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Variation of Terrestrial Gamma Radiation with Season in the valley region of Manipur, India

H. Subhaschandra Singh[1], A. Ronibala Devi[2], N. Phulen Singh[3], B. Arunkumar Sharma[2], Th. Basanta Singh[1] and N. Bhumeshwar Singh[1]

[1]Department of Physics, Manipur International University, Ghari-795140, Manipur, India
[2]Department of Radiation Oncology, RIMS, Imphal-795004, Manipur, India
[3]Department of Physics, Standard College, Kongba, Imphal-795005, Manipur, India

Corresponding Author: B Arunkumar Sharma[2], e-mail: arunsb2000@yahoo.co.uk

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ABSTRACT

Natural gamma radiation from radioactive contamination is an important environmental part that may have an effect on ecosystems and human health. Natural gamma radiation exists at low levels everywhere and is usually regarded as safe; higher amounts, however, can be hazardous to ecosystems and human health. The effects of natural gamma radiation depend on a number of factors, such as air conditions, geological composition, and geographic location. Therefore, knowledge of the seasonal variation of natural gamma radiation is necessary for assessing potential risks and establishing appropriate mitigation measures in tandem.

The aim of this research is to evaluate the effective dose rates resulting from terrestrial gamma radiation in specific areas and examine the seasonal variations in dose rates employing statistical methods. The research area comprises two valley districts of Manipur, namely Imphal east and Thoubal districts, respectively. It is noted that throughout all seasons, the effective dose rates of the areas under study follow a normal distribution for all seasons. The effective dosage rate exhibits seasonal variation, with the highest values recorded in the summer (May and June), winter (December–January) and rainy season (July–September). The maximum and lowest recorded gamma dose rates of Imphal east district are 0.86 ± 0.07 mSv/y during the summer and 0.78 ± 0.06 mSv/y during the rainy season. On the other hand, maximum and minimum dose rates of Thoubal are observed in the summer season (0.82± 0.11 mSv/y) and in the rainy season (0.74± 0.09 mSv/y), respectively. The terrestrial gamma radiation dose rate relationship between the two districts is poor, according to an inter district assessment of effective dose rates during a similar season.

Key words: effective dose rate, normal distribution, seasonal variation, Imphal east, Thoubal

Introduction:

The evaluation of the gamma radiation dose from naturally occurring radioactive sources, primarily ^{238}U and ^{234}Th and associated decay series, as well as ^{40}K, is particularly significant because natural radiation is the principal source of the world population's external gamma exposure [1-2]. To determine the radioactive background level in soils, a number of radiological evaluations have been carried out [3–8]. Since beta and alpha radiation are not particularly intrusive, only gamma radiation is important for any real-world field application. The mineralogy and geochemistry of the bedrock play a major role in determining environmental radioactivity and the corresponding external exposure caused by natural gamma radiation [9–11]. However, the distribution and emission of radionuclides from the original bedrock source are influenced by weathering and soil-forming processes [12]. Therefore, mechanisms of formation and transport that have existed since the beginning of soil determine the level of radioactivity in soil. Moreover, it is suggested that the concentration of radionuclides and gamma ray attenuation are significantly influenced by the kind and thickness of the soil cover, porosity, bulk density, humidity, and temperature [13–16]. Low radioactivity in December was associated with moist soil, whereas high radioactivity in July was associated with dry soil, according to reports [17]. Although there were some outliers, a different investigation also found that, on average, gamma radiation exposure rate values increased somewhat in warmer seasons and decreased in colder ones [18]. The differences were typically not statistically significant, although they were related to precipitation and varying soil water content in these instances. It was also proposed that environmental elements like temperature and rainfall patterns, in addition to the type of soil and its intended use, have an impact on soil radioactivity. Natural gamma-ray emission at the ground surface may be shown to vary with soil moisture and temperature in accordance with the unique variations in radionuclides [19–20]. In order to learn more about the natural gamma radiation of habitation locations, assess any potential risks to human health, and establish any necessary precautions, it is crucial to investigate seasonal fluctuations in gamma radiation exposure.

In north-eastern India, the state of Manipur has five distinct seasons: summer (May to June), rainy (July to September), autumn (October to November), winter (December to February), and spring (March to April) [21].

The two valley districts of Manipur namely Thoubal and Imphal east constitute the current study area. With an area of 497 square kilometers, Imphal east District is situated in the central part of Manipur, within the coordinates 24° 48′ 0′ N, 93° 57′ 0′ E. Meanwhile, Thoubal District, covering 324 square kilometers, is located in the southern region of the state, within the coordinates 24° 39′ 0′ N, 93° 59′ 0′ E. Fifty sites were selected from each of the two districts, totaling one hundred, in order to evaluate the seasonal variations in naturally occurring gamma radiation exposure rates. The study locations for each district are dispersed over an approximate aerial distance of 6 to 7 km, which indicates that relative variations in radioactivity are limited within a narrow range [22].

In this work, seasonal fluctuations in gamma doses were investigated using statistical methods. Mean and variance are the two most important parameters to consider when describing a random variable. The relationship of variance between two seasonal data sets is evaluated using the correlation coefficient (r) and coefficient of variation (υ). Analysis of Variance (ANOVA), a one-way classification technique, is used to assess if the means of two seasonal data sets are equal. The significant level of relationship between two seasonal data is checked at the 5% level of probability. The above statistical tests are standard tests for determining the strength of the relationship between two random variables [23–24].

Materials and Methods:

2.1 Measurement of Gamma radiation dose rate (Survey meter):

A micro-Roentgen survey meter (SM) based on the NaI(Tl) scintillator manufactured by Nucleonix Systems Pvt. Ltd. in Hyderabad, India, was used for real-time measurements. The sensitivity of the survey meter is 1 μR/hr. The gamma dose rate at the specific site was determined by maintaining a height of approximately one meter above the ground. The gamma dose rate for a certain area is determined by averaging the five consecutive measurements that were acquired from each station. The time frame for taking all of the measurements was March 2023–February 2024.

2.2 Statistical Analysis

2.2.1 χ^2 – test of normality: One of the most popular methods for assessing the qualitative significance of an experimental result's departure from theory is the χ^2 – test of normality. χ^2 –test for the goodness of normality is given by

$$\chi^2=\sum_{i=1}^{k}\{O(I_i)' - I_i'\}^2/I_i' \qquad - \quad - \quad - \qquad (1)$$

where k is the effective number of classes, $O(I_i)'$ is the observed frequency, and I_i' is the expected frequency distribution.

A 5% level of probability is typically used as the critical limit for the acceptability of the hypothesis if the random variable has a normal distribution. If not, the value of χ^2 is significant at least up to the minimum probability level of 1%, which is the lowest critical limit typically assigned to the χ^2 distribution for acceptability of the hypothesis [23–24]. If the hypothesis of normality of frequency distribution is accepted, then the variable is sufficiently random, and theoretical fitting to the experimental distribution of the data is the best at that level of probability. Subsequently, the mean ± standard deviation (s.d.) will contain 66.67% of the population, while the mean ± 2 s.d. will contain 95% of the population.

2.2.2 Correlation coefficient (r):

Using a scatter plot, this statistical test measures the statistical relationship between two variables. This statistical test measures the statistical association between two variables using a scatter plot. It is represented by the following equation and is based on the covariance method:

$$r = \frac{N\sum XY-(\sum X)(\sum Y)}{\sqrt{[\{N\sum X^2-(\sum X)^2\}\{N\sum Y^2-(\sum Y)^2\}]}} \qquad - \quad - \quad - \qquad (2)$$

for relationship interpretation between two random variables, r is 0.00 to 0.30, negligible correlation, 0.30 to 0.50, a weak linear relationship, 0.50 to 0.70, moderate linear relationship, 0.70 to 0.90, strong linear relationship and 0.90 to 1.00, very strong correlation [25].

2.2.3 Coefficient of Variation (ʋ): It is a measure of relative variability and is calculated as the standard deviation divided by the mean. It is a helpful statistical technique for assessing the way various data series vary from one another. It is given by:

$$\upsilon = 100(\acute{s}/\bar{x}), \text{ where } \acute{s}^2 = \{1/(n-1)\}\ \Sigma f_i(x_i-\bar{x})^2 \qquad - \quad - \quad - \qquad (3)$$

shows variation in variances ($\acute{s}^2$) with season

2.2.4 ANOVA: The analysis of variance (ANOVA) of a one-way classification is employed to test for equality of means when "season" is assumed to be a study parameter. To assess the acceptability of the hypothesis that the means are equal, the resulting ANOVA, or Fisher (F), is compared with table values at the 5% probability level.

Results and Discussion:

One hundred sites are selected; fifty in each of the two districts, and Tables 1(a) and 1(b) show the effective gamma dose rates. The histogram of effective dose rate distribution for the study area aligns with a normal distribution, as indicated by acceptable χ^2 values at the 5% probability level similar with earlier report of Devi *et al* [26]. The mean ± s.d. and coefficient of variation (ʋ) for five different seasons are given in Table 2. The most likely value of the effective dose rate for Imphal east district is 0.81 ± 0.03 mSv/y, i.e., about 66.67 % of the effective dose will be in the range of 0.84 to 0.78 mSv/y, and for Thoubal district, it is 0.78 ± 0.03 mSv/y, i.e., about 66.67 % of the effective dose will be in the range of 0.81 to 0.75 mSv/y, respectively. The effective dose rate of the Imphal east region is in agreement with the earlier reported value of 0.86 ± 0.12 mSv/y (Imphal east) by Sharma *et al.* [6], with average radioactive contaminants in the soil as ^{226}Ra: 92 Bq/kg, ^{232}Th: 129 Bq/kg, and ^{40}K: 1195 Bq/kg, and for the Thoubal region, with a value of 0.61 ± 0.15 mSv/y by Singh *et al.* [5], with average radioactive contaminants in the soil as ^{226}Ra: 72 Bq/kg, ^{232}Th: 70 Bq/kg, and ^{40}K: 1089 Bq/kg. The coefficient of variation of Imphal east district ranges from 7.19 – 8.93 whereas for Thoubal it ranges from 12.32 – 13.20 respectively.

Seasonal variation of the annual effective dose in Imphal East as well as Thoubal Districts is shown in Figure 1. Annual effective dose of Imphal east is found to be maximum in summer season with a value of 0.86 ± 0.07 mSv/y, followed by spring season: 82 ± 0.07 mSv/y, autumn season: 0.81 ± 0.07 mSv/y, winter season: 0.79 ± 0.07 mSv/y, and least with rainy season: 0.78 ± 0.06 mSv/y. Whereas, the maximum annual effective dose of Thoubal is observed in the summer season, with a value of 0.82 ± 0.11 mSv/y, followed by the spring season (0.80 ± 0.11 mSv/y), the winter season (0.77 ± 0.10 mSv/y), the autumn season (0.76 ± 0.10 mSv/y), and the rainy season (0.74 ± 0.09 mSv/y).

The coefficient of variation ratio (υ_i/υ_j), correlation coefficient (r) as well as ANOVA analysis of different seasons of Imphal east and Thoubal Districts is shown in Table 3a and 3b. In Imphal east district, the mean effective dose rate of the summer season is significantly different from the rest of the seasons at the 5% level of probability. On the other hand, the mean value of the effective dose rate for the winter season of Thoubal is not significantly different at the 5% level of probability except for the summer season.

The coefficient of variation ratio of Imphal east ranges from 1 to 1.2 (i.e., the variation of one seasonal data is either equal to 1 or not more than 1.2 times that of the other one) whereas, for Thoubal it ranges from 1.0 to 1.1.

In Imphal east district, the correlation between summer and the rainy season is weak, whereas with autumn, winter, and spring, it is strong (r, range: 0.81 to 0.86). The correlation between the rainy season and the rest of the seasons is weak (r, range: 0.26 to 0.35), and the means are also significantly different at the 5% level of probability except for the winter season. The relationship between the autumn, winter, and spring seasons is very strong (r = 0.93), and the means are not significantly different at the 5% level of probability. In case of Thoubal, correlation of winter with any other season is moderate (r, range: 0.44 to 0.49). The relationship between rainy and autumn seasons is very strong (r = 0.95), and the means are not significantly different at the 5% level of probability. The statistical behaviour of either rainy or autumn with any other remaining seasons shows an almost similar response. The relationship between winter and rainy or autumn is moderately weak (r = 0.49), but the means are not significantly different. The summer season is showing a very strong relationship with the rainy or autumn seasons (r, 0.90 and 0.95), but the means are significantly different. Spring has a very strong relationship with summer, rainy, and autumn (r, range: 0.97 to 0.98) as well as means are not significantly different except autumn season.

The above seasonal effect may be broadly grouped into three categories based on their statistical behaviour: pre-monsoon (summer and spring seasons), monsoon (rainy and autumn seasons), and post monsoon (winter season). This finding is in agreement with the earlier report on the variation of gamma absorbed dose rates between pre-monsoon and post monsoon by Sharma *et al.* [27] and pre-monsoon, monsoon and post-monsoon by Devi *et al.* [26].

The statistics for inter-seasonal variation of the annual effective dose in two districts for five different seasons are given in Table 3c. Effective dose rates for the same season in the two districts show no correlation (r, range: -0.22 to 0.11) with higher value of coefficient of variation ratio (r, ranges from 1.4 – 1.7). However, the mean values of effective dose rates for the same season are not significantly different from each other at the 5% level of probability except for the autumn season. It indicates that the relationship between terrestrial gamma radiation dose rates between the two districts is poor.

Conclusion:

According to the current investigation, the effective dose rates in a given area are distributed normally. Seasonal variation of the effective dose rate is observed in two valley districts of Manipur, especially in summer (May and June), winter (December –January) and rainy (July–September). The maximum and minimum dose rates for Imphal east District are observed in the summer season (0.86 ± 0.07 mSv/y) and in the rainy season (0.78 ± 0.06 mSv/y). Similarly, for Thoubal district, maximum and minimum dose rates are observed in the summer season (0.82 ± 0.11 mSv/y) and in the rainy season (0.74 ± 0.09 mSv/y), respectively. An inter-district assessment of the effective dose rate for the same season found that there is little correlation between the two districts' levels of terrestrial gamma radiation.

Seasonal variation of terrestrial gamma radiation is observed to be very small, even though statistically significant among pre-monsoon, monsoon, and post-monsoon. Such a study in this region of Manipur is important, as earlier measurements were not carried out.

Seasonal variation plays a significant role in shaping the impact of natural gamma radiation levels on human health and the environment. Continuous monitoring and integrated modelling approaches are crucial for predicting seasonal variations. Understanding the complex interactions between environmental factors and radiation dynamics is essential for assessing risks and implementing effective mitigation strategies.

This seasonal study of natural radiation in this region of Manipur will provide baseline radiological data. This data will be useful for the radiological safety concerns of the people inhabiting in this valley region.

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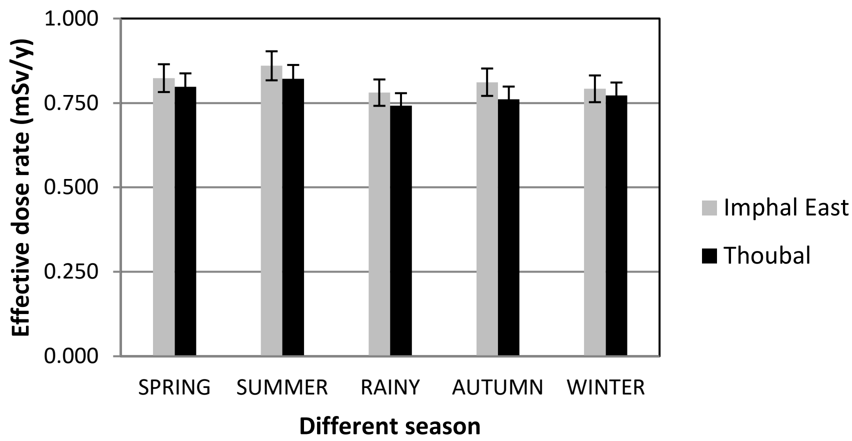

Figure 1: Inter-district seasonal variation of terrestrial gamma Effective dose rates (Imphal east and Thoubal districts)

Table1(a): Imphal east District, seasonal effective dose rate (mSv/y)

Sl. No.	Site name	Summer	Rainy	Autumn	Winter	Spring
1	Tiger Camp	1.03	0.75	0.97	0.95	0.99
2	Monkol	0.95	0.73	0.92	0.88	0.92
3	Khongjil Khongjal	0.87	0.81	0.77	0.79	0.81
4	Makeng	0.88	0.75	0.83	0.85	0.86
5	Pukhao	0.87	0.66	0.76	0.72	0.76
6	Chingkhu	0.86	0.78	0.77	0.78	0.78
7	Khongbal Tangkhul	0.87	0.75	0.84	0.75	0.84
8	Laikol Awang	0.96	0.84	0.90	0.84	0.92
9	Sangolmang	0.84	0.83	0.81	0.83	0.83
10	Nongpok Kakching	0.87	0.81	0.81	0.81	0.81
11	Kameng	0.74	0.74	0.76	0.77	0.77
12	Khongjil Khongjal Makha	0.80	0.79	0.79	0.76	0.79
13	Matakhong	0.91	0.77	0.96	0.94	0.97
14	Nurathel Makha	0.79	0.79	0.77	0.79	0.79
15	Iyampal	0.79	0.71	0.71	0.68	0.71
16	Nurathel	0.77	0.85	0.75	0.75	0.77
17	Gourgobind Girl's College	0.79	0.73	0.71	0.71	0.73
18	Yumnam Khounou	0.87	0.89	0.81	0.81	0.89
19	Laikot Mamang	0.73	0.73	0.71	0.70	0.73
20	Makeng Chongou	0.93	0.88	0.86	0.84	0.88
21	Khongnang Makhong	0.93	0.70	0.91	0.89	0.91
22	Keirao-Langdum	0.73	0.73	0.72	0.70	0.73
23	Keibi	0.88	0.83	0.81	0.83	0.83
24	Taorem	0.93	0.88	0.88	0.84	0.88
25	Lamlai	0.87	0.65	0.84	0.80	0.86
26	Purum Likli	0.86	0.77	0.76	0.73	0.77
27	Sadukoireng	0.81	0.72	0.73	0.69	0.72
28	Leitanpokpi	0.83	0.76	0.77	0.73	0.77
29	Pukhao Khbam	0.75	0.75	0.73	0.74	0.75
30	Keibi Kumuda	1.00	0.71	0.94	0.93	0.96
31	Pangei Makha	0.93	0.87	0.90	0.87	0.89
32	Chonthaba	0.82	0.76	0.74	0.75	0.76
33	Chingmeirong	0.78	0.78	0.78	0.73	0.78
34	Maphau Dam	0.86	0.82	0.81	0.79	0.82
35	Waiton	0.82	0.83	0.83	0.80	0.83
36	Soibam Leikai	0.95	0.81	0.91	0.90	0.93
37	Khomidok	0.77	0.77	0.77	0.74	0.77
38	Meitei Langol	0.81	0.75	0.72	0.73	0.75
39	Kairang Muslim	0.78	0.78	0.78	0.74	0.78
40	Andro High School	0.82	0.77	0.73	0.74	0.77
41	Salangthong	0.80	0.72	0.71	0.72	0.72
42	Pangei Awang	0.89	0.81	0.81	0.73	0.81
43	Khundrakpam	0.88	0.80	0.80	0.76	0.80
44	Heikak	0.86	0.86	0.84	0.84	0.86
45	Yungnubi	0.91	0.81	0.88	0.83	0.88
46	Moirang purel	0.89	0.81	0.87	0.81	0.89
47	Isika	0.92	0.86	0.86	0.83	0.86
48	Kamu Yaithibi Mayai	0.91	0.76	0.90	0.85	0.91
49	Topchingtha Maning	0.98	0.85	0.90	0.89	0.93
50	Monthou	0.86	0.71	0.72	0.70	0.71
Mean =		**0.86**	**0.78**	**0.81**	**0.79**	**0.82**
s.d.=		0.07	0.06	0.07	0.07	0.07

Table 1(b): Thoubal district, seasonal effective dose rate (mSv/y)

Sl. No.	Site name	Summer	Rainy	Autumn	Winter	Spring
1	Phanjangkhong	0.89	0.82	0.88	0.68	0.87
2	Salungpham Mayai Leikai	0.85	0.77	0.78	0.73	0.81
3	Bumpakhullen	0.88	0.80	0.80	0.59	0.81
4	Wangbal	0.94	0.84	0.87	0.88	0.88
5	Yelang Khangpok	1.06	0.95	0.98	1.01	1.02
6	Universal College, Yairipok	0.72	0.65	0.65	0.70	0.68
7	Khongjom	1.00	0.85	0.91	0.73	0.98
8	Khekman	0.89	0.75	0.82	0.82	0.86
9	Ingourok	0.91	0.80	0.84	0.89	0.88
10	Chingdompok	0.87	0.76	0.81	0.87	0.85
11	Langmeidong	0.91	0.82	0.88	0.72	0.90
12	Nongpok Sekmai	0.82	0.73	0.77	0.82	0.79
13	Thoubal College, Thoubal	0.84	0.85	0.87	0.92	0.89
14	Yairipok	0.71	0.63	0.66	0.72	0.69
15	Shikhong Bazar	0.71	0.62	0.64	0.69	0.67
16	Yairipok Police Station	0.66	0.61	0.62	0.66	0.64
17	Sugnu	1.02	0.89	0.87	0.75	1.00
18	Toupokpi	0.89	0.84	0.82	0.90	0.88
19	Wangu Lamkhai	0.91	0.85	0.85	0.86	0.88
20	Loushipat	0.88	0.76	0.79	0.89	0.86
21	Sora	0.86	0.75	0.82	0.87	0.85
22	Chairrel	1.07	0.97	0.93	0.84	1.05
23	Pol-Star College, Wabgai	0.97	0.88	0.91	0.86	0.96
24	Heirok	0.86	0.74	0.81	0.84	0.82
25	Tentha	0.81	0.75	0.74	0.81	0.78
26	Thoubal Nongangkhong	0.80	0.75	0.75	0.81	0.78
27	J.N.V. Kakching	0.87	0.76	0.83	0.73	0.86
28	Kakching Lamkhai	0.89	0.83	0.81	0.84	0.87
29	Thoubal Melagound	0.81	0.73	0.78	0.81	0.79
30	Y.K. College, Wangjing	0.80	0.76	0.74	0.81	0.79
31	Keikman Makha Leikai	0.70	0.67	0.69	0.70	0.70
32	Irong Chesaba	0.59	0.56	0.59	0.61	0.59
33	Athokpam	0.58	0.55	0.57	0.90	0.58
34	Leisangthem	0.79	0.73	0.73	0.79	0.77
35	Maibam Konjil	0.76	0.69	0.66	0.69	0.71
36	Lamlong	0.76	0.68	0.67	0.73	0.71
37	Iramsiphai	0.66	0.64	0.63	0.75	0.66
38	Phundrei	0.84	0.73	0.75	0.79	0.80
39	Heirokpat 1	0.77	0.70	0.70	0.68	0.73
40	Kha-Manipur College, Kakching	0.79	0.69	0.74	0.80	0.77
41	Wabagai Awang	0.72	0.63	0.63	0.82	0.66
42	Thoubal	0.70	0.67	0.67	0.63	0.70
43	Palen Bazar	0.75	0.70	0.73	0.67	0.74
44	Thongjao	0.76	0.66	0.70	0.63	0.72
45	Mantak	0.77	0.69	0.68	0.66	0.71
46	Wabagai Bazar	0.83	0.73	0.78	0.74	0.82
47	Laimanai	0.87	0.76	0.77	0.60	0.85
48	Kakching Makha Leikai	0.79	0.73	0.72	0.76	0.77
49	Arong Nongmaikhong	0.74	0.69	0.70	0.75	0.74
50	Thounaojam	0.81	0.70	0.69	0.77	0.78
Mean =		**0.82**	**0.74**	**0.76**	**0.77**	**0.80**
s.d.=		0.11	0.09	0.09	0.09	0.11

Table 2: Effective Dose Rate for Five Different Seasons in Imphal east and Thoubal Districts, Manipur

Imphal east & Thoubal districts of Manipur		Effective Dose Rate for five different seasons (mSv/y)					
		Spring	Summer	Rainy	Autumn	Winter	Average
Imphal east	Mean	0.82±0.07	0.86±0.07	0.78±0.06	0.81±0.07	0.79±0.07	0.81±0.03
	υ	8.79	8.25	7.19	8.93	8.75	
Thoubal	Mean	0.80±0.11	0.82±0.11	0.74±0.09	0.76±0.10	0.77±0.10	0.78±0.03
	υ	13.20	12.97	12.32	12.49	12.36	

Table 3: Statistics for five different seasons in Imphal east and Thoubal districts, Manipur

Table 3a: Imphal east district

Imphal east District	Rainy & Winter	Rainy & Autumn	Rainy & Spring	Rainy & Summer	Summer & Winter	Summer& Autumn	Summer & Spring	Autumn & Spring	Winter & Autumn	Winter & Spring
υ_i/υ_j	1.2	1.2	1.2	1.2	1.1	1.0	1.1	1.0	1.0	1.0
r	0.35	0.30	0.33	0.26	0.81	0.86	0.85	0.95	0.93	0.95
ANOVA	0.81*	5.68	8.77	38.66	23.65	11.50	8.34	0.26*	1.91*	3.62*

Table 3b: Thoubal district

Thoubal District	Winter &Spring	Winter &Summer	Winter& Rainy	Winter & Autumn	Rainy& Autumn	Spring & Rainy	Spring &Autumn	Summer& Rainy	Summer & Autumn	Spring & Summer
υ_i/υ_j	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0
r	0.48	0.44	0.48	0.49	0.95	0.97	0.97	0.90	0.95	0.98
ANOVA	1.65*	5.98	2.61*	0.37*	1.00*	8.08	3.48*	16.13	9.14	1.25*

Table 3c: Imphal east and Thoubal districts

Thoubal/ Imphal East(')	Spring/Spring'	Summer/Summer'	Rainy/Rainy'	Autumn/Autumn'	Winter/Winter'
υ_i/υ_j	1.5	1.6	1.7	1.4	1.5
r	0.09	0.06	-0.22	0.11	0.04
ANOVA	1.36*	4.56*	6.57**	9.15	1.43*