

Observed trends in rainfall: northern Nigeria

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Isohyetal mapping with a very meagre data base

Kaduna State, in Northern Nigeria, (originally extending 9° to 13.5° N, 7° to 8.5° E) was collecting daily rainfall records at more than 120 sites in the 1950s, about 50 of which were in the Katsina Emirate (now Katsina State). Using all these records, isohyetal mapping of rainfalls for the period 1941 to 1970 was used for descriptive and for planning purposes (see Figure 6). Northwards from 10° N observed downward trends in annual rainfall amounts (Figures 1, 2 & 3) indicate the necessity for new isohyetal mapping for 21st century use. In what follows I address the problem of producing isohyetal mapping when the number of northern rainfall reporting sites has diminished from over 50 in the mid-20th century to less than 12 by the end of the century. A close correlation found between rainfall expectations and latitude allows, for the purpose of isohyetal mapping, the expected rainfalls at each of the original sites to be estimated for present day (2008) rainfalls and for the future (2030).

Rainfall records retrieved from various State and Federal archives were used for Water Master Planning reports for Kaduna State (including the Katsina Emirate) in 1978 & 1979 and for Kaduna and Katsina States separately in 1997 and 1999 (Refs 1, 2 & 3). I was responsible for the surface water resources inputs for the 1997 and 1999 reports. The quality of the recent rainfall data was not all good. Several rain gauge sites inspected showed that the network was failing to maintain standards. A lucky new find was the raingauge records for the Emir's Palace in Katsina, a gauge that had not submitted its uninterrupted records since 1932 to any of the national archives.

Figure 1 Annual rainfalls, Emir's Palace

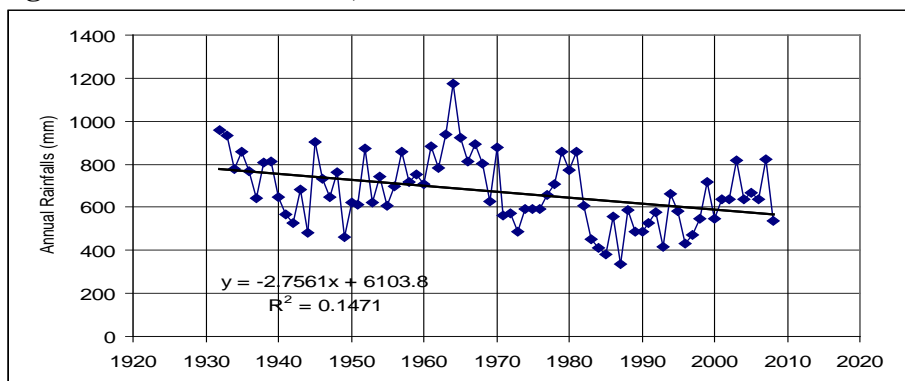


Figure 2 Annual rainfalls, Katsina Airport
(Note: unreliable after 1987 – raingauge leaking)

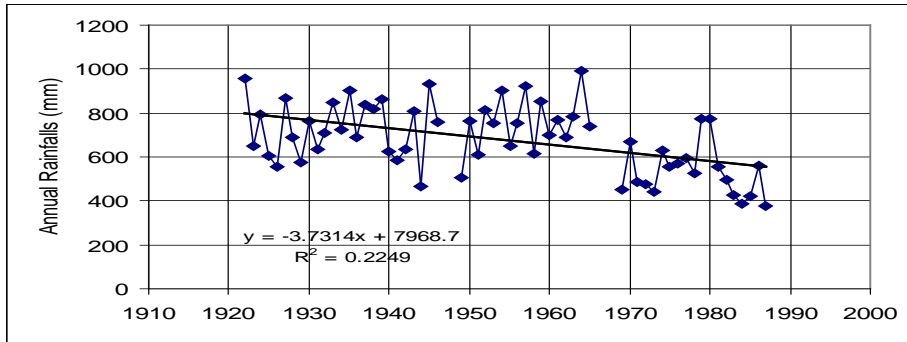
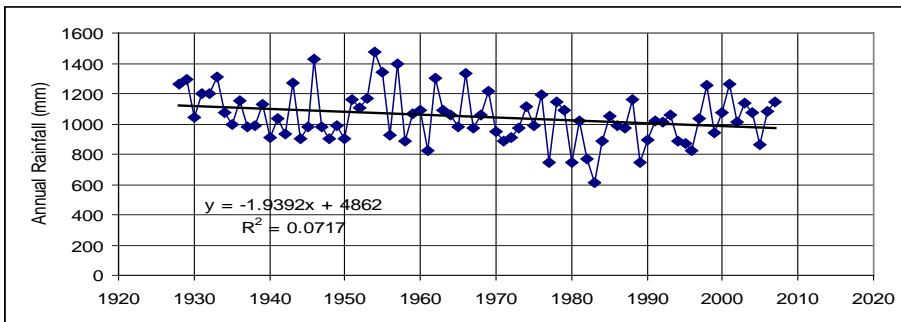


Figure 3 Annual rainfalls, Samaru Agricultural Station



Rainfalls strongly correlated with latitude

For the 1999 Water Master Planning report for Katsina State (Ref 3), the procedure adopted was to obtain a regression equation for the mean annual rainfall (MAP) at different latitudes for the period 1941-1970, together with a comparable equation for the decade 1989-1998. A comparison of the two regression equations indicates the amount of change in the intervening years. It also indicates that more than the whole of Katsina State is affected. The effect is just appreciable in Kaduna State from about latitude 10⁰ N, the amount of the effect increasing with latitude and tending to level off at the Nigerian/Niger border.

For the period 1941 - 1970 (source: Table 2) the regression equation, with R² of 0.926, for mean annual rainfall (mm) is:

$$\text{MAP} = 10287 e^{-0.203 (\text{Lat N})}$$

For the decade, 1989 – 1998 (source: records summarized in Table 3), the regression equation, with R² of 0.986, is:

$$\text{MAP} = 17593 - 2548.1 (\text{Lat N}) + 95.048 (\text{Lat N})^2$$

Comparing these two periods indicates a downward trend from 1955 applicable as mm per

year from 10.5° to 13.2° N (in Kaduna State and in Katsina State) which can be expressed in terms of latitude alone:

$$\text{Annual Trend (mm)} = 245.78 - 34.877 (\text{LatN}) + 0.767 (\text{LatN})^2 + 0.0331 (\text{LatN})^3$$

This relationship has been used to adjust the mean annual rainfalls - for 112 rain gauges listed in the earlier planning studies - to the year 2008 and, in to the future, for the year 2030. These 112 estimates of expected annual rainfalls are shown as isohyetal mapping for a north western portion of Nigeria from latitude 9° N to 13° N and longitude 6° to 9° E (see Figs 7 & 8). This isohyetal mapping presents information in a way that conveys not just amounts of rainfall but also, implicitly, an indication of reliability. This is because standard deviations for each of the annual series are around the same amount of rainfall (about 160 mm, see Table 1). Variability is more or less inversely proportional to rainfall amounts (Figure 9).

Figure 4 Reduction of rainfall since the period 1941-70 until 1989-98
(Source Table 2 & Table 3)

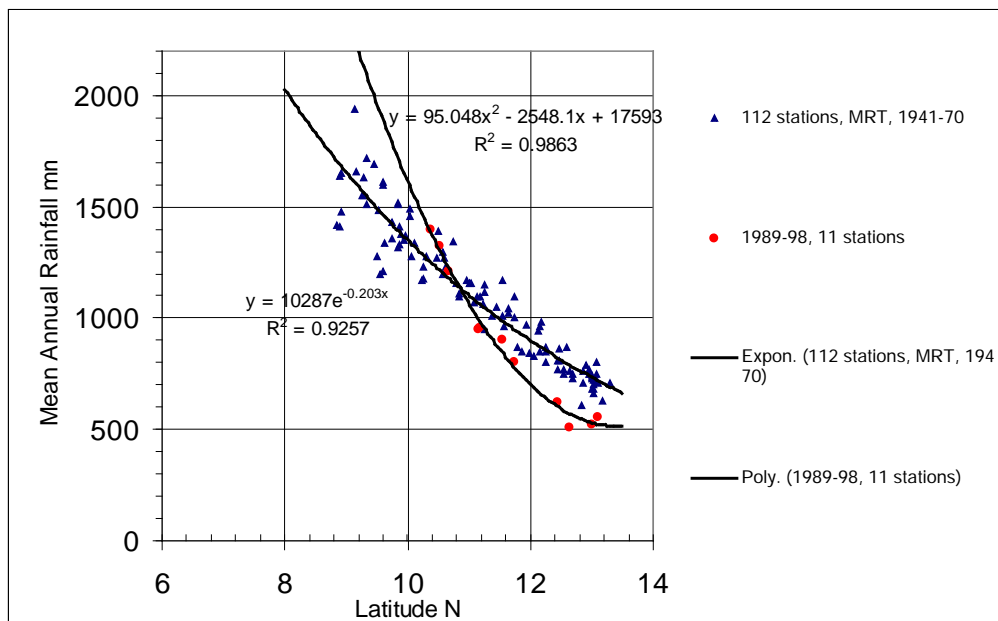


Figure 5 Downward trend, annual rainfalls in Northern Nigeria

(Source: regression equations quoted above, shown in Fig 4)

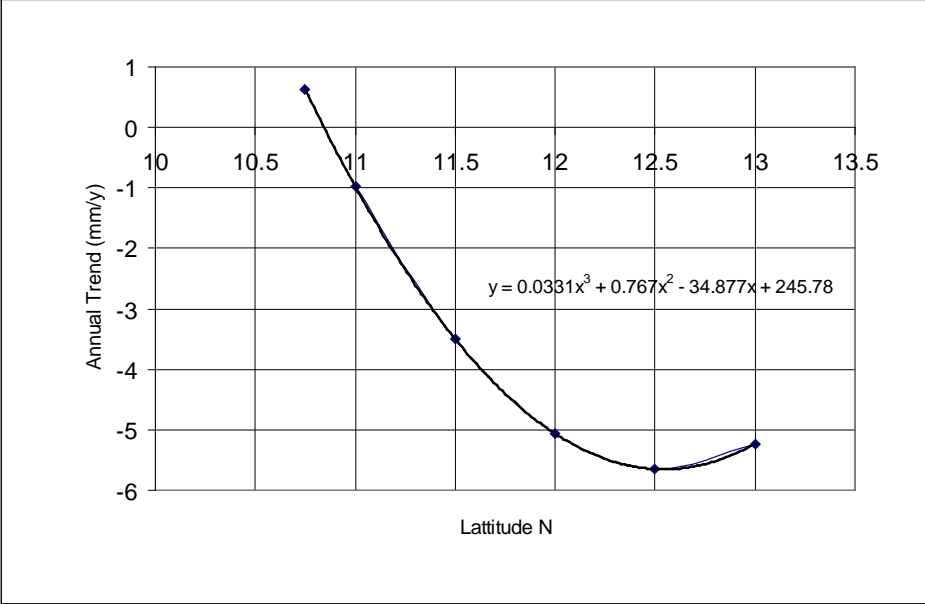


Fig 6 Annual rainfalls (mm) from 120 station records, 1941-1970
 (Source: data listings, Ref 1,2,3)

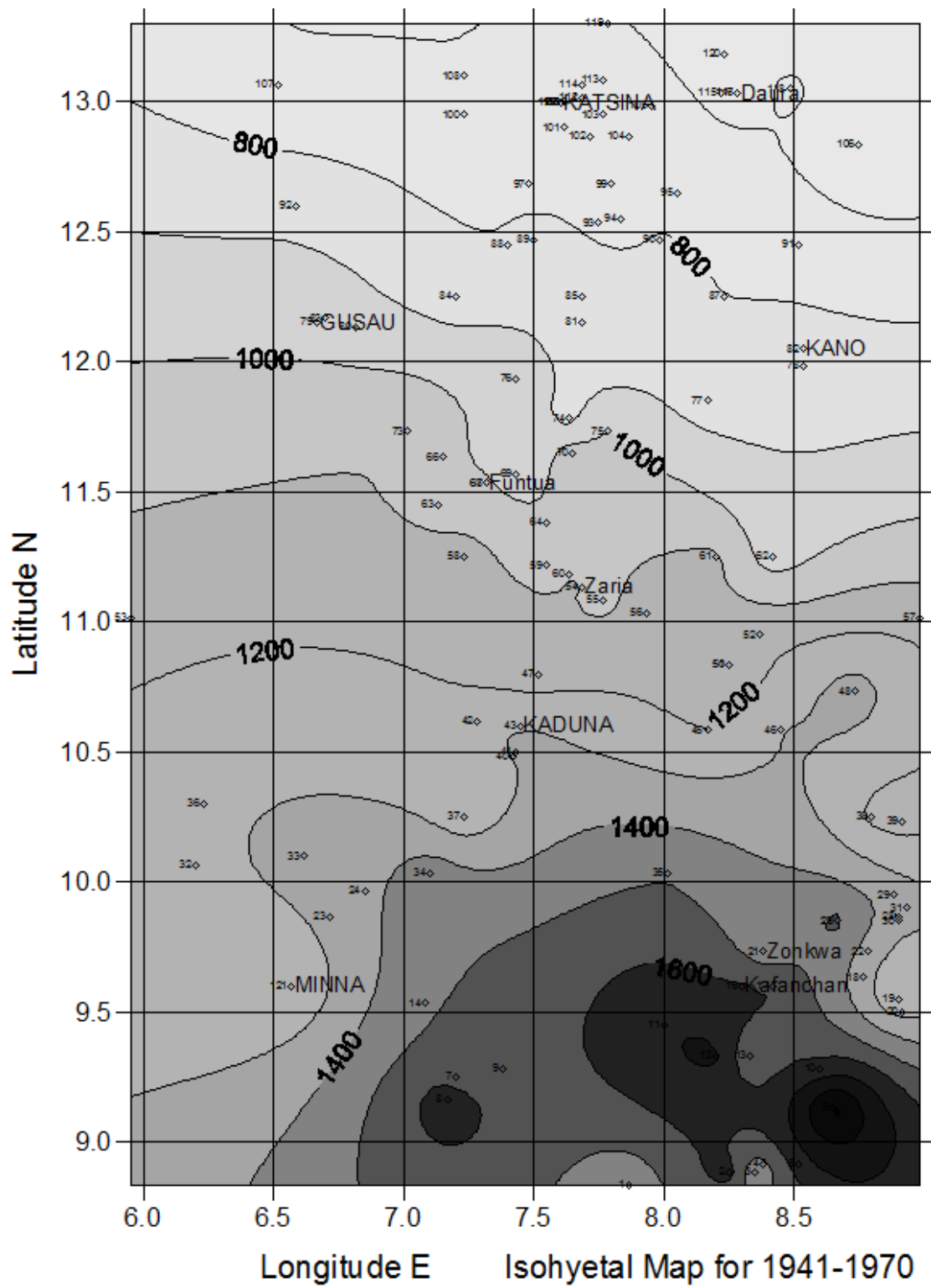


Fig 7 Annual rainfalls (mm) estimated for 2008 by regression

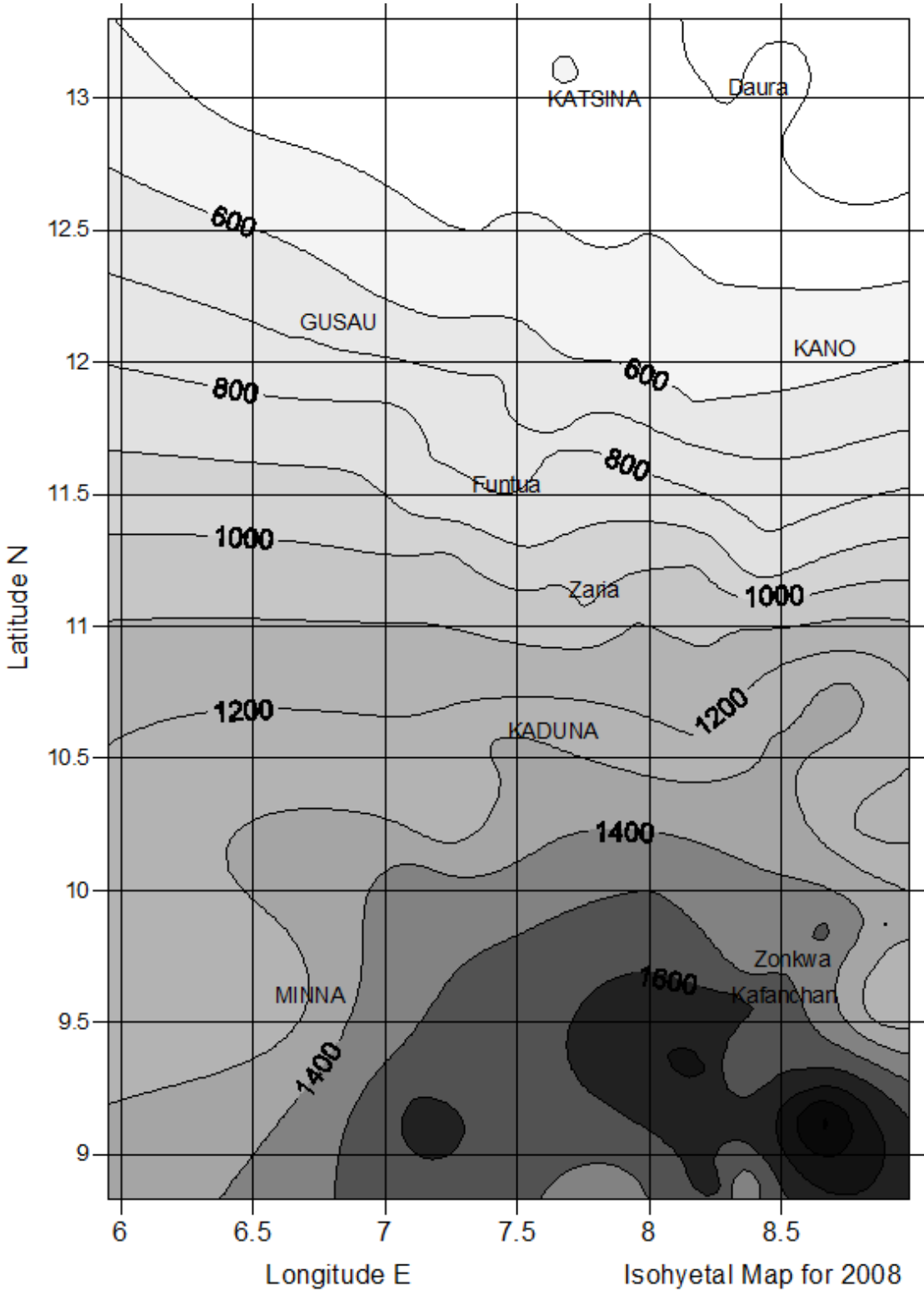
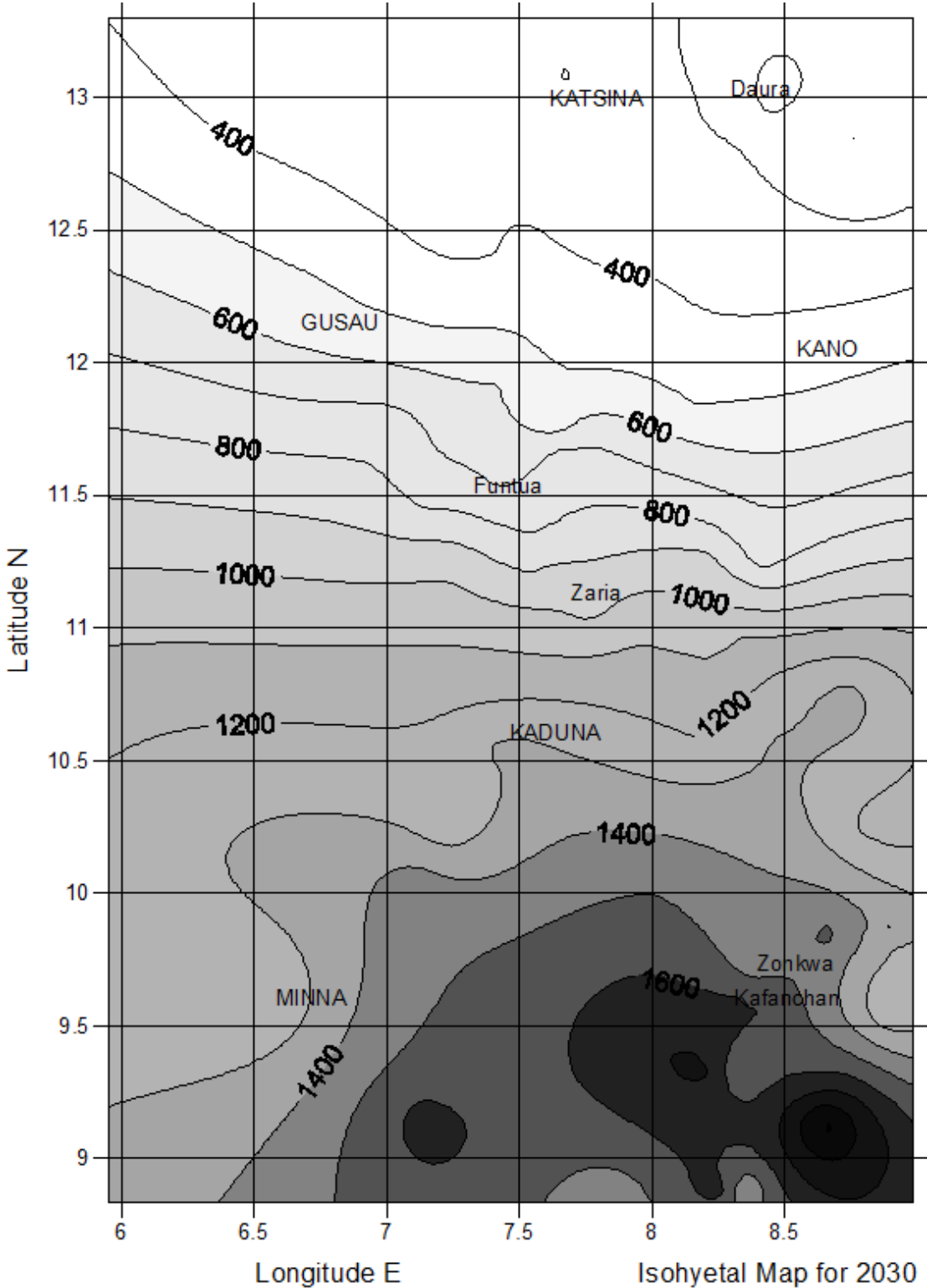


Fig 8 Annual rainfalls (mm) estimated for 2030 by regression



Isohyetal maps and rainfall reliability

Reliabilities of rainfall, for some northern rain gauges, are tabulated (Table 1) and the results presented graphically (Fig 9), these data revealing the inverse proportionality. This result is as expected, but nevertheless merits close attention. It indicates that if the downward trend persists, the reliability of the annual rainfall amounts in the higher latitudes will decrease. If the power trend line of the plotted points (Fig 9) were extrapolated to follow the curvature observed, then expected annual rainfalls of 300 mm will have coefficients of variation approaching 50%, indicating that by 2030 there may be one year in six, on average, with less than 150 mm of rainfall at some most northerly sites.

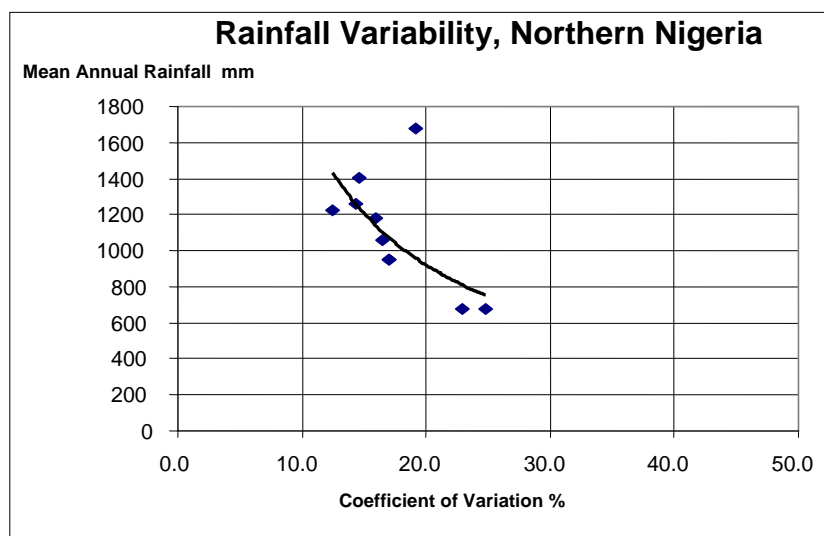
Table 1 Reliability of Annual Rainfall

(Source: Ref 3)

Station	MAP(mm)	SD(mm)	CV(%)	n
Emir's Palace Katsina	675	167	25	67
Katsina Airport	677	155	23	61
Zaria Dam	954	162	17	21
Yelwa	954	162	17	25
Samaru Agric	1058	174	16	61
Funtua CAP Ginnery	1180	189	16	25
Birnin Gwari	1223	153	13	26
Kaduna South	1263	182	14	40
Kachia	1406	205	15	19
Kafanchan	1679	322	19	21

Figure 9 Variability of expected annual rainfall

(Source: Table 1 above)



Outcomes

Rainfall records at Sokoto, the drying up of Lake Chad since the 1890s, and the trend observed in Katsina State over the last 50 years are in accordance with results from climate modelling at the Hadley Centre which has indicated a reduction in annual rainfalls of about 4 mm/y over the next 100 years at the Nigerian edge of the Sahel. It was also reported that Sahelian rainfalls generally diminished in magnitude by about 2 standard deviations over the period 1950 to 1985 (Ref 4). The downward trend perhaps may not continue, but if it should do so then tentative rainfall predictions for 2030 (Fig 8) are likely to come true. The general effect on the natural environment is woodlands becoming thorn scrub and savannah becoming desert, with sustained rain fed agriculture becoming unviable. The conditions predicted at the latitude of Katsina Town by the year 2030 then look so ominous that major migrations of people southward could be expected. The IPCC Report Climate Change 2007 states (Ref 5) that “...*In West Africa, the long-term decline in rainfall from the 1970s to the 1990s caused a 25-35 km southward shift of the Sahelian, Sudanese and Guinean ecological zones in the second half of the 20th century.*”

Extending the water-related data base

Elsewhere in that same report (Ref 5) attention is drawn to the importance of collecting data. When I visited Katsina State with a Nigerian hydrogeologist colleague at the beginning of 2009. I had decided – at my own expense (!) – to install water level recorders at a few of their water supply dams in order to implement a water-related data collection agenda of my own devising which I call *Aggregated Flow-Event Monitoring* (see *Water-related Data Collection in Africa*, **Circulation 66**, August 2000, for an early account of this procedure). As it turned out I was warmly welcomed at the Katsina State Water Ministry, made chairman of the State Hydrology & Hydrogeology committee (with an adequate budget), and I then drew up a shopping list for the required equipment. When and if this equipment, which includes a sufficient number of water level data loggers and rain gauges, is installed an assessment of state-wide water resources is feasible in terms of incident rainfalls, catchment runoffs, flood event profiles, ground water fluctuations, sediment transport and estimates of water balance between rainfalls, surface runoff, surface evaporation and ground water recharge. However, there is a hitch: the state governor has now made conditions before releasing funds. My colleague and I are currently engaged in resolving this stalemate. We are also well advanced in setting up an NGO to remind the various Nigerian government agencies of the objectives, and also to provide assistance in achieving them.

Table 2 Rainfall station summary

No (a)	Station name (b) (c)	Lat (d)	Long (e)	Opened (f)	Elev (g)	MRT (h)	WAP (j)		
850750	1 Keffi JPS	8	50	7	52	1941	457	1420	1403
850810	2 Gudi Min of Works	8	53	8	15	1954	396	1640	1553
850820	3 Alushi EKAS	8	53	8	21	1954	366	1410	1399
850821	4 Akwanga Agric Stat	8	55	8	23	1967	366	1480	1484
850830	5 Wamba DO	8	55	8	31	1931	320	1650	1659
900830	6 Arum NA	9	8	8	39	1954	610	1940	2126
910710	7 Diko SIM	9	15	7	12	1948	541	1550	1528
910711	8 Abuja NA	9	10	7	10	1947	488	1660	1640
910720	9 Bwari JPS	9	17	7	23	1962	579	1550	1466
910830	10 Tayu NA Sch	9	17	8	36	1954	610		1633
920800	11 Kwoi ECWA Sch	9	27	8	0	1952	732	1690	1739
920810	12 Jagindi JPS	9	20	8	12	1954	488	1720	1633
920820	13 Dogon-Kurmi RS	9	20	8	20	1960	488	1510	1729
930700	14 Kafin JPS	9	32	7	5	1962	610		1485
930750	15 Kurmin-Musa JPS	9	34	7	59	1956	671	1500	1476
930810	16 Kafanchan MD	9	36	8	18	1935	762	1610	1640
930820	17 Kagoro SIM	9	36	8	25	1952	823	1600	1658
930840	18 Riyom Agric Dept	9	38	8	46	1947	1234	1340	1371
930850	19 Barakin-Ladi ATMN	9	33	8	54	1933	1311	1200	1206
930852	20 Ropp North ATMN	9	30	8	55	1937	1341	1280	1270
940820	21 Zonkwa Agric Stat	9	44	8	23	1947	838	1430	1488
940840	22 Vom Vet Dept	9	44	8	47	1946	1265	1360	1400
950640	23 Kuta SIM Dispensary	9	52	6	43	1955	366	1330	1325
950650	24 Shiroro Gorge NEPA	9	58	6	51	1960	335	1370	1292
950750	25 Kachia SPS	9	52	7	57	1959	732		980
950840	26 Miango SIM	9	51	8	40	1953	1128	1520	1524
950842	27 Miango Kent Academy	9	51	8	40	1953	1189	1510	1544
950850	28 Jos Aerodrome	9	52	8	54	1922	1285	1410	1410
950851	29 Naraguta Sch of Fore	9	57	8	53	1939	1158	1350	1387
950852	30 Rayfield Mines	9	51	8	54	1955	1298	1320	1356
950853	31 Lamingo Hydro Dam	9	54	8	56	1956	1280	1380	1383
1000610	32 Tegina SIM	10	4	6	12	1955	274	1280	1317
1000630	33 Bassa CFC	10	6	6	37	1959	305	1340	1339
1000700	34 Serkin Pawa Rly Stat	10	2	7	6	1954	427	1460	1399
1000800	35 Kurmin Biri Rly Stat	10	2	8	1	1953	701	1490	1418
1010610	36 Tugan-Bako Baptist S	10	18	6	14	1964	381	1280	1237
1010710	37 Gwagwada Rly Stat	10	15	7	14	1954	549	1230	1273
1010840	38 Jengre SDA Mission	10	15	8	48	1955	945	1180	1194
1020720	39 Shanga JPS	10	14	8	55	1954	1341	1170	1239
1020720	40 Kaduna Junction	10	29	7	25	1916	585	1270	1291
1020721	41 Kakuri Fed Prisons	10	28	7	24	1960	610	1700	1418
1030710	42 Afaka Forest Reserve	10	37	7	17	1960	610	1230	1211
1030720	43 Kaduna Aerodrome	10	36	7	27	1939	645	1271	1291
1030721	44 Kaduna Hydro Stat	10	30	7	26	1959	591	1390	1326
1030810	45 Kauru JPS	10	35	8	10	1956	594	1200	1102
1030820	46 Kudaru Min of Works	10	35	8	27	1941	762	1300	1313
1040730	47 Birnin-Yero Rly Stat	10	48	7	31	1953	671	1160	1203
1040840	48 Ririwai Mining Stat	10	44	8	44	1963	881		1341
1050710	49 Sabon-Birni JPS	10	50	7	18	1957	594		1075
1050810	50 Dutsin-Wai BCGA	10	50	8	15	1931	655	1110	1136
1050811	51 Dutsin-Wai JPS	10	50	8	15	1961	655	1100	1108
1050820	52 Takalafia PO	10	57	8	22	1938	701	1170	1148
1100550	53 Kotonkora NA	11	1	5	57	1957	479	1160	1171
1100740	54 Zaria Aerodrome	11	8	7	41	1943	655	1100	1064
1100743	55 Zaria Waterworks	11	5	7	46	1915	653	1070	1078
1100750	56 Maigana Agric Stat	11	2	7	56	1926	671	1160	1078
1100850	57 Burra JPS	11	1	8	59	1955	914	1160	1160
1110710	58 Kaya JPS	11	15	7	14	1956	671	1150	1090
1110730	59 Shika Agric Research	11	13	7	33	1941	640	1060	1048

Continued next page

Table 2 Rainfall station summary (Continued)

No (a)	Station name (b) (c)	Lat (d)	Long (e)	Opened (f)	Elev (g)	MRT (h)	WAP (j)
1110731	60 Samaru Agric Stat	11 11	7	38 1934	686	1100	1081
1110810	61 Ikara Pry Sch	11 15	8	12 1963	701		1115
1110820	62 Tudun-Wada JPS	11 15	8	25 1960	616		948
1120700	63 Dandume JPS	11 27	7	8 1931	701	1050	938
1120730	64 Danja JPS	11 23	7	33 1950	616	1010	958
1130700	65 Daudawa Govt	11 38	7	9 1944	701	1070	1029
1130701	66 Daudawa JPS	11 38	7	9 1950	640	1020	937
1130710	67 Funtua JPS	11 32	7	19 1927	640	1010	1031
1130713	68 Funtua CAP Gi	11 32	7	19 1951	640	1170	1129
1130720	69 Bakori LA Sch	11 34	7	26 1951	640	960	910
1130730	70 Kafur JPS	11 39	7	39 1950	610	1040	977
1140700	73 Faskari JPS	11 44	7	1 1950	640	1100	1022
1140730	74 Malumfashi JP	11 47	7	38 1927	655	870	932
1140740	75 Mafata JPS	11 44	7	47 1955	625	1000	922 ?
1150720	76 Kankara Eleme	11 56	7	26 1950	579	970	904
1150810	77 Kabo Girls Sc	11 51	8	10 1957	457	850	952
1150831	78 Kano Govt Far	11 59	8	32 1922	503	840	833
1200640	79 Gusau Agric S	12 9	6	40 1942	457	960	
1200641	80 Kotorkoshi Ag	12 8	6	49 1956	457	940	
1200740	81 Musawa LA Sch	12 9	7	41 1950	457	850	
1200830	82 Kano Aerodrom	12 3	8	32 1916		830	
1210640	83 Gusau Aerodro	12 10	6	42 1952		980	
1210710	84 Dan-Musa Educ	12 15	7	12 1952		850	
1210740	85 Matazu JPS	12 15	7	41 1950		870	
1210810	87 Bichi Element	12 15	8	14 1950		800	
1220720	88 Safana JPS	12 27	7	24 1950		810	
1220730	89 Dutsin-Ma JPS	12 28	7	30 1950		860	
1220750	90 Kusada Elemen	12 28	7	59 1950		810	
1220830	91 Dambatta JPS	12 27	8	31 1950		770	
1230630	92 Kaura-Namoda	12 36	6	35 1946		870	
1230740	93 Kafinsoli Agr	12 32	7	45 1934		770	
1230750	94 Kankiya PS	12 33	7	50 1950		750	
1230800	95 Ingawa Elemen	12 39	8	3 1950		760	
1240720	97 Kurfi Educati	12 41	7	29 1952		750	
1240741	99 Bindowa JPS	12 41	7	48 1950		730	
1250710	100 Mallamawa JPS	12 57	7	14 1963		750	
1250730	101 Batagarawa JP	12 54	7	37 1951		790	
1250740	102 Rimi JPS	12 52	7	43 1950		760	
1250741	103 Tsagero Eleme	12 57	7	46 1950		770	
1250750	104 Mani Elementa	12 52	7	52 1950		710	
1250751	105 Mashi Element	12 59	7	57 1950		750	
1250840	106 Baure JPS	12 50	8	45 1962		610	
1300630	107 Shinkafe NTC	13 4	6	31 1962		720	
1300710	108 Jibiya JPS	13 6	7	14 1950		710	
1300730	109 Gidado Centra	13 0	7	37 1950		740	
1300731	110 Gafai JPS	13 0	7	37 1950		730	
1300732	111 Gobaran JPS	13 0	7	37 1950		680	
1300740	112 Katsina Aerod	13 1	7	41 1922		720	
1300741	113 Kaita Element	13 5	7	46 1950		750	
1300742	114 Yandaki JPS	13 4	7	41 1955		800	
1300810	115 Daura Farm Ce	13 2	8	13 1947		680	
1300811	116 Daura JPS	13 2	8	17 1950		660	
1300812	117 Daura SPS	13 2	8	17 1958		700	
1300820	118 Zango Element	13 3	8	29 1950		720	
1310740	119 Dankama Eleme	13 18	7	47 1950		710	
1310810	120 Maiaduwa Elem	13 11	8	14 1950		630	
	121 Minna			1961		1210	
	122 Emir's Palace, Katsina	13 00	7	36 1932		737	

Source: Reference 1, 2; both reports list the same stations with some differences in the analysis.

Notes: Column (a) is a version of the standard Dept of Met. Services numbering;
 (f) gives the year records commence - some stations may have closed since; (h) is the mean annual rainfall adjusted to a standard period 1941-1970 (Reference 1);
 (j) is the mean annual rainfall adjusted to the standard period 1926-1975. Stations listed in *italics* were not plotted on the isohyetal mapping above.

Table 3 Average monthly rainfalls for selected stations, 1989-1998

	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Daura								13	6 N	8	21 E		
Avg	0	0	1	7	35	57	183	161	96	13	0	0	554
SD	0	0	4	14	21	46	88	66	82	16	0	0	167
Emir's Palace, Katsina								13	0 N	7	36 E		
Avg	0	0	2	4	46	54	130	175	101	8	0	0	519
SD	0	0	6	7	37	16	45	37	63	12	0	0	71
Roni								12	39 N	8	16 E		
Avg	0	0	0	6	14	58	145	204	72	9	0	0	506
SD	0	0	0	9	14	22	41	105	36	16	0	0	127
Dutsin-ma								12	27 N	7	30 E		
Avg	0	0	1	9	50	76	135	205	126	22	0	0	624
SD	0	0	3	14	41	36	57	76	47	21	0	0	157
Karaye								11	44 N	8	2 E		
Avg	0	0	4	8	50	109	220	243	144	28	0	0	805
SD	0	0	12	24	29	25	56	116	90	48	0	0	187
Ranka								11	33 N	8	17 E		
Avg	0	0	6	17	73	143	201	300	143	23	0	0	905
SD	0	0	10	31	46	46	50	109	73	22	0	0	190
Samaru								11	11 N	7	38 E		
Avg	0	0	4	37	117	142	199	271	146	40	0	1	957
SD	0	0	13	36	51	37	39	83	51	25	1	2	140
Zaria								11	9 N	7	47 E		
Avg	0	0	0	36	113	110	209	269	168	44	0	0	949
SD	0	0	1	39	85	33	40	81	44	48	1	0	114
Kangimi Dam								10	40 N	7	35 E		
Avg	0	0	6	41	155	170	229	303	228	74	2	0	1207
SD	0	0	11	31	40	87	59	73	83	64	5	0	168
Kaduna North								10	31 N	7	26 E		
Avg	0	0	2	38	155	191	279	332	226	101	0	0	1324
SD	0	0	4	34	77	61	105	102	70	64	0	0	223
Saminaka								10	23 N	8	42 E		
Avg	0	0	13	67	145	219	282	376	217	76	1	0	1396
SD	0	0	17	37	37	58	68	68	97	46	2	0	237

Source: Analysis of the monthly rainfalls listed in Appendix A of Ref 3.

Notes: i) SD is the standard deviation of the annual series;
ii) units for the mean rainfalls are mm.

References

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