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Spatiotemporal variability in shifting wetness pattern in Mizoram

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सार – वर्षा प्रतिरूपों में स्थानिक-कालिक परिवर्ततिता ने मिज़ोरम राज्य की पर्वतीय स्थलाकृति में आर्द्रता परिवर्ततिता को समझने हेतु एक महत्वपूर्ण आधार प्रदान किया है। वर्षा की तुलना स्टैंडर्डाइज़्ड प्रेसिपिटेशन इंडेक्स (SPI) नॉर्मल डिस्ट्रीब्यूशन के बाद क्षेत्रीय नमी में बदलाव की स्टडी के लिए सबसे असरदार और बड़े पैमाने पर अपनाया जाने वाला इंडिकेटर हो सकता है।मिजोरम के उत्तर-पूर्वी भारतीय राज्य में समय-समय पर होने वाले बदलाव (8-64 महीने) और नमी के पैटर्न में अचानक बदलाव (1990 के दशक के आखिर में) में काफी स्थानिक बदलाव देखा गया। आखिर में, हमने मिजोरम के लुसेई पहाड़ी इलाके में गायब डेटा इंटरपोलेशन स्टडी और सही नमी ज़ोनिंग के ज़रिए असरदार पॉलिसी प्लानिंग में उनके असरदार इस्तेमाल के लिए हायरार्किकल क्लस्टरिंग और प्रिंसिपल कंपोनेंट एनालिसिस (PCA) तकनीक के आधार पर रेन गेज स्टेशनों को क्लासिफ़ाई किया।

ABSTRACT. The spatiotemporal variability in rainfall patterns unveiled the crucial juncture for understanding the wetness variability under the hilly topography of the North East Indian state of Mizoram. Unlike rainfall, the Standardized Precipitation Index (SPI) may be the most effective and widely adapted indicator for regional wetness variability studies following a normal distribution. Significant spatial variability was observed in periodicity (8-64 months) and an abrupt shift in wetness pattern (late 1990s) across the North East Indian state of Mizoram. Finally, we classified the rain gauge stations based on hierarchical clustering and principal component analysis (PCA) technique for their effective use in missing data interpolation studies and effective policy planning through rational wetness zoning across the Lusei hill region of Mizoram.

Key words – Standardized precipitation index, Change point analysis, Clustering, Principal component analysis, Mizoram

1. Introduction

The agricultural production systems in North East Indian states bear the highest sensitivity toward the projected climate change driven by a projected increase in erratic regional rainfall events (Mall *et al*., 2006; Das *et al*., 2009). Simulation studies projected a 0.3% to 3% increase in mean annual rainfall by 2030s over the 1970s across different North East Indian states, along with the projected increase in average daily rainfall intensity by 1–

6 mm day-1 (INCCA, 2010). Mizoram is one of the vast climatologically diverse sister-lands, having a 2108700 ha geographical area with 75.18% forest cover under the rolling undulated topography of Lusei hills in NE India. The state receives >250 cm average annual rainfall with low intra-annual variability. Despite heavy rainfall events from April to September, the state experienced a drought-like situation during non-rainy winter months of insufficient moisture availability for the agricultural crops (rabi season), hydropower generation and daily household water use. Moreover, the rapid urbanization, replacement of natural vegetation by croplands under the fragile agro-ecosystem of rainfed shifting cultivation practices followed by permanent long-term land use changes (orchard establishment) resulted in the associated present rise in air temperature that invades the future possibility of more erratic rainfall occurrence in different North Eastern Indian states including Mizoram (Ramankutty *et al*. 2006; Deka *et al*. 2009; Saha *et al*. 2016).

The inceptive reporting on climate change in NE India verified the contrasting rainfall trend between two subdivisions of the lower Brahmaputra basin over the distant past (Mirza *et al*., 1998). The overall decrease in summer monsoon rainfall was evident over the South Assam Meteorological Subdivision (Das *et al*., 2009), with a non-significant increasing trend in annual rainfall and a reduced number of rainy days over the Barak Valley region (both include the state boundary of Mizoram). In contrast, Saikia *et al*. (2013) reported a significant reduction in annual rainfall (7.7%) with an increased number of rainy days (9%) over different districts of Mizoram. A gradual shift from humid to per-humid was also observed over Mizoram (Raju *et al*., 2013). Later on, Jain *et al*. (2013) reported the past tendency for enhanced monsoon precipitation without any significant change in annual rainfall over NMMT (Nagaland, Manipur, Mizoram, and Tripura ~ 70,495 sq. km) hydro-meteorological subdivision. The contrasting increasing and declining annual wetness trend between northern and southern Mizoram was evident (Saha *et al*., 2015). Variable topography and diverse catenary sequence engulfed the considerable variability in the monthly, seasonal, and annual rainfall-driven short-term and long-term wetness trends in the NE Indian states of Mizoram (Jhajharia *et al*., 2011; Jain *et al*., 2013; Saha *et al*., 2015). For agricultural activity, seasonal reliability is more important than annual reliability (Das *et al*., 2009). Therefore, comprehensive outlook on-site specific regional wetness variability analysis (seasonal and annual) are emphasized as the prime requirement for optimizing water resource management plans for attending regional water security and suitable crop planning in undulating hilly terrain under shifting cultivation, adaptation of successful precision farming techniques in the scattered low-lying areas, ecosystem functioning and livelihood security development through secondary agriculture in Mizoram (Mall *et al*., 2006). We assessed the spatial and temporal variations of shifting wetness pattern and periodicity of wetness time series. To account for existing variablity, raingauge stations were grouped based on relative performance similarity using hierarchical clustering and principal component analysis (PCA) across the Lusei hill regions of Mizoram.

2. Data and methodology

Location, data availability and analysis of rainfall time series: The recorded rainfall dataset from twelve rain gauge stations were collected from the Department of Agriculture, Govt. of Mizoram (1986-2019; Fig. 1a). The variability in average annual rainfall ranged between 2122.2 mm (Champhai) to 3593.3 mm (Neihbawih). The rainfall data gap was replaced by the monthly average for Lunglei (2008–2010), Lawngthlai (2010–2011) and Tlabung (2009-10). The rainfall dataset was free from any first-order autocorrelation. The outliers were replaced with arithmetic mean values for season-wise analysis winter (January–February), pre-monsoon (March-May), monsoon (June–September), and post-monsoon (October–December).

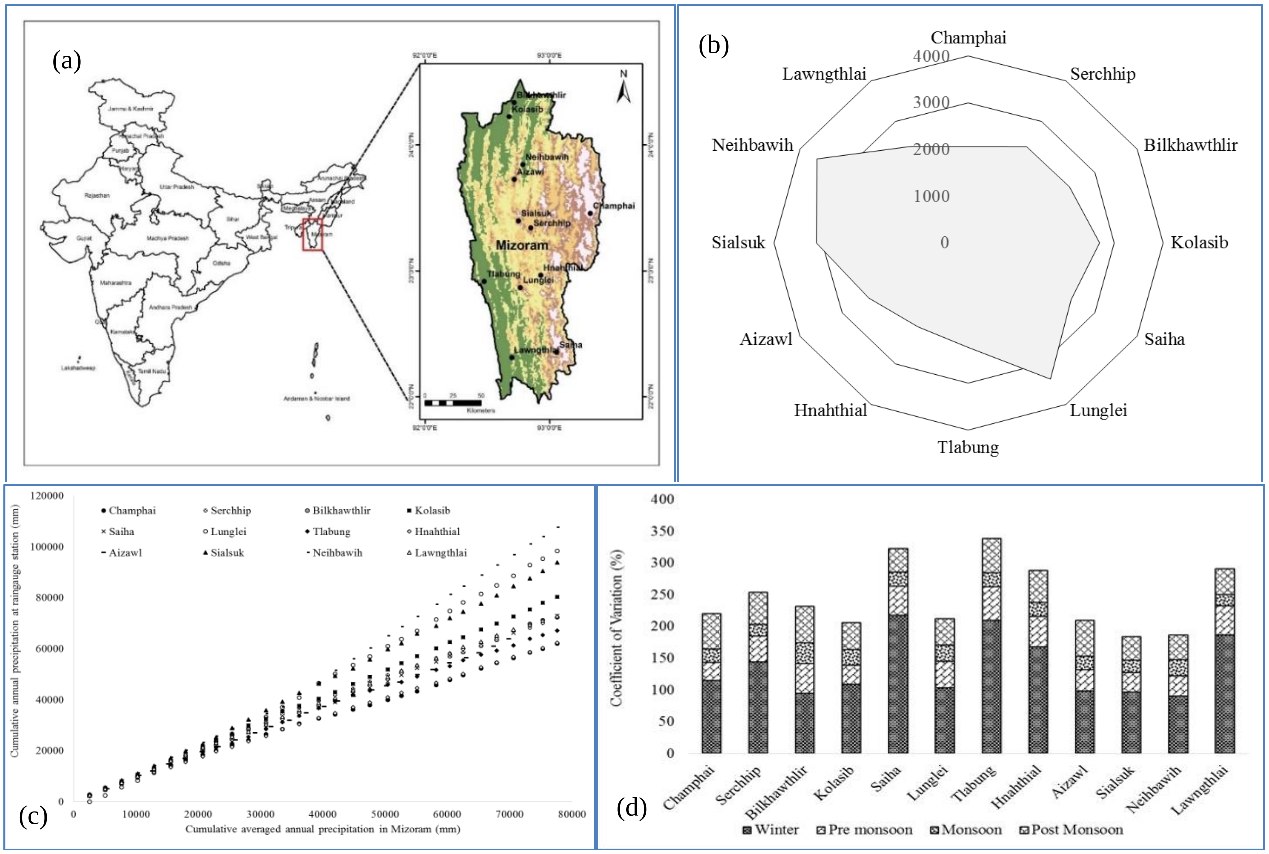
Standardized Precipitation Index (SPI) calculation: Location-specific SPI series is defined as the corresponding probability of occurrence for the difference between precipitation value (xi) and arithmetic mean(μ), divided by standard deviation (δ) over various time scales viz. one month (1-SPI), two months (2-SPI), three months (3-SPI), four months(4-SPI), six months (6-SPI), 12 months (12-SPI) and 24 months (24-SPI) (Saha et al., 2015).

$$\text{SPI} = \frac{xi - \mu}{\delta} \qquad (1)$$

Positive values indicate excess rainfall; negative values indicate a moisture deficit condition. If SPI < -0.99 indicates an extremely dry event,> +0.99 indicates an extremely wet event.

Change-point (CP) detection analysis: We adapted Pettit's test (P), the Standard normal heterogeneity test (SNHT), Buish and test (B), and von Neumann's test (V) to identify the shift period calculated SPI based on wetness time series. This was further verified using two comparative evaluation tests: parametric t and non-parametric Mann–Whitney (M-W) test.

Periodicity assessment using wavelet analysis: The periodicity of short (1-SPI and 2-SPI), mid (3-SPI and 6–SPI), and long-term (12-SPI) wetness time series for all



Figs. 1(a-d). (a) Location details stations (b) annual rainfall in mm (c) double mass curve (d) coefficient of variation in seasonal rainfall for the selected rain gauge stations at Mizoram

the locations were analysed for their respective robust wavelet components (with Morlet wavelet basis function) at a 5% significance level using R software (version 3.5). We discarded any identified variations within five years from the initiation and termination point of each SPI time series.

Hierarchical clustering and Principal Component Analysis: Hierarchical clustering algorithm was adapted to derive the functional relationship assessment among SPI time series using Ward's minimum variance method (Euclidean distance; Saha *et al*., 2018). The re-affirmation of variability in the generated homogeneous sub-clusters was verified using Principal Component Analysis and supportive correlation studies using varimax rotation with the Kaiser Normalization method for the combined SPI dataset.

3. Results and discussion

The average annual rainfall varies from Champhai (2067 mm) to Neihbawih (3593.3 mm) across the Mizoram state (Fig. 1b). Subsequently, the coefficient of variation (%) of the annual rainfall time series ranged between 12.3 (Kolasib) to 23.8 (Lunglei). The coefficient of variation in seasonal rainfall was higher during the winter months and, at minimum, during the monsoon season (Fig. 1c). To maintain the consistency of the rainfall time series (1986-2020), we replaced the missing values with a long-term average. The consistency of the annual rainfall time series was examined using a double mass curve, *i.e*., the cumulative plot of annual precipitation for each station versus the cumulative average annual precipitation of individual rain gauge stations in Mizoram (Fig. 1d). We observed considerable consistency for the deviating rainfall time series of Sialsuk, Neihbawih, and Lunglei, with directional breaks.

The scatter plot between 1- SPI and monthly rainfall deficit (%) for all rain-gauge stations were combined, characterizing the relationship between monthly rainfall deficit (%) and 1-SPI time series. The slope (m) of the best-fitted linear curve varied between 0.29 (minimum during August) -4.69 (maximum during December) having statistically significant R^2 values ($p<0.01$; Supplementary Fig. 1). We characterized the slope in terms of slope angle (degree unit; q = tan -1m). The comparative plot between slope angle and respective

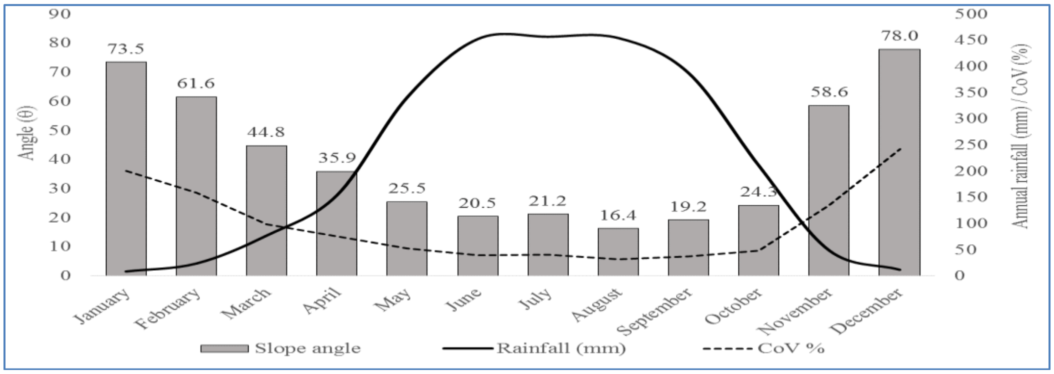
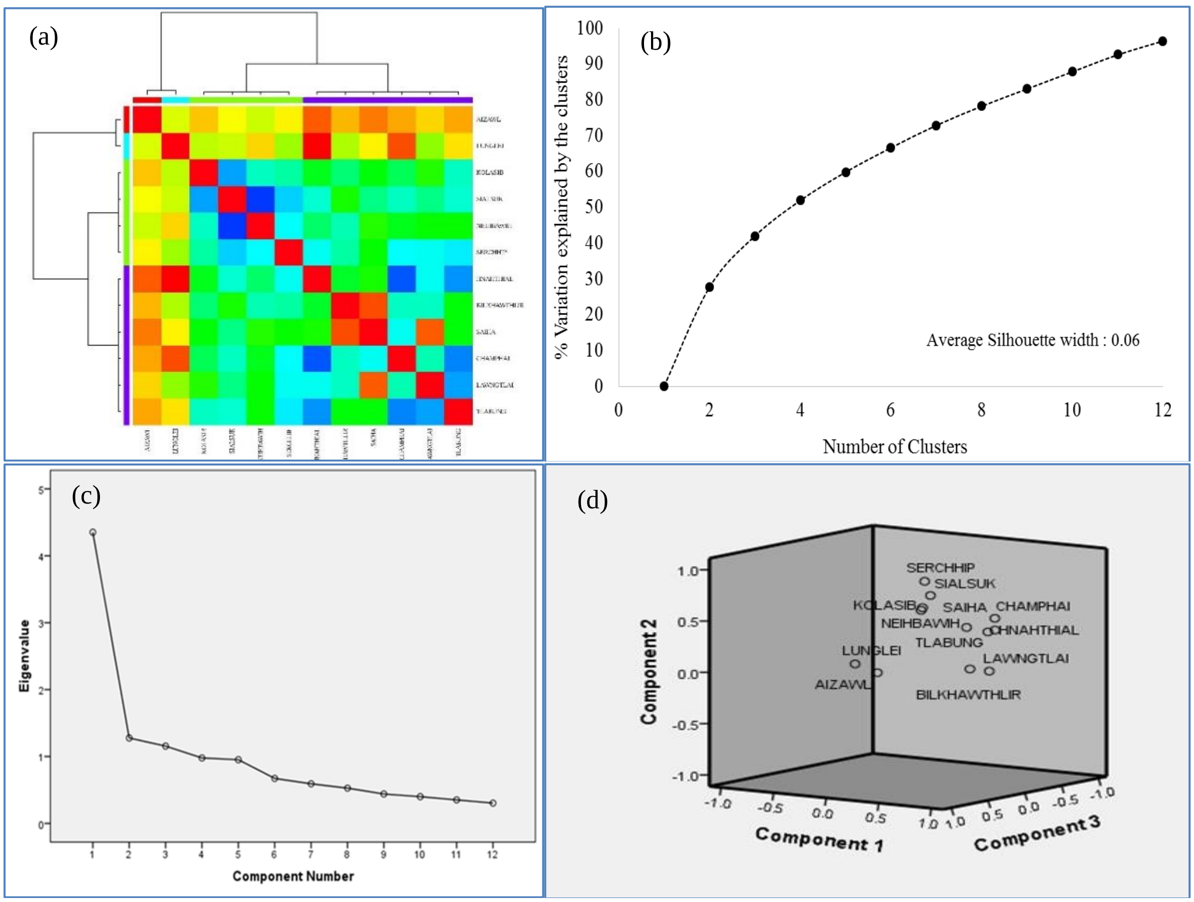


Fig. 2. Relation between slope angle (plotting 1-SPI against rainfall deficit %) and monthly rainfall variability in Mizoram



Figs. 3(a-d). Hierarchical clustering derived (a) dendrogram-heat plot, (b) relative variation explanation by the number of clusters with Silhouette distance, (c) scree plot and (d) Principal Component of combined SPI-based wetness series in 3D rotated space in Mizoram

monthly average rainfall or coefficient of variation (CoV %) might be used as the defining alternative criteria for the advent of major monsoon receiving months for any location (Fig. 2). If q< 45º, CoV declined below 100 signified the advent of effective onset of rain during March (pre-monsoon shower). On the contrary, the q value continued to be lower until the effective monsoon withdrawal in October from northeast India (CoV% < 100). As rainfall ceases, the slope angles go beyond 45º during winter. Hence, northeast Indian states received substantial rainfall during the pre-monsoon season (~30% of annual rainfall; Saha *et al*., 2015) other than only monsoonal rainfall received during the Southwest monsoon as in the rest part of India (Saha *et al*., 2018). The crop season under shifting cultivation was also traditionally synchronized by the tribal communities based on these rainfall patterns, which started with pre-monsoon showers (from March to April onwards) in Mizoram.

TABLE 1

Abrupt change point detected in seasonal and annual rainfall time series at different rain gauge stations in Mizoram

Stations	Months	Pettit Test	Standard Normal Homogeneity Test	Buishand Test	Von Neuman Test	Change Point Detection Test	T-Test	Mann–Whitney test
Champhai	Annual	130^{NS}	8.38 ^{NS}	1.55* (1994)	1.27**	Buishand Test	1.98	150*
	Post-Monson	134 ^{NS}	14.72 ^{NS}	1.57* (1993)	1.29*	Buishand Test	3.10**	159**
Serchhip	Annual	174* (2004)	12.59** (2004)	1.73* (2004)	1.47*	Pettit and SNH Test	3.89**	200**
	Pre-monsoon	142 ^{NS}	7.38 ^{NS}	1.68* (2004)	1.88 ^{NS}	Buishand Test	3.34**	188**
	Post-Monsoon	154 ^{NS}	11.20** (1992)	1.56* (2002)	1.38*	Pettit and SNH Test	3.64**	130**
						Buishand Test	3.79**	197**
Kolasib	Post-Monsoon	136 ^{NS}	9.20* (2008)	1.46 ^{NS}	1.01**	SNH Test	3.53**	161**
Aizawl	Winter	130* (1998)	12.98** (1998)	1.70* (1998)	1.70 ^{NS}	Pettit and SNH Test	3.14**	130**
						Buishand Test	3.98**	146**
Sialsuk	Monsoon	174* (1994)	12.57** (1994)	1.64* (1994)	1.40*	Pettit and SNH Test	-5.70**	15**
						Buishand Test	-6.29**	12**
Neihbawih	Annual	222** (1998)	19.66** (1998)	2.29** (1998)	0.82**	Pettit and SNH Test	-7.16**	17**
						Buishand Test	-8.42**	6**
	Pre-monsoon	197* (1999)	13.26** (1999)	1.81** (1999)	1.19**	Pettit and SNH Test	-4.96**	19.5**
						Buishand Test	-4.90**	20.5**
	Monsoon	222** (1998)	15.76** (1998)	2.24** (1998)	1.12**	Pettit and SNH Test	-5.48**	18**
						Buishand Test	-6.46**	6**

*[Note: ** and * denote significant trend at p< 0.01 and p<0.05 level, respectively;* ^{NS} signifies non significant; *Values indicate Pettit's test, SNHT Test, Buishand Test and Von Neumann's test statistics; year of the change in the parentheses if the change was significant.]*

Policy planners should focus on this aspect of distinctness in periodic intra-seasonal rainfall variability in Mizoram towards a framework design of climate-resilient agriculture shortly.

The periodic shifts in SPI time series identified the past accord of significant changes in the wetness, which occurred across the studied rain gauge stations in Mizoram (Table 1). Changepoint (CP) analysis of seasonal SPI-based wetness series identified a recent higher degree of spatiotemporal variability across Mizoram. Multiple tests were adapted to identify CPs (Chakraborty *et al*., 2017). The Von Neuman test confirmed the presence of CPs but rarely identified the year of the abrupt shift. Therefore, we only accepted the CPs if the results of the two tests were comparable. The abrupt shift in annual wetness (12-SPI based) was evident in Serchhip (2004) and Neihbawh (1998). During 1998, an abrupt shift in the wetness time series (2-SPI based) was identified in Aizawl during winter and Neihbawh during the monsoon season (4-SPI based). At Sialsuk, abrupt CPs were evident in the monsoon wetness time series during 1994. The abrupt shifts often signified periodic land use change (Meena *et al*., 2015) and location-specific regional climate variability (Menon *et al*., 2013), as there was no recorded history of shifting rain gauge station locations as confirmed by the Department of Agriculture, Govt. of Mizoram.

Wavelet spectrum analysis captured a high degree of spatiotemporal variability in SPI-based time series in Mizoram (Table 2). The scattered presence of periodicity in the 1-SPI time series varied for 8-16 months of meteorological droughts at Serchhip and Neihbawih. The

TABLE 2

Wavelet power analysis for assessing periodicity for the SPI time series in Mizoram

Stations	1-SPI	2-SPI	3-SPI	4-SPI	6-SPI	12-SPI	24-SPI
Champhai	-	-	-	-	32 months up to 2005	16-32 months; 128 months	128 months
Serchhip	8-16 months till 2000	-	-	-	-	-	-
Bilkhawthlir	-	-	32 months	32 months since 2000		128 months	128 months
Kolasib	-	-	-	-	32 months up to 2005; 64 months up to 2010	64 months	64 months
Saiha	-	32 months	32 months	32 months	16-32 months	16-32 months	32-64 months
Lunglei	-	8-16 months up to 2000	-	32 months up to 2005	32-64 months	32-64 months	64 and 128 months
Tlabung	-	-	-	32 months	32 months up to 2010	32 and 64 months	64 months
Hnathial	-	32 months till 2005	32 months up to 2005	-	32 months	32 months	128 months
Aizawl	-	32 months till 2000	32 months till 2000	32 months till 2000; 16 months during 1995- 2013	-	32-64 months	32 months
Sialsuk	-	-	-	-	-	-	64 months
Neihbawih	8-16 months till 2000	8-16 months up to 2000	-	32 months	32 months	32-64 months	-
Lawngthlai	-	-	-	-	-	64 months	64 and 128 months

average periodicity of agricultural drought was 32 months, dominated by 2-SPI, 3-SPI, 4-SPI, and 6-SPI-based time series in Mizoram. However, the wetness periodicity was extended to 32-128 months for a long-term wetness time series of 12-SPI and 24 SPI-based hydrological drought events across Mizoram. The hierarchical clustering technique of all combined SPI-based time series identified prominent groups among the rain gauge stations under our present study. (Fig. 3a). The first four sub-clusters accounted for ~51.8% variability with an average silhouette width of 0.06 (Fig. 3b). Three principal components existed in the combined datasets of SPI time series with 56.52% accounted variability (Fig. 3c). However, three initial clusters accounting 41.9% variability from hierarchical clustering (Fig. 3b) resembled similarity with those three- identified PCs in three-dimensional plot (Fig. 3d). Stations within each of the clusters identified had considerable similarity over the data recording period (1986-2016). Therefore, the dataset from clustered rain gauge stations within each group may be used interchangeably for missing data interpolation in future climatological studies (Saha *et al*., 2018). The adopted methodology in our present study is suitable for further replication to identify the non-stationary changes in wetness time series from similar humid tropical high rainfall receiving regions of the Indian Sub-continent.

4. Conclusions

Our present study showed higher spatiotemporal variability in wetness pattern and periodicity across the Lusei hill region of Mizoram, northeast India. The abrupt shifts in wetness time series signified the localized impact of climate variability from increased anthropogenic disturbances in the recent past. Despite observed variability, the long term regional wetness trend remained stable over the past three decades. Effective real-time monitoring of regional wetness and supportive policy planning on climate-resilient agriculture should acknowledge the distinctness of existing variability in Mizoram.

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Supplementary

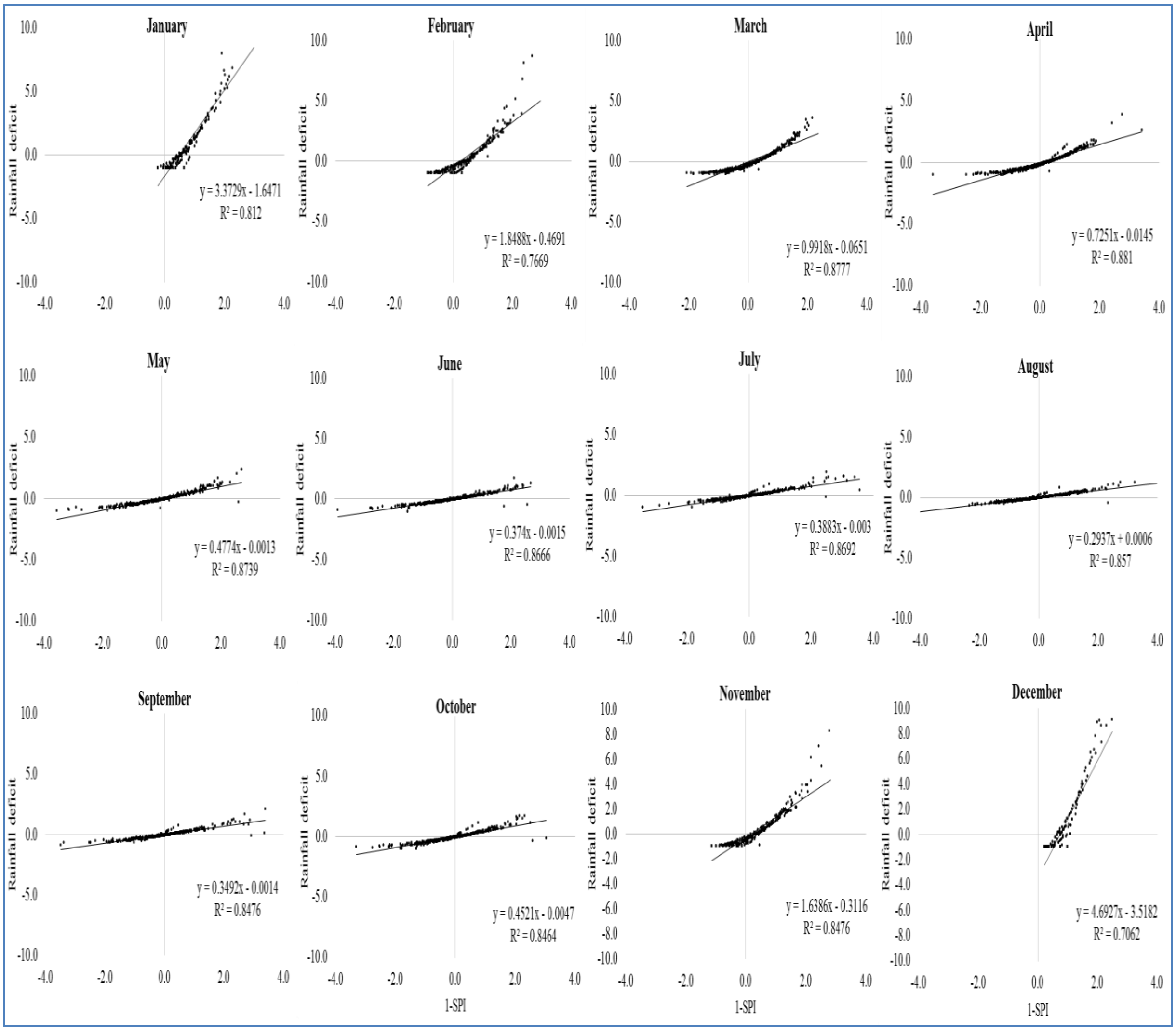

Fig. 1(Supplementary). Relative plot between I-SPI and monthly rainfall deficit (%)