PRECIPITATION CONCENTRATION INDEX AN APPLICATION FOR SRI LANKA

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1.0 Introduction

Periodic variations in mateorological and climatological elements are fundemental aspect at any location. The occurrence of precipitation has more periodic variations than other such elements. To study those sort of variations a number of climatologists have proposed research methods in terms of precipitation. For many applied climatic studies which ranging from flood to drought prediction to agricultural planning, the rainfall data is equally significant. There are many methods available to express the seasonal concentration of precipitation (rainfall). One of those method has been applied here to express the seasonal concentration or distribution of average monthly rainfall received in Sri Lanka.

2.0 Preamble

The current methods which are used to express the seasonal concentration of precipitation appear to be fall into following broad categories. Many investigators have used Harmonic analysis to express the seasonal concentration of precipitation which based on wave amplitude and phase angle relations. This approach was first applied to climatological observations by Brookes and Carruthers in 1953. For precipitation data it is well exemplified by the work of Horn and Bryson, who have published maps of the United States illustrating phase angles based upon precipitation distribution (1960). The same technique has been used by Chih-Pin and Wallace whose completed maps show by means of arrows, he normalized amplitude and phase of the annual precipitation cycle in the Northern Hemisphere (1966). "Both of these works provide results that are useful for depicting cycles (Oliver 1980). Using annual monthly rainfall from 1931 — 1960 the harmonic analysis of the annual March of rainfall over Sri Lanka has been carried out (Balachandiran 1993). However for duplicating these works requires a sophisticated knowledge of harmonic analysis which cannot be considered an easily-used measure Oliver 1980). The second category of methods is Graphical Analysis which is well employed by the work of Markham (1970). He used the ratio of vector to scalar mean. This is an approach similar to the analysis of wind consistency. The method provided both a measure of concentration and the time (month) at which it

occurred. But the method cannot be easily adapted. The third type of approach to precipitation concentration is the use of statistically derived indices. Such an index was proposed and applied for United States, Africa and Australia by Oliver (1980) by following Gibbs and Martin (1962) who developed the Index. He had shown the monthly precipitation concentration by using average monthly means of precipitation. An introductory work using PCI values for Sri Lanka rainfall has been done (Balachandiran 1993).

3.0 Methodology

The methodology first introduced by Gibbs and Martin (1962) for industrial data and later it was modified by Oliver (1980) for monthly rainfall distribution. "Gibbs and Martin developed an index to measure the diversification of employment in industry for comparative regional units. "Using the formula"

$$1 - \Sigma x^2 / (\Sigma x)^2$$

Where x is the number of employees given in industrial category, they showed that industrial diversification could be measured on a scale passing from 0 — no industrial deversification to a value approaching 1 — high diversification. As an example, table 1 shows two hypothetical communities in which the total number of workers is the same, in one, the total work force is concentrated in a single industry: in the other, each of the twelve industries has an equal number of employees. Accordingly the index diversification varies from 0, indicating total industrial concentration, to 0.9157 total diversification (Gibbs and Martin 1982). The Gibbs Martin Index was extensively used by Clements and Sturgis (1971) who, in their analysis showed the maximum value of absolute diversification depends upon the number of cases used. In the example of twelve industry tabulation (Table 1) it is seen to be 0·9157 with ten industries the maximum value would be 0.9000. These authors also noted that for the index to be valid in comparative studies the same number of categories must be used" (Oliver 1980).

"The Gibbs — Martin Index can be applied to evaluate and campare relative concentration of categories other than industries. The concentration of precipitation over the period of a year could be assessed. In such, an application may be a climatic station and each category would be month of the year. The index would be valid for comparative purposes because each case would camprise twelve categories, the months of the year" (Oliver 1980)

According to him although the direct use of the Gibbs — Martin Index could serve a climatological purpose, it should be noted that the stress of the economic index is diversity (non concentration). "For climatic application it

would seem more appropriate that the scale be reversed and that uniformity of precipitation be indicated by a low index, with increasingly seasonal distribution being shown by a higher value. It is therefore more appropriate to use.

$$100 \left[\Sigma x^2 / (\Sigma x)^2 \right]$$

Where x is mean monthly rainfall for each month of the year. The value is not subtracted from unity and to obviate extensive use of fractions, is multiplies by 100. Given this modification and its direct application to climatic data, the derived value might now be conveniently called Precipitation concentration Index PCI. Values of the PCI for individual climatic stations are demonstratad in Table 2. Minimum PCI values are obtained for those stations in which rainfall is the same for each month of the year. In such a case $100 \left[\Sigma x^2 / (\Sigma x)^2 \right]$ will represent the lowest value possible for twelve categories; PCI 8.3. Highest Index values will be found in those cases when the annual prepiatation occurs in one month. Theoretically the PCI will range from 8.3 for equal monthly distribution to 100 for extreme monthly distribution". Table 03 prepared for five stations which receive rainfall in twelve months, nine months, six months, three months and one month using synthetic rainfall data. In which it is to be notified that the station of which rainfall is distributed uniform among the year has the PCI value of 8.3 the station distributed among nine months has the PCI value of 11.1, the station distributed among six months has the PCI value of 16.6, the station has distributed for three months 33.3 and the station has the rainfall for a month only has PCI value of 100.

" Perhaps the most basic measure of rainfall variability over the period of a year is the standard deviation (s) of the data set. Direct use of the standard deviation is not altogether applicable for comparative studies because its value depends upon the actual amounts of rainfall that occur. For example, if a station received an annual total of four inches of precipitation, and if this occurred during one month, the standard deviation would be 0.33. Such a value could be obtained from a monthly series that experienced a small variation of precipitation distributed throughout the year. To overcome this problem the Coefficient of Variance (CV) is used, where.

$$CV = 100 \left(S / \bar{x} \right)$$

The CV is an open-ended scale that ranges from 0 to an undefined upper limit. Like the CV, the proposed PCI also includes the standard deviation in its derivation:

$$\Sigma x^2 / (\Sigma x)^2 = \Sigma x^2 / (n\bar{x})^2$$
$$= (\Sigma x^2 / n) / n(\bar{x})^2$$
$$= [(\Sigma x^2 / n) - (\bar{x})^2 + (\bar{x})^2] / n(\bar{x})^2$$
$$= [S\bar{x}^2 + (\bar{x})^2] / n(\bar{x})^2$$
$$= [S\bar{x}^2 / (\bar{x})^2 + 1] / n$$

This equation indicates that the PCI is the variance — mean ratio plus one divided by the number of observations. Thus it can also be expressed as

$$PCI = \{CV(\bar{x})\}^2 + 1/n$$

in effect, the PCI is the equivalent of the produced of the CV and mean squared plus 1 / n. The main value of this medification is that the resulting index is bounded by limits ranging from a value approaching 0 for uniform distribution to 100 for maximum seasonality.

A comparison of S, CV and PCI for hypothetical data sets prepared by Oliver given in Table 4. As can be seen, the standard deviation provides no insight into distributional differences, and the CV will equal 100 percent only wheres is equal to $\bar{x}$. Example B in Table 4 is one case where this occurs. Note that the CV for even monthly increments exhibits no clear pattern. By contract, the PCI double when the same monthly increment occurs in half a designated period (e. g. in Table 4 the PCI at station C is 25, at D it is 50 (Oliver 1980).

The PCI, with its limits, permits grouping of data sets according to the derived value. A PCI of less than 10 suggests uniform distribution, and a value from 11 to 20 denotes a seasonal distribution. An index above 20 represents marked seasonal differences, with increasing values indicative of increasing monthly concentration (Oliver 1990). As an example, for a few stations in Sri Lanka derived PCI values are given in Table 05. The PCI values corresponding to the concentration of rainfall for number of months are given below based an synthetic rainfall data as the example in Table 03.

Months	PCI	Months	PCI
12	8.3	6	16.6
11	9.0	5	20.0
10	10.0	4	25.0
9	11.1	3	33.3
8	12.5	2	50.0
7	14.3	1	100.0

4.0 Analysis :

Oliver had applied the methodology for average monthly precipitation data for Africa, Australia and the United States. In Sri Lanka there are more than six hundred stations observe rainfall. However only sixty rainfall station have been selected for the study (Table 06 and fig 01). The average monthly rainfall for these stations for 1931 — 60 and actual monthly rainfall for particular years such as 1966 and 1964 have been used. The study has been carried out by following Oliver.

4.1 Normal concentration

The average monthly rainfall figures have been used to calculate PCI value to reveal the seasonal and monthly concentration of rainfall. As an example Table 06 shows the derivation of PCI values for nine stations belong to different places in Sri Lanka. These stations have depicted PCI values as follows. Dehiiwito - 8.98, Nuwara Eliya - 9.08, Colombo - 10.32, Gal Oya - 11.75, Vavuniya - 12.78, Trincomalee - 13.71 Mannar - 16.05, Jaffna - 18.30 and Palai - 20.28. Among the PCI values the highest value calculated for Palai and the lowest value for Dehiowita. To look into the uniformity of the monthly precipitation concentration in Sri Lanka the following are categorized using sixty PCI values.

Categories of Concentration

	PCI	Distribution	Stations
1.	8.51 — 10.50	Uniform Distrbution	24
2.	10.51 — 12.50	Uniform Ditribution for eight to eleven months	14
3.	12.51 — 14.50	Distribution for seven to eight months	09
4.	14.51 — 16.50	Distribution for six to seven months	07
5.	16.51 — 18.50	Distribution for six months	01
6.	18.51 — 20.50	Distribution for five months	05

These can be said as categories of concentration. The fig 01 shows the categories of concentration of rainfall in Sri Landa 1931 — 60 where the isolines are drawn using an interval of 2.0 PCI values. PCI values from 8.51 — 10.50 clearly indicate the uniform concentration of rainfall in the Wetzone of Sri Lanka particularly in the regions of South West and Western portion of central massif[1]. There is no dry month occure during the year in these regions. How-

1. Climatologically Sri Lanka is divided into two Zones as Wet Zone and Dry Zone. There are a few definitions to explain it. But according to Prof. G. Thambyahpillay the Isoyet for — 500 mm of the South west monsoon season rainfall decides the Zones.

ever, within this boundary, the areas of Hambantota and Tangalla also have included (fig. 01), because th PCI valus for the areas show less than 10.50. The index values of the places are 10.26 and 9.87 respeetively, even though these areas receive much less rainfall compared to the Wetzone. But according to the index they show the uniform concentration of precipitation in the average picture. Generally an increasing trend of PCI values towards North and North East regions has been observed. In the most of the South East, Uva and North Central regions the PCI values are between 10.51 — 12.50 where it shows the concentration from eight to eleven months. More rainfall occur during the Northeast monsoon and in the other Intermonsoon sesons[2]. The values for the rest of the Island show a well marked seasonality, range from 12.51 to 22.50 where the rainfall only occur during the North east monsoon and inter monsoon season[II].

Monthly concentration towards further North is decided by two seasons such as the Inter monsoon season[II] and North east monsoon, particularly the North receives more during Inter monsoon[II] due to the developments related to low presure depressions which occure in the Bay of Bengal Zone but on other hand the East receives certain amount of rainfall during the same season and more during the North east monsoon season. This fact is clearly depicted by the PCI values which are less than 15 in the East except Batticaloa and Vakaneri. The vast region from West to East covering Puttalam, Vavuniya, Trincomalee, Topawewa and Irakkamam has concentration of seven to eight months. In the East Batticaloa and Vakaneri also have same concentration. Area from Marichchukaddai to Mullaitivu have concentration of six to seven months. Killinochchi and its surroundings have six months concentration. The Jaffna Peninsula has the concentration for five months.

Generally the PCI shows the seasonal or monthly concentration of the rainfall but it doesnot name the season but show the seasonality; Further, it doesnot give the amount of rainfall but show the concentration of rainfall. In a region the amount of rainfall may be less but if it is distributed over the year the PCI will show the uniform rainfall concentration. On the otherhand a particular region could receive more rainfall during three or four months or during a season then the PCI will show higher values.

As Oliver pointed out the Sahara region has PCI values less than 10 and so the values not show the seasonal concentration but show the uniform con-

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2. Sri Lanka experiences four seasons as follows:

South west monsoon season	:	May to September
Inter monsoon season[II]	:	October to November
North east monson season	:	December to February
Inter monsoon season[I]	:	March to April

centration. The region is a desert and receives very less rainfall which is uniformly distributed throughout the year. One should understrnd this fact clearly when using the PCI values.

In conclusion it can be said that the concentration of rainfall is reflection of the weather and climate of the region. The PCI values calculated from average monthly rainfall of Sri Lanka have given clear picture of rainfall concentration from which one could identify the respective seasonality provided he knows the weather and climate of Sri Lanka. As these concentrations calculated from average monthly rainfall figures (1931 — 60) these can be treated as normal concentration values. So far, the PCI values calculated from the average monthly rainfall were discussed. An analysis of the year by year variation in rainfall sessionality ean be made on comparison of PCI values for actual monthly rainfall each year with the PCI values calculated from the average monthly rainfall. It will express the rainfall dificiencies and drought. The PCI values of two years such as 1966 and 1974 have given in figures 2 and 3 for respective stations and they have depicted interesting variations.

4.2 Concentration In 1966

Fig. 02 shows the PCI values for monthly rainfall of 1966 for the respective stations in which the isolines are drawn at an interval of two. Six categories of concentration have identified as follows.

Categories of Concentration for 1966

	PCI				Stations
1)	10.01	—	12.00	—	09
2)	12·01	—	14,00	—	22
3)	14.01	—	16.00	—	13
4)	16.01	—	18.00	—	07
5)	11.01	—	20.00	—	06
6)	20.01	—	22.00	—	03

(see fig. 2)

Generally the normal concentration pattern have not reflected in the PCI values for the year of 1966. Wet Zone usually belongs to uniform concentration, but in 1966 the concentration shows about nine, eight and seven months concentration. A narrow area from Galle to Central massif shows nine months concentration. The South East Sri Lanka shows eight months concentration but even there Tissamaharama shows five months concentration. The area extended from Kurunegala to Batticaloa shows six months concentration. Further towards the North and West the concentration decreases. The areas of Puttalam, Vavuniya, Nedunkeni have five months concentration. The areas from Marichchukaddi to Killinochchi have four months and the areas from Murunkan to

Pallai haxe nearly three months concentration. In fact the year 1966 shows less concentration than the normal. In some places it has more concentration (fig. 02).

4.3 Concentration in 1974

Fig. 03 shows the PCI values for monthly rainfall of 1974 for the fifty respective stations in which the isolines are drawn at an interval of 04.

Categories of Concentration for 1974

PCI				Stations
1) 9.01	—	13.00	—	22
2) 13.01	—	17.00	—	11
3) 17.01	—	21.00	—	11
4) 21.01	—	25.00	—	01
5) 25.01	—	29.00	—	02
6) 29.01	—	33.00	—	02

The concentration values do not depict the average pattern and there are notable variation. Wetzone shows less concentration only for ten months. This area extends from Galle to Gammaduwa. One place in the Dry Zone, Vavuniya also shows the same concentration, and it is more than the average. Most of the areas of the central massif show the same concentration. The areas from Hambantota to Koslanda and the Western coast and Mullaitivu show nine months concentration. Western coast shows less than the normal. In the South East, Tissamaharama and Lakugalla and the area from Puttalam through Annuradapura to Trincomalee show six months concentration. Horuwapotana area and north of Mannar show four months coneentration. Mannar and the areas around Maha Oya, Vakaneri and Batticaloa show between three and four months concentration. Marichchukaddai and Dandeniya show three months concentration. In fact, during 1974, the monthly concentration does not show average pattern in most places and it has very less concentration pattern, for example Topawewa has 39.67 PCI value and it shows less than three months concentration and Marichchukaddai shows 29.58 PCI values of three months concentration.

5.0 Conclusion

Oliver (1980) who prospored the PCI, said it has valuable application for the study of agroclimatic analogs where both amount and relative distribution is needed; for the climatic study of drought frequency and potential and for the climatic classification. Further monthly evapatranspiration, water deficit and water surplus can be used as X variable in the Index equation. He adds that it would add a new dimension in the explanation of precipitation deficinncies on squential basis.

In this paper PCI has used to analyse the concentration of rainfall for sverage monthly rainfall of 1931 — 60. Further to that it is also used to explain the rainfall deficiencies during 1966 and 1974. Likewise each year could be compared with the normal.

RAINFALL CONCENTRATION INDEX

(FOR AVERAGE MONTHLY RAINFALL, 1931-60)

CALCULATED BY S.BALACHANDIRAN 1993.

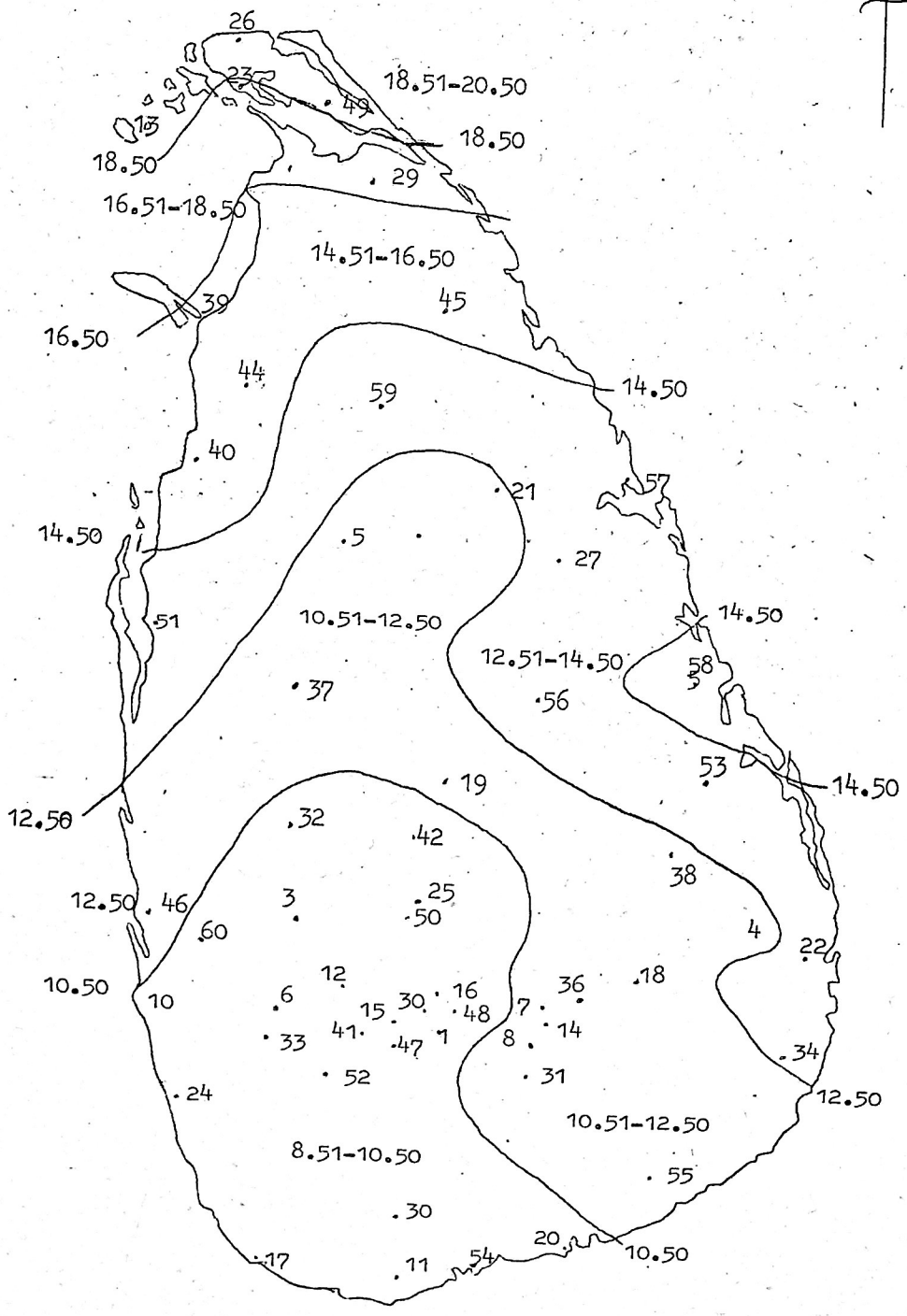

FIG.1

SCALE: 1:2,000,000

RAINFALL CONCENTRATION INDEX

(FOR MONTHLY RAINFALL, 1966)

CALCULATED BY S.BALACHANDIRAN 1993

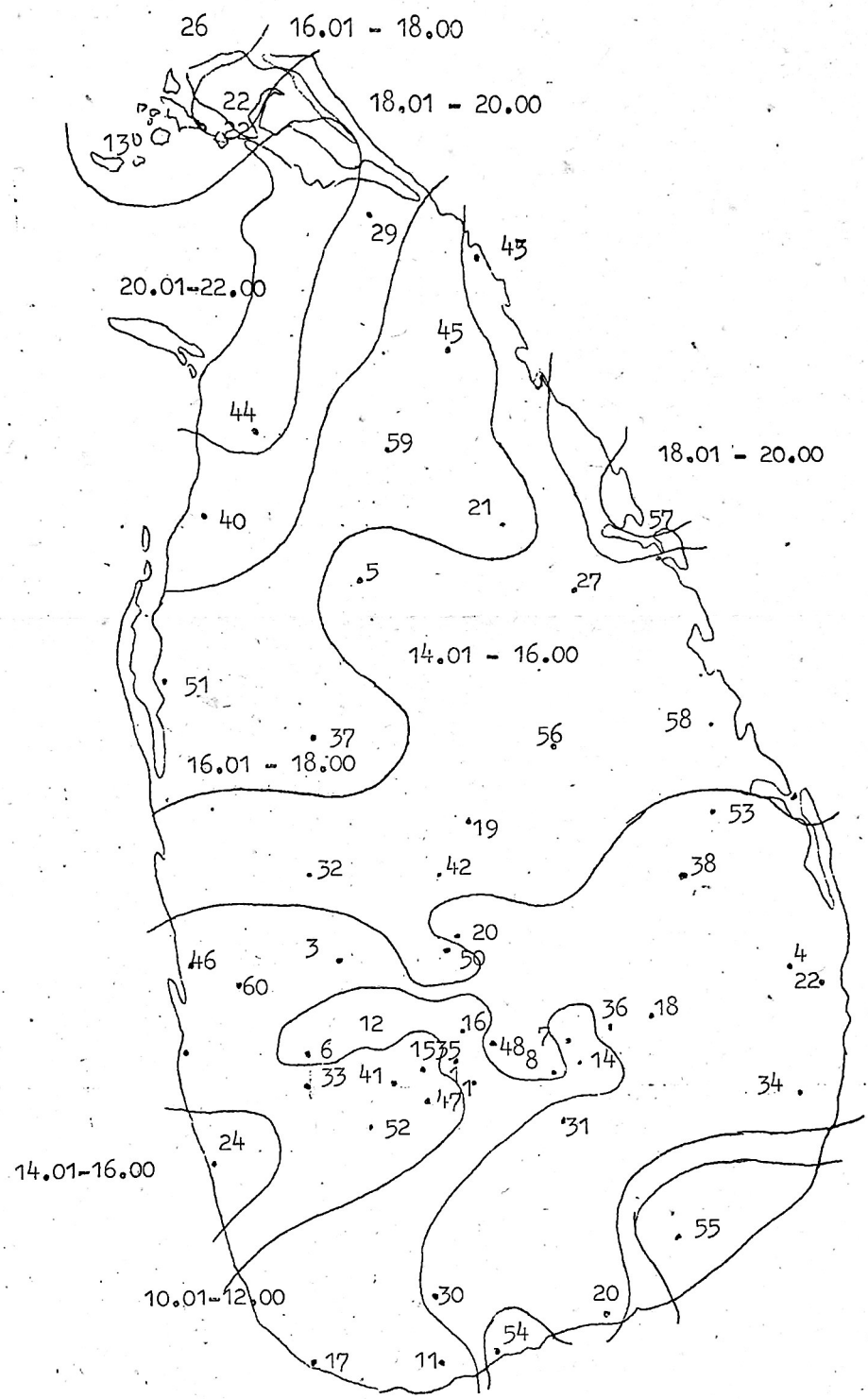

FIG.2

SCALE: 1:2,000,000

RAINFALL CONCENTRATION INDEX

(FOR MONTHLY RAINFALL, 1974)

CALCULATED BY S.BALACHANDIRAN

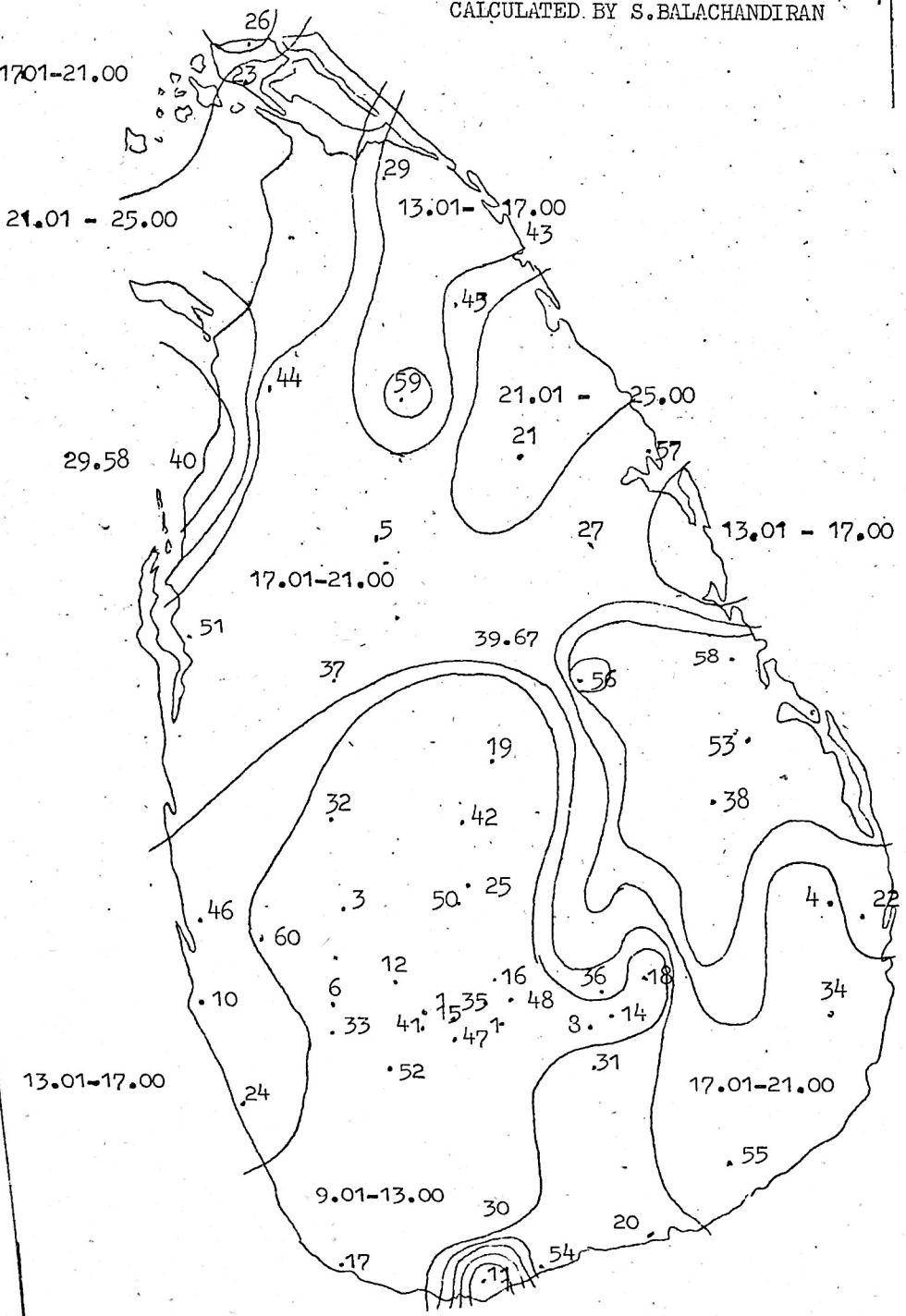

FIG: 3

SCALE: 1:2,000,000

RAINFALL CONCENTRATION INDEX

(FOR MONTHLY RAINFALL, 1974)

CALCULATED BY S.BALACHANDIRAN

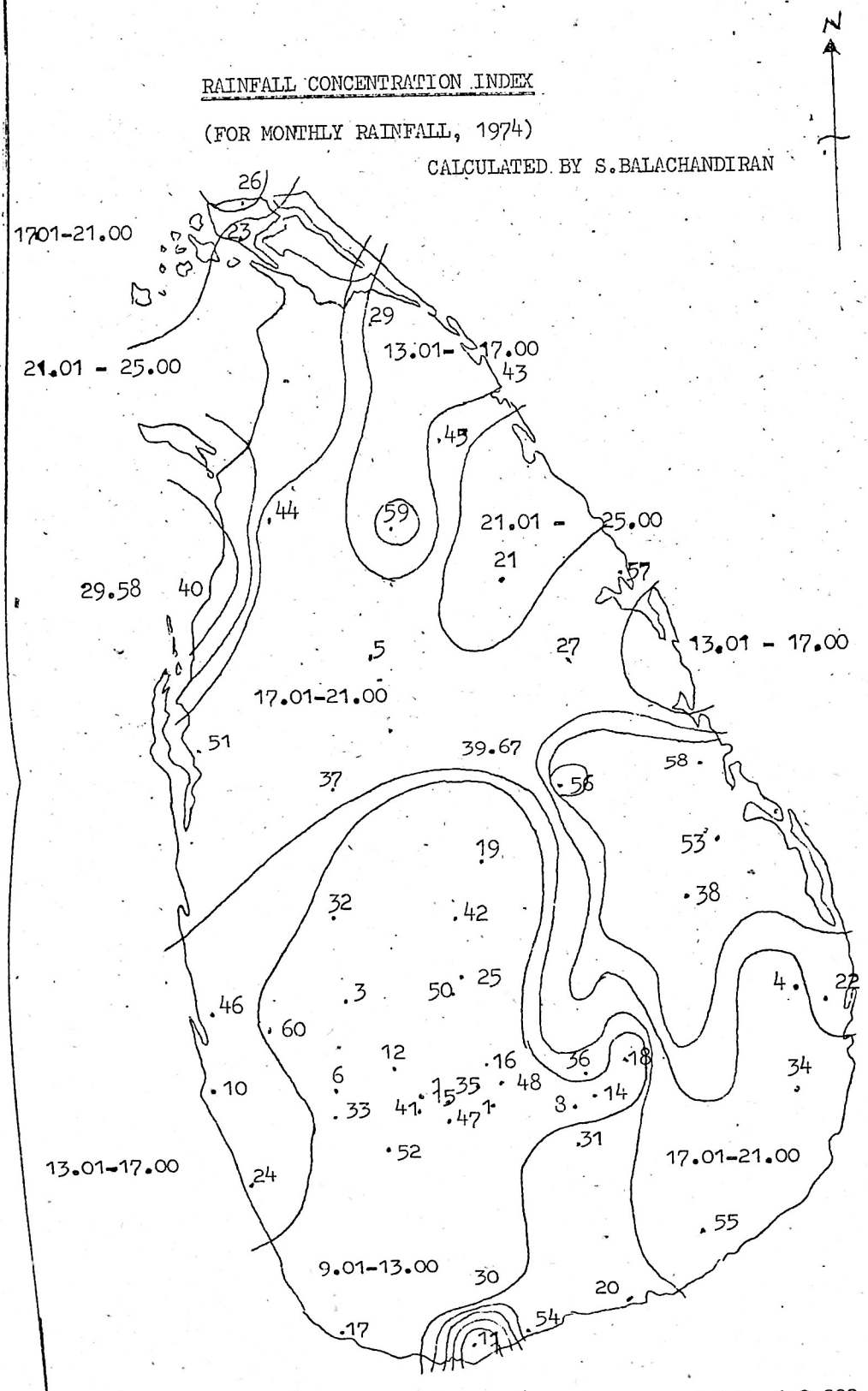

FIG: 3

SCALE: 1:2,000,000

TABLE — 1

Gibbs — Martin index of Employment Diversification

Industry	Number of persons Employed			
	Community A		Community B	
	x	x^2	x	x^2
1	600	360,000	50	2500
2	—	—	50	2500
3	—	—	50	2500
4	—	—	50	2500
5	—	—	50	2500
6	—	—	50	2500
7	—	—	50	2500
8	—	—	50	2500
9	—	—	50	2500
10	—	—	50	2500
11	—	—	50	2500
12	—	—	50	2500
	$\Sigma x = 600$	$x^2 = 360,000$	$\Sigma x = 600$	$\Sigma x^2 = 30,000$

$\Sigma (x)^2 = 360,000$

$$= 1 - \frac{\Sigma x^2}{\Sigma (x)^2}$$

$$= 1 - \frac{360,000}{360,000}$$

$$= 0$$

$\Sigma (x)^2 = 360,000$

$$= 1 - \frac{\Sigma x^2}{\Sigma (x)^2}$$

$$= 1 - \frac{30,000}{360,000}$$

$$= 0.9167$$

(Oliver)

TABLE — 2

Application of Gibbs — Martin Index to Precipitation Seasonality

a. Range of Values, Synthetic Data (Inches)

	Example 1	Example 2
January	4.0	0.5
February	4.0	0.0
March	4.0	0.0
April	4.0	0.0
May	4.0	0.0
June	4.0	0.0
July	4.0	0.0
August	4.0	0.0
September	4.0	0.0
October	4.0	0.0
November	4.0	0.0
December	4.0	0.0
Σx	48.0	0.5
$\Sigma (x)^2$	2304	0.25
Σx^2	192	0.25
Index	$100. \frac{192}{2304}$	$100. \frac{0.25}{0.25}$
	= 8.3	= 100

(Oliver)

TABLE — 3

Application of Gibbs — Martin Index to Precipitation Seasonality

(Range of Values, Synthetic Data (Inches)

	Station — 1	Station — 2	Station — 3	Station — 4	Station — 5
January	5.0	5.0	5.0	0.0	5.0
February	5.0	5.0	5.0	0.0	0.0
March	5.0	5.0	5.0	0.0	0.0
April	5.0	0.0	5.0	0.0	0.0
May	5.0	0.0	5.0	0.0	0.0
June	5.0	0.0	5.0	5.0	0.0
July	5.0	5.0	0.0	5.0	0.0
August	5.0	5.0	0.0	5.0	0.0
September	5.0	5.0	0.0	0.0	0.0
October	5.0	5.0	0.0	0.0	0.0
November	5.0	5.0	0.0	0.0	0.0
December	5.0	5.0	0.0	0.0	0.0
	60.0	45.0	30.0	15.0	5.0
M x =	60.00	45.00	30.00	15.00	5.0
M $(x)^2$ =	3600.00	2025.00	900.00	225.00	25.0
M x^2 =	300.00	225.00	150.00	75.00	25.0
Index =	$100 - \frac{300}{3600}$	$100 - \frac{225}{2025}$	$100 - \frac{150}{900}$	$100 - \frac{75}{225}$	$100 - \frac{25}{25}$
	8.3	11.1	16.6	33.3	100

(Author)

TABLE 4

Comparative Statistical Values for Synthetic Data Series

	A	B	C	D	E
January	4.0	4.0	4.0	4.0	4.0
February	4.0	4.0	4.0	4.0	—
March	4.0	4.0	4.0	—	—
April	4.0	4.0	4.0	—	—
May	4.0	4.0	—	—	—
June	4.0	4.0	—	—	—
July	4.0	—	—	—	—
August	4.0	—	—	—	—
September	4.0	—	—	—	—
October	4.0	—		—	—
November	4.0	—	—	—	—
December	4.0	—	—	—	—
x =	48.0	24.0	16.0	8.0	4.0
$\bar{x}$ =	4.0	2.0	1.33	0.66	0.33
S. D =	0.0	2.0	1.90	1.49	1.11
CV =	0.0	100.0	143.0	223.0	333.00
PCI =	8.3	16.7	25.0	50.0	100.00

(Oliver)

TABLE 5

Precipitation Concentration Index

Average monthly Rainfal in inches (1931 — 60)

Month	Dehiowita	Nuwaraeliya	Colombo	Galoya	Vavuniya	Trincomalee	Mannar	Jaffna	Pallai
January	5.15	5.71	2.93	14.53	5.45	8.29	3.44	3.80	4.39
February	5.00	2.99	3.39	9.25	2.11	3.75	1.32	1.45	1.75
March	11.33	3.80	4.20	5.78	2.46	1.90	1.75	1.18	1.21
April	16.05	6.05	9.39	8.16	5.64	3.02	3.48	2.76	1.84
May	19.76	9.32	11.39	4.49	4.37	2.67	1.94	2.47	2.20
June	17.07	10.48	7.33	1.16	0.47	0.73	0.19	0.64	0,24
July	11.60	8.76	4.70	2.14	1.06	2.13	0.28	0.65	0.36
August	12.83	7.07	3.97	4.45	2.69	4.05	0.63	1.24	0.60
September	11.96	6.50	4.72	3.46	3.11	3.50	0.93	1.87	1.31
October	1.37	8.75	12.13	10.52	8.75	9.24	6.60	9.59	7.84
November	17.48	8.21	12.15	16.20	11.55	13.98	9.56	16.19	16.41
December	9.37	7.51	6.15	16.33	10.92	14.72	7.97	10.50	12.31
$\Sigma x =$	178.02	85.15	82.52	96.47	58.61	67.98	38.09	52.54	50.46
$\Sigma (x)^2 =$	31905.10	7250.32	6809.55	9306.46	3435.13	4621.28	1450.84	2739.47	2546.21
$\Sigma x^2 =$	2866.37	658.60	702.70	1094.25	439.05	633.82	232.86	501.80	516.52
Index =	8.98	9.08	10.32	11.75	12.78	13.71	16.05	18.30	20.28

(Author)

TABLE — 6

Selected Stations

01. Agrapatana
02. Allai Tank
03. Ambanpitiya
04. Amparai
05. Anuradhapura
06. Avisawella
07. Badulla
08. Bandarawella
09. Batticaloa
10. Colombo
11. Dandeniya Tank
12. Dehiowita
13. Delft
14. Demodara
15. Dikoya
16. Elamulla
17. Galle
18. Galoya
19. Gammaduwa
20. Hambantota
21. Horowapotana
22. Irakkamam Tank
23. Jaffna
24. Kalutara
25. Kandy
26. Kankesanthurai
27. Kantalai
28. Kayts
29. Kilinochchi
30. Kirama
31. Koslanda
32. Kurunegala
33. Labugama
34. Lahugala
35. Lindula
36. Madulsima
37. Midiyawa Tank
38. Maha Oya
39. Mannar
40. Marichchukaddy
41. Maskeliya
42. Matale
43. Mullaitivu
44. Murunkan
45. Nedunkeni
46. Negombo
47. Norwood
48. Nuwara Eliya
49. Pallai
50. Peradeniya
51. Puttalam
52. Ratnapura
53. Rugam Tank
54. Tangalla
55. Tissamaharama
56. Topawewa
57. Trincomalee
58. Vakeneri
59. Vavuniya
60. Veyangoda

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