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TEMPORAL VARIATION OF RAINFALL EROSIVITY IN SOUTHERN NIGERIA

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ABSTRACT

Rainfall amount and short-interval (e.g., ≤ 15 minutes) intensities are characteristics which distinguish tropical rains from temperate region rains in terms of erosivity. Therefore, the product of the two characteristics was used to evaluate trends in rainfall erosivity at Ibadan (a sub-humid zone) and Port-Harcourt (a humid zone), southern Nigeria using autographic rainfall charts that covered 1977 to 1999. The charts were analyzed at 15-minute intervals to obtain the maximum daily intensity, I_m. Thus, erosivity index was the product of daily rainfall amount (A) and I_m, and this is commonly referred to as the AI_m index. Descriptive statistics were used to characterize erosivity while trends were evaluated using standardized deviations. Mean annual AI_m was 684 cm^2 h^{-1} in Ibadan and 975 cm^2 h^{-1} in Port-Harcourt. Annual erosivity index was as high as 1374 cm^2 h^{-1} in Ibadan and 1491 cm^2 h^{-1} at Port-Harcourt. Although daily erosivity was statistically similar between the two locations, it was 1.86 times higher in April and 3.6 times higher in December at Ibadan than Port-Harcourt. Peak daily erosivity index was attained in March, April and November, suggesting the significant influence of convective storms. Daily erosivity index was close or lower than the long-term average in Ibadan but was higher than the average for Port-Harcourt. A lag period may occur between the two locations in attaining daily peak erosivity, but this can occur in the same year at both locations. Furthermore, the standardized deviations showed that between 1977 and 1988, rainfall erosivity exceeded the long-term average by as much as 2.59 deviation in Ibadan and 1.69 in Port-Harcourt but the trend between 1989 and 1999 showed a range of deviations from -1.72 to 0. Therefore, there was a decreasing trend in erosivity between 1977 and 1999. However, this was attributed to decreasing trend in rainfall amount, which did not translate to decreasing trend in soil erosion risks high rainfall intensities were considered. This was demonstrated by the fact that Ibadan which has about half the annual rainfall as Port-Harcourt had equal erosivity index values in some years due to bolstering of erosivity by high intensity rains.

Key words: Rainfall erosivity, Climate Change, Temporal variation, Southern Nigeria.

INTRODUCTION

Climate change has become a global issue in terms of its effect on agriculture, environment and human health. According to Hulme and Viner (1998), changes in total rainfall in different tropical regions resulting from different combination of frequency and intensities indicate that rainfall intensities are increasing over most of Africa. Servat et al. (1997) and Paturel et al. (1997) showed that there is a decreasing trend in rainfall in West Africa. Jagtap (1995) provided evidence of this decreasing trend in Nigeria. Understanding the impact of this change on soil erosion by rainfall, requires long-term data for evaluation of rainfall erosivity, which is the potential ability of rain to cause erosion (Lal, 1990; Hudson, 1995; Renard et al., 1997). The data required are such that rates of rainfall at short-intervals (preferably ≤ 15 minutes) must be known, and these are very rare in many developing nations. Therefore, trends in rainfall erosivity have been generally evaluated using commonly available rainfall amount data.

Rainfall amount plays a significant role in erosivity of tropical rainfall as demonstrated by the significant positive relationship it has with erosivity indices such as kinetic energy or its combination with rainfall intensity (Lal, 1976; Kowal and Kassam, 1976; Obi and Salako, 1995). In this regard, Lal (1976) considered the combination of daily rainfall (A) amount and maximum intensity (I_m), expressed as AI_m, as a reliable index for evaluating index of tropical rainfall. The index, which was developed in Ibadan, southwestern Nigeria has, however, not been as widely used as the product of kinetic energy (E) and maximum 30-minute intensity, I_{30}, (EI_{30} index) proposed for evaluating rainfall erosivity factor, R, in the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The main reason for this is that the EI_{30} has a comparative advantage of fitting RUSLE for soil erosion prediction. Nonetheless, comparative analysis of rainfall erosivity, particularly in the tropics is better done with indices which take into consideration the peculiarities of tropical rainfall, such as high intensities exceeding 75 mm h^{-1} (Lal; 1976; 1990; Hudson, 1995). Therefore, the aim of this study was to evaluate temporal changes of rainfall erosivity in two contrasting ecological zones of southern Nigeria, taking into consideration contributions by rainfall amount and short-interval intensities.

MATERIALS AND METHODS

This study was carried out by analyzing autographic rainfall charts covering 1977 to 1999 for Ibadan (7^o 30^I N; 3^o 54^I E) and 1977 to1997 for Onne, near Port-Harcourt (4^o 40^I N; 7^o 26^I E). The charts were collected from the Agro-Ecological Studies and Crop Modeling Unit of the Resource and Crop Management Division, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Ibadan is in the southwestern part of Nigeria having a mean annual rainfall of 1300 mm. It is in a sub-humid rainfall zone. Port-Harcourt is located in the southeastern part of Nigeria and has an annual rainfall amount of 2400 mm. The raingauge used for chart records was thee Universal Recording raingauge (Belfort Instrument Company, 1979), which was a weighing-type gage in which weight of rainfall was converted into a curvilinear movement of a recording pen, traced on a rectangular chart. The records were collected daily as traces of rainfall amount versus time of occurrence during the day. The records could be resolved to desired time intervals during analysis but 7.5 minute appeared to most practical least interval for such resolutions.

The data from Ibadan covered 47-95% of annual rainfall, except in 1994 in which the single chart which accounted for 3% of annual rainfall was analyzed. Also, in the HF 45-94% of annual rainfall was covered, except for 1991 when only 7% of annual rainfall was covered. The data for 1994 in Ibadan and 1991 were not included in computation of annual means of rainfall characteristics, just as the missing annual data were excluded.

The rainfall charts were analyzed generally (about 87% of charts) at 15-minute intervals. The remaining charts were analyzed at ≤ 7.5 minute intervals to obtain very high intensities (> 100 mm h^{-1}). Rainfall characteristics evaluated were daily rainfall amount (A in mm) and maximum rainfall intensity (I_{15} in mm h^{-1}), from which the product, AI_m was computed in cm^2 h^{-1} (Lal, 1976).

A power-law relationship was used to relate rainfall erosivity index, AI_m (cm^2 h^{-1}), maximum-30 miniute intensity (I_{30} in mm h^{-1}) and I_{15}, eachdesignated L, to daily rainfall amount (mm):

$$L = aA^b \qquad (1)$$

where:

a and b are constants.

Annual values of L and A were also used for Eqn. (1).

Standardized deviations (Servat et al., 1997; Paturel et al., 1997) were calculated to obtain variations in daily rainfall erosivity in each month of the year (January-December) and annual erosivity from 1977 to 1999, as follows:

$$\text{Standardized deviation} = (x_i - \mu)/s \qquad (2)$$

where:

x_i = mean value of daily AI_m index in each month or year, i

μ = long-term mean (1977-1999) of the individual daily or annual AI_m

s = standard deviation over the period, 1977-1999.

Both Ibadan and Port-Harcourt means were compared using general analysis of variance.

RESULTS AND DISCUSSION

Daily rainfall erosivity

Overall means of daily AI_m index of 8.96 cm^2 h^{-1} for Ibadan and 7.88 cm^2 h^{-1} for Port-Harcourt were similar (Fig. 1). However, when the means were considered on monthly basis for the rainy season (March-October), there was a large difference in April with Ibadan being 1.86 times higher than Port-Harcourt. The daily AI_m index at Ibadan was 3.6 times greater than Port-Harcourt in December. The maximum AI_m index, however, indicated that in April Ibadan had an exceptionally higher erosivity (3 times higher) than Port-Harcourt whereas in November, Prot-Harcourt had 1.8 times higher erosivity than Ibadan (Fig. 2).

The mean and the maximum daily erosivity showed that April was a month with very high erosivity at Ibadan, and the observation of a high daily mean erosivity in December was merely by chance because the maximum daily erosivity was comparatively low (Figs. 1 and 2). All these months were relatively dry months. In Port-Harcourt, peak daily erosivity was also observed in March and November. These months (March, April and November) are relatively dry months constituting either the onset or cessation period of rainfall. Rains in such months are mainly convective storms of short duration but with high intensities which reach their peaks as soon as the rains start (Salako, 1986; Obi and Salako, 1995; Salako et al., 1995). The dominance of convective storms is usually as a result of heating of the earth surface, and they have been observed to be dominant in relatively dry months or dry areas (Ojo, 1977; Nyssen et al., 2005).

Annual erosivity

The mean annual AI_m index for Ibadan was 684 $cm^2 h^{-1}$ whereas it was 975 $cm^2 h^{-1}$ in Port-Harcourt (Fig. 3). Both locations agreed very well in trends and quantity of rainfall erosivity between 1983 and 1986. Annual rainfall erosivity between 1977 and 1988 were higher than the erosivity between 1989 and 1999.

Although daily erosivity was generally higher in Ibadan than Port-Harcourt (Figs. 1and 2), annual erosivity was higher in Port-Harcourt than Ibadan (Fig. 3). This showed that both locations were at risk of soil erosion arising from different rainfall characteristics. At Ibadan, higher erosion risks were due to higher rates (intensities) of rainfall whereas at Onne its was due to higher frequency and volume of rainfall.

The coincidence of peak rainfall erosivity at Ibadan and Port-Harcourt in 1985 (Fig.3) confirmed further that soil erosion risks are equally high in both agroecological zones in spite of differences in annual rainfall. Peak erosivity between 1977 and 1988 were higher than peak erosivity between 1989 and 1999. This was attributed to observed trend of decreasing rainfall amount in West Africa (Jagtap, 1995; Servat et al., 1997; Paturel et al., 1997).

Trends in rainfall erosivity

In Ibadan, daily rainfall erosivity was higher than the long-term average in 7 out of 12 months whereas it was higher in all months at Port-Harcourt (Fig. 4). Furthermore, the standardized deviations were closer to zero (equal to long-term average) in Ibadan than Port-Harcourt, suggesting that daily erosivity was more variable in Port-Harcourt than Ibadan.

The trends indicated by daily erosivity by standardized deviations showed an almost symmetric variations between Ibadan and Port-Harcourt (Fig.4). This symmetry suggests that a replication of rainfall erosivity characteristics occurred at both locations at different scales or magnitude at any given time of the month. Furthermore, Fig. 4 suggests existence of a lag period in incidence of highly erosive storms between the two locations, even though such storms can occur in the same year. The daily time of occurrence of relatively low or high erosive storms in one of the locations would not be the time for a similar occurrence in the other location but the potential erosivity was similar. The magnitude of occurrence was determined by effects of local features such as topography or relief in Ibadan and proximity to the sea (Atlantic ocean) in Port-Harcourt. At a macroscale, rainfall generation is attributed mainly to the position of Inter-Tropical Convergence Zone (ITCZ) in the tropics but local effects act as strong modifiers of storm types (Ojo, 1977), even in the same geographical zone.

Annual trends showed more extreme variations in erosivity between 1977 and 1988 than subsequent years (Fig. 5). In Ibadan, 9 out of 12 years spanning 1977 to 1988 showed higher than long-term average rainfall erosivity. For Port-Harcourt, there were 8 years within the period with higher erosivity than the long-term average. Subsequent years generally had less

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than long-term average erosivity.

The most erosive year in Ibadan was 1985 with a standardized deviation of 2.59 (Fig.5). In Port-Harcourt, the most erosive year was 1987 with a standardized deviation of 1.77. The year, 1985, was the second most erosive year in Port-Harcourt with 1.4 standardized deviation.

The standardized deviations for annual erosivity confirmed a decreasing trend in erosivity, especially from 1989 to 1999. Furthermore it showed that the coincidence of peak annual erosivity in 1985 (Fig. 3) was as a result of a relatively high erosivity at both locations in that year (Fig. 5). The possibility of annual erosivity exceeding long-term averages in both Ibadan and Port-Harcourt appeared similar as indicated by the number of years in which this trend was observed. This confirms further a similarity in potential risks of soil erosion in spite of varying characteristics of rainfall. It follows that the decreasing trend of rainfall erosivity, which occurred due to decreasing trend of rainfall amount (Jagtap, 1995; Servat et al., 1997; Paturel et al., 1997) did not imply decreasing soil erosion risks. Rainfall intensities could be increasing even with decreasing rainfall amount (Obi and Salako, 1995, as indicated by the fact that Ibadan with about half the rainfall in Port-Harcourt had a similar erosivity. As Bonell (1998) observed, any change in rainfall characteristics which favors higher intensities would cause a shift toward disequilibrium of tropical forest hydrology, leading to increased overland flow and erosion. Hulme and Viner (1998) stated that most of tropical Africa is experiencing increases in rainfall intensities.

Predicting erosivity index from daily rainfall amount

Daily rainfall explained, significantly, up to 90% of the variation in AI_m but annual data were lower in r^2 values (Table 1). Regression parameters were similar for both Ibadan and Port-Harcourt. Relating AI_m to A (Eq. 1) is expected to yield high r^2 values and such a regression would not have been necessary if rainfall-duration data at short intervals of the day are routinely collected. Calculating rainfall intensities at short intervals of about 15 minutes or less as carried out in this study is rare in many developing nations (Lal, 1976; Mbagwu and Salako, 1985; Salako, 1988; Obi and Salako, 1995; Salako et al., 1991; 1995). Quite often, the paucity of such data has influenced decisions to evaluate rainfall erosivity factor, *R*, from only rainfall amount data in both developing and developed nations (Arnoldus, 1977; Salako, 1988; Oduro-Afriyie, 1996; Lal, 1998; Elsenbeer et al., 1993; Yu and Rosewell, 1996a; 1996b; Mikhailova et al., 1997; Yu, 1998). Recent technological advances have made rainfall-duration data possible with electronic systems in weather stations, and these may improve precision and accuracy of such data if properly utilized.

CONCLUSION

The product of daily rainfall amount and rainfall intensities at 15-minute intervals was used to evaluate temporal variation in rainfall erosivity between 1977 and 1999 at Ibadan (sub-humid zone) and Port-Harcourt (humid zone). Daily rainfall attained its peak erosivity in March, April and November, suggesting that convective storms contributed significantly to soil erosion at both locations. Although daily rainfall erosivity was generally higher in

Ibadan than Port-Harcourt, a reverse trend was observed with annual erosivity. This showed that rainfall characteristics such as high intensities were dominant at Ibadan whereas large amounts of rainfall contributed more to erosivity at Port-Harcourt. Daily rainfall erosivity trends were symmetric between locations, suggesting contrasting effects of local features on storm types in different months and also implying a potential replication of erosivity characteristics in both locations. The attainment of peak daily erosivity may lag between the two rainfall zones but the occurrence of such in one of the zone would imply a similar occurrence in the other in a given year. Although a decreasing trend was in rainfall erosivity was observed due to decreasing trend in rainfall amounts, high erosivity values observed at Ibadan suggested that if rates of rainfall were considered, there still existed great risk of soil erosion and environmental degradation in southern Nigeria.

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Table 1: Regression parameters of the model, $L = aA^b$, for the prediction of rainfall erosivity index from daily rainfall amount in southern Nigeria

1a: Daily parameters of erosivity indices with independent variable being daily rainfall, *A* (in mm); *P* < 0.001, number of observations > 1500 days

Dependent variable, daily *L*	Intercept, a	Slope, b	Coefficient of determination, r^2
	Ibadan		
I_{30} (mm h^{-1})	3.71	0.698	0.65
I_m or I_{15} (mm h^{-1})	4.42	0.77	0.64
AI_m ($cm^2 h^{-1}$)	0.04	1.76	0.90
	Port-Harcourt		
I_{30} (mm h^{-1})	1.80	0.82	0.87
I_m or I_{15} (mm h^{-1})	2.91	0.77	0.73
AI_m ($cm^2 h^{-1}$)	0.03	1.77	0.93

1b: Annual parameters of erosivity indices with independent variable being annual rainfall, *A* (in mm); *P* < 0.01, number of observations , 15 years for Ibadan, 12 years for Port-Harcourt

Dependent variable, annual *L*	Intercept, a	Slope, b	Coefficient of determination, r^2
	Ibadan		
I_{30} (mm h^{-1})	8.62	0.76	0.46
I_m or I_{15} (mm h^{-1})	26.34	0.67	0.56
AI_m ($cm^2 h^{-1}$)	0.40	1.07	0.66
	Port-Harcourt		
I_{30} (mm h^{-1})	2.29	0.90	0.74
I_m or I_{15} (mm h^{-1})	12.96	0.72	0.49
AI_m ($cm^2 h^{-1}$)	0.01	1.44	0.89

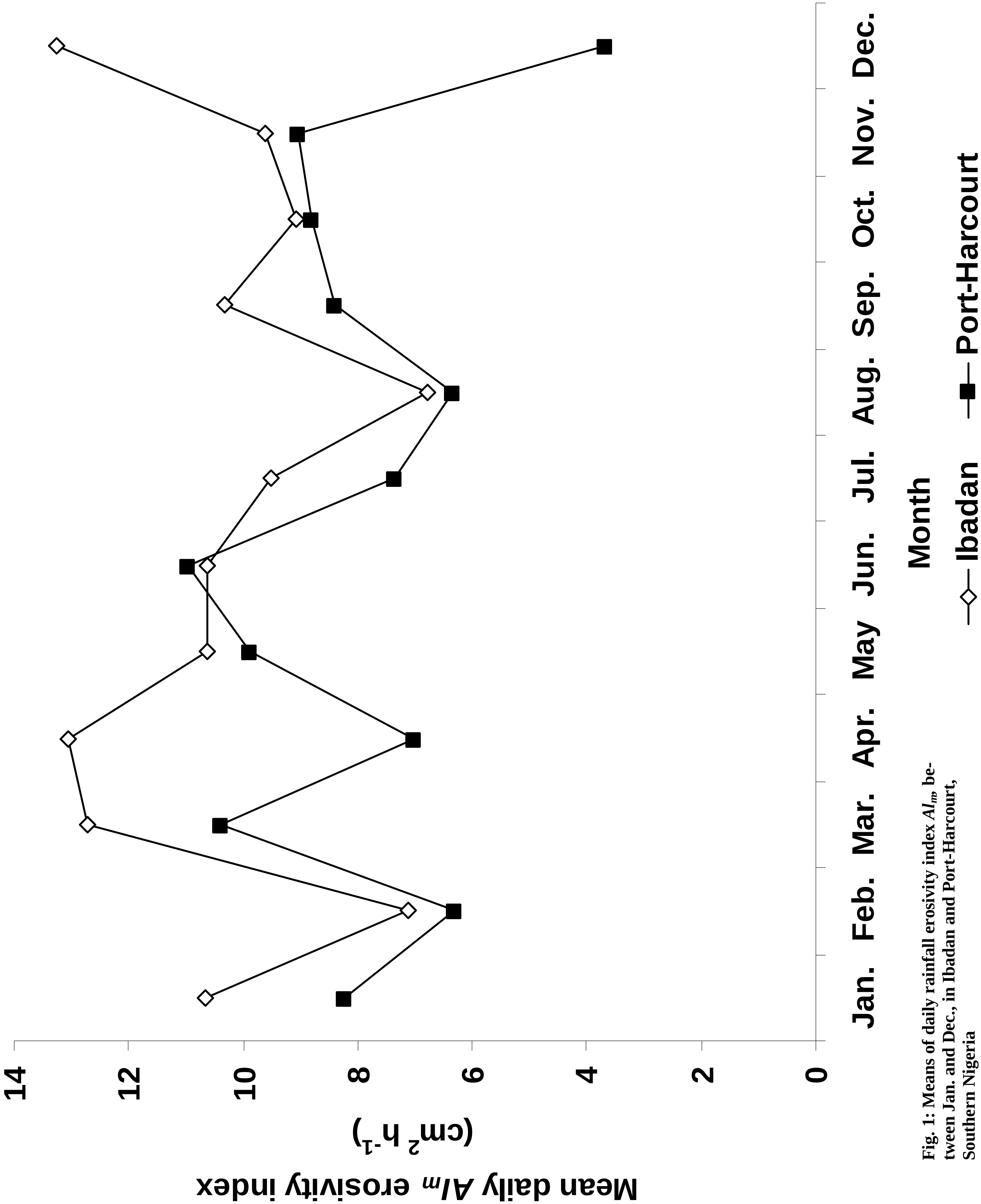

Fig. 1: Means of daily rainfall erosivity index AI_m, between Jan. and Dec., in Ibadan and Port-Harcourt, Southern Nigeria

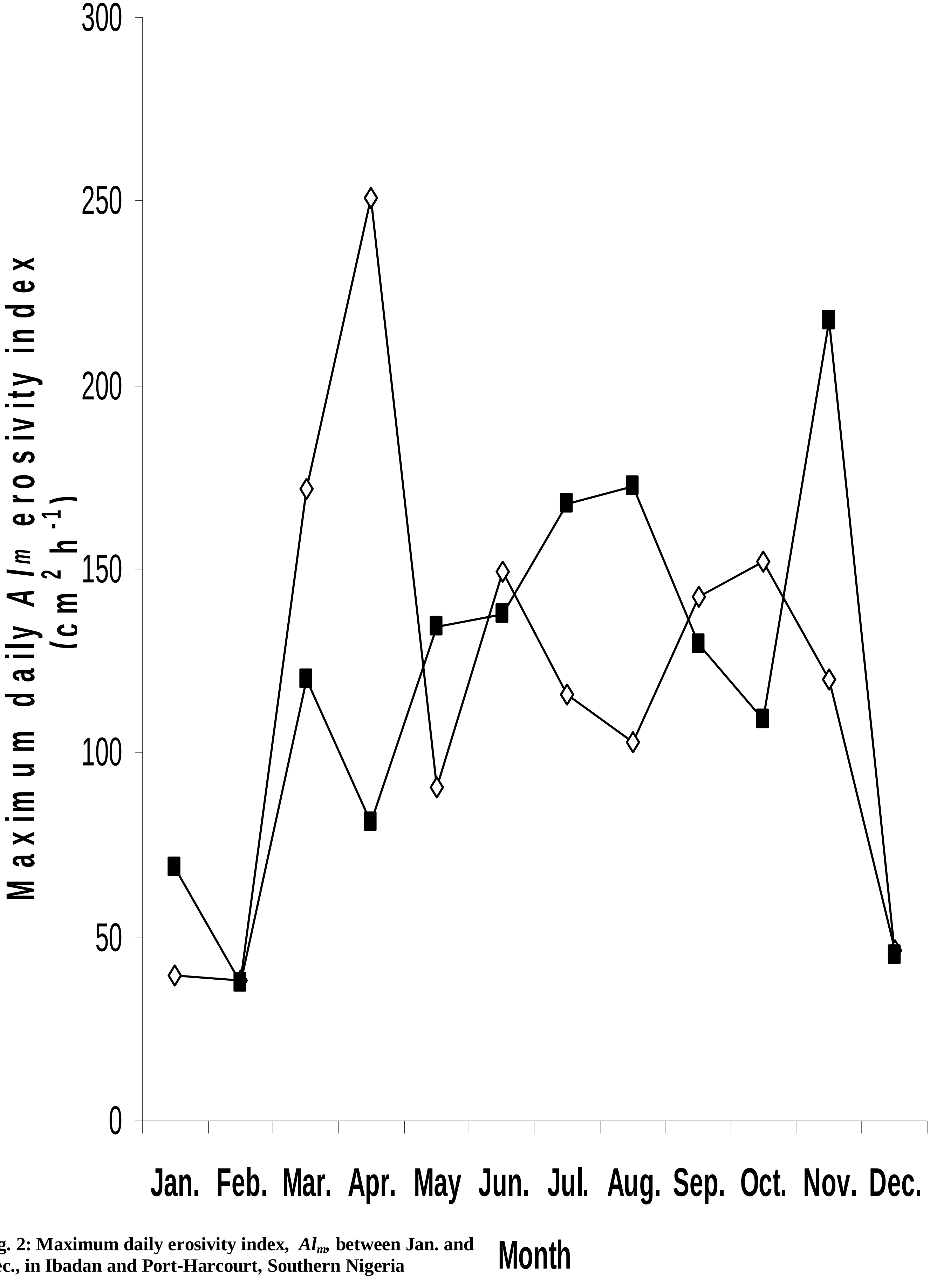

Fig. 2: Maximum daily erosivity index, *AI$_m$*, between Jan. and Dec., in Ibadan and Port-Harcourt, Southern Nigeria

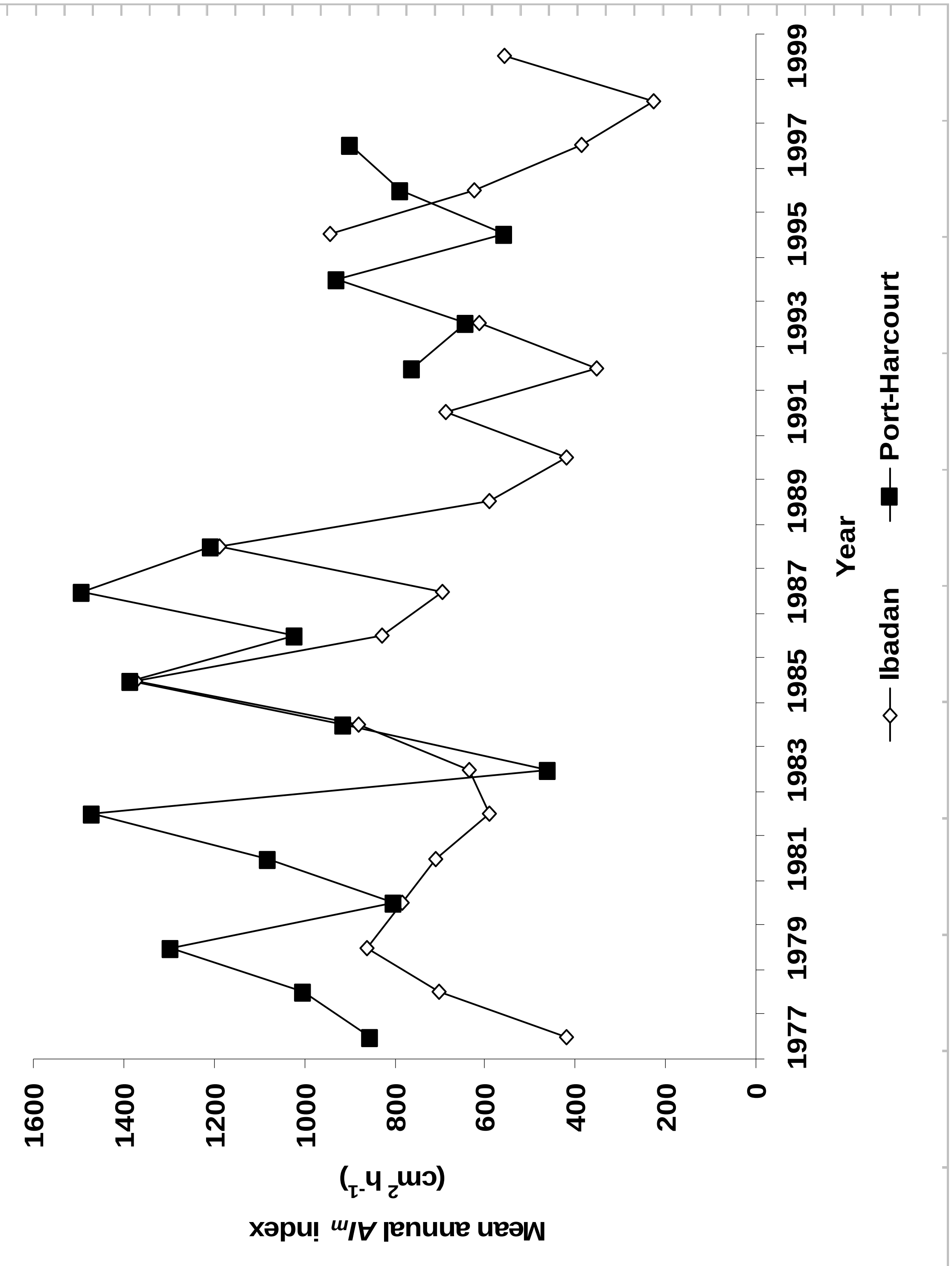

Fig. 3: Mean annual rainfall erosivity index, AI_m, between 1977 and 1999 in Ibadan and Port-Harcourt, Southern Nigeria

urt	684.2464	380.8644	1954.394	975.36
	266.5625	128.1722	473.3106	291.8976

1998	-1.72191
1999	-0.47533

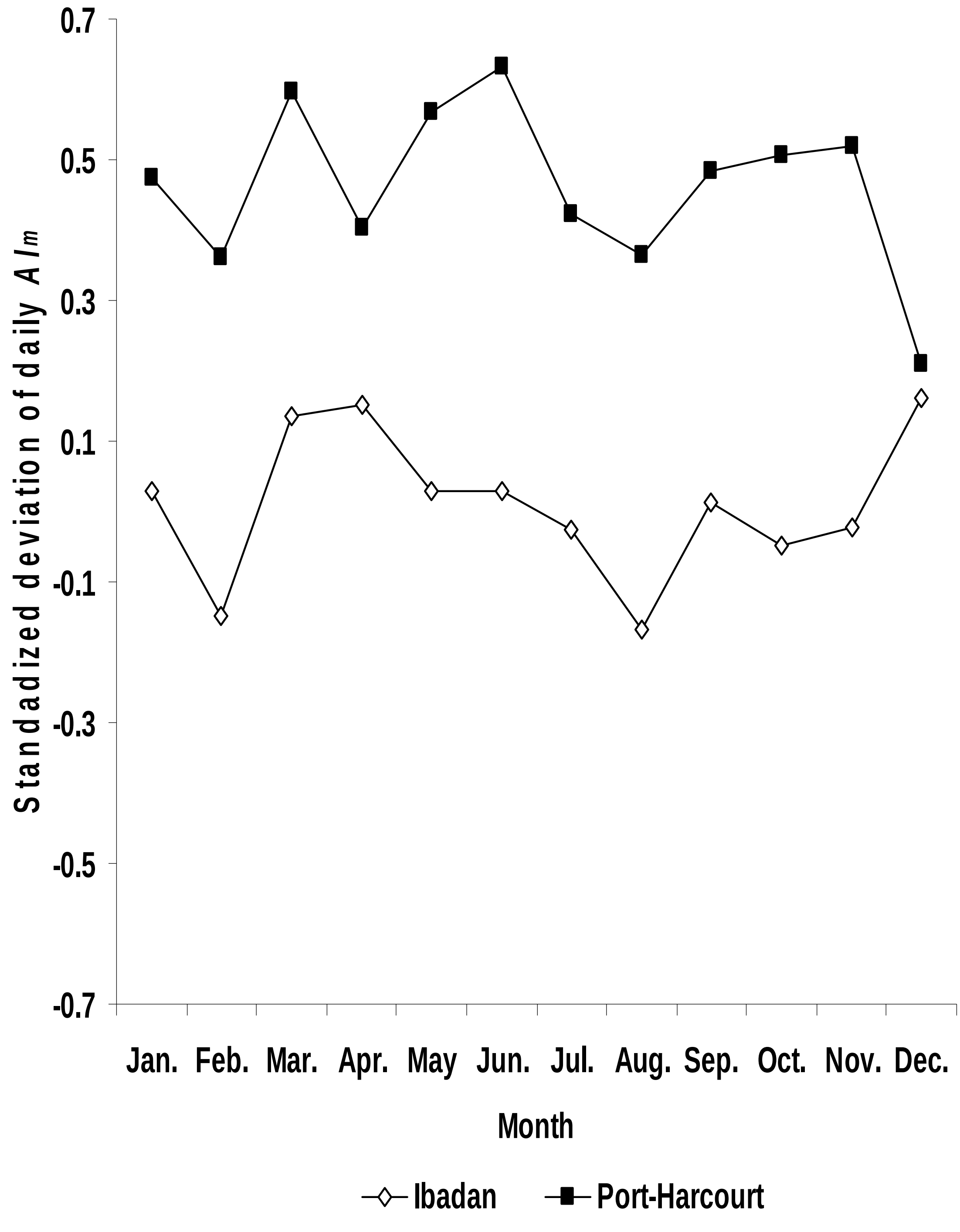

Fig. 4: Standardized deviations of daily rainfall erosivity between January and December in Ibadan and Port-Harcourt, Southern Nigeria

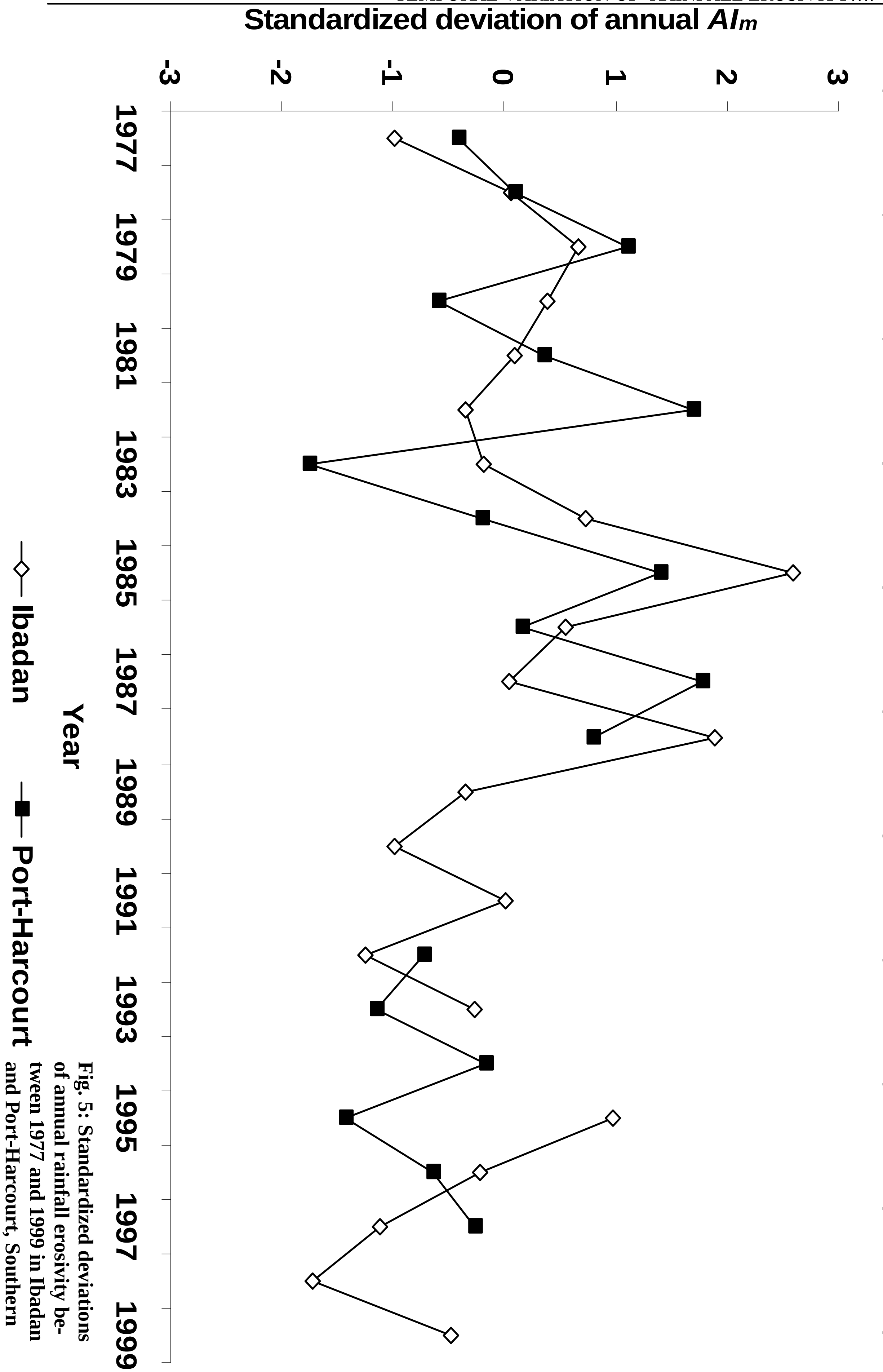

Fig. 5: Standardized deviations of annual rainfall erosivity between 1977 and 1999 in Ibadan and Port-Harcourt, Southern Nigeria