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Review

An experiment in intra-seasonal agricultural drought monitoring and early warning in the Sudano-Sahelian Belt of Nigeria

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ABSTRACT: The highly variable rainfall and recurring drought in dry sub-humid and semi-arid regions constitute a major socio-economic problem that influences people's livelihoods. Agricultural drought is the most common of all drought types and is the most challenging to track and forecast owing to its ease of occurrence and impact on socio-economic sustainability. In Nigeria as is the case in large parts of sub-Saharan Africa, drought frequency, intensity and effect have dominated the literature since the great Sahelian drought of the late 1960s and early 1970s. This study proposes a simple drought monitoring and early warning (EW) methodology based on an experiment over Kano, Nigeria, hinged on an Intra-seasonal Rainfall Monitoring Index (IRMI, Usman and Abdulkadir, 2012) determined for each pentad, using daily rainfall totals for a period of 30 years. The onset dates and drought intensity levels were used to define EW statements at three levels: advisory, alert and emergency. An experimental application of the scheme identified and detected late initiation conditions of real monsoon onset (RMO) in those seasons that eventually witnessed disastrous rainfall situations. Generally, the result reveals that the years between 1970 and 1990 over Kano, Nigeria, which ended as years of severe drought or worse, showed enough signals of poor rainfall distribution (deficient moisture) at the beginning for the scheme to have enabled a very high degree of forecast accuracy. It is concluded that strict monitoring of the rainfall regime especially during its onset phase is capable of revealing danger signals in the rainfall regime early enough to enable mitigation. Such mitigation is critical for the management of agricultural productivity in the predominantly rainfall-dependent farming systems in the Sudan-Sahel zone as confirmed by earlier studies.

KEY WORDS real monsoon onset; agricultural drought; early warning; Sudan-Sahel; sustainability

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1. Introduction

Drought is a recurring environmental hazard in dry sub-humid and semi-arid regions where people's livelihoods depend largely on subsistence agriculture and animal husbandry. Drought, in all its forms, is injurious to the well-being of the people and hampers attempt by all concerned to achieve sustainable development in the region. Agricultural drought is the most common of all the drought types in Nigeria and represents the most challenging to track and forecast owing to its ease of occurrence. The 1969–1973 drought remains topical because it had a serious impact on the agricultural sector in Nigeria. Usman (2000a) presented among others, reviews of studies on the losses arising from this drought and cites the fact that the groundnut pyramids of Kano in northern Nigeria that disappeared in the immediate wake of that episode are yet to return, as evidence of subsisting problems.Other studies, e.g. Lovanna (1986) for Morocco, have also reported drought-related losses in other parts of Africa which informed Rahmato (1991)'s conclusion that drought is the prime reason for 30 million people who constantly face the threat of famine and starvation on the African continent. Consequently, there is need to develop and test the intra-seasonal agricultural drought monitoring and EW to minimize risk and vulnerability as well as enhancing capacity and resilience to agricultural drought.

An EW system to mitigate the negative impacts of droughts in the region needs an effective rainfall monitoring system, a reliable hazard and socio-economic vulnerability assessment and the analysis of such data. With appropriate information, farmers can be put in a position to forestall these impacts through the adoption of simple water, farm, seed or animal farming techniques. Vordzorgbe (2003) and Joseph *et al.* (2010) point to this fact in asserting that early warning (EW) has the potential to contribute significantly to reduce current and future disaster losses as an important non-structural component of risk reduction. Umma *et al.* (2012) identified effective

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EW system and improved water conservation system as essential to sustainable farmer's livelihood in the event of drought. It is in this context that the United Nations expects and encourages all nations to work assiduously to put in place EW schemes for all hazards that their people are exposed to. Recent efforts following in the wake of UN Decade for disaster reduction (1990s) have involved further commitments as contained in the Yokohama declaration (1994) and the Hyogo plan of action (2005) with EW as a central requirement for reducing threats to human security.

Luckily, because drought episodes are related to varying forms of precipitation deficit and flood occurrences are related to precipitation surpluses, opportunities do exist for the development of EW and monitoring schemes that incorporate both. These were explored using IRMI. Usman *et al.* (2005) features an elaborate discussion of the conceptual issues underlying this possibility. Several schemes have been developed and tested for drought forecasting and many operations and research centres run models dedicated to the forecasting of drought in Africa albeit with varying degrees of success depend upon the complexity of the methodology involved.

An example of a non-complex scheme developed for Africa is the effort by Stewart (1991) which examined the possibility of using the information on onset date of rain for Niamey, Niger Republic, as an indicator of the ensuing rainfall season and to utilize it to adjust planting and input decisions more optimally for the season. AGRHYMET (2005) used daily or decadal rainfall, potential evapotranspiration and soil water holding capacity above the wilting point, to give EW indicators of crop water balance. Another study, by Usman and Abdulkadir (2012) also showed similar possibilities with respect to the 1970–1999 rainfall over Minna and Kano.

1.1. Methodology

This study proposes a simple drought monitoring and EW methodology hinged on an Intra-seasonal Rainfall Monitoring Index (IRMI) developed by Usman and Abdulkadir (2012) as a tool for determining the real onset date of the summer monsoon rains. IRMI is computed on a pentad by pentad basis from the beginning of May using the expression, $(\mathrm{Cpt})^2\ /(\mathrm{hpt} \times \mathrm{Nb} \times 100)$, where Cpt is cumulative pentad rainfall since May 1, hpt is the highest pentad total rainfall since May 1, Nb is number of breaks in rainfall (pentads with less than 5 mm of rainfall) and 100 is a factor. The effective onset of rains is defined as the pentad within which IRMI becomes ≥ 1 for the first time. This way, the index rises gradually as the rains become steady and then falls as the rains cease. See Usman and Abdulkadir (2012) for additional details. Consequently, IRMI is capable of determining the actual pentads of effective onset and cessation of the rains at the individual farm level with the simplest of daily rainfall records, a very clear superiority over the probabilistic seasonal onset forecasts that currently dominate agricultural decision-making across the country.

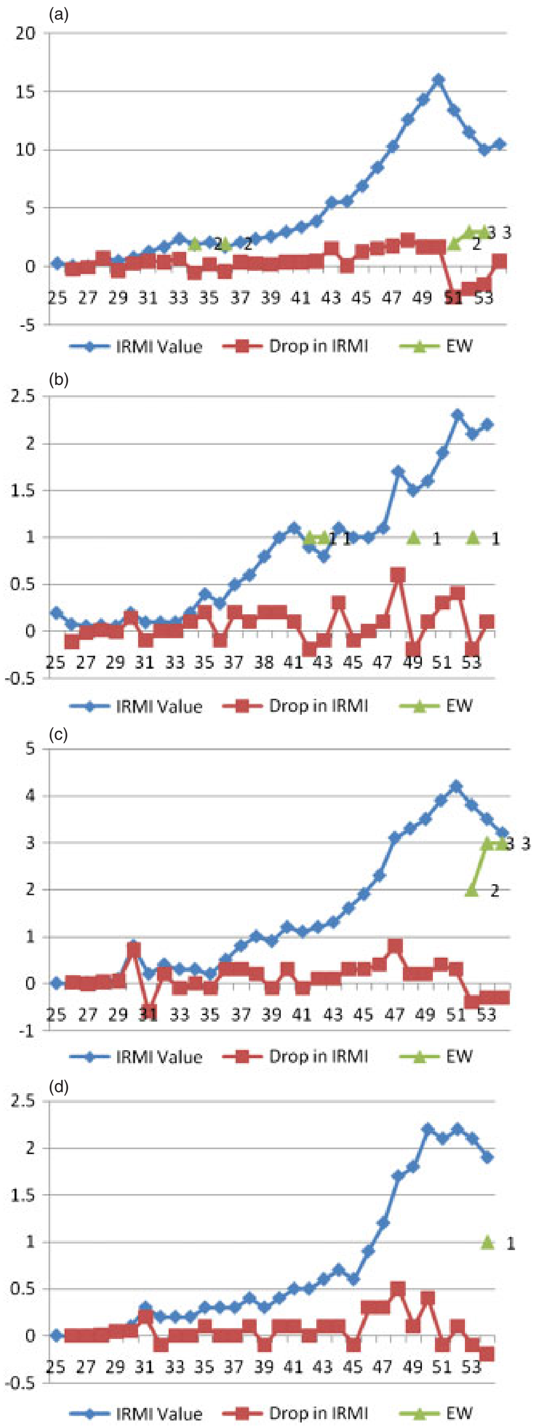

Figure 1. (a) 1980 Drop in IRMI value and early warning. (b) 1981 Drop in IRMI value and early warning. (c) 1982 Drop in IRMI value and early warning. (d) 1983 Drop in IRMI value and early warning. This figure is available in colour online at wileyonlinelibrary.com/journal/joc

IRMI was used to develop a drought monitoring and EW scheme for semi-arid and dry sub-humid regions (Figure 1(a)–(d)). The premise is that IRMI is computed on a pentad by pentad basis and its value of each pentad is a measure of the amount and spread of rain received and thus a good indication of the moisture situation. By inference, the presence or otherwise of agricultural

Table 1. IRMI-based drought monitoring scheme.

On set classification		Rainfall receipt (moisture supply condition)	Hazard categories
IRMI ranges	IRMI classes		
IRMI > 10	1	Abundant (high rainfall total within short time spans)	Flood
1 < IRMI ≤ 10	2	Adequate	No drought, No flood
0.1 < IRMI ≤ 1	3	Deficient	Mild drought
0.010.01 < IRMI ≤ 0.1	4	Very deficient	Severe drought
IRMI ≤ 0.01	5	Extremely deficient (low rainfall totals over long time spans)	Very severe drought

Table 2. Drought early warning scheme using effective onset dates.

Effective onset dates (pentad number)	Onset phase drought (moisture deficit) intensity	Early warning phase
30th June (36th)	Mild	Advisory
25th July (41st)	Severe	Alert
5th August (43rd)	Very severe	Emergency

drought, (Usman and Abdulkadir, 2012), the beginning (or onset) of drought and its corresponding intensity can be determined and its development monitored as the season progresses. A classification proposed in this regard is that classes 1 and 2 are indicative of abundant and adequate moisture conditions whereas classes 3, 4 and 5 are indicative of deficient, very deficient and extremely deficient moisture conditions as presented in Table 1.

The IRMI value in each pentad is used as an indication of the hazard categories (Table 1), such that when IRMI is less than 1 (occurrence of classes 3, 4 and 5) in any pentad it is indicative of increasingly smaller rainfall amounts spread out over longer number of days in respective order. In other words, these classes could be interpreted to represent mild, severe and very severe drought conditions, respectively. In addition, because this index is computed each pentad, the temporal pattern exhibited by its values can be utilized as a tool for developing an agricultural EW scheme in these rainfall regimes. Two schemes are described in this regard, the first using onset dates (similar to the work by Stewart, 1991, for some stations in Niger republic) and the second scheme incorporating the pattern of drop in IRMI values and associated drought intensity to provide EW information considering the cropping season calendar (Tables 2 and 3).

Effective onsets of rainfall on or before pentad number 36 will be indicative of a good rainfall season in the semi-arid and dry sub-humid zones of Nigeria north of latitude 10^{o}N as long as damaging breaks do not occur in succession within the growing season. If rainfall is not effective before pentad 36 (30 June), it should be an indication of a problem of some sort as this will impact negatively on the length of the growing season and should be used to issue an advisory statement to farmers. Effective onset of rain at about pentad 41 (25 July) is an indication of deficient moisture conditions (severe drought), and this should justify the issuance of an alert to farmers and responsible disaster management authorities. Also, a very severe deficient moisture situation that will occur if the seasonal rains are not effective by the 43rd pentad (5 August), should warrant the declaration of an emergency as the growing season is not likely to be long enough for crops to mature and yield any tangible harvest for the season. In all cases, corresponding contingency measures designed as an integral part of an agricultural disaster risk management plan can be activated to forestall adverse socio-economic impacts.

Similarly, as the Sudano-sahelian belt of Nigeria is characterized by high intra-seasonal variability of rainfall, and after its effective onset, moisture conditions may still vary enough to distort crop growth and development, it is proposed that the change in IRMI values can be monitored and used in an EW context especially for drought occurrences (Table 3). This change in IRMI values is computed for each pentad as the difference between current IRMI value and the preceding IRMI value, given as:

$$\Delta(\mathrm{IRMI}) = \mathrm{IRMI}_{\mathrm{p}} - \mathrm{IRMI}_{\mathrm{p}-1}$$

where Δ(IRMI) is change in IRMI value, p represents the current pentad and $p-1$ the previous.

The drops in IRMI values were interpreted as ‘Not significant’, ‘Significant’ and ‘Highly Significant’ moisture stress conditions and related to conditions for the issuance of EW statements; advisory, alert and emergency (Table 3). This scheme is predicated on the fact that a drop in IRMI between two successive pentads is indicative of a worsening condition and vice versa. Occurrences of mild drought (drop by 0.1) for two pentads will intensify the impact of moisture deficiency on crops; as a result, advice should be given for agricultural drought after the first two pentads of mild drought. If the situation persists for three pentads, then the farmers should be alerted on the intensity of drought and potentials for crop loss. The worst situation will be the successive occurrence of mild drought for six or more pentads. This should activate an emergency phase in disaster management, as there may be the need for the replanting of crops. Similarly, the situations for significant and highly significant IRMI drop occurrences are indicated in Table 3. The drop in IRMI values, drought category and proposed EW statements were tested against the backdrop of the fact that the generally variable soil moisture levels due

Table 3. Drought early warning using drop in IRMI values.

Drop in IRMI	Interpretation	Early warning statement		
		Advisory phase	Alert phase	Emergency phase
Drop ≤ 0.1	Not significant	Two successive occurrences	Three successive occurrences	Six successive occurrences
0.1 < Drop < 0.3	Significant	One occurrence	Two successive occurrences	Four successive occurrences
Drop ≥ 0.3	Highly significant	—	One occurrence	Two successive occurrences

Table 4. Application of the scheme on change in IRMI values to Kano rainfall data showing pentads within which conditions were met for the respective EW statements.

Advisory (Pentad No.)	Alert (Pentad No.)	Emergency (Pentad No.)
1973 (47 and 54)	1970 (50)	1977 (52)
1973 (46 and 52)	1971 (49)	1979 (47)
1975 (54)	1972 (38, 42, 44, 51 and 54)	1982 (53 and 54)
1976 (43, 47 and 53)	1973 (48 and 52)	1993 (52)
1978 (46, 48 and 50)	1974 (54)	
1979 (52 and 54)	1975 (39, 44 and 47)	
1980 (51)	1976 (41, 51 and 54)	
1981 (42, 43, 49 and 51)	1977 (51)	
1983 (54)	1978 (44 and 51)	
1984 (35, 38, 40, 44 47 and 51)	1979 (46, 51 and 53)	
1985 (53)	1980 (34, 36 and 51)	
1987 (50)	1982 (52)	
1989 (54)	1984 (35 and 36)	
1990 (49 and 54)	1985 (42 and 54)	
1993 (34)	1986 (54)	
1994 (53)	1988(54)	
1996 (34, 37, 39 and 54)	1990 (53)	
1997 (35 and 53)	1991 (53)	
1998 (50)	1992 (32, 35 and 54)	
	1993 (51 and 54)	
	1995 (47)	
	1997 (34, 42 and 44)	
	1998 (34 and 51)	

to rainfall fluctuations should be monitored in aid of rain-fed agriculture. Rainfall must be well distributed without long breaks and must allow the ground to retain enough water for plants to grow to maturity without interruption. After the onset of effective rainfall, breaks and dry spells may still occur to distort crop growth and development. This agrees with the conclusion by Sultan and Janicot (2004) that the onset of ‘useful’ rains, (i.e. the first rains sufficient to ensure enough moisture in the soil at the time of planting and not followed by prolonged dry spells) is necessary to provide for the survival of seedling after sowing. Thus, the need still exists for drought EW. With this respect, it is proposed that the change in IRMI value is used in an EW scheme as described in Table 3 to depict varying moisture conditions that could distort crop growth and development throughout the year. A test of this on available historical data is shown in Table 4, depicting pentads within which the three EW conditions (advisory, alert and emergency) were met.

2. Results and discussion

It is established that semi-arid and dry sub-humid areas (especially in the Tropics) are characterized by high inter-annual and intra-seasonal rainfall variability (Usman *et al.*, 2005, etc). An examination of inter-pentad IRMI differences over Kano confirms this and reveals that all the years covered by the study are characterized by drops in IRMI values, with significant drops occurring at different stages during the hydrological growing seasons. It is noted that the alert and emergency conditions were registered in most of the seasons of their occurrence, between late August and mid-September pointing the possible role of changes in prevalent circulation systems over West Africa in determining temporal distribution of rainfall. Nicholson (2013) confirms northward shift and intensification of the latitudinal temperature and pressure gradients over West Africa. Significantly, the drought intensity levels of the early 1980s were aggravated by drop in IRMI values (Figure 1). In 1980, drops of −0.5 and −0.4 in the 34th and 36th pentads were indicative of severe drought and this could have been used to issue an agricultural drought alert statement. Similarly, drop in IRMI value of −0.4 in the (52nd pentad) and −0.3 for two consecutive pentads (53rd and 54th pentads) were indicative of very severe drought, hence an emergency statement in terms of agricultural drought could have been issued in 1982 since most crops would have dried

Table 5. Application of the RMO scheme to rainfall data over Kano.

Year	Effective onset dates (Pentad No.)	Inferred drought intensity	Possible early warning statement
1970	25 July (41st)	Severe	Alert
1971	30 July (42nd)	Severe	Alert
1972	10 June (32nd)	None	Normal
1973	10 August (44th)	Very severe	Emergency
1974	20 July (40th)	Mild	Advisory
1975	30 June (36th)	None	Normal
1976	30 June (36th)	None	Normal
1977	10 August (44th)	Very severe	Emergency
1978	10 June (32nd)	None	Normal
1979	10 July (38th)	Mild	Advisory
1980	5 June (31st)	None	Normal
1981	20 July (40th)	Mild	Advisory
1982	20 July (40th)	Mild	Advisory
1983	25 August (47th)	Very severe	Emergency
1984	15 June (33rd)	None	Normal
1985	5 July (37th)	Mild	Advisory
1986	10 July (38th)	Mild	Advisory
1987	20 August (46th)	Very severe	Emergency
1988	10 July (38th)	Mild	Advisory
1989	15 August (45th)	Very severe	Emergency
1990	25 July (41st)	Severe	Alert
1991	10 June (32nd)	None	Normal
1992	5 June (31st)	None	Normal
1993	15 June (33rd)	None	Normal
1994	15 August (45th)	Very severe	Emergency
1995	20 July (40th)	Mild	Advisory
1996	10 June (32nd)	None	Normal
1997	5 June (31st)	None	Normal
1998	10 June (32nd)	None	Normal
1999	10 July (38th)	Mild	Advisory

up before maturity. It is known that prevalent easterly waves over the sub-region are at peak during the months of July–September (Grist, 2001) and that seasons within which conditions were met for the issuance of alert and emergency warnings were those in which this peak was most probably weak such that the rain-bearing systems failed to take rooting and rainfall events therefore became few and far-between. This will be examined in details in another study.

Finally, the occurrence of these classes of drought in the early months of planting and the associated variability in moisture condition is tested using daily rainfall data for Kano in the Sudan-Sahel zone of Nigeria. As Oroda (2001) concluded, the environmental and weather conditions in most countries are highly precarious and the sub-region experiencing frequent droughts and crop failure whose result is famine requires a reliable and effective EW for environmental monitoring and food security. The data, for the period 1970–1999 was collected from the Nigerian Meteorological Agency archives. Specifically, advisory, alert and emergency EW statements could have been issued using the scheme as indicated in Table 5 for the concerned drought onset pentads in each of the years eventually documented as drought years: 1970, 1971, 1973, 1974, 1977, 1983, 1987, 1989

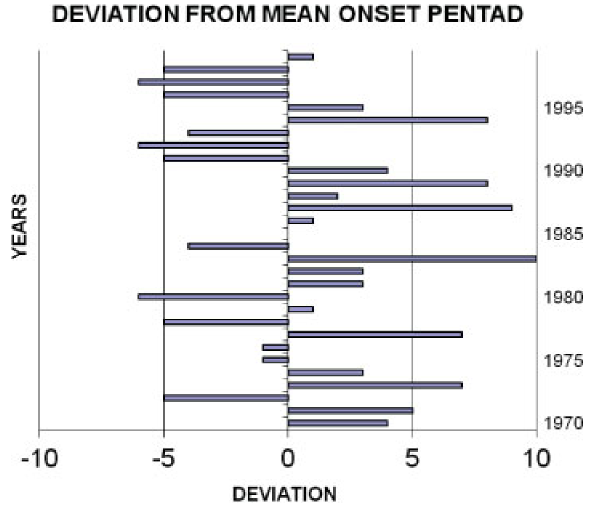

Figure 2. Deviation from mean onset pentad (RMO). This figure is available in colour online at wileyonlinelibrary.com/journal/joc

and 1990. This possibility is pertinent because repeated occurrences of advisory or alert conditions would certainly intensify the effect on crops during the growing season.

A further examination confirmed this character of inter-annual onset date variability. Generally, real monsoon onset (RMO) dates as indicated in Table 5, occurred, for 50% of the years, between July and early August potentially impacting negatively on those rainfed cropping seasons. Delayed RMO dates meant poorer rainfall distribution to varying degrees indicating different rainfall deficit (drought intensity) levels. Thus, the years that are now recognized as drought years showed enough signals (of deficient moisture supply condition) at the beginning of the growing season for the scheme proposed herein to have enabled a very high degree of monitoring/forecast accuracy – confirming the assertion by Usman *et al.* (2005) that a drought episode is a creeping phenomenon, the onset of which is usually slow. Particularly, rainfall was not effective until the 43rd pentad in 1980 (35 days of deficient moisture beyond the 36th pentad, the onset pentad), 40th pentad in 1981 (20 days of deficient moisture) and 47th pentad in 1983 (55 days of deficient moisture) by inference, the gradual moisture stress experienced after the 36th pentad in each of the years proved that the varying levels of drought intensity were apparent early enough for necessary intervention (Figures 1 and 2). Instructively, the years recorded to have had above normal rainfall totals over Kano including 1972, 1975, 1976, 1978, 1980, 1984, 1991, 1992, 1993, 1996, 1997 and 1998, all had well-distributed rainfall; arising from relatively early RMO dates. Hence, adequate monitoring will enhance accurate agricultural drought forecast and early detection of normal rainfall and drought years.

Most of the 1970s and early 1980s were characterized by drought as evident in the positive deviation typical of the decade's RMO pentads (Figure 2 and Table 5) even though there were also years with adequate number of rainfall days such as in1980 and 1991 (negative deviation in RMO pentads) with about 125 days of adequate rainfall, 1992 with 115 days, and 1972 and 1978 with 110 days of adequate moisture for agriculture, during which drought events were not functions of late effective onset of rain. However, these years also experienced drops in IRMI values and thus, the varying drought intensity levels could have been used to issue EW statements in the concerned pentads during the hydrologic growing season (HGS) (Table 4). In 1970, 1971, 1974, 1982 and 1990, RMO was beyond 41st pentad (25 July) indicating that there were only about 60 days of adequate moisture for agriculture and 90 days of deficient moisture. In 1973, 1977, 1983, 1987, 1989 and 1994, rainfall was adequate for about 50 days only with RMO beyond 43rd pentad (10 August) an indication of very severe moisture stress; the least number of days of adequate rainfall was in 1983 and 1987 when rainfall was concentrated in a short wet season of about 40 days (RMO in 47th and 46th pentad, 25 and 20 August), respectively. These are too short for effective crop growth, as there is hardly any crop grown in this region that grows to maturity within 40 days. As a result, these years are classified generally as years of very serious problems agriculturally.

Deviation from mean onset pentads again reveals that most of the seasons are characterized with variability (Figure 2); with predominantly negative deviations indicating earlier onset of rains during the 1950s, 1960s and 1990s. The positive deviations of the 1970s and the 1980s signify a later onset of rain during these decades. A comparison of the results of this scheme with the Moisture Quality Index (MQI) developed by Usman (2000b) indicates that there is a strong positive correlation of 0.78 between the two schemes, implying that seasons with later than normal onset of rains, tended to end up being of poor seasonal rainfall quality. In summary only 40% of the hydrological growing seasons around Kano had normal rainfall onset, 30% had mild drought implied during onset phase, 10% had severe and 20% had very severe agricultural drought implied during the onset phase, respectively.

What this implies is that the occurrence of the various classes of drought in the early months of planting say May, June, July and August can be used to give EW to farmers and other users of climatic information in the study area (Table 5). Effective onset of rainfall before pentad 36 is seen to be a precursor to a good rainfall year. If rainfall is effective beyond pentad 36, (30 June) then an indication of mild drought which should be used to give advisory statement to farmers is implied. An effective onset of rain at about pentad 41 (25 July) points to an implication of severe shortages in moisture availability arising from shorter growing season and this can be used to alert the farmers on the intensity of potential agricultural drought. There is a big likelihood of an emergency if the rain is not effective up till pentad 43 (5 August). As a result of late onset of rain, planting may be discouraged between May and early June except for crops that are highly drought-resistant as there may be false onset of rain before 30 June. In addition, except for crops with short-growing periods, no planting can take place after July.

These patterns of rainfall variability and late onset and their agreement with documented seasonal rainfall patterns are indicative of the fact that agricultural drought is a function of late effective onset of rain. Only two-fifth of the study period had effective onset of rain on or before 30 June (36 pentad) in 1972, 1975, 1976 1978, 1980, 1984, 1991, 1992 1993, 1996, 1997 and 1998. Mild seasonal drought was suggested at onset in 1974, 1979, 1981, 1982, 1985, 1986, 1988, 1995 and 1999. In all of these cases, advisory statements could have been issued early in the concerned season. Severe drought was implied at onset in 1970, 1971 and 1990, whereas suggested droughts were very severe in 1973, 1977, 1983, 1987, 1989 and 1994. Alert and emergency statements could have been issued in these respective groups of years. It is the view of the authors that the schemes described herein identifies and detects adverse conditions of RMO that could lead to disaster conditions in the course of the rainfall season.

3. Conclusion

IRMI classes were used to determine moisture supply condition and drought categories, based on effective onset dates and drop in moisture supply conditions (drop in IRMI values). Drought intensity levels were determined (mild, severe and very severe) using effective onset dates and changes in moisture supply conditions, pointing to the promise of easy adoption for monitoring and development of EW statements during the hydrologic growing season. The application of an intra-seasonal drought monitoring scheme to rainfall data over Kano showed about two-third of the HGS in Kano were drought-prone (Table 5) and that moisture supply condition is generally deficient between May and June in this region. This application quite clearly agrees with the general observations of researchers like Adefolalu (1986), Stewart (1991), Usman (2000b, 2005) and AGRHYMET (2005) in the area of agricultural drought. An indication of the efficacy of the new schemes is based on a simple premise of potential for village-level (on-farm) applications. Drought is an inherent characteristic of Sudano-Sahelian zone in Nigeria and the worst situations in the period under study included the years when rainfall was only effective for less than 60 days within the HGS.

It is obvious that the years of very severe drought showed enough signal (late onset of rains) at the beginning to have allowed relevant authorities avert the great human suffering witnessed in the Sudano-Sahelian zone. The IRMI EW scheme captured these signals adequately and apparently holds serious promise of an easy-to-use versatile tool for drought warning and mitigation planning.

References

Adefolalu DO. 1986. Further aspects of Sahelian drought as evident from rainfall regime of Nigeria. *Meteorol. Atmos. Phys.* **36**(3–4): 277–295.

AGRHYMET (2005). Drought monitoring and early warning in the Sahel: The AGRHYMET experience. *A Paper Presented At The World Conference On Disaster Reduction*. Kobe, Japan, 18–22 Jan. www.unisdr.org (accessed January 1, 2012).

Grist JP. 2001. Easterly waves over Africa. Part I: the seasonal cycle and contrasts between wet and dry years. *Mon. Weather Rev.* **130**: 197–211.

Hyogo plan of action (2005). Hyogo Framework for Action 2005–2015: building the resilience of nations and communities to disasters. Report of the World Conference on Disaster Reduction (A/CONF.206/6). http://www.unisdr.org/we/inform/publications/1037 (accessed July 20, 2013)

Joseph EQ, Bernard E, Gilbert LR. 2010. Early warning systems: a review. *J. Terr. Obs.* **2**(2): 25–44.

Lovanna R. 1986. Sustainable drought management in Morocco. Report prepared for the World Bank.

Nicholson SE. 2013. The West African Sahel: a review of recent studies on the rainfall regime and its interannual variability. *ISRN Meteorol.* **2013**: 32, DOI: 10.1155/2013/453521.

Oroda AS. 2001. Towards establishing an operational early warning system for food security in the Horn of Africa. Remote sensing and geo-informatics. *J. Neth. Rem. Sens. Board (BCRS)* **2**: 26–30.

Rahmato D. 1991. Famine and survival strategy, Scandinavian Institute of Africa studies, Lund. www.books.google.com (accessed March 7, 2011).

Stewart JI. 1991. Managing climate risk in agriculture. In *Risk in Agriculture*. ISBN 0-8213-1965-5, pp. 17–37.

Sultan B, Janicot S. 2004. The pre-onset and onset monsoon systems over West Africa. *CLIVAR Exchanges* **27**: 231–242.

Umma H, Rajib S, Yukiko T. 2012. *Farmer's Perception and Adaptation Practices to Cope with Drought: Perspectives from North Western Bangladesh*. www.elsevier.com/locate/ijdrr (accessed Nov 20, 2012).

Usman MT. 2000a. An instability index for monsoon onset characterisation over the Nigerian Sahel. *Environ. Rev.* **3**(2): 367–379.

Usman MT. 2000b. An operational index for assessing inter annual rainfall variability and agricultural droughts over the Sahel. *Afr. Climatol. Res. Ser.* **3**(1): 23–33.

Usman MT, Abdulkadir A. 2012. On determining the 'Real' onset date of seasonal rains in the semi-arid and sub-humid areas of West Africa. *Nat. Hazard (NHAZ)*, DOI: 10.1007/s11069-012-0514-9.

Usman MT, Archer ERM, Johnton P, Tadross M. 2005. A conceptual framework for enhancing the utility of rainfall hazard forecasts for agriculture in marginal environments. *Nat. Hazards* **34**: 111–129.

Vordzorgbe S. 2003. Regional report on early warning of natural disaster in Africa. Report prepared for the Second International Conference on Early Warning, 16–18 October, UN/ISDR. Nairobi, Kenya.

Yokohama declaration 1994. Guidelines for Natural Disaster Prevention, Preparedness and Mitigation. In *World Conference on Natural Disaster Reduction Yokohama, Japan*. http://www.ifrc.org/Docs/idrl/I248EN.pdf 20/07/2013.

