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Evaluation of Global Rainfall Products for Hydrological Modelling and Water Resources Management in Nigeria, Part I: Zonal and Temporal Analyses

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Abstract: *In a bid to provide alternative to ground observations (station data) and solve the problem of inadequate rainfall data for various climatic researches in Nigeria, six widely available reanalysis and simulated rainfall products were extensively evaluated for the period 1980–1999 (20 years), using observed rainfall data for 18 stations over Nigeria. The products evaluated were Climate Research Unit (CRU), Global Precipitation and Climatology Project (GPCP), Regional Climatic Model Version3 (RegCM3), Community Atmospheric Model Version3 (CAM3), CPC-Merged Analysis of Precipitation (CMAP) and University of Delaware Precipitation (UNIDEL). The country was grouped into Forest, Savanna and Sahel ecological zones on which the evaluation of the products was based. Annual Mean, Coefficient of Variation and time series Plots used to determine the degree of agreement between the rainfall products and station observations (raingauge data). It was found that the performance of the products was generally better in the Sahel and in the dry seasons than other two zones and the wet seasons, respectively. Generally, the results show that UNIDEL is the most reliable of the six products while CAM3 is the least. Although variability was high for all the products, the results could serve as basis for calibrating the products over Africa and with caution, the products could still be useful in various areas of water resources planning and development which include flood modelling, erosion control, irrigation scheduling, drainage engineering, etc.*

Keywords: *Evaluation, Rainfall products, Forest, Sahel, Savanna*

INTRODUCTION

Dearth of adequate climatic data has been the bane of many scientific researches in the area of hydrology, climate change, water management, etc., in many developing countries of Africa. Unfortunately, the economy of many of the countries in the region is dependent on rainfed agriculture that is subject to the vicissitudes of nature, therefore making availability of adequate climatic information a necessity for successful agricultural planning and development. Meanwhile, rainfall is an important meteorological parameter, which has direct application to agricultural production and other aspects such as water resources development (Oumal et al., 2005). Shifts or variation in rainfall in its extent and distributions is an aspect having direct implication for mankind food supply (Ajayi, 1998). This aspect is of particular concern in sub-Sahara Africa, where per capita food availability declined consistently over the past three decades (IITA, 1994).

Feidas (2009) noted that rainfall data is important in many applications, such as water resources management for agriculture and power, flood and drought monitoring. Given that precipitation is a major component of the earth's water and energy cycles, reliable information on the monthly spatial distribution of precipitation is also crucial for climate science, climatological water-resource research studies, and for the evaluation of regional model simulations. Besides, many scientific predictions are to the effect that climate change would have more negative impacts on many developing countries through water (Sadoff and Muller, 2008; IPCC, 2001). Analysing and detecting historical changes in the climatic system is one of the most important necessities of research into climate change (IPCC, 1996). In this general context, rainfall is the most

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important climatic variable owing to its manifestation as deficient resource (droughts) or a catastrophic agent (floods).

Conventionally, measured data from rain gauge networks are still the most reliable source of area-averaged precipitation for the land surface of the earth (Adeyewa and Nakamura, 2003). The advantage is enormous; however, rain gauges catch less precipitation than actually reaches the ground surface owing to turbulence around its aperture. Besides, the observations suffer sampling error in representing areal means; they are not available over most oceanic and underdeveloped land (Xie and Arkin, 1996). Despite this, evidences abound to the effect that available rainfall data are a far cry from what is required for reasonable agricultural planning and water resources development in Nigeria. This is in view of the gross dependent on measured data from rain gauge networks which are scattered all over the country.

In a bid to solve the data problem, many studies have been undertaken in search of alternative methods of collecting data. New tools are now available in the form of satellite systems to help overcome the deficiency of rain gauge networks by means of remote sensing. Remote sensing is the art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Ouma et al., 2005). Recently, interesting techniques to estimate areal rainfall using satellite-based sensors have been developed. The use of cloud brightness, cloud top temperatures, cloud types, cloud areas, and the duration of cold convective cloud over an area as parameters in quantifying the areal rainfall is one of the techniques (Ouma, et al., 2005). Inspite of the enormous advantage of satellite rainfall, factors such as sampling frequency, diurnal cycle of rainfall, the non-uniform field of view of sensors, and the uncertainties in rain retrieval algorithms cause biases and random errors (Adeyewa and Nakaruma, 2003).

In many data-short environment, where spatial distribution of stations measurement is low due to many factors and given that satellite technology is still recent, expensive and requires high technological know-how; reanalysis data is more favoured as a relatively cheaper alternative with adequate spatial extent. However, many reanalysis products are available globally which have been generated using different models and datasets. In view of the indirect nature of the relationship between reanalysis data and observed data, the products need adequate and thorough evaluation and validation from different parts of the world. The present report presents the first part of the two of such reports of an evaluation of six rainfall products which are: Climate Research Unit (CRU), Global Precipitation and Climatology Project (GPCP), Regional Climatic Model Version3 (RegCM3), Community Atmospheric Model Version3 (CAM3), CPC-Merged Analysis of Precipitation (CMAP) and University of Delaware Precipitation (UNIDEL) in Nigeria. The study has as its objectives (i) evaluation of the accuracy of the six rainfall products which are CRU, GPCP, RegCM3, CAM3, CMAP and UNIDEL over Nigeria and (ii) evaluation of the suitability and implications of each of the products for water resources planning and agricultural development in Nigeria.

MATERIALS AND METHODS

Description of the Study Area

Nigeria, the study area is located on the latitude 4^o to 14^o North of the equator and longitude 3^o to 15^o East of the Greenwich Meridian (approximately). It lies at the southern edge of the West African region, covering an area of about 923,200 km^2. The climate of Nigeria is more varied than those of any other country in West Africa. This is as a result of the great length from south to the north (1100 km), which covers virtually all the climatic belts of West Africa (Iloeje, 1981). The climate is dominated by the influence of three main wind currents. These are the tropical maritime (TM) air mass, the tropical continental (CT) air mass and the equatorial easterlies (Ojo, 1977). The first air mass (MT) originates from the southern high-pressure belt located off the Namibian coast, and along its way picks up moisture from over the Atlantic Ocean and is thus wet. The second air mass (CT) has the

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high-pressure belt north of the Tropic of Cancer as its origin. This air mass is always dry as a result of little moisture it picks along its way. The first two air mass (MT and CT) meet along a starting surface called the Intertropical Discontinuity (ITD). The third air mass (equatorial easterlies) is a somehow erratic cool air mass, which comes from the east and flow in the upper atmosphere along ITD. This air mass penetrates occasionally to actively undercut the MT or CT air mass and give rise to line squalls or dust devils (Iloeje, 1981).

The ecological zones of the country are broadly grouped into three, which are; Sahel, Savanna and the Forest zones (Fig. 1). The climate is semi-arid in the north, humid in the south and also humid strip along the coast with rainfall averages over 2000 mm. Rainfall commences at the beginning of the raining season around March/April from the coast (in the south), spreads through the middle belt, reaching its peak between July and September, to eventually get to the northern part very much later. The reverse of the situation also holds for the rainfall retreat period (Ojo, 1977).

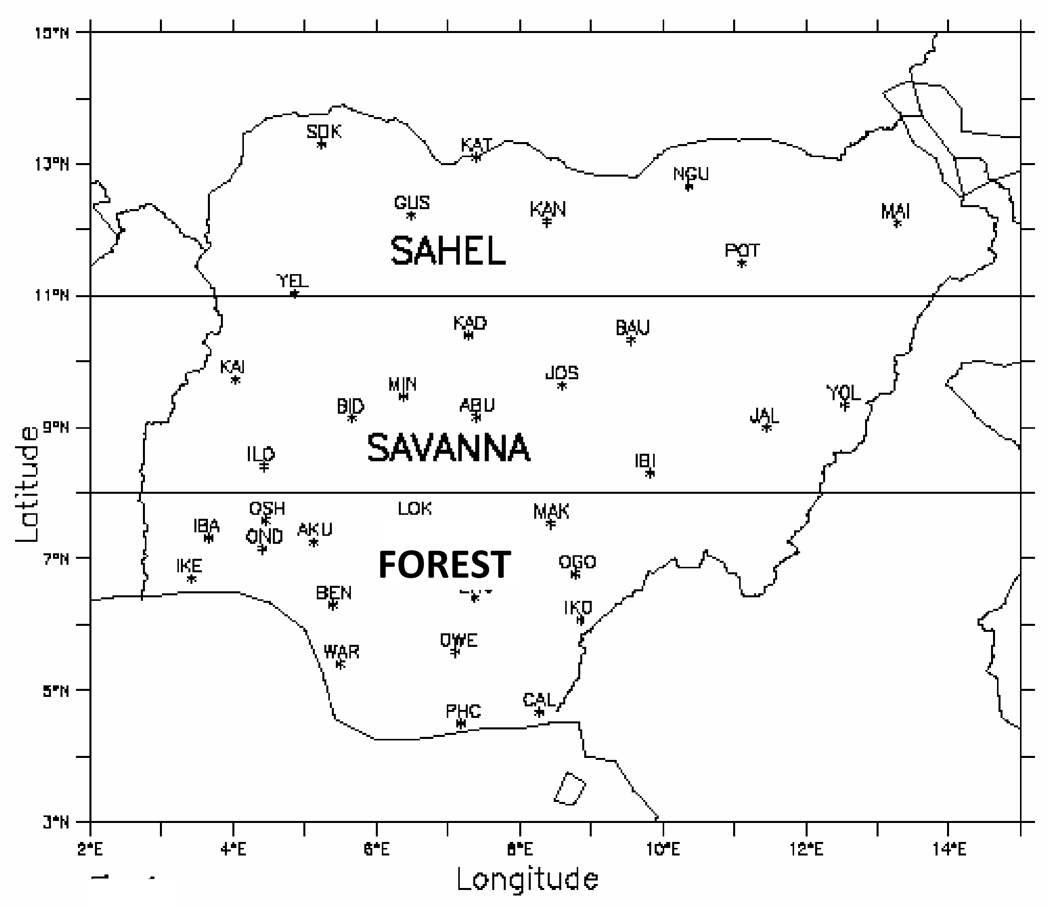

Fig. 1: The three major climatic zones of Nigeria and the distribution of rain gauge stations
Source: Oloruntade (2010)

Data Sources

The Raingauge Data

Rain gauge data utilized for this study were obtained from the data section of the Nigerian Meteorological Services (NIMET), Oshodi Lagos, Nigeria; an agency under the Federal Ministry of Aviation. NIMET is affiliated to the World Meteorological Organization (WMO), a specialized agency of the United Nations. Data on rainfall used in this study are available between 1980 and 1999 (20 years) covering 18 stations. The period was selected given the general belief that the decade 1980s signaled the end of the drought of the 1970s, while the last decade of the century (1990s) heralded the global attention of scientists to the phenomenon of climate change. Data collected were processed into monthly and annual for analytical convenience. The six global rainfall products used in this study are as briefly presented below (Table 1).

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Table 1: Brief description of the rainfall products

Model/Product	Acronym	Spatial Resolution	Reference/web page
Climate Research Unit	CRU	0.5° x 0.5°	New et al. (1999), Mitchell and Jones (2005)/http://www.cru.uea.ac.uk
Global Precipitation and Climatology Project	GPCP	2.5° x 2.5°	Huffman et al., (1995,1997)/http://www.cdc.noaa.gov/cdc/data.gpcp.html
University of Delaware Precipitation	UNIDEL	0.5° x 0.5°	Willmot and Matsuura (2001), Legates and Willmott (1990)/ http://climate.geog.udel.edu/~climate/html
CPC-Merged Analysis of Precipitation	CMAP	2.5° x 2.5°	Xie and Arkin, 1997, Yin et al. (2004)/ http://www.cmap.cdc.noaa.gov/cdc/data.cmap.html
Community Atmospheric Model Version 3	CAM3	3° x 3°	Collins et al. (2004) and Bonan et al. (2002)
Regional Climatic Model Version 3	RegCM3	3° x 3°	Grell et al. (1994), Kiehl et al. (1996)

DATA ANALYSIS

Evaluation was carried out over Nigeria on zonal basis. Based on the available data, each agro-ecological zone was represented by the following stations.

Forest: Akure, Enugu, Ikeja, Benin, Calabar and Owerri
Savanna: Ilorin, Kaduna, Jos, Bauchi, Minna and Yola.
Sahel: Maiduguri, Sokoto, Kano, Nguru, Gusau, and Potiskum.

First, to evaluate the strength of agreement between the rainfall products and the gauge data, Annual Mean and Coefficient of Variation (CV) were computed for each of the products following the standard methods found in many statistical textbooks. Moreover, plot of annual time series of all the products with the station observations was done to identify the comparativeness of the temporal pattern of the data in all the 18 stations.

RESULTS AND DISCUSSION

Summary of Annual Rainfall Statistics

Table 2 and Fig. 2 show the summary of Annual Mean and Coefficient of Variation (%) for all stations. Taking any difference less than ±500 mm/yr in Annual Mean between the observed and the products as insignificant, then it can be seen that in most of the stations, the differences are generally not significant. However, there were significant differences in some instances as recorded by CAM3 in Enugu, Calabar, Kaduna and Kano where the differences between the Annual Mean for the observed and CAM3 are within the range of ±500 mm/yr. Similar scenario is seen in RegCM3 in which significant differences are recorded in Ikeja, Kaduna, Jos, Minna and Potiskum. CMAP also had Annual Mean difference of ±500 mm/yr in Yola, while GPCP recorded significant differences in Calabar, Owerri and Yola. UNIDEL was closest to the observed in Potiskum where the difference was -3 mm/yr and did not record any significant difference in all stations except in Kano. In the same vein, CRU had a very

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close Annual Mean with the observed in most stations (<±200 mm/yr differences) except in Calabar and Benin where the differences are significant. The performance of CRU was best in Potiskum with difference of +3 mm/yr. The results show that the products are better in the stations with less annual rainfall than those with high annual rainfall. UNIDEL could be adjudged best followed by CRU, GPCP, CMAP, CAM3 and RegCM3 (the least).

Table 2: Summary of Annual Statistics (Mean (mm/yr) and coefficient of Variation (%))

	Observed	CRU	GPCP	UNIDEL	CMAP	CAM3	RegCM3
station	Mean (CV)	Mean (CV)	Mean (CV)	Mean (CV)	Mean (CV)	Mean (CV)	Mean (CV)
Akure	1405(16)	1473(33)	1774(32)	1325(34)	1785(38)	1569(20)	1546(35)
Enugu	1772(20)	1900(17)	1944(9)	1884(13)	1951(19)	1287(6)	1764(14)
Ikeja	1568(22)	1408(13)	1439(15)	1381(16)	1237(19)	1797(6)	2011(13)
Benin	2242(6)	1890(18)	1944(9)	2161(14)	1951(19)	2151(4)	1869(11)
Calabar	2963(14)	2452(11)	2531(9)	2831(10)	2739(14)	2101(6)	2725(35)
Owerri	2393(15)	2260(15)	1944(9)	2302(10)	1951(19)	1916(5)	2203(27)
Ilorin	1210(18)	1209(15)	1249(12)	1232(11)	1130(15)	1334(7)	1236(12)
Kaduna	1173(10)	1094(12)	1080(18)	1179(8)	970(21)	994(9)	1824(10)
Jos	1207(10)	1199(14)	1507(10)	1266(7)	1392(15)	973(8)	2413(10)
Bauchi	1068(10)	1038(16)	980(20)	1146(8)	876(26)	951(7)	1156(15)
Minna	1219(8)	1130(11)	1444(10)	1141(8)	1355(14)	1141(9)	1952(9)
Yola	893(16)	1037(16)	1518(11)	931(14)	1282(12)	1052(7)	891(19)
Maiduguri	769(33)	521(25)	792(17)	543(22)	647(19)	1059(8)	721(17)
Sokoto	598(21)	546(23)	529(18)	571(18)	461(17)	834(8)	934(13)
Kano	859(41)	1048(14)	1248(12)	1160(14)	1130(15)	1286(8)	1219(12)
Nguru	378(27)	468(27)	365(24)	427(20)	315(25)	776(10)	581(18)
Gusau	988(16)	759(17)	1080(18)	810(15)	970(21)	1025(6)	1122(12)
Potiskum	644(25)	641(20)	809(17)	647(19)	690(20)	931(9)	1204(14)

Zonal and Temporal Pattern

Zonal and temporal comparisons of the rainfall products with the station data generally show that the pattern (the peaks and lows) are in considerable agreement for the majority of the stations under study (Fig. 2 (a-r)). However, in places like Akure, between 1980 and 1982 there was under-estimation of >500 mm/yr by most of the products whereas the patterns were very similar in the remaining years (Fig. 2a). In Enugu and Benin, under-estimation of the rainfall values was observed for the entire products except for UNIDEL and CMAP that had values that were occasionally higher than the observed (Fig. 2b & d). Ikeja and Calabar show equally very good agreement except for RegCM3 which tends to overestimate in both locations between 1998 and 1999 (Fig. 2c & e).

In Ilorin, the peaks and lows of the products and the observed were in good agreement, although CAM3 still shot ahead in most of the years (Fig. 2g). The same trend was observed for Kaduna and Jos, but it was RegCM3 that over-estimated by over 500 mm/yr in all the years in both stations; while all others had differences of <500 mm/yr over or below the observed (Fig. 2h & i, respectively). The results for Bauchi and Minna also show good agreement between the products and the observed, but while RegCM3 over-estimated in 1984 by over 500 mm/yr; UNIDEL and observed appear very close all through, for Bauchi and Minna, RegCM3 over-estimated by over 1000 mm/yr (1985) and 500mm/yr (all through), respectively in the two stations (Fig. 2j & k, respectively). However, while all others show over-estimation in virtually all the years in Yola, only RegCM3 and UNIDEL closely under-estimated.

The pattern observed in Maiduguri, Sokoto, Nguru and Potiskum (Fig. 2m, n, p & r, respectively) was that CAM3 and RegCM3 over-estimated from 1980-1999 while others show very good agreement with the observed in all the years. CAM3 particularly over-estimated by over 600 mm/yr (1988) in Maiduguri, about 500 mm/yr (1987) in Sokoto, over 500 mm/yr (1985) in Nguru and >400 mm/yr (1991) in Potiskum, while RegCM3 had the highest over-estimation of over 300 mm/yr (1988) in Maiduguri, >500 mm/yr (1987) in Sokoto, <400 mm/yr (1987) Nguru and >700 mm/yr (1997) in Potiskum. Gusau (Fig. 2q) show good pattern but the observed was higher than all estimates by close to 400 mm/yr in 1983 whereas in Kano (Fig. 2o), all products over-estimated from 1980 till 1996 when CRU and CMAP coincided with the observed. RegCM3 had the highest over-estimation of over 500 mm/yr in 1984 while all estimates were below the observed by about 500 mm/yr in 1998.

A critical assessment of the spatial analysis show that the estimates could be adjudged best in Ilorin where the differences in the estimates and the observed were <500 mm/yr in most years except in 1999 when RegCM3 showed a wide gap. The poorest could, however, be taken as Calabar where most products were greater than the observed by over 500 mm/yr except CAM3 which was in agreement with the observed from the lower side in most of the years.

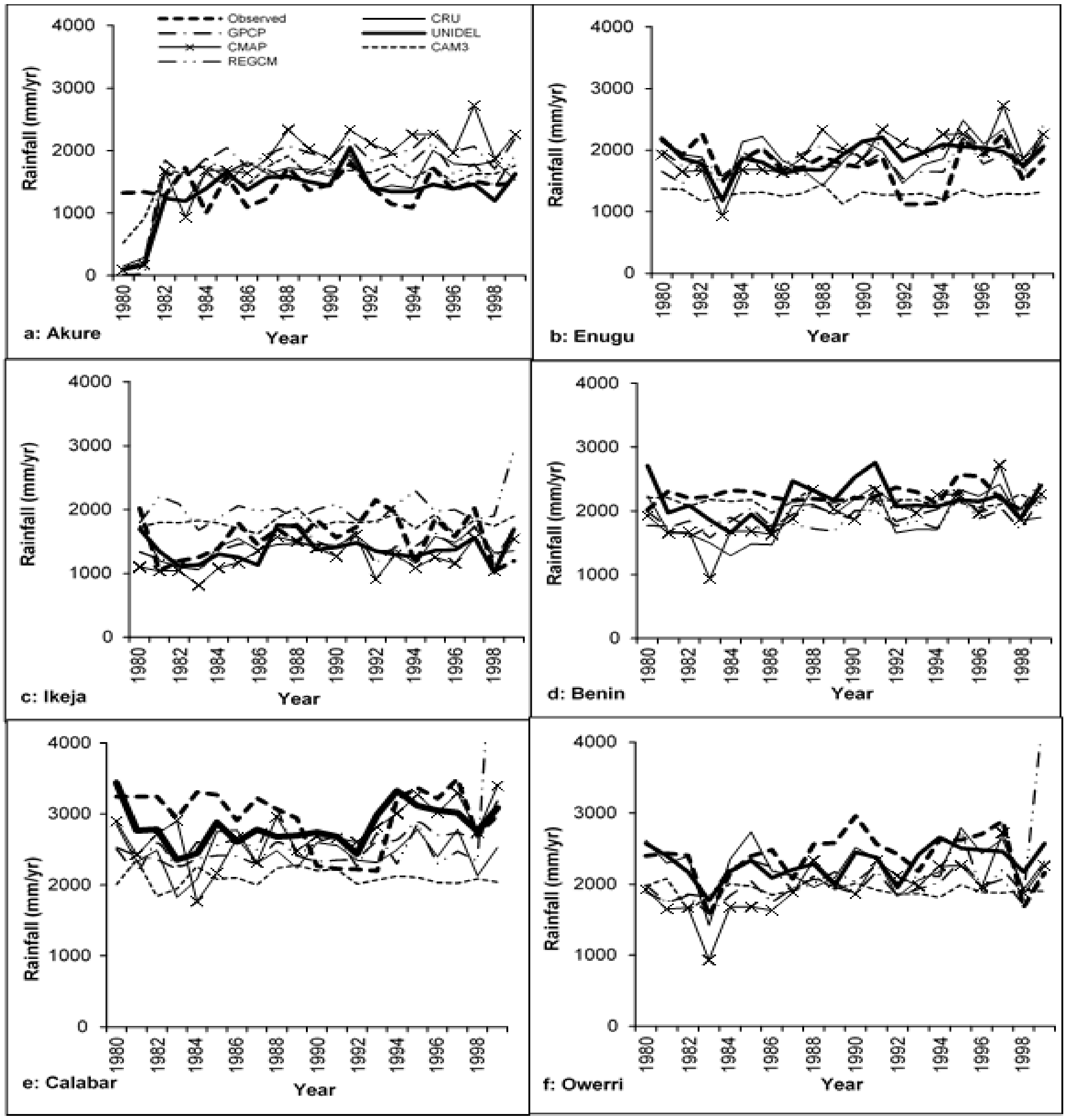

Fig. 2: Zonal comparison of rainfall products with the observed (a) Akure, (b) Enugu, (c) Ikeja, (d) Benin, (e) Calabar and (f) Owerri

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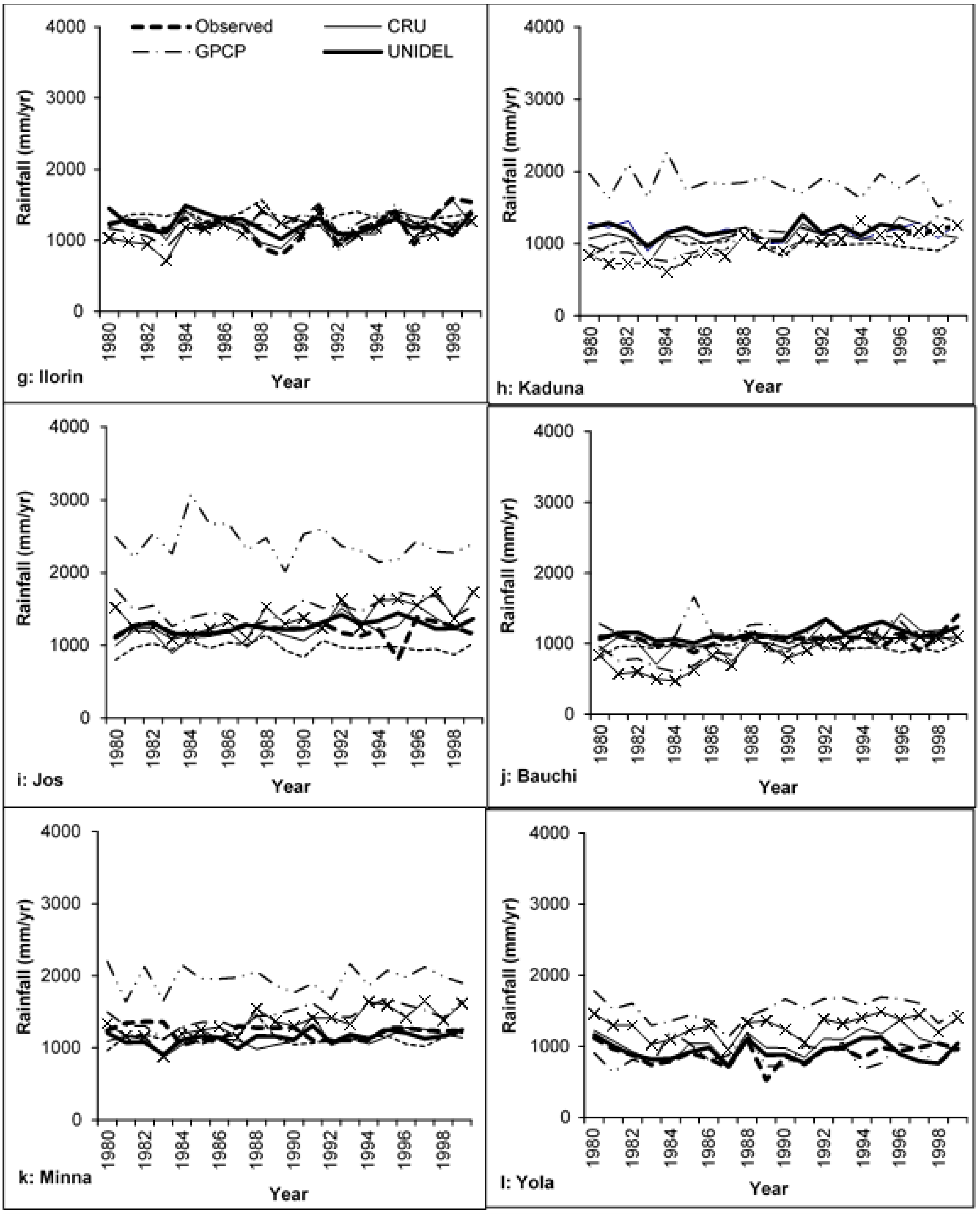

Fig. 2: Zonal comparison of rainfall products with the observed (g) Ilorin, (h) Kaduna (i) Jos, (j) Bauchi, (k) Minna and (l) Yola

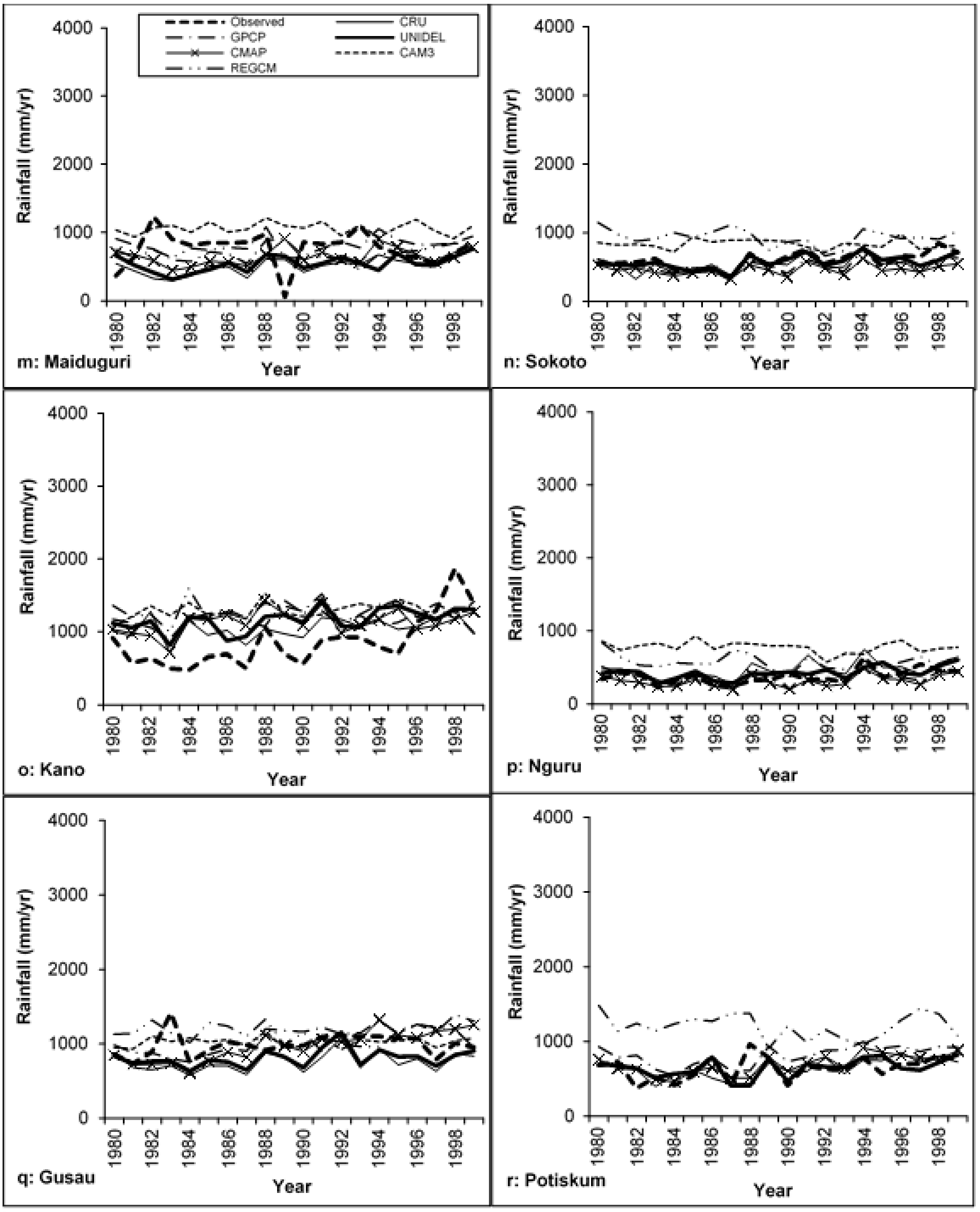

Fig. 2: Zonal comparison of rainfall products with the observed (m) Maiduguri, (n) Sokoto, (o) Kano, (p) Nguru, (q) Gusau and (r) Potiskum

DISCUSSIONS

The implications of the results obtained in this work are far-reaching. Funk and Verdin (2003) stated that an indispensable part of crop monitoring for food security in Africa is the characterization of rainfall variation in time and space. In this era of climate change and variability, early warning system can rely upon indirect estimates of precipitation in order to compensate for sparse and late-reporting rain gauge stations. Hence, the performance of the products may have formed the basis for their possible calibration for future applications. Future climate study may take a cue from the result by improving on the available dataset which can as well be used to generate new dataset for other data-scarce region of Africa. Since, CRU and UNIDEL have been found fairly okay, they could be jointly used in flood monitoring along the Lower Niger Basins, particularly around Ilorin. Also in water resources management for irrigation and power especially in Ilorin and Minna area, where most products agreed with the observed, the products will be found useful. It could be recollected that many hydropower stations are located around this zone, hence, climate impact modelling for hydropower generation may find the products useful. In drought monitoring, the combination of UNIDEL, CMAP and CRU could serve as good alternatives to station data in places like Maiduguri. Flow prediction along rivers in the north east of Yola and Bauchi can as well be carried out with some of the products when used together.

However, in view of the poor performances of the products in the forest zone, they cannot be effectively used where accuracy is the critical requirement. Nevertheless, the combination of two or more of the products (especially CRU and UNIDEL) would help in water resources project planning, management of crop growing season and little rain forecasting. Other areas include the study of soil and water losses in low and high intensity rainfall in the zone (Owerri, Enugu, etc.) as earlier used in Iraq by Hussein and Othman (1988), as the products could be assessed in lieu of rain gauge where the latter appears unavailable.

No doubt that with the level of bias (underestimation and overestimation) shown, these products are capable of generating sufficient bias in their output when used in various models as observed by Fekete et al. (2004) who showed that uncertainty in precipitation translates to at least the same and typically much greater uncertainty in runoff in relative terms when different precipitation datasets were applied as forcings to a water balance model to estimate runoff. Harris et al. (2007) reported that 3B41RT algorithm suffered from systematic underestimation (negative bias) for the March 2002 storm event which also resulted in an underestimated flood hydrograph in their use of TRMM-based rainfall products in flood modeling. Consequently, the use of the products in all instances especially modelling should be done with caution, moreso that reanalysis rainfall is yet to be fully developed in Nigeria.

CONCLUSION

The overall results of this study suggest that the various products (CRU, GPCP, UNIDEL, CMAP, CAM3 and RegCM3) are in good agreement with the station data. However, the performance is such that UNIDEL could be adjudged best followed by CRU, GPCP, CMAP, CAM3 and RegCM3 in that order. UNIDEL is the most reliable while RegCM3 is the least. Besides, zonal analysis also show that the estimates are most reliable in the Sahel, followed by Savannah and least in the Forest. The estimates are, however, more reliable in the dry months of all the zones. It is therefore recommended that further work should be carried out to possibly evolve a definite relationship in form of equation and a conversion factor for the products. Also, each of the products could be evaluated separately in the various zones of the country using thesame dataset to make the study more comprehensive and detail. There is the need for improvement in the spread of observation stations and continuous replacement of obsolete equipment to enhance the integrity of the data.

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