig.3. Scatter Plot Matrix for outdoor gamma dose rate in summer and winter season.

Table 3. Statistical modeling for outdoor gamma dose rate in summer and winter season

(a) Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.533[a]	0.284	0.188	23.75
2	0.414[c]	0.171	0.061	21.44

(b) ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10050.26	6	1675.04	2.97	0.016[a]
	Residual	25373.51	45	563.86		
	Total	35423.77	51			
2	Regression	4278.21	6	713.04	1.55	0.183[c]
	Residual	20674.09	45	459.42		
	Total	24952.31	51			

(c) Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence nterval for BI	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	19616.01	13043.01		1.50	0.14	-6653.97	45885.98
	Altitude	-0.29	0.18	-0.42	-1.57	0.123	-0.65	0.08
	Temperature (in summer season)	-41.54	37.29	-0.91	-1.11	0.271	-116.65	33.57
	Relative Humidity (in summer season)	6.10	6.13	1.48	0.99	0.325	-6.25	18.44
	Pressure (in summer season)	-6.87	4.22	-0.80	-1.63	0.111	-15.38	1.64
	Wind speed (in summer season)	-23.25	24.44	-1.08	-0.95	0.347	-72.48	25.98
	Geology	-2.58	0.82	-0.60	-3.17	0.003	-4.22	-0.94
2	(Constant)	7955.13	4485.56		1.77	0.083	-1079.26	16989.52
	Altitude	-0.21	0.17	-0.36	-1.27	0.210	-0.54	0.12
	Temperature (in winter season)	-0.90	4.12	-0.066	-0.22	0.828	-9.20	7.40
	Relative Humidity (at winter season)	-0.97	1.32	-0.27	-0.74	0.466	-3.64	1.69
	Pressure (in winter season)	-7.57	4.46	-0.60	-1.70	0.097	-16.56	1.42
	Wind speed (in winter season)	-5.26	5.97	-0.20	-0.88	0.383	-17.29	6.76
	Geology	-2.08	0.82	-0.58	-2.54	0.014	-3.72	-0.43

a.Predictors: (Constant), Geology, Altitude, Relative Humidity (in summer season), Pressure (insummer season), Temperature (in summer season), Wind speed (in summer season). b.Dependent Variable: Outdoor Gamma Dose Rate (in summer season)
c.Predictors: (Constant), Geology, Altitude, Relative Humidity (in winter season), Wind speed (in winter season), Temperature (in winter season), Pressure (in winter season). d. Dependent Variable: Outdoor Gamma Dose Rate (in winter season)

Table 4. Total Variance explained for outdoor gamma dose rate in summer and winter season by Eigenvalues for factors.

	Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
		Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Outdoor Gamma Dose Rate (in summer season)	1	2.987	42.67	42.67	2.99	42.67	42.67
	2	2.367	33.81	76.48	2.37	33.81	76.48
	3	0.944	13.49	89.96			
	4	0.484	6.92	96.89			
	5	0.179	2.56	99.45			
	6	0.035	0.495	99.94			
	7	0.004	0.056	100.00			
Outdoor Gamma Dose Rate (in winter season)	1	2.964	42.343	42.343	2.964	42.343	42.343
	2	2.052	29.311	71.655	2.052	29.311	71.655
	3	0.958	13.683	85.338			
	4	0.544	7.771	93.109			
	5	0.304	4.340	97.449			
	6	0.115	1.647	99.096			
	7	0.063	0.904	100.000			

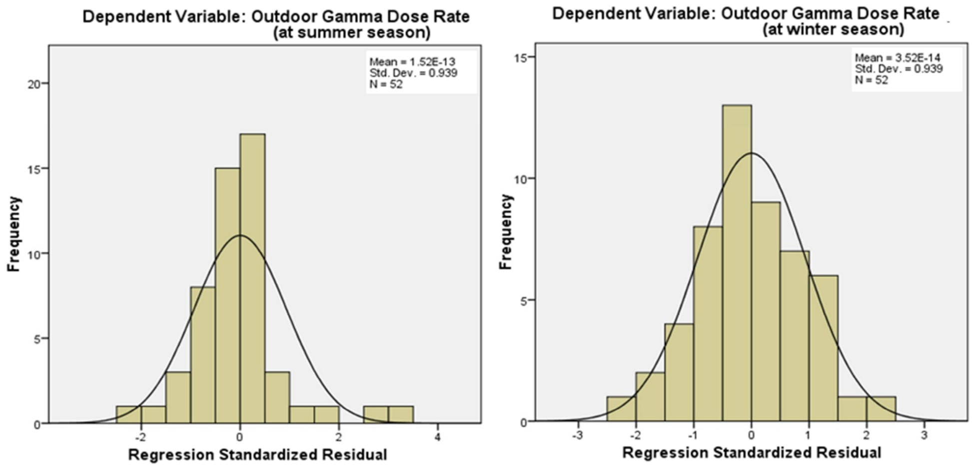

Fig.4. Histogram for regression standardized residual of outdoor gamma dose rate in summer and winter season.

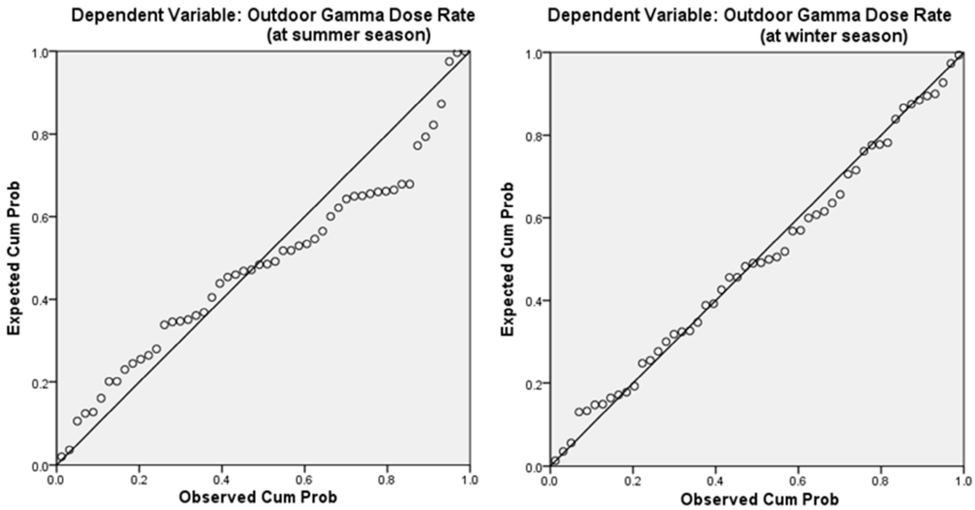

Fig.5. Normal P-P Plot of Regression Standardized Residual for outdoor gamma dose rate in summer and winter season.

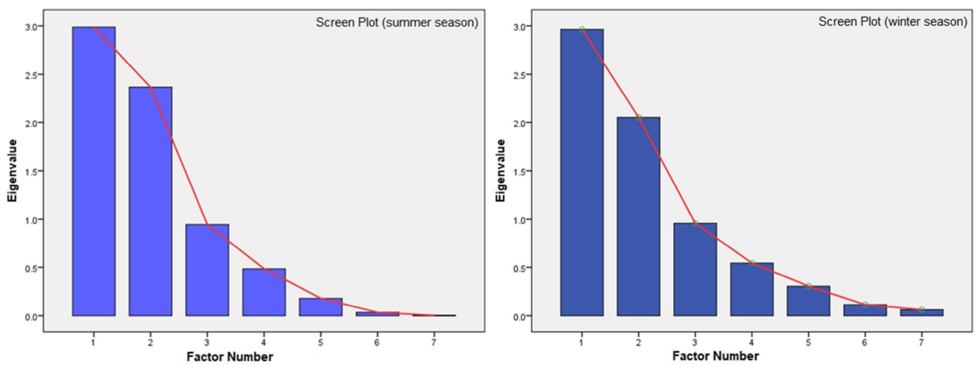

Fig.6. Screen Plot of Eigenvalues in the summer and winter season.

Table 5. Two factor matrix for outdoor gamma dose rate in summer and winter season through Principal Component analysis.

Parameters	Factor		Parameters	Factor	
	1	2		1	2
Outdoor Gamma Dose Rate (in summer season)	0.126	0.501	Outdoor Gamma Dose Rate (in winter season)	-0.321	-0.213
Altitude	-0.525	0.747	Altitude	-0.740	0.483
Temperature (in summer season)	0.410	0.853	Temperature (in winter season)	0.919	0.094
Relative Humidity (in summer season)	0.880	0.369	Relative Humidity (in winter season)	0.861	0.313
Pressure (in summer season)	0.575	-0.786	Pressure (in winter season)	-0.055	-0.946
Wind speed (in summer season)	0.951	-0.088	Wind speed (in winter season)	0.842	-0.266
Geology	-0.720	-0.265	Geology	0.127	0.837

Extraction Method: Principal Component Analysis. a. 2 components extracted.

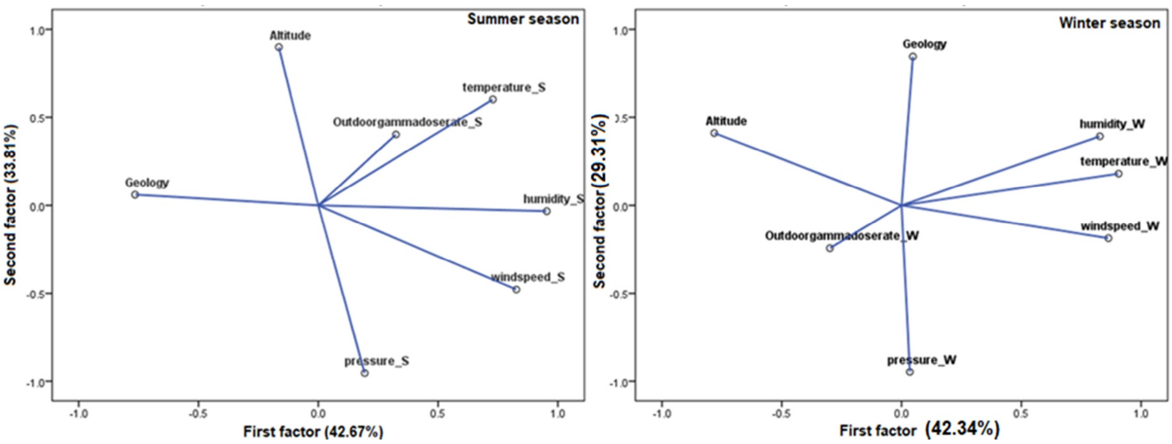

Fig.7. Varimax rotated factor plot for summer and winter season.

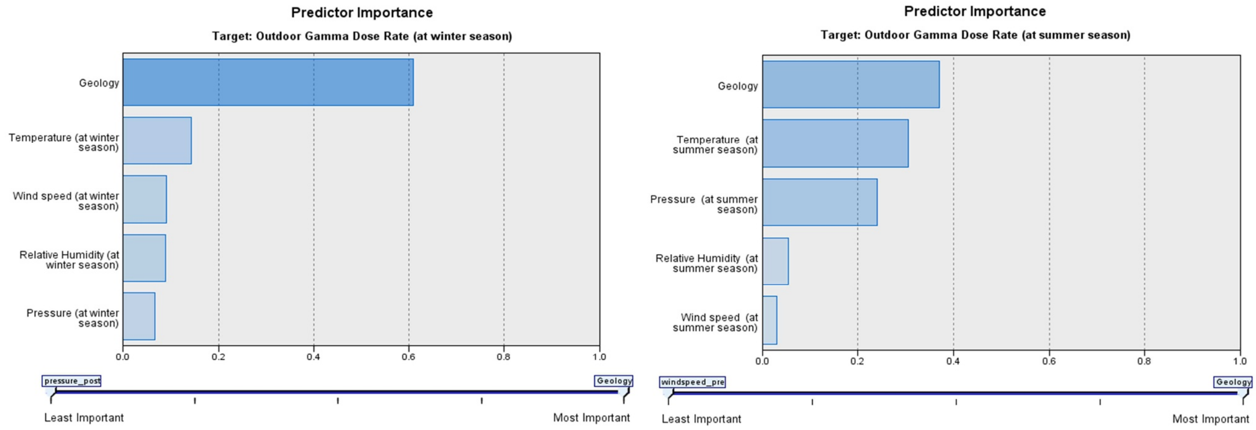

Fig.8. Linear modeling predictor importance for values of outdoor gamma dose rate in summer and winter season.

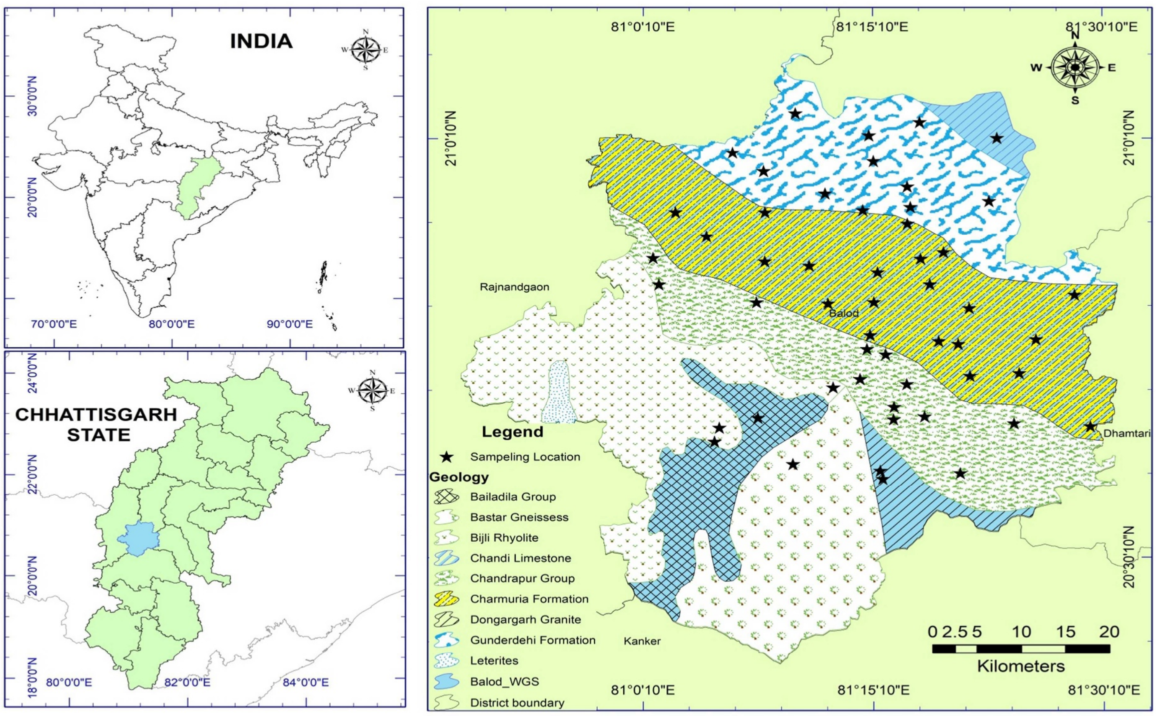

Fig.9. Geology map for study areas of Balod district, Chhattisgarh.

Table 6. Statistical data for outdoor gamma dose rate in summer and winter season based on the geology of the area

Geology	Outdoor Gamma Dose Rate	N	Min.	Max.	Range diff.	Mean	Geometric Mean	Std. Dev.	Kurtosis	Variance	Skewness	Median	Std. Error of Mean
Chandi	Winter	1	142	142	-	142	142	-	-	-	-	142	-
	Summer	1	148	148	-	148	148	-	-	-	-	148	-
Gunderdehi Formation	Winter	10	107	179	72	150	149	20	1.56	403	-0.87	151	6
	Summer	10	133	186	53	162	161	15	0.32	230	-0.38	163	5
Dongargarh Granite	Winter	3	135	194	59	161	159	30		907	0.99	154	17
	Summer	3	147	271	124	193	186	68		4612	1.65	161	39
Bastar Gneisses	Winter	1	165	165	-	165	165	-	-	-	-	165	-
	Summer	1	172	172	-	172	172	-	-	-	-	172	-
Bijli Rhyolite	Winter	2	124	188	64	156	153	45		2048		156	32
	Summer	2	123	132	9	128	127	6		41		128	5
Chandrapur Group	Winter	15	103	169	66	140	138	21	-1.28	455	-0.06	133	6
	Summer	15	110	184	74	143	141	23	-0.84	531	-0.14	144	6
Charmuria Formation	Winter	20	115	201	86	139	137	21	2.91	435	1.57	133	5
	Summer	20	122	205	83	145	144	19	4.48	367	1.84	141	4
Overall	Winter	52	103	201	98	144	142	22	-0.10	489	0.51	141	3
	Summer	52	110	271	161	150	148	26	7.68	695	1.93	148	4

Fig.8, which reflected that geology is the most important factor to reach the target value outdoor gamma dose rate in the summer and winter season. For both seasons, temperature is the second most important parameter for the outdoor gamma dose rate. In summer and winter season wind speed and pressure are the least important. The geology of the study area is shown in Fig. 9, and overall statistical data are shown in Table 6. In this table, various statistical analyzed parameters such as variance, skewness, and kurtosis with standard error are mentioned. The highest variation in gamma dose rate was found in Dongargarh granite area that was 124 nSv/h at the summer season with the highest mean value of 193 nSv/h; lowest gamma radiation found was 128 nSv/h in Bijli rhyolite in the summer season.

Cluster Analysis

Cluster analysis is the technique to identify the similarity between groups or classified a similar number of groups among data set (Yim et al. 2015). In this study, the outdoor gamma dose rate in summer and winter season show a similar number of clusters. The results of cluster analysis are shown in Figure 10, 11 and 12, which shows agglomeration coefficient values, Icicle plots and dendrogram clusters, respectively. Variation in agglomeration coefficient values was found to be 39-43 stage of data analysis. Icicle plot indicated only one group of cases 21 (Aroud) and 10 (Rauna) have the same set of data from the summer and winter season. Dendrogram cluster was reflected in the similar group of the cluster and found seven clusters which can explain all location data set (outdoor gamma dose rate) in summer and winter season.

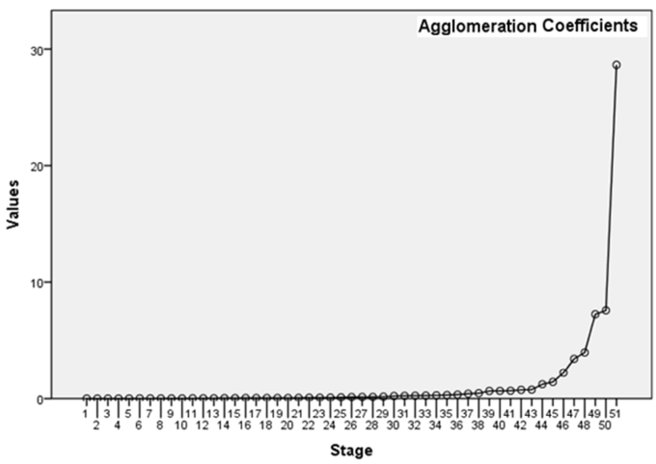

Fig.10. Agglomeration coefficients values with stages of the cluster.

Outdoor Gamma Dose Rate Ratio in Summer and Winter Season

The outdoor gamma dose rate ratio between summer and winter

Table 7. Descriptive statistics of altitude and meteorological parameters in the summer and winter season.

Descriptive Statistics													
Season		N	Range	Min.	Max.	Mean		Std. Dev.	Variance	Skewness		Kurtosis	
		Stat.	Stat.	Stat.	Stat.	Stat.	Std. Error	Stat.	Stat.	Stat.	Std. Error	Statistic	Std. Error
Altitude (m)	-	52	80.00	323.00	403.00	350.88	5.31	38.31	1467.99	0.66	0.33	-1.62	0.65
Temperature (K)	Winter	52	7.79	290.31	298.10	294.35	0.23	1.62	2.63	-1.66	0.33	2.54	0.65
	summer	52	1.41	305.79	307.20	306.41	0.08	0.58	0.33	0.24	0.33	-1.92	0.65
Relative Humidity (%)	Winter	52	18.77	68.21	86.98	83.03	0.85	6.10	37.26	-1.91	0.33	1.86	0.65
	summer	52	17.07	9.85	26.92	14.79	0.89	6.41	41.12	1.15	0.33	-0.34	0.65
Pressure (hPa)	Winter	52	6.92	966.64	973.56	970.58	0.24	1.76	3.11	-0.28	0.33	-0.71	0.65
	summer	52	10.20	960.12	970.32	966.23	0.43	3.09	9.56	-0.76	0.33	-0.71	0.65
Wind speed (m/s)	Winter	52	3.16	0.99	4.15	3.29	0.12	0.84	0.70	-0.53	0.33	-0.68	0.65
	summer	52	3.60	1.16	4.76	2.37	0.17	1.22	1.50	1.27	0.33	-0.07	0.65

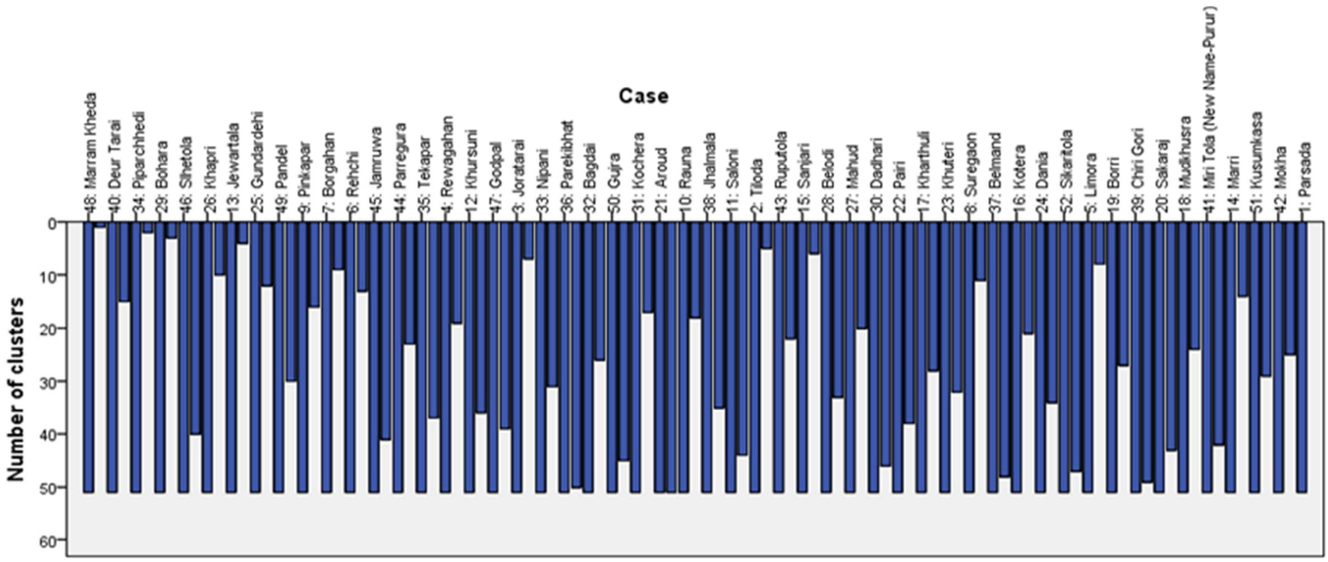

Fig.11. Icicle Plots of the cluster for Outdoor gamma dose rate in summer and winter season

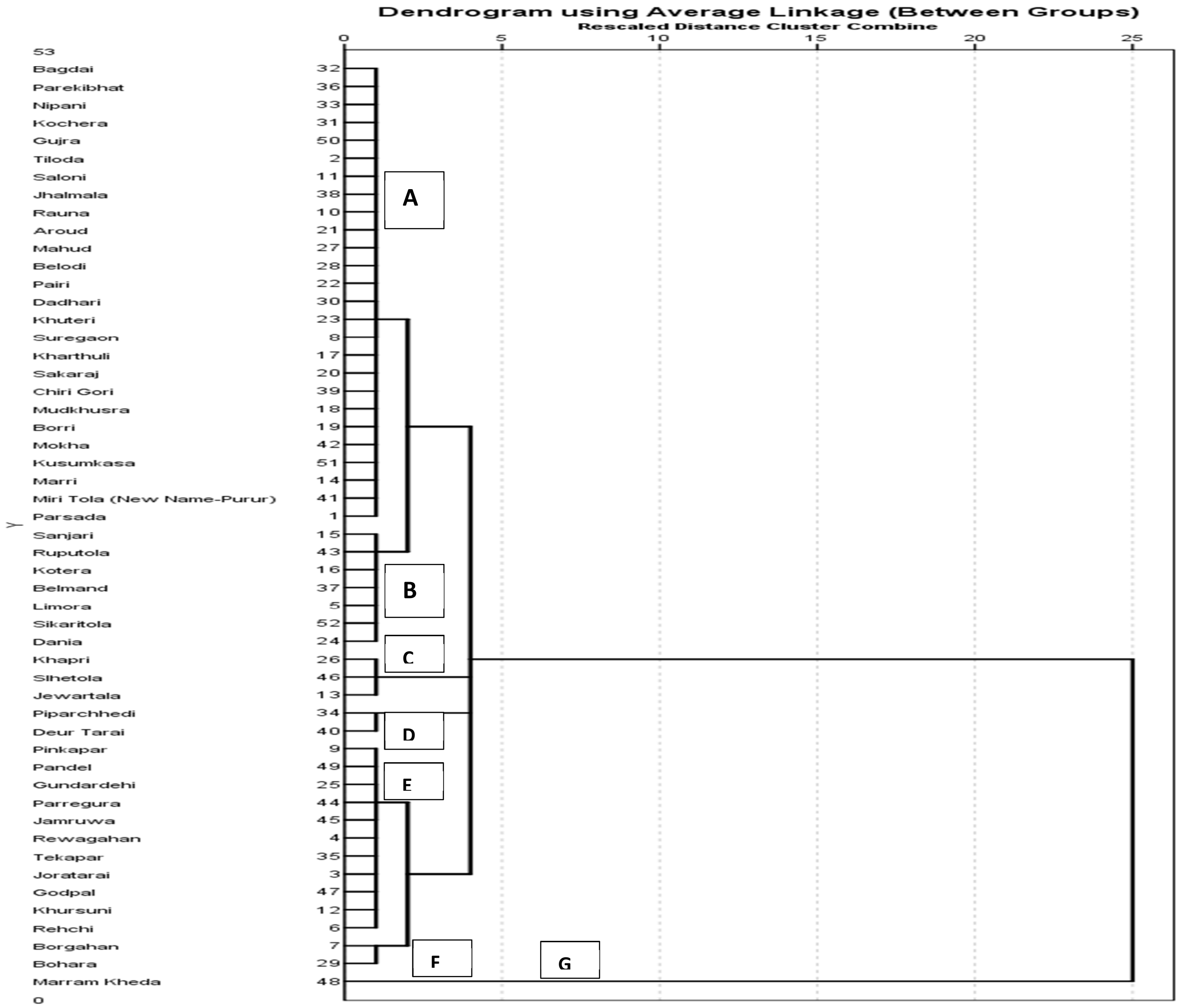

Fig.12. Dendrogram cluster formation between Outdoor gamma dose rate in summer and winter season.

was varied in the range from 0.69 to 1.61, with an average arithmetical value of 1.06. The average arithmetic value of the outdoor ratio between summer and winter is almost equal to 1, which indicates that the season has no impact on the outdoor gamma dose rate for the study region.

Overall statistical data of altitude and meteorological parameters (temperature, relative humidity, pressure and wind speed) in summer and winter season for study area is given in Table 7.

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