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SPECTRAL ANALYSIS OF RAINFALL SERIES IN KENYA

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ABSTRACT

Rainfall series in various parts of Kenya is subjected to spectral analysis. Contrary to past investigations, it is found that no rainfall behaviour at any rainfall station possesses a ten-year cycle neither is there any important five-year cycle. Most rainfall series in central Kenya possess an average cycle of between 2½ to 3½ years while those on the Coast and Lake Victoria area have a 2.2-year cycle. There are secondary cycles of various lengths for most stations.

SPECTRAL ANALYSIS OF RAINFALL SERIES IN KENYA

I. Introduction

Public policy makers and farmers in Kenya are concerned with rainfall variation. Long droughts have been responsible for crop failure and deaths of both domestic animals and wild life. On the other hand heavy rains following these droughts have caused flood damage in certain areas.

A study of rainfall variation was done by Lumb (1966) and Morth (1967) using rainfall data of the Lake Victoria catchment area. The data was analyzed in the time domain using autocorrelation functions of the rainfall series. They both discovered a 10 year cycle. This suggests that rainfall in most parts of Kenya would tend to possess this cycle due to common factors influencing rainfall behaviour in this country.

Obasiand Rodhe (1974) subjected annual rainfall series (averaged over 9 stations in central Kenya) to spectral analysis. Two prominent peaks of equal power were found. The two peaks had average periods of 3 and 5 years. Strictly speaking spectral power corresponding to the latter was stronger. There was a third peak with a period of about 20 years. This peak was, however, not very prominent. Failure to use spectral windows such as those suggested by Tukey, Parzen and others, was responsible for the artifical peaks in the spectrum.

The object of this paper is to investigate the validity of the existence of these periodicities using spectral methods of analysis.

2. A Review of the Theory of Spectral Analysis.

Time series data are formed by recording results of an experiment at equidistant points in time in an ordered form, say $x_1, x_2, \ldots\ldots, x_T$

The time series will exhibit widely fluctuating properties and the series itself is a function of time.

In studying the behaviour of a time series, statisticians usually decompose the series into a deterministic component (the trend), a cyclical component, a seasonal component and a purely random component. To gain detailed knowledge of the phenomena described by the series it pays to study each of these movements in isolation.

The trend and the seasonal component are deterministic and once they are known they are of little interest as long as conditions remain sufficiently stable.

The trend distorts spectral estimates near the lower frequency area. For monthly data, excessive power at seasonal frequenncies may obscure the existence of peaks at non-seasonal frequencies. Further, the existence of a trend may prevent the autocorrelation function from falling to zero at appropriate lags when the series is studied in the time domain. Moreover, spectral methods are only applicable to stationary series.

The first step, therefore, is to detrend and deseasonalize the data. For a single series the autocovariance function is given by

$$(2.1)\quad C_{xx}(\tau) = \frac{1}{n} \sum_{t-1}^{n-\tau} (X_t - \bar{X})(X_{t+\tau} - \bar{X}),$$

where $\bar{X} = \frac{1}{n} \sum_{t=1}^{n} X_t$ is the mean of the time series,

τ = lag or time delay,

n = the number of the observations under study.

It is sometimes useful to reduce the covariance function to its dimensionless form. This is achieved by dividing (2.1) by the variance to obtain the following autocorrelation funcation:

$$(2.2)\quad R_{xx}(\tau) = \frac{C_{xx}(\tau)}{C_{xx(0)}}$$

A plot of $R_{xx}(\tau)$ against τ is called a correlogram.

Alternatively, a time series may be described in the frequency domain by the Fourier transform of the autocorrelation function given by

$$(2.3)\quad f_{xx}(\omega_j) = \frac{1}{2\pi} \sum_{\tau=-M}^{M} R_{xx}(\tau)\lambda(\tau)\, e^{-\omega_j\tau}$$

$$= \frac{1}{2\pi}\left[R_{xx}(0)\,\lambda(0) + \sum_{\tau=1}^{M} R_{xx}(\tau)\lambda(\tau)\,\{e^{i\omega_j\tau} + e^{-i\omega_j\tau}\}\right]$$

$$= \frac{1}{2\pi}\left[1 + \sum_{\tau=1}^{M} R_{xx}(\tau)\lambda(\tau).\,\{\mathrm{Cos}\,\omega_j\tau + i\,\mathrm{Sin}\,\omega_j\tau + \mathrm{Cos}\,\omega_j\tau - i\,\mathrm{Sin}\,\omega_j\tau\}\right]$$

$$= \frac{1}{2\pi}\left[1 + 2\sum_{\tau=1}^{M} R_{xx}(\tau)\lambda(\tau)\,\mathrm{Cos}\,\omega_j\tau\right]$$

$$= \frac{1}{2\pi} + \frac{1}{\pi}\sum_{\tau=1}^{M} R_{xx}(\tau)\lambda(\tau)\,\mathrm{Cos}\,\omega_j\tau$$

where $f_{xx}(\omega_j)$ = estimate of normalized power spectrum averaged over a frequency band centered at ω_j,

M = the number of frequency bands to be estimated or the truncation point.

$\lambda(\tau)$ = is a lag window = 1 for $\lambda(0)$.

$\omega_j = \frac{2\pi j}{2M} = \frac{\pi j}{M}$, $j = 0, 1, \ldots, M$

$$(2.4.)\quad f_{xx}(\omega_j) = \frac{R_{xx}(0)\lambda(0)}{2\pi} = \frac{1}{2\pi}$$ is a flat white noise spectrum.

Apart from suggesting a model for the available data, spectral methods have certain advantages over correlation methods. These advantages are discussed in some detail by authors such as Granger and Hatanaka (1964), Nerlove (1964), Jenkins and Watts (1968) and many others.

If monthly data are used their spectrum will exhibit narrow and sharp peaks at seasonal frequencies, if the data possess a seasonal movement. Seasonal frequencies, periods, and the number of times a cycle is completed in a year are given in Table 1.

Table 1

Seasonal Frequency (cycles per month)	Period (Months)	Number of times cycle completed in a year
0.083	12	1
0.167	6	2
0.250	4	3
0.333	3	4
0.417	2.4	5
0.500	2	6

3. The Data

Monthly rainfall data recorded at Kabete station from 1916-1973 was used in the analysis. The data are given in Table 2. Annual data for the same station was available from 1910-1973. These are shown in Table 3 together with the data of other 8 stations in Central Kenya (columns 1 to 9).

TABLE 2

KABETE MONTHLY RAINFALL (millimetres)

					Month						
Year	J	F	M	A	M	J	J	A	S	O	N	D
1916	83	55	118	317	170	33	0	41	97	35	152	70
1917	163	90	223	323	200	154	18	68	53	120	40	3
1918	2	8	11	242	103	29	27	2	17	85	59	67
1919	3	114	70	175	129	31	62	40	0	81	115	21
1920	60	0	248	332	107	34	6	11	41	86	183	171
1921	24	48	37	224	39	9	9	19	0	27	130	85
1922	97	86	265	342	119	16	17	37	56	97	58	152
1923	55	110	242	374	419	59	24	8	15	53	165	34
1924	0	27	138	171	80	22	7	50	3	18	139	57
1925	181	44	136	84	73	33	20	28	0	33	114	66
1926	38	29	144	231	152	26	13	34	67	66	158	15
1927	27	24	213	195	129	43	14	0	0	53	73	59
1928	19	6	45	125	350	47	1	12	5	68	169	46
1929	15	1	3	371	148	3	49	29	71	77	137	189
1930	74	82	262	387	334	23	12	4	8	70	155	37
1931	28	52	173	394	122	44	16	20	107	102	104	108
1932	74	36	189	299	169	27	24	16	19	52	92	158
1933	144	0	37	56	58	7	17	54	10	65	123	85
1934	3	25	33	126	193	49	31	10	0	65	48	67
1935	0	150	48	108	121	62	0	53	12	53	144	117
1936	96	142	148	218	53	67	6	12	14	66	89	104
1937	8	1	191	331	331	112	4	17	16	146	243	96
1938	30	56	125	105	101	7	9	9	38	37	149	118
1939	22	17	138	233	46	9	13	17	17	27	59	6
1940	49	66	106	271	300	38	41	14	1	50	92	37
1941	35	113	144	343	187	85	2	12	1	7	89	190
1942	21	42	245	269	221	87	28	36	1	30	41	114
1943	1	80	44	184	65	44	2	20	10	9	77	57
1944	22	0	90	172	33	21	23	8	64	65	131	70
1945	43	74	57	43	210	104	69	37	24	1	155	29
1946	10	3	21	147	145	15	11	70	138	217	66	48
1947	101	28	180	343	332	105	32	2	48	8	79	57
1948	9	6	98	210	122	77	3	39	23	69	93	200
1949	1	38	17	260	58	10	3	24	18	10	63	123
1950	38	19	114	254	73	22	8	45	9	74	81	11
1951	11	4	100	352	315	126	32	24	3	103	144	225
1952	16	24	29	376	207	1	11	6	44	22	79	24
1953	33	0	45	135	198	42	17	34	36	53	132	34
1954	37	76	1	303	297	26	36	17	5	34	113	28
1955	54	75	33	207	133	3	17	15	28	66	58	220
1956	202	91	99	175	136	9	10	10	10	122	32	42
1957	157	25	43	201	450	95	11	6	51	65	175	87
1958	25	160	36	141	346	44	93	1	8	10	55	55
1959	20	79	116	78	130	1	15	54	21	41	288	57
1960	41	7	248	192	109	33	7	10	32	79	76	33
1961	3	13	76	175	152	28	33	38	48	178	549	371
1962	201	43	41	180	302	58	3	41	10	86	117	127
1963	87	55	103	385	465	29	5	65	19	7	176	319
1964	50	120	56	436	135	17	28	70	12	29	78	94
1965	75	8	23	322	80	48	14	10	7	89	143	163
1966	147	51	203	220	112	41	4	64	19	46	165	48
1967	0	9	24	285	488	37	26	44	44	138	136	40
1968	0	123	210	246	185	48	6	6	6	52	285	163
1969	82	90	104	40	119	3	6	40	9	33	111	14
1970	132	3	132	423	166	35	10	6	10	29	131	35
1971	68	11	27	235	300	23	27	20	20	24	74	134
1972	17	83	57	28	171	115	17	8	49	198	146	31
1973	140	65	8	232	43	42	4	9	62	19	107	41

Source: East African Meteorological Department

TABLE 3

ANNUAL RAINFALL(millimetres):

CENTRAL KENYA, KISUMU, LODWAR AND MOMBASA.

(1) YEAR	(2) EMBU	(3) KABETE	(4) KIAMBU	(5) MACHAKOS	(6) MERU	(7) MURANGA	(8) NAKURU	(9) NGONG	(10) NYERI	(11) AREAL	(12) KISUMU	(13) LODWAR	(14) MOMBASA
1891													1182
1892													682
1893													1630
1894				1066									964
1895				1316									873
1896				658									1[illegible]57
1897				805									1335
1898				617									561
1899				543									893
1900				1481									1565
1901				1004		1144							1477
1902				1085		1209							1224
1903				911		1319					1513		860
1904				728		1230	668		684		1090		1518
1905				1085		1222	929		1152		1353		1445
1906				1214		1139	783		1225		1810		1863
1907				835		1313	1006		815		773		1180
1908	945		968	716		1023	973		718		1337		1345
1909	1117		915	763		1269	859		1045		860		1592
1910	882	705	672	700	1128	1007	691	581	748	790	831		874
1911	907	1100	1101	971	1250	1221	727	780	854	990	924		1087
1912	1371	1440	1481	1425	2000	1537	1040	1256	954	1389	1176		955
1913	1091	900	889	1196	1550	1126	890	768	1095	1056	1096		1089
1914	1164	1125	1134	886	1697	1239	970	726	683	1069	1241		845
1915	1090	1050	1054	893	1457	1310	904	693	766	1024	1191		1459
1916	1194	1171	1137	898	1409	1352	1135	957	879	1126	1430		1076
1917	1157	1455	1401	1009	1722	1503	1733	1193	1322	1388	1779		1037
1918	948	652	779	679	1287	913	622	388	770	782	825		897
1919	1065	841	1188	1181	1176	986	1039	933	1075	1054	1186		999
1920	1162	1279	1197	912	1142	1187	979	1188	1281	1147	1058		1404
1921	860	651	637	404	866	707	651	628	662	674	1042		994
1922	1017	1342	1234	1073	1037	1130	881	926	877	1063	1165	44	1887
1923	1208	1518	1551	1156	1582	1313	1137	1200	1187	1317	1430	249	917
1924	901	712	638	797	1243	699	738	814	933	831	924	107	892
1925	721	812	855	879	1040	853	672	635	720	799	1178	49	1316
1926	1515	973	969	1020	1609	1328	920	958	1076	1151	1257	232	1094
1927	842	830	816	1165	1537	747	650	673	800	896	820	55	1074
1928	885	893	826	588	1223	1056	736	767	979	884	1102	131	1059
1929	1008	1093	1138	747	1389	1152	717	670	1149	1007	876	88	1297
1930	1176	1525	1658	1283	1950	1473	1292	1292	1094	1416	1239	193	1004
1931	1244	1196	1239	1105	1496	1344	867	804	870	1129	975	63	1306
1932	1059	1155	1047	1100	1479	1436	989	824	1102	1132	1330	119	1345
1933	858	655	816	836	1194	885	666	485	909	812	1066	185	1031
1934	960	648	630	703	1188	1070	569	512	856	782	957	82	1580
1935	1027	868	1190	876	1353	1076	684	763	984	980	1218	198	1293
1936	1145	1035	965	1028	1414	1169	938	1026	921	1071	1198	369	1498
1937	1186	1486	1661	1252	1584	1784	949	1122	1072	1344	1339	186	1469
1938	1142	784	851	757	1858	1008	824	861	750	915	1554	206	1376
1939	562	603	556	529	988	653	610	424	694	624	879	155	1037
1940	1263	1065	1203	790	1127	1221	865	891	917	1038	1310	132	1633
1941	972	1188	1212	1073	1482	1273	959	881	803	1094	1336	221	1285
1942	1110	1135	921	927	1075	1253	840	926	907	1010	1017	210	1087
1943	847	593	679	524	1103	1250	750	504	660	768	936	86	938
1944	842	699	780	867	1138	703	655	632	743	784	1228	83	1296
1945	692	846	965	484	800	892	929	727	875	801	862	259	1233
1946	1401	891	946	687	1417	1197	663	500	660	929	1421	64	1263
1947	1273	1316	1467	1242	1593	1400	1087	1002	1279	1296	1100	257	1881
1948	1030	949	869	962	1627	1201	907	688	623	984	872	173	1221
1949	600	625	615	590	825	769	752	433	459	630	951	77	724
1950	1200	748	885	651	1627	1302	757	605	757	998	763	933	915
1951	1361	1439	1630	1585	2216	1761	1098	1153	1308	1506	1562	183	1529
1952	648	839	883	786	940	957	786	979	710	836	1125	154	710
1953	1117	759	661	760	1536	1300	699	401	821	896	974	133	1552
1954	1210	974	826	928	1044	1329	1088	726	937	1007	980	640	841
1955	730	909	959	937	1252	877	940	671	1078	928	850	168	846
1956	1016	942	845	539	1388	1345	967	674	906	958	1007	96	1082
1957	1231	1365	1479	1043	1575	1340	741	1325	1268	1263	943	169	1214
1958	1230	973	1355	1022	1404	1498	1055	704	1020	1140	915	405	1017
1959	943	901	9939	673	1281	1063	718	635	1007	907	710	306	1319
1960	742	865	966	797	1217	938	760	672	712	852	963	125	1077
1961	1961	1664	1694	1547	2950	1885	1411	1455	1615	1798	1497	498	1336
1962	890	1209	1062	823	1298	1235	919	1068	757	1029	1517	202	760
1963	1586	1715	1768	1393	2067	1998	1050	1605	1140	1591	1274	214	1231
1964	1004	1125	915	753	1624	1061	947	875	1071	1042	1172	165	763
1965	908	982	781	702	946	1028	471	705	707	803	875	184	1068
1966	1097	1118	989	729	1494	1026	768	791	948	996	1157	262	1419
1967	1492	1271	1285	1040	2150	1601	662	1280	1158	1327	1011	481	1543
1968	1797	1330	1253	1191	2270	1812	782	1077	1332	1449	1262	224	2151
1969	871	651	575	859	1471	910	654	531	730	806	1005	191	978
1970	882	1112	973	776	1004	1159	1056	770	981	968	1001	175	736
1971	763	963	1192	890	957	965	866	727	732	895	698	91	717
1972	1181	922	890	721	1700	1389	845	793	958	1045	1485	206	1622
1973	638	772	620	804	1000	720	727	572	962	757		212	1202
1974												290	

Source: East African Meteorological Department.

An areal average for the 9 stations in Central Kenya is shown in column (10) of the table. The longest series in Central Kenya is that of Machakos and Muranga whose recording started in 1894 and 1901 respectively.

It was also necessary to study annual rainfall variation on the East Coast, the arid North and the Lake Victoria area. Kisumu station (column 11) was chosen to represent the Lake Victoria region. This station has fairly long data starting from 1903 to 1974. The data for 1955 was not recorded and the value used for that year was an estimate. In addition the annual data for the Lake Victoria catchement was also used. This data was used by Mörth (1967) for the period 1899-1937. The data was estimated by regression methods over a very long period and is likely to be in errors. Further, although this series was used it is rather too short for spectral analysis. It is not shown here.

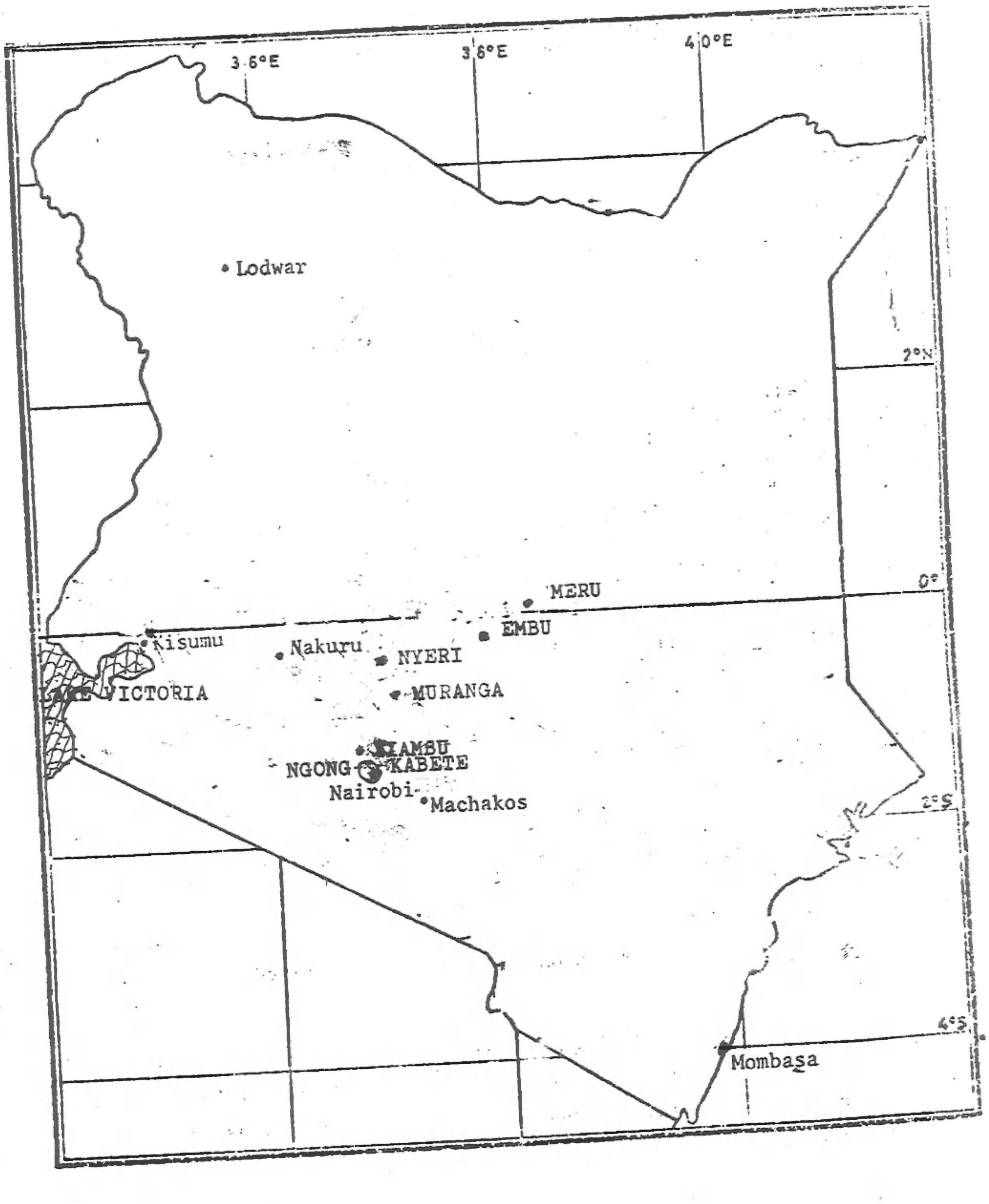
The arid North is represented by annual rainfall data read at Lodwar from 1922 to 1974 (column 12). There was no data for the war years 1939, 1940 and 1941. The values for these years were estimated.

Mombasa representing the coastal area has the longest and uninterrupted data of all the stations. The data for this station starts from 1891 to 1973. These are given in column 13 in Table 3.

The geographical position of the meteorological stations mentioned above are shown in Figure 1.

Figure 1

MAP OF KENYA SHOWING RAINFALL
STATIONS USED IN THE ANALYSIS



4. Spectral Analysis of the Data

The spectral window used was Parzen's with a trunction point M = 50 for monthly series and M = 15 for all annual series.

The first data to be subjected to spectral analysis was the Kabete monthly series in their original form. The spectrum[1] in Figure 2 shows very high power in the low frequency area represented by frequencies less than 0.03 cycles per month or periods greater than 33 months. This implies the existence of an upward trend in the data over the sample period. The power densities at low frequencies is so domineering that peaks at seasonal frequencies, corresponding to those in Table 1, have been considerably reduced or disappeared altogether.

To remove excessive power at low frequency the data were prewhitened by the method of first differences. The spectrum of the pre-whitened series is in Figure 3. Not only are peaks prominent at the majority of seasonal frequencies, they have also become narrower and sharper as expected. The peak with an average period of 6 months, contributing about 68% to total variance, is the most important. The 12 month cycle contributes less than 14% and is the least important of the existing peaks. There are no peaks at the frequency band centred at 0.417 cycles per month.

When the Kabete annual series was subjected to spectral analysis power density was so dominant at low frequencies that no peak was found in the middle frequency band nor in the high frequency band. As a result it was decided to pre-whiten all the data used in the rest of this paper.

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[1] See Appendix

Figure 4 shows the normalized spectral density function for the pre-whitened Kabete annual series. The spectrum is dominated by a peak associated with a 3.2 year cycle. There is a less important 5-year cycle corresponding to the frequency band centred at 0.2 cycles per year or 2 cycles per decade.

The spectrum of the areal average of nine stations in Central Kenya is different from the Kabete spectrum in that it possesses an extra peak associated with a 2.2 year cycle as shown in Figure 5. This cycle is more important than the 5-year cycle. However, the most important cycle in the spectrum is the one corresponding to the 3.2 year cycle.

The dissimilarity between the spectrum of the average series and that of Kabete which is a part of the areal average demands that a few of the stations in the area be studied individually. Additional stations studied, were Machakos, Meru and Nakuru.

The spectrum of Machakos is in Figure 6. There is a "strong" peak corresponding to a frequency band centred at 0.2 cycles per year. This indicates a dominant cyclical component whose period is 3 1/2 years. There is a subsidiary peak cprresponding to a cycle of 2 1/2 years. Spectral power drops rapidly at frequencies lower than 0.2 cycles per year and those higher than 0.4 cycles per year.

Like the Machakos spectrum, the Meru spectrum in Figure 7 does not possess a 5-year cycle. Rather, the spectrum has one peak lasting for an average period of 2.6 years. At high frequencies the spectrum is flat. This indicates the existence of White noise at frequencies higher than 0.45 cycles per year.

The last of the stations to be analysed in central Kenya is Nakuru whose spectrum is in Figure 8. The 2.5 year cycle contributes about 31% to total variation, while the 3.1 year cycle contributes 29%. There are no peaks at frequencies lower than 0.325 cycles per year.

Now it seems clear that the 2.2 period in the spectrum of the areal average is a result of the Machakos' 2.6, Meru's 2.5 and Nakuru's 2.5 year cycles, together with similar cycles of the stations not analysed individually. The 3.2 year cycle is a combination of Machakos' 3.5, Kabete's 3.2 and Nakuru's 3.2 year cycles. The 5 year cycles is a reflection of the 5 year cycles in the Kabete spectrum.

The spectrum of Lake Victoria catchment area is shown in Figure 9. There is an important peak indicating a cylical component with a period of 3.2 years. A secondary peak exists corresponding to a cycle of 2.2 years. As mentioned earlier these data cannot be relied upon. To check on the realities of the periodicities of these data, the data recorded at Kisumu PC's office was analysed. Rainfall at this station should be influenced by the factors influencing rainfall in the Lake Victoria area in general. The Kisumu spectrum in Figure 10 is similar to that of the Lake Victoria catchment area in that both spectra have a peak corresponding to a 2.2 year cycle and dissimilar in that there is no 3.2 year cycle in the Kisumu spectrum. There is a negligible contribution at the peak with a 5 year period.

Mombasa spectrum (Fig. 11) like Kisumu has a dominant 2.2 year cycle with a peak contributing to 33% of total variance. There is also a second peak with a period of 3.2 years.

Figure 12 shows that the most important peak for Lodwar rainfall series is the one corresponding to a 2.3 year cycle. A 3.3 year cycle is also important. There is no sign of a period longer than this.

Table 4 is a summary of the results of the above analysis. The table also provides a contrast of the spectra by the number of peaks and by distinguishing important cycles by the amount of contribution to total variance by components of various periods. The dominant peaks for Kisumu, Mombasa and Lodwar correspond to cycles of about the same periods.

Table 4

Contribution to Variance by Components Corresponding to Peaks in the Spectra.

Period (Years)	Kabete	Areal Ave.	Machakos	Meru	Nakuru	Lake Victoria	Kisumu	Mombasa	Lodwar
2.2		26%				29%	32%*	33%*	
2.3									32%*
2.5			23%		31%*				
2.6				28%*					
3.1					29%				
3.2	30%*	28%*				35%*		23%	
3.3									29%
3.5			28%*						
5.0	19%	20%					12%		

* most dominant peak

Usually stability is achieved by widening the frequency band although this is done at the expense of fidelity or resolution. Band width is inversely related to the truncation point. Thus the reduction of the truncation point may lead to the disappearance of the weak peaks in the spectrum.

Figure 13 shows the nine spectra resulting from the reduction of M from 15 to 6. Most spectral power is now concentrated at high frequencies. All spectra are fairly smooth below 2.9 cycles per decade.

Table 5 is a summary of the results of these spectra. Each spectrum has one peak corresponding to periods in the first comlumn of the table. A station possessing that period is indicated by a star.

The Kisumu and Mombasa spectra are very similar. Both have a 2 year cycle. On the other hand Meru, Nakuru and Lodwar are now alike in that they all possess a cycle of a period ranging from 2 to 2.2 years. Lake Victoria catchment area has a cycle exceeding that of Kisumu by almost two months. The three-year cycles for Kabete and the nine stations in Central Kenya, as well as the 3 1/2 year cycle for Machakos have peaks showing up very clearly even at this low truncation point.

Table 5

Important peaks when M = 6

Period (Years)	Kabete	Areal Ave.	Machakos	Meru	Nakuru	Lake Victoria	Kisumu	Mombasa	Lodwar
2							*	*	
2-2.2				*	*				*
2-2.4						*			
2.7-3	*	*							
3.4			*						

5 Conclusion

The spectra of all the rainfall series reveal that high frequencies contribute much more to the variance of the process than do the low frequencies. There is, therefore, no possibility of cycles of more than 5 years.

In central Kenya Meru, and Nakuru rainfall patterns possess an approximately 2 1/2 year cycle. The latter, however, has a secondary peak corresponding to a cycle of about 3 years. Machakos has two cycles, one dominant cycle of 3 1/2 years and a less dominant cycle of 2 1/2 years. Kabete has a definite 3.2 year cycle. A second peak lasting 5 years is insignificant.

Kisumu, Mombasa and Lodwar have dominant 2.3 year cycles approximately. The last two of these rainfall stations have secondary peaks lasting for a period of approximately 3.3 years. The similarities of the 3 stations may be ascribed to their proximity to large masses of sea and lake waters.

The spectrum for the Lake Victoria catchment area is dissimilar from the spectra of rainfall stations near large masses of water in that the dominant peak occurs with a period of 3.2 years as opposed to 2.3 years. Its secondary peak rather than correspond to a 3.2 year cycle, corresponds to a 2.3 year cycle. This is the reverse of the other stations in similar situations. This may be ascribed to three causes.

1. That the series is too short to have any meaningful application of spectral methods.
2. The data was estimated by regression methods for too long a period creating uncertainties about the accuracy of the estimates.
3. The averaged data may have included a station (or stations) with a different rainfall pattern.

What is interesting,however,is that the 10 year cycle claimed by earlier research workers, using these data, does not exist. The maximum period found is about 3 years. Even this is doubtful when compared to the dominance of the 2.3 year cycle found in the spectra of the other 3 stations in similar conditions.

This investigation has further revealed that if the study of periodicities in the rainfall series is carried out for the purpose of policy-making, the use of areal averages may be misleading. Rather, individual analysis of rainfall behaviour at a particular station is more appropriate.

Rainfall behaviour in Kenya suggests, therefore, that irrigation schemes capable of combating drought for periods upto about 4 years are required, Areas near masses of water require shorter periods. However, for the more arid areas of the country such as Lodwar irrigation schemes lasting for infinite periods are required since the highest amount of rainfall recorded here is insufficient for most useful crops. The use of land surrounding lakes for agricultural purposes must be encouraged not only because of irrigation facilities the lakes provide but also because of the shorter periods of drought that exist near these surroundings.

6. Appendix

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09/20/10      20/01/75      ICL  1900 STATISTICAL ANALYSIS      XD53/22
TIME SERIES ANALYSIS    MATRIX  MASAYA  VARIABLE  MONTH
WINDOWED NORMALIZED SAMPLE SPECTRAL DENSITY FUNCTION
COMPUTATION NUMBER IS        100
TRUNCATION POINT IS         50
WINDOW TYPE IS              PARZEN
```

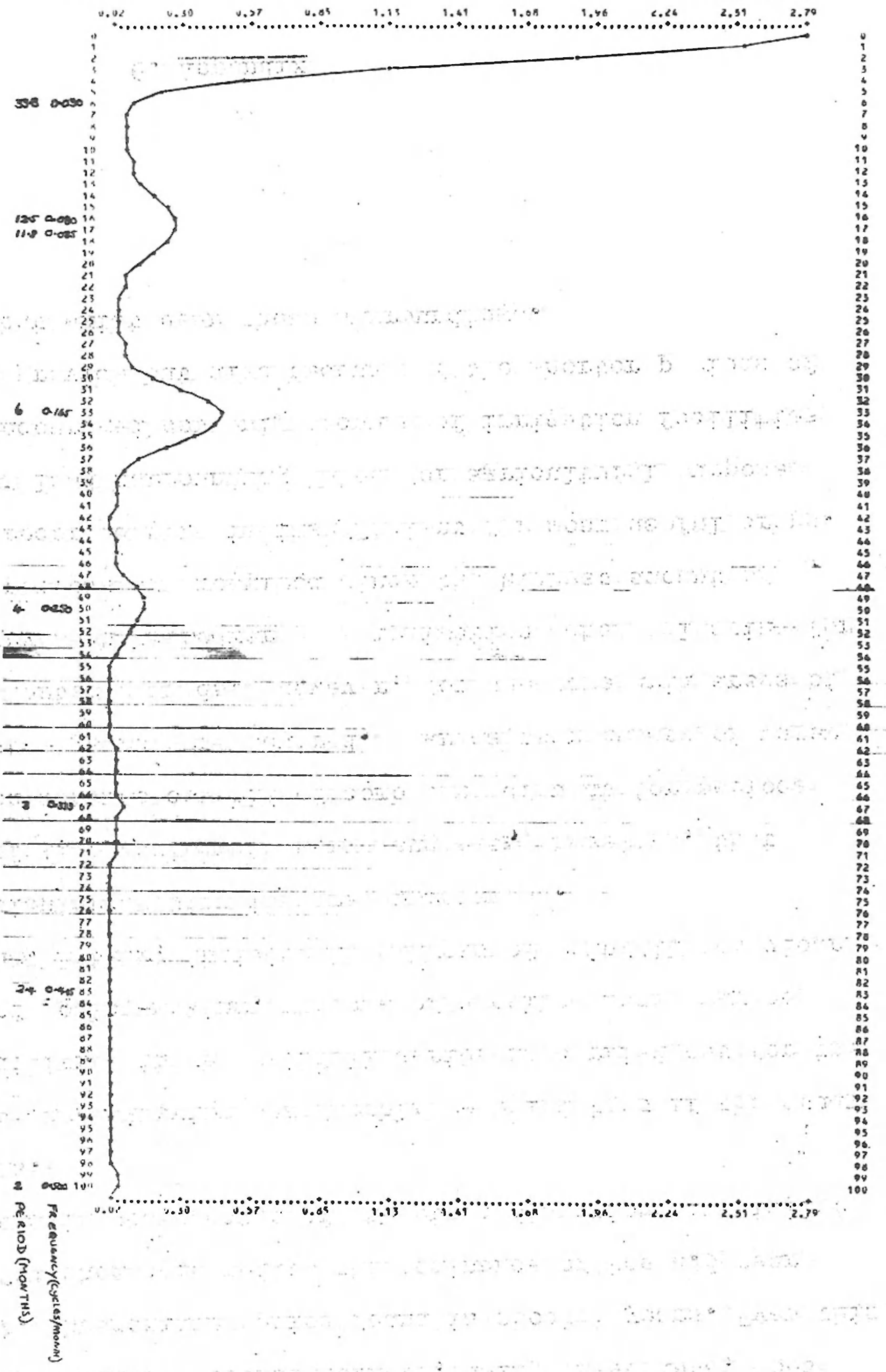


Figure 3

SPECTRUM OF KABETE MONTHLY RAINFALL
(Prewhitened)

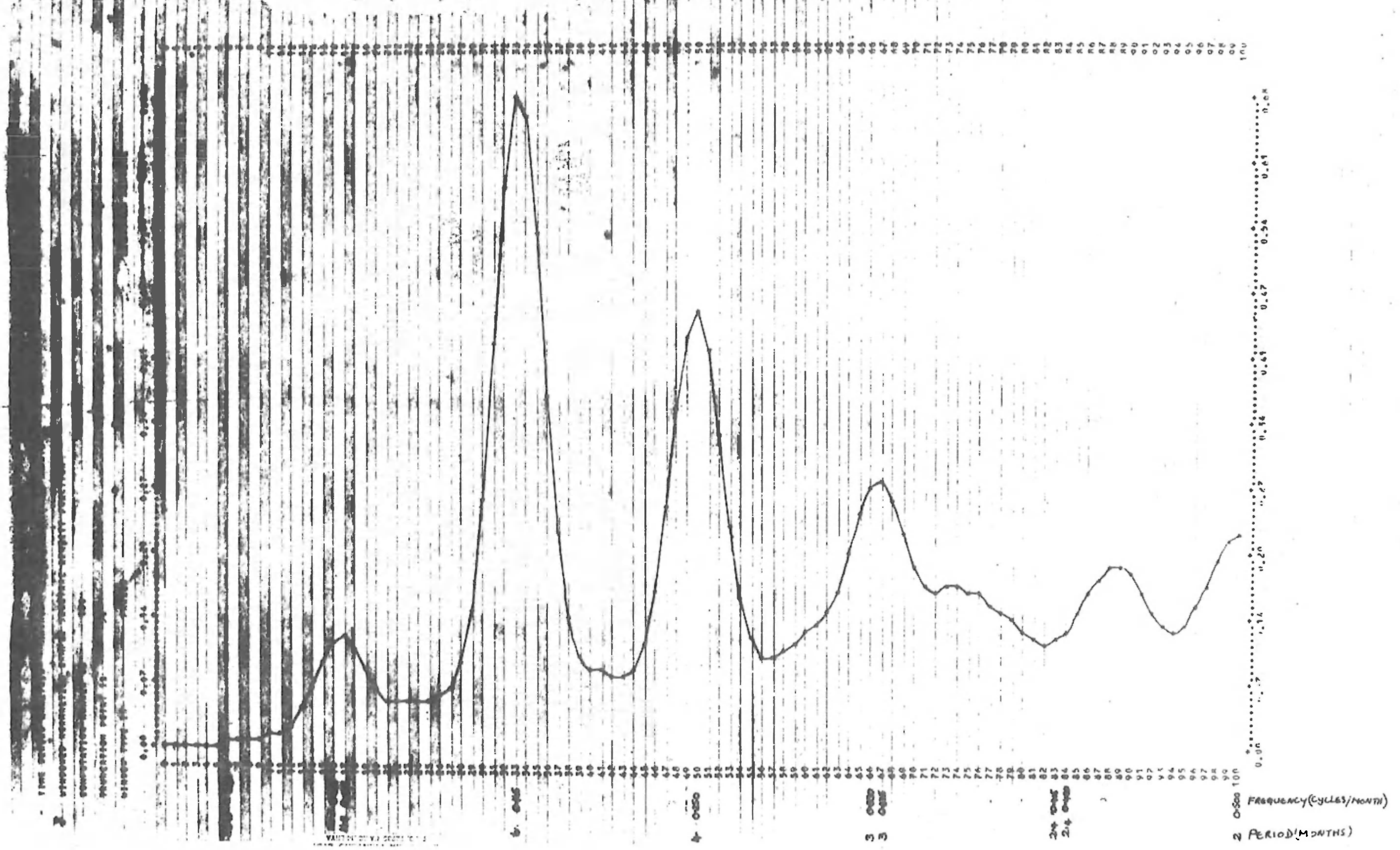


Figure 4

SPECTRUM OF ANNUAL RAINFALL AT KABETE.

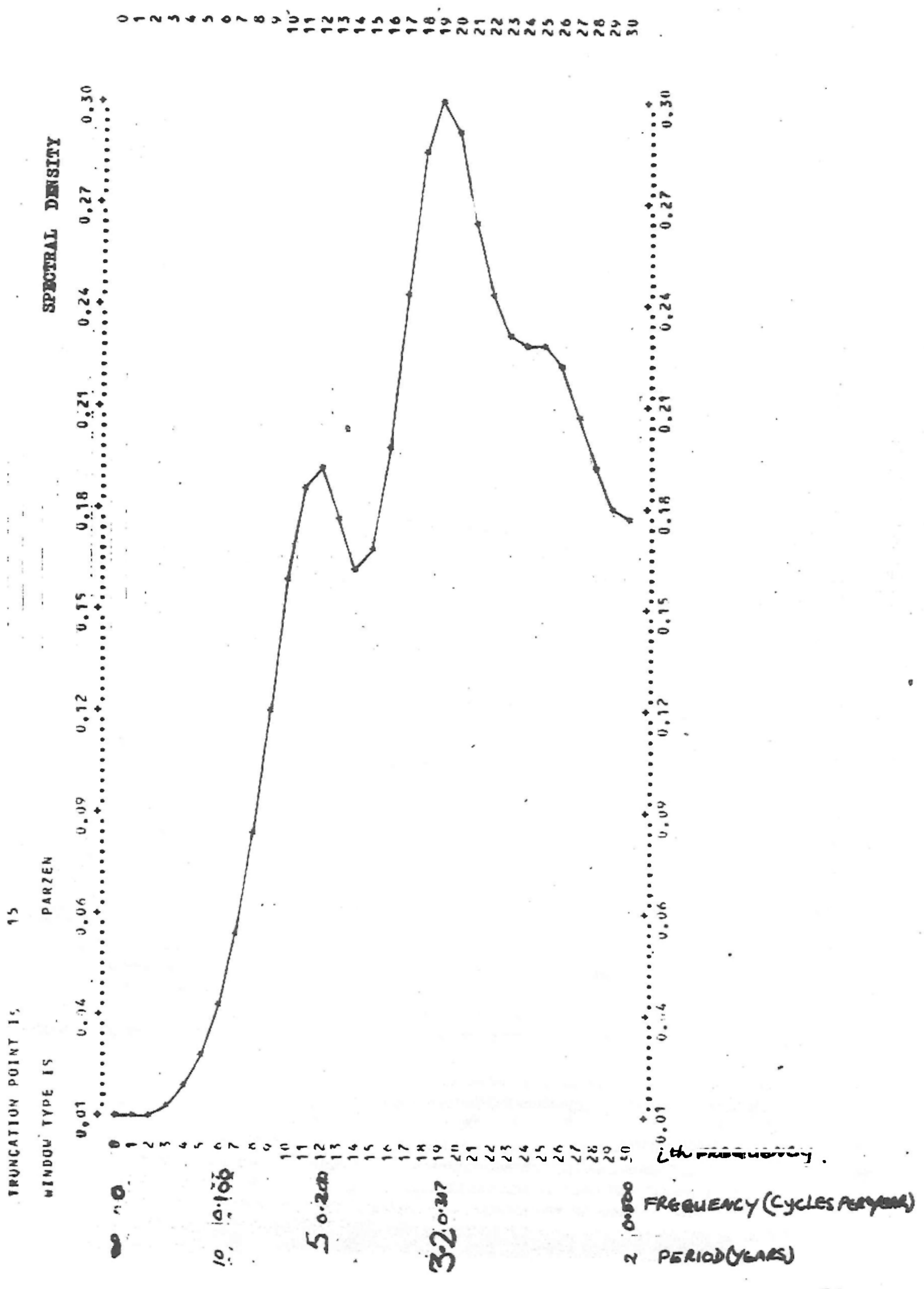


Figure 5

SPECTRUM OF ANNUAL RAINFALL AVERAGED OVER 9 STATIONS IN CENTRAL KENYA.

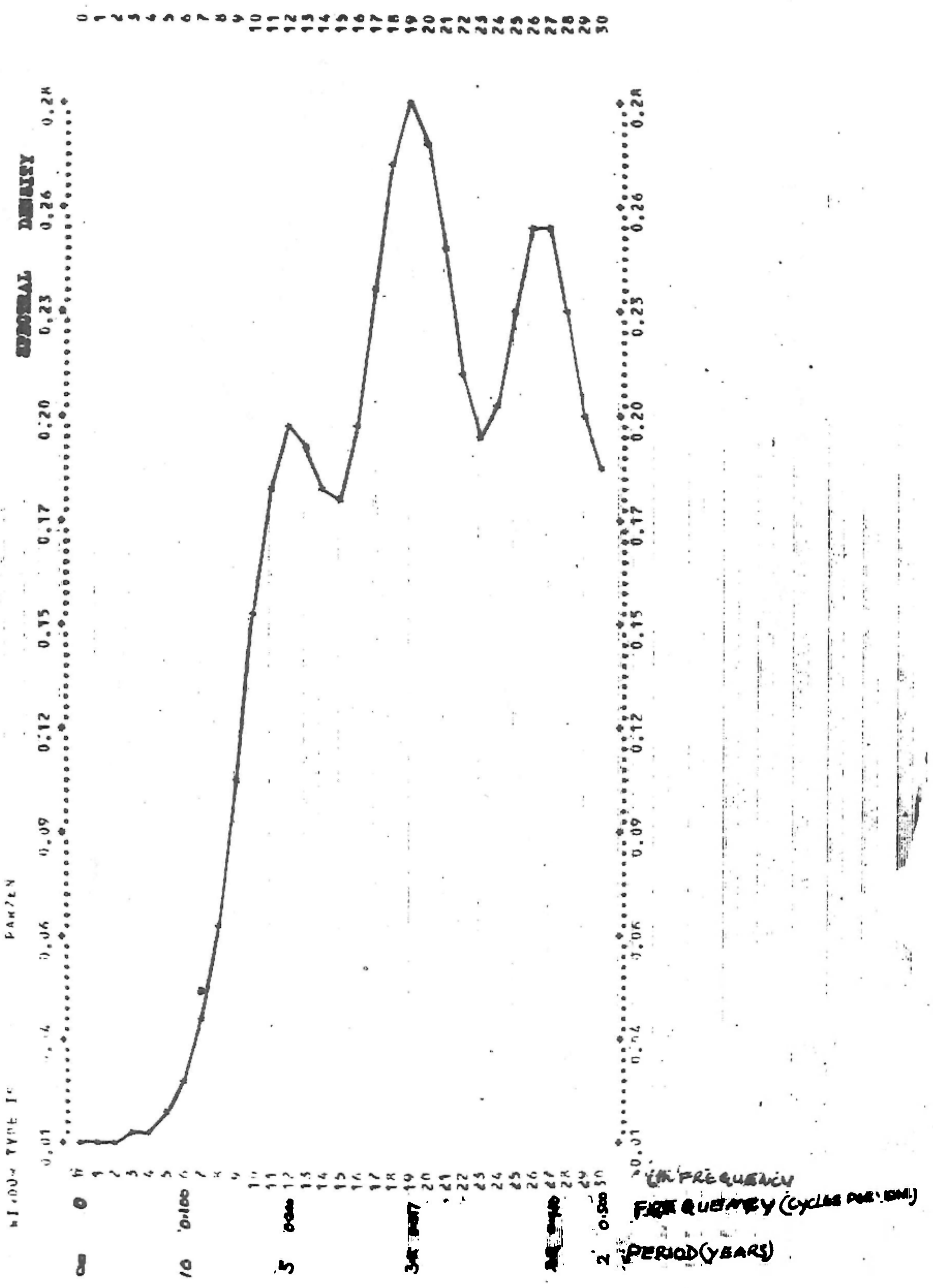


Figure 6
SPECTRUM OF ANNUAL RAINFALL AT MACHAKOS

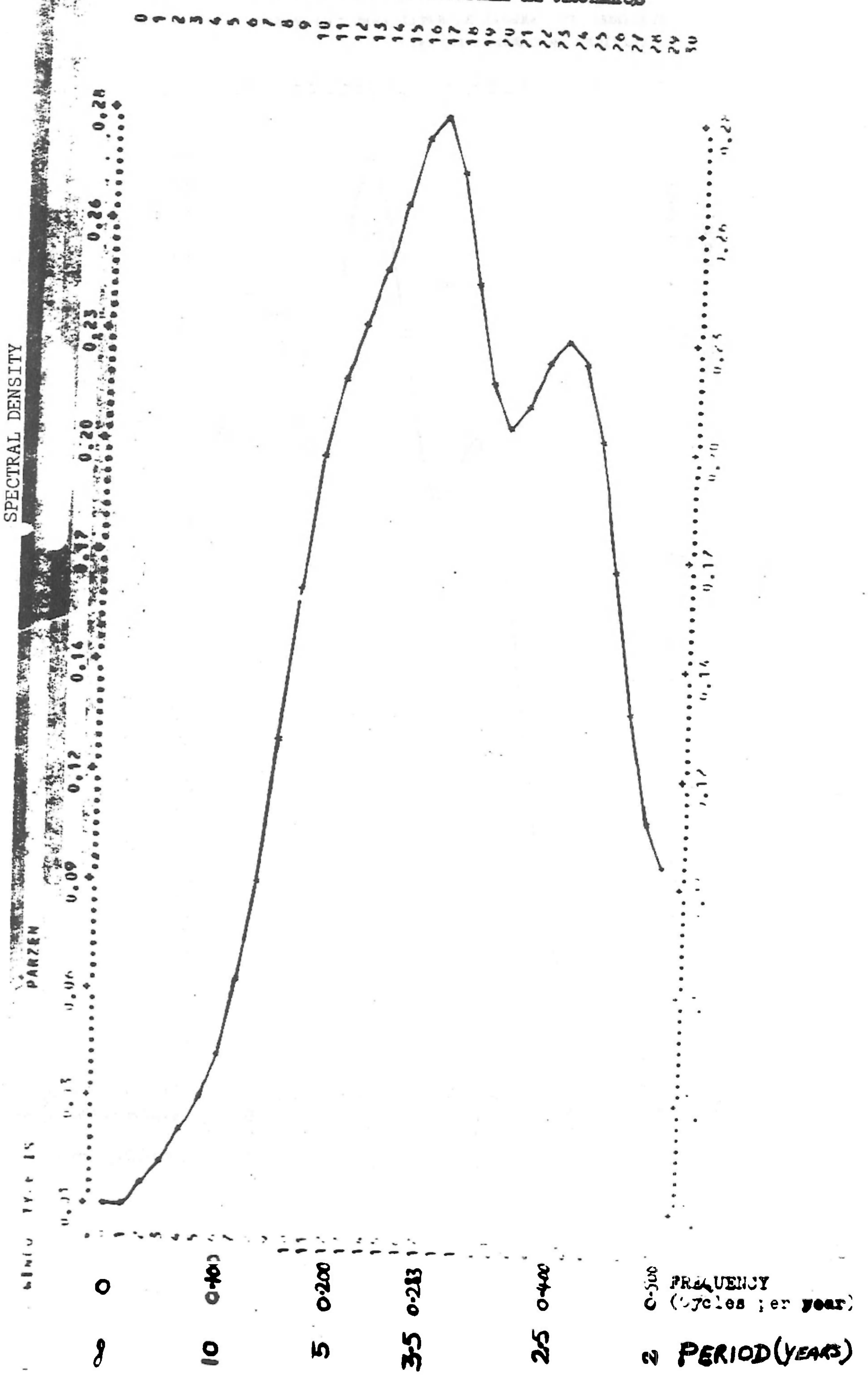


Figure 7

SPECTRUM OF ANNUAL RAINFALL AT MERU

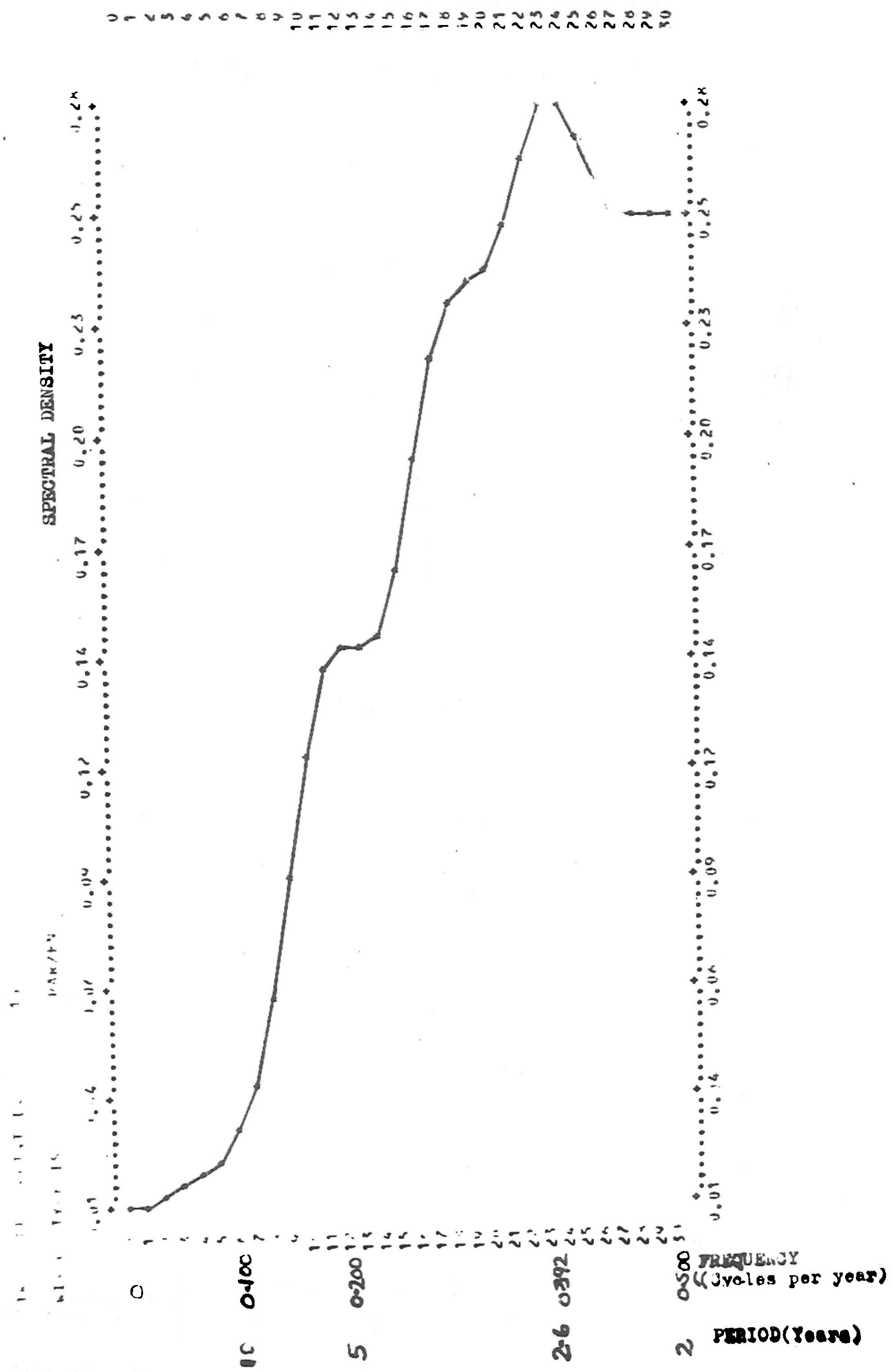


Figure 8

SPECTRUM OF ANNUAL RAINFALL AT NAKURU

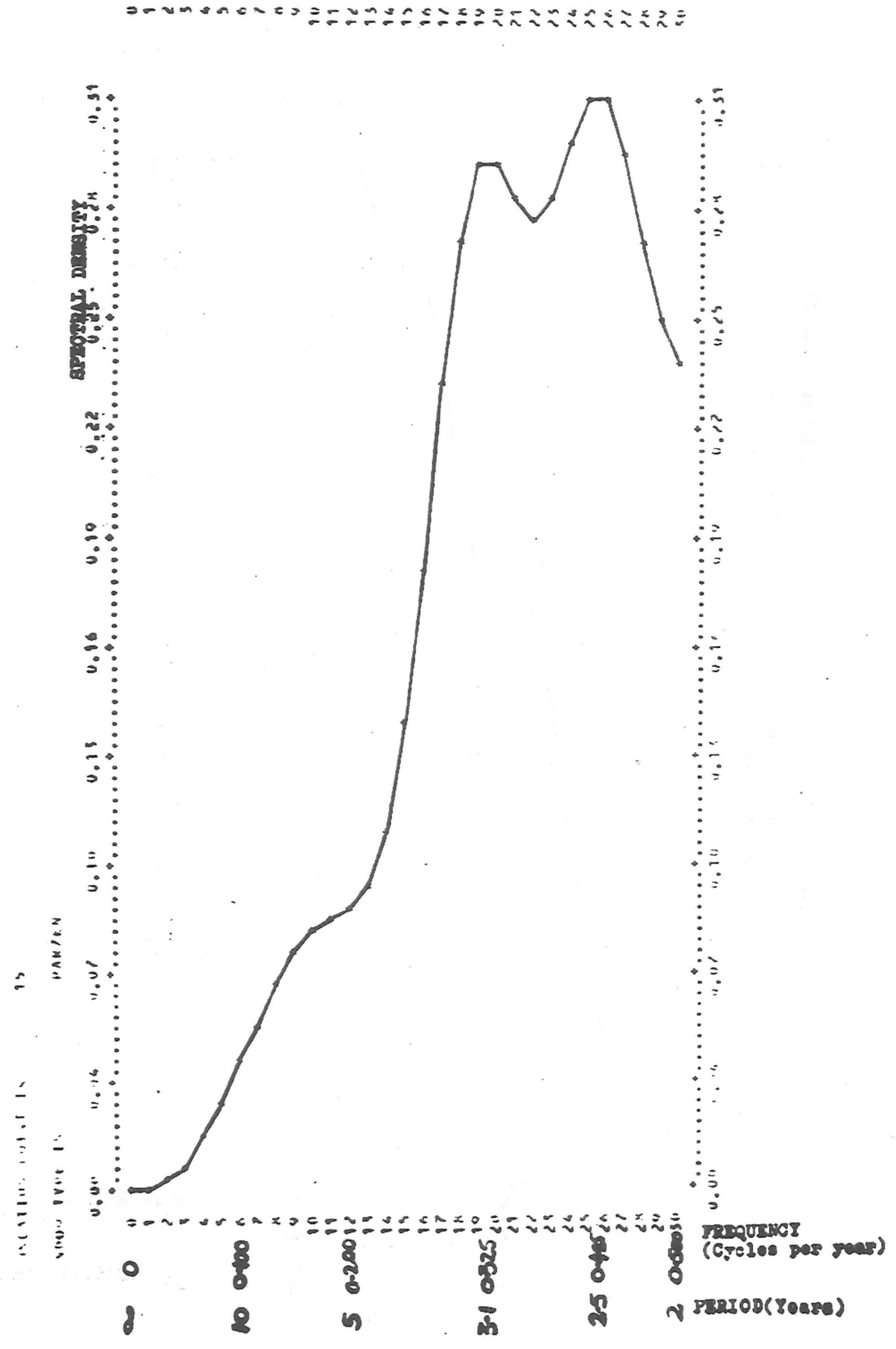


Figure 9

SPECTRUM OF LAKE VICTORIA CATCHMENT ANNUAL RAINFALL.

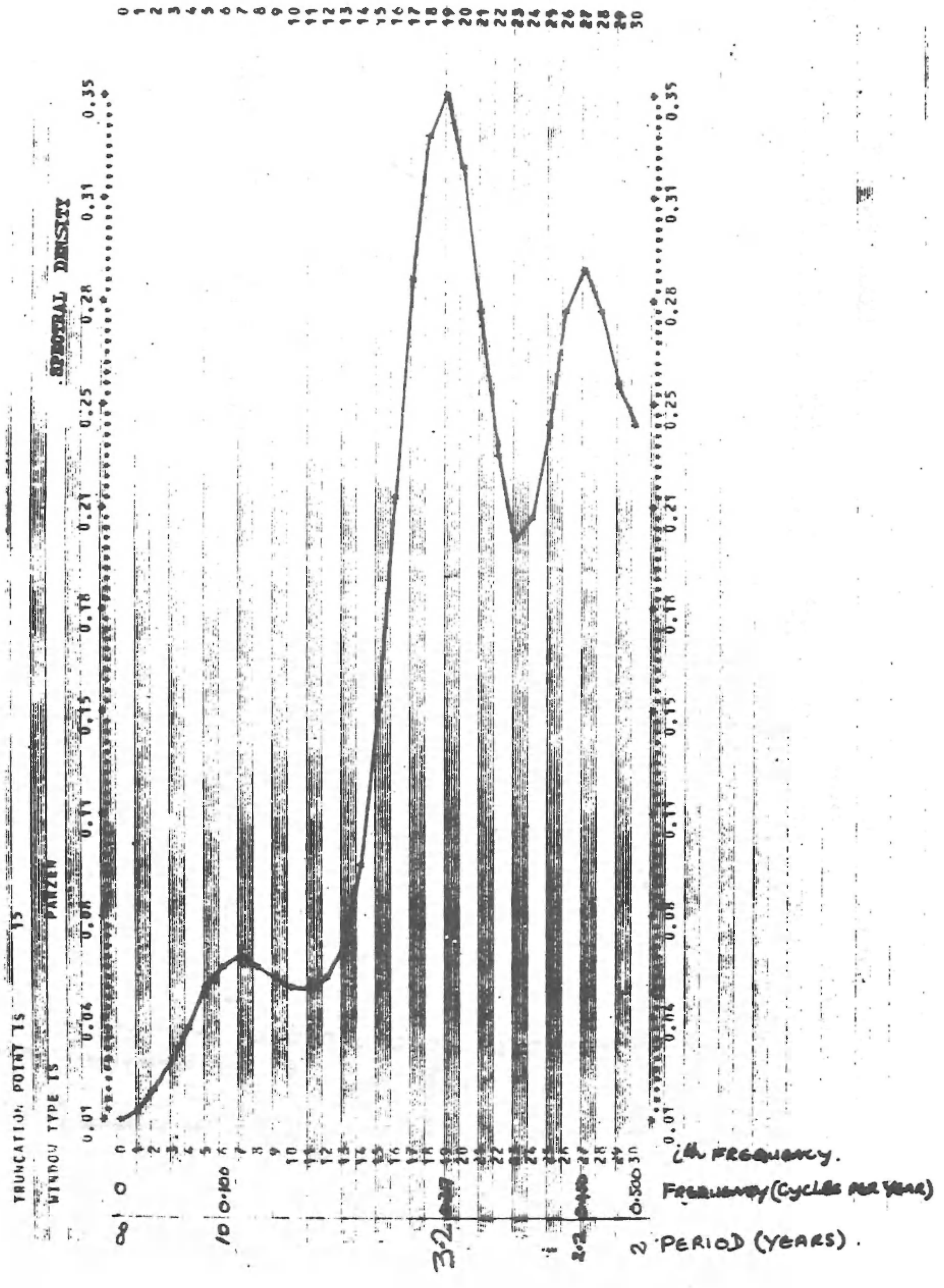


Figure 10

SPECTRUM OF ANNUAL RAINFALL AT KISUMU PC's OFFICE

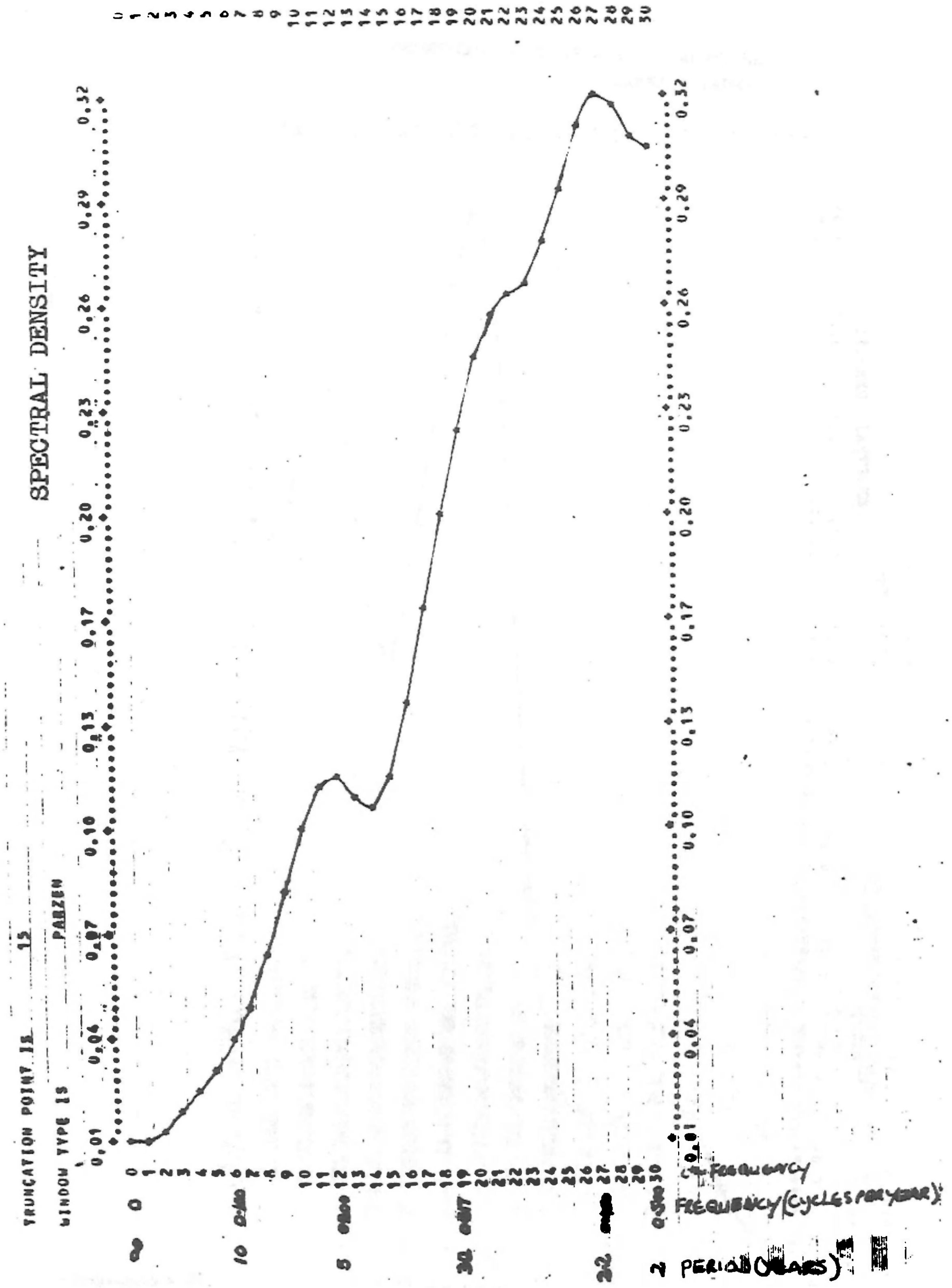


Figure 11

SPECTRUM OF ANNUAL RAINFALL AT MOMBASA

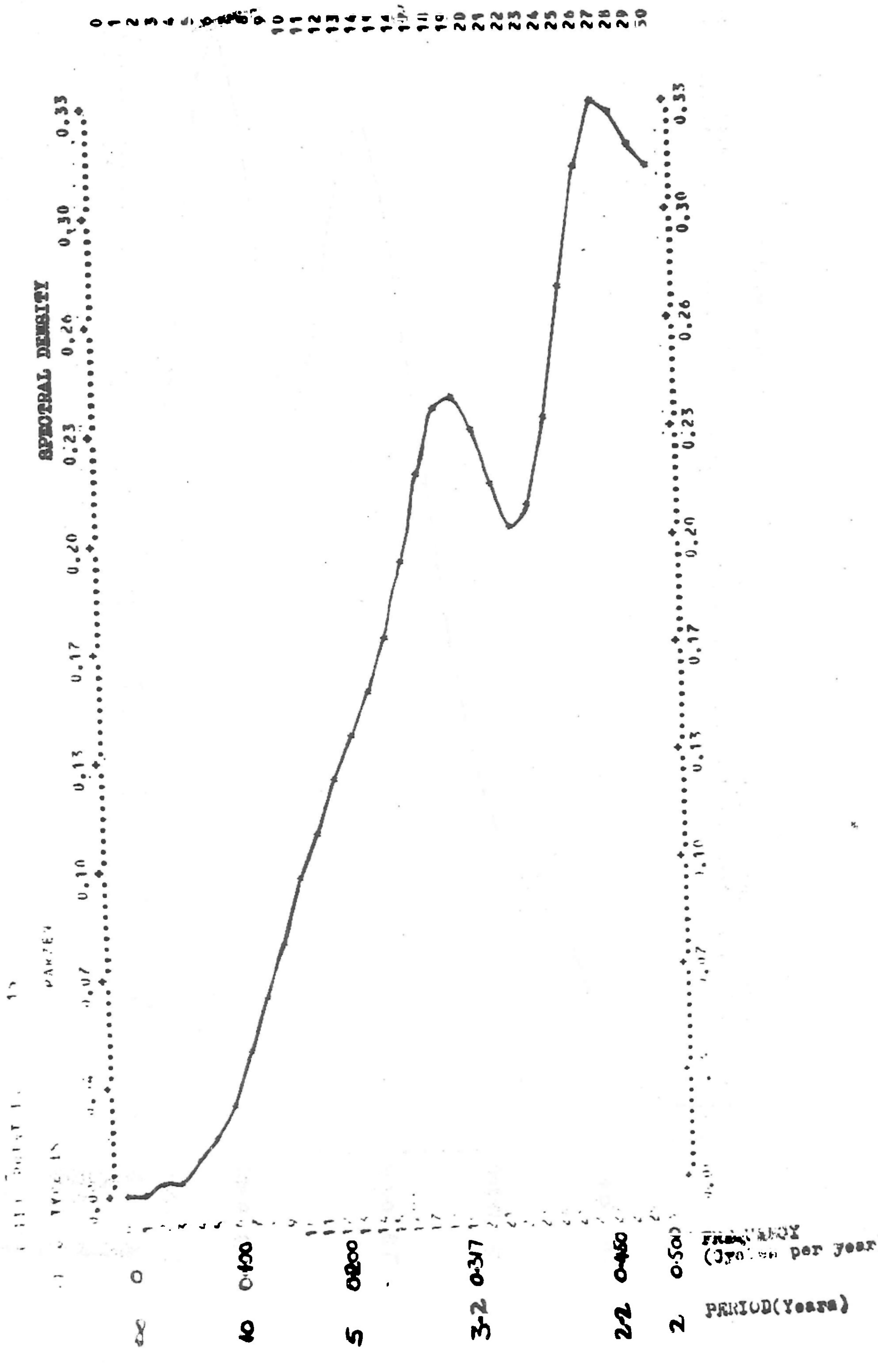


Figure 12

SPECTRUM OF ANNUAL RAINFALL AT LODWAR

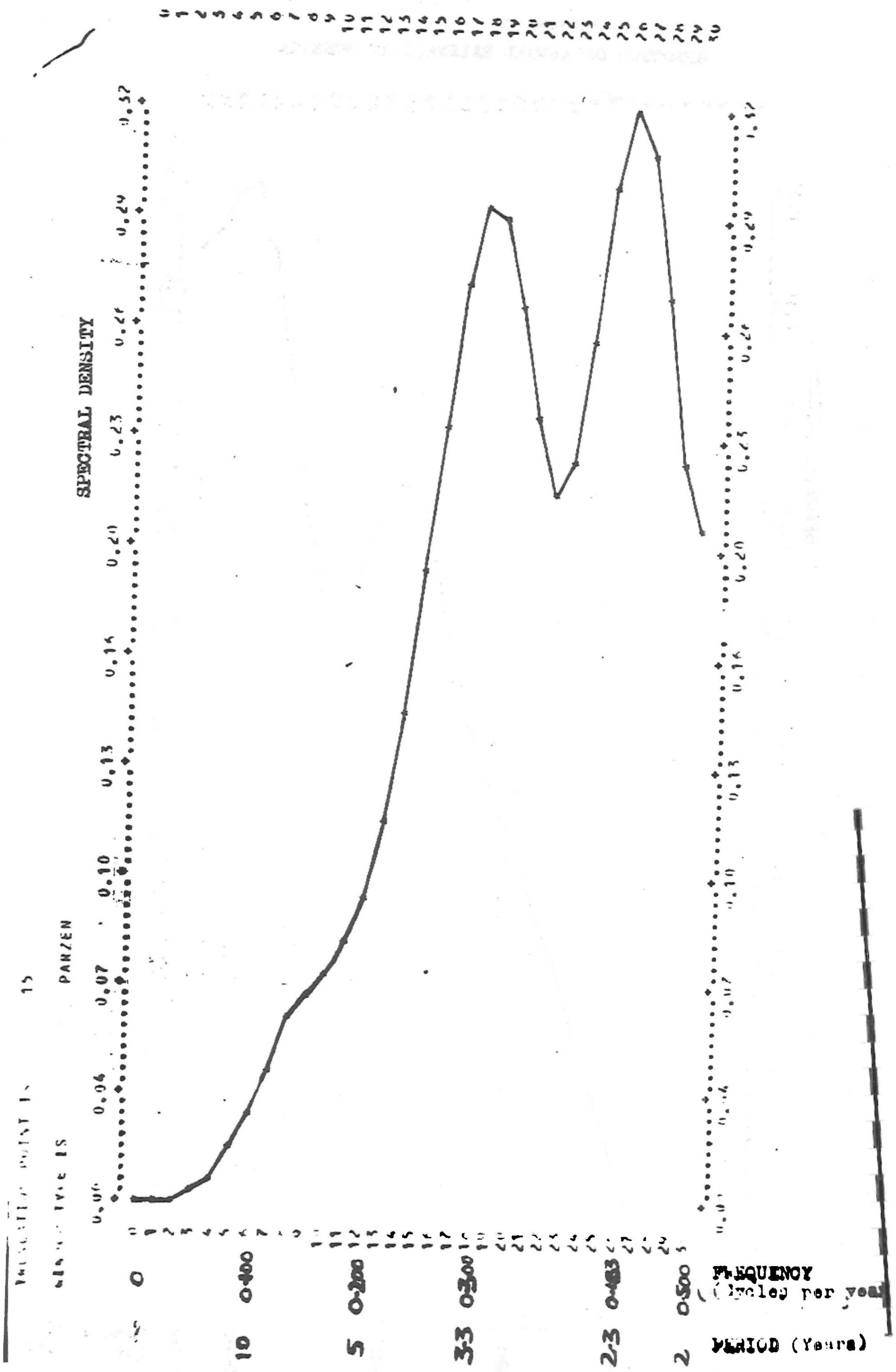
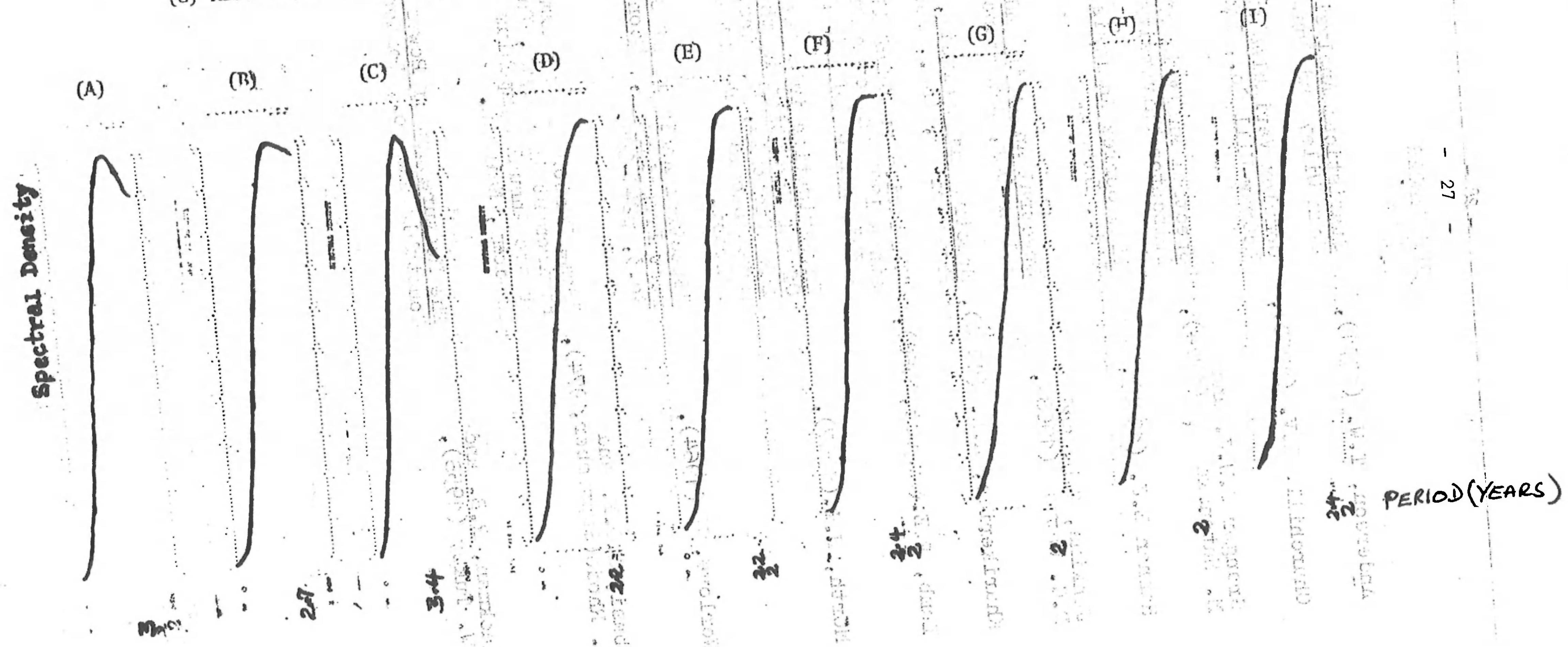


Figure 13 :

SPECTRA WITH M=6

(A) KABETE (B) AREAL AVERAGE: CENTRAL KENYA (C) MACHAKOS (D) MERU (E) NAKURU (F) LAKE VICTORIA

(G) KISUMU (H) MOMBASA (I) LODWAR



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