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Practical Benefits of Geospatial Technology in Drought Prone Sudano-Sahelian Lake Chad Basin: Early Warning and Agricultural Planning

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Abstract: Peasant farmers in Lake Chad Basin plant seed weeks or months earlier than an onset of rainfall. They are using local knowledge of a dry season to predict planting dates. They are forced to plant early because rain-onset and probable occurrence of agro-meteorological droughts are unknown. Nowadays, the benefits of geospatial technology coupling Earth observation (EO) data and GIS are immense especially for monitoring precipitation from space. Thus, with geospatial unique technologies (GEONETCast download near real-time EO data) in the University of Maiduguri and Kano University of Science and Technology, peasant farmers can be informed timely about the onset of rains at different locations, duration and occurrence of droughts in the Lake Chad Watershed. This joint research (ongoing) evaluates practical benefits of geospatial technology for rainfall early warning and agricultural planning in the Basin. The specific objectives are to extract precipitation from space to determine intensity, when and where it may rain; and validate Meteosat Second Generation Multi-Sensor Precipitation Estimate (MSG – MPE) with in-situ weather data (2005 – 2014). The 10-year data for the study were downloaded from ESA Tiger INITIATIVE Project at the Universities downloaded from GEONETCast stations. The study applies the theory of Water Vapour and Infrared. This theory is rated one of the best especially in tropical Africa where in-situ agro-meteorological stations are inadequate. The key findings of the study include determination of rainfall onset, drought monitoring facilities and early warning in Lake Chad. GEONETCast technology covers the entire Africa, therefore, the study strongly recommends the replication of the research in other parts of Africa.

Key words: Lake Chad Basin · Tiger INITIATIVE · Geospatial technology · GEONETCast · MSG – MPE · Early warning · Agro-meteorological droughts monitoring · and farmers

INTRODUCTION

One-third of the people in Africa live in drought-prone areas and are vulnerable to its impacts [1]. Due to its characteristics and impacts, drought has become one of the most important natural hazards in sub-Saharan Africa and often resulted in serious economic, social and environmental crises [2]. Since the devastating Sahelian drought of the early 1970s, drought has occurred in many parts of Africa [3], such as the Horn of Africa – particularly Ethiopia, Eritrea and Somalia [4, 5] and Sudano Sahelian Region of Nigeria [6, 7].

Lake Chad Basin is an endorheic watershed without an outlet, Figure 1. The basin according to IUCN [8] used to hold one of the largest areas of wetlands in the Sahelian region. Over past decades, the basin has experienced a series of devastating hydro-meteorological droughts. According to CRED 2013, drought has affected more than 10 million people in the Lake Chad member States in the last decade. Therefore most scholars regarded the region as a drought-prone Lake Chad member States (Niger, Chad, Sudan, C.A.R., Cameroon and Nigeria). When drought occurs, it affects a large spatial area for seasons at a time, which results in a large proportion of the population being affected by drought than other natural disasters. Nigeria having the largest proportion of the population in the region (Lake Chad), is mostly affected by drought than other disasters, therefore needs to be closely monitored for informed decisions on agricultural planning. Being one of the costliest natural disasters of the world [9-11] and major threats to people's livelihood and socio-economic

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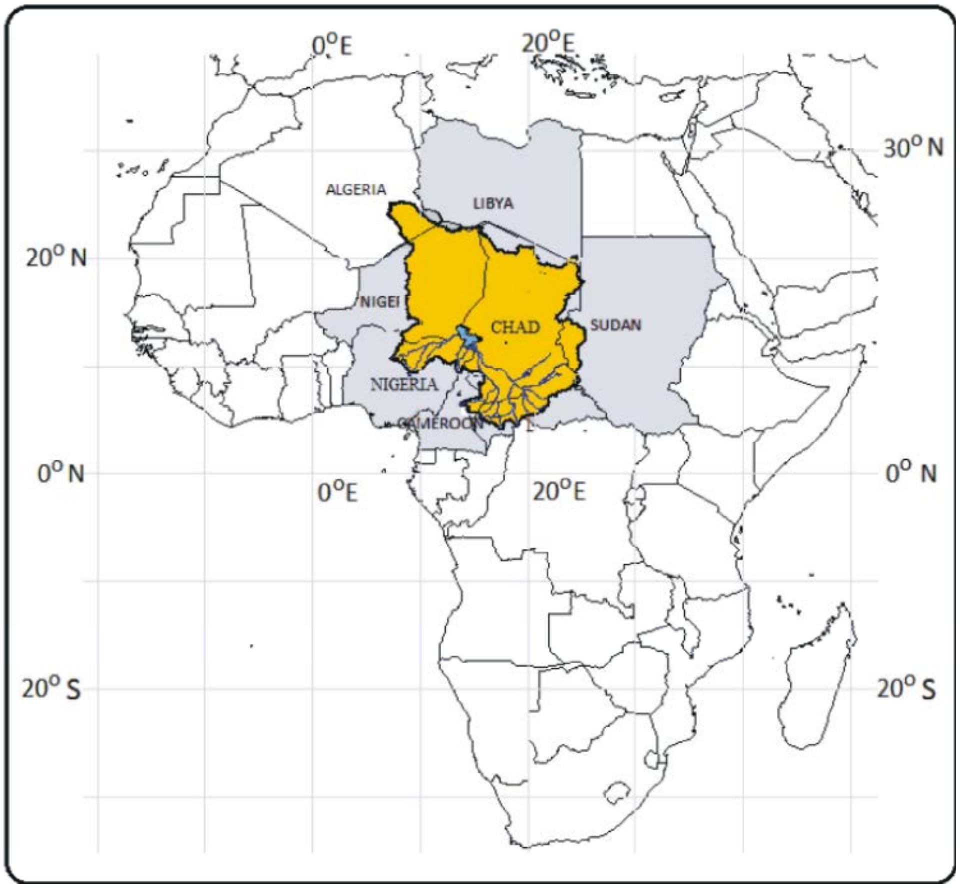

Fig. 1.1: The Lake Chad Basin in Africa
Source: Modified from Lake Chad Basin Commission, N'Djamena, Chad 2006

activities especially in Lake Chad Basin, closely effective monitoring of major drought parameters (rainfall) is of paramount importance. Unfortunately, meteorological stations in the Lake Chad Basin are not rationally and adequately distributed. Where available, some of the stations are more than 250km apart that was established more than 60 years ago.

Mindful about the problem of an inadequate distribution network of in-situ weather stations for effective monitoring of rainfall, peasant farmers who mainly rely on rainfed farming particularly in Komadugu Yobe sub-basin of lake Chad plant seeds weeks or months earlier than the onset of rainfall. They are using local knowledge of the dry season to predict planting dates because rain-onset and probable occurrence of agro-meteorological droughts are unknown. Even though fewer studies on the onset, retreat of rainfall and reoccur of drought were carried out in some parts of the basin, the impact is not felt as the farmers still resort to their local knowledge for agricultural planning.

Nowadays, the benefits of geospatial technology (coupling Earth observation (EO) and GIS) are immense especially for monitoring precipitation from space (precipitating clouds). GEONETCast is one of the geospatial technologies capable to deliver near-real-time Earth observation data such as vegetation, MSG products (meteorological image data – EUMETSAT, NOAA-NESDIS meteorological and MPEF in form of AMV, CDS, CLM, CLA) for environmental management. This is a joint study (ongoing) that evaluates practical benefits of geospatial technology for rainfall early warning and agricultural planning in drought-prone Basin. The specific objectives of the study are to extract precipitation from space and determine intensity, when and where it may rain; it also validates Meteosat Second Generation Multi-Sensor Precipitation Estimate (MSG – MPE) with in-situ weather data (2011 – 2014). Four-year data for the study were downloaded from ESA Tiger INITIATIVE of the Joint Project (Maiduguri and Kano States, Nigeria) at the University's GEONETCast stations.

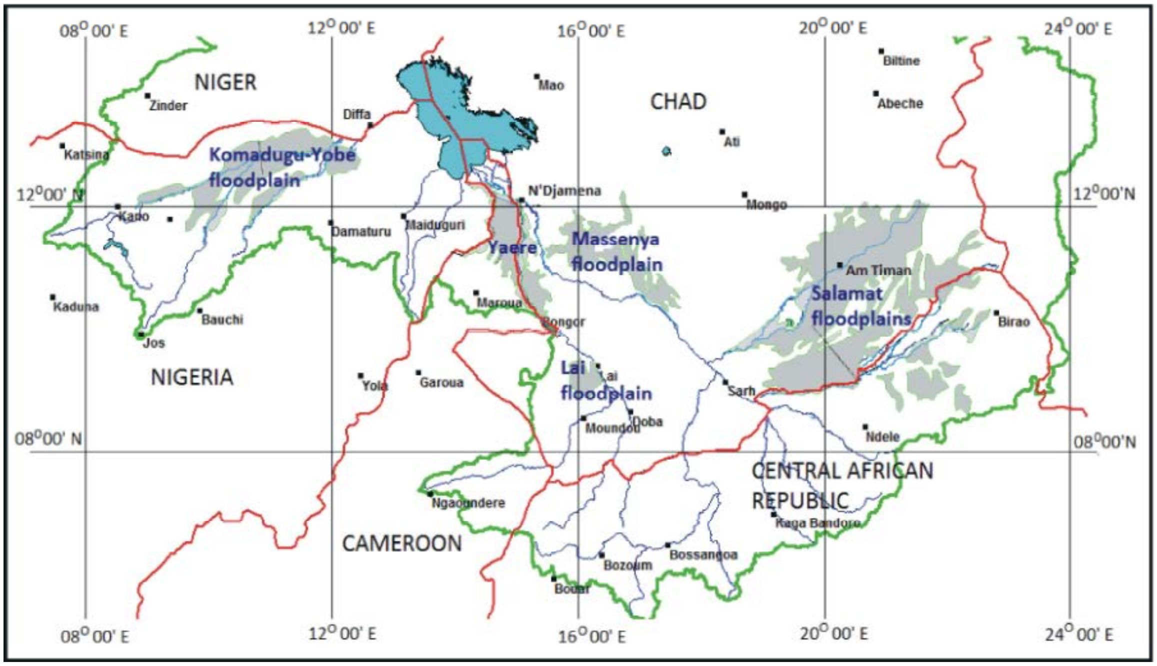

Fig. 3.1: Komadugu Yobe Floodplain (Nigeria) in Active Lake Chad Basin and
Source: Modified from Department of Geography Geospatial Database, 2020

The study considers the Theory of Water Vapour and Infrared especially in the Komadugu Yobe sub-basin of Lake Chad, where in-situ agro-meteorological stations are inadequate. Thus, with geospatial unique technologies in University of Maiduguri and Kano University of Science and Technology Wudil, peasant farmers can practically benefit in terms of occurrence of drought early warning and agricultural planning activities in the Lake Chad Watershed.

The Theory of Water Vapour and Thermal Infrared: Water vapour (as gaseous phase of water in the hydrosphere) is a major player in climate change. It is transparent, like most constituents of the atmosphere [12]. Under typical atmospheric conditions, water vapour is continuously generated by evaporation and removed by condensation. It is less dense than most of the other constituents of air and triggers convection currents that can lead to clouds. Researchers since 1970s such as Bignel [13]; and Shine, [14] have recognised two distinct components of water vapour continuum: self-continuum, which is interpreted as the interaction between water vapour molecules and whose strength scales closely with the vapour pressure squared; and a foreign-continuum, due to interaction of water vapour with other molecules. The foreign-continuum depends linearly on the water vapour pressure and on the foreign gas pressure [14]. Therefore, the continuum absorption coefficient of water vapour in air, α_{WC} (v, T), is the sum of the self α_{WCS} (v, T) and foreign α_{WCF} (v, T) contributions as shown in Equation 2.1.

$$\alpha_{WC}(v,T) = \alpha_{WCS}(v,T) + \alpha_{WCF}(v,T) = \frac{1}{K_B T} C_S(v,T) P_{H_2o}^2 + \frac{1}{K_B T} C_F(v,T) P_{H_2o}^2 P_F \qquad \text{(Eqn. 2.1)}$$

where K_B is the Boltzmann constant, T is Temperature, while C_S and C_F, represent self and foreign gas, P^2_{H2O},P_F, water vapour and foreign gas at a given temperature (T), as defined by Burch and Alt [12].

Location of the Study Area and Methodology

Location of the Study Area: Komadugu Yobe Basin (KYB) is one of the sub-basins of Lake Chad Watershed, lying South-west (Figures 1.2 and 2.1). It is enclosed by Hadejia-Jama'are Komadugu Yobe Basin (HJKYB) watershed referred to as Nigerian sector of the Lake Chad. It is located from latitude 09° 50' 17"N to 14°38' 25" N and from longitudes 07° 19' 05"E to 15°12'55" E. While the area (HJKYB) covers approximately 300, 000km^2 inhabiting more than 15 million people (Lake Chad Basin Commission, 2004), it is bounded to the North, North East and East by Niger, Chad and Cameroon Republics respectively. In Nigeria, the sub-basin is bounded by Adamawa and Gombe States to the South, Kaduna and Katsina States to the West.

The climate of HJKYB Watershed is semi-arid and arid characterised with dry and wet seasons with low annual precipitation for a period of four to five months, low relative humidity and high temperature. Potential evaporation at Maiduguri is about 2000mm and rainfall scarcely attains 700 mm in a year [15] or normal monthly rainfall is below 200 mm. Northward of Komadugu Yobe Floodplain, covering Manga grassland (Figure 2.1), the annual precipitation is less than 400 mm with 60 days growing season July – August [16]. The area falls within those severely affected by drought of the seventies and eighties. The rainfall is subjected to wide annual variations due to prevalence of drought. The length of dry season exceeds eight months (October to June). Air is perpetually dry except for about four months in the middle of the very brief wet season [17, 18].

The irregularity of rainfall over the years in the ecological zone has tended to influence the thinking that the region is changing from one climatic type to another, where according to Francis [19], the semi-arid region of Nigeria is changing to Sudano-Sahelian region – meaning, aridity is continuing in the region. This could be the reason of reported cases of droughts in the region for years and decades and fluctuations on the onset and retreat of rainfall.

MATERIALS AND METHODS

The materials used for the research include hardware and software packages and geospatial data. While the geospatial data included rainfall and remotely sensed EO data, the hardware packages were Global Positioning System (GPS), digital camera and GEONETCast systems. The software packages on the other hand, include ILWIS 3.8.4 digital image processing software and geostatistical extension of ArcGIS10.3. The software packages were carefully chosen because of their flexibility and capability to transform all the spatial datasets sourced from different coordinates.

The theory of Water Vapour and Infrared assumes that cloud-top temperature brightness is related to cloud height, which in turn is related to cloud thickness and to rainfall rate [20,21]. This holds that colder, brighter clouds are associated with heavier rain and warmer, less bright clouds are associated with light or no rain. Therefore, rates of rainfall are related to the magnitude of the resulting brightness temperature difference. Multi-Sensor Precipitation Estimate (MPE) uses an algorithm combining data from the SSM/I instrument on the US-DMSP satellites with Met-7 and MSG TIR channel. According to Kidder *et al*. [21], small brightness temperature differences (<11K) between WV06.2 and TIR10.8 (of MSG) gives an indication for precipitating clouds.

In-situ rainfall data spanning from 2005 – 2014 (10 years) were used in this study (Table 2.1). The data were sourced from Nigerian Meteorological Agency (NIMET) Oshodi– Lagos, University of Maiduguri and Niger Hydrologie Niger. The data were collected from 8 in-situ meteorological stations in the sub-basin of Lake Chad: Maiduguri, Nguru, Potiskum, Kano – Nigeria; and Diffa, Maina Soroa, Magira and Zinder – Niger Republic. Table 2.1 shows the type, temporal, dates, sources and format of the in-situ meteorological data used for the study. The rainfall data from in-situ stations were compared to calibrate the estimated EO data at the respective stations (location) of the weather stations. The locations of all the in-situ meteorological stations were observed with GPS Pro-Max and plotted on EO data.

EO data for the study (Table 3.1) were sourced from European Space Agency (ESA) TIGER Initiative Project, which led to establishment of GEONETCast systems (stations for download of the data stream and specialized software for processing Meteosat 2nd generation (MSG) in University of Maiduguri and Kano University of Science and Technology, Wudil. GEONETCast Station is a platform for Global Earth Observation System of Systems (GEOSS). It delivers the benefits of satellite EO data (such as MSG products) and information providers and consumers worldwide. MSG uses Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument to record data at 3km spatial resolution and is owned by European Organisation for the Exploitation of Meteorological

Table 3.1: Meteorological and EO Data for the Study

SN	Type of Data	Temporal Resolution	Spatial Resolution	Date Available	Source(s)
1.	MSG 9	15-mins	3km	2011 to 2014	EUMETSat
Climate (in Excel format)					
2.	Precipitation	Monthly	Point	2011 to 2014	NIMET - Oshodi; UniMaid; Hydrologic Office, Diffa-Niger
3.	Temperature	"	"	"	

Source: EUMETSat, NIMET, GEONETCast University of Maiduguri

Satellites (EUMETSAT). The MSG (in 12 bands) was used for retrieving meteorological information (such as precipitation and temperature). The study therefore utilizes a four-year period for joint collaborative research work between 2000 and 2007 by the Universities in Maiduguri and Wudil (Borno and Kano States respectively).

RESULTS AND DISCUSSION

Extraction of Precipitation from Space: Extraction of rainfall from space was made from two MSG channels (thermal infrared – TIR and water vapor – WV). Equation 4.1 to 4.n (as modified from Kidder *et al.* [21]) were used and since rate of rainfall is related to the magnitude of the resulting brightness temperature depression, the equations were used to extract and convert cloud low temperature to rain (e.g. for 24 hours of 01 May 2014).

pcl:=iff((ir_201405010000_CH_5_9_band_2–wvc_201405010000_CH_5_9_band_1)<11, 1, 0) ...4.1
pcl:=iff((ir_201405010015_CH_5_9_band_2–wvc_201405010015_CH_5_9_band_1)<11, 1, 0) ...4.2
pcl:=iff((ir_201405012345_CH_5_9_band_2–wvc_201408262345_CH_5_9_band_1)<11, 1, 0) ...4.n

where: pcl is precipitating cloud; ir is thermal infrared channel and wvc is the water vapour channel. Note the file name nomenclature, being the year, month, day and time (15-minute temporal resolution). This gave a Boolean map shown in pixel either 1 (for precipitating cloud or 0 with none), Figure 4.1.

Using Equation 4.1:
Rain2014July27:=maplistapplic(Maplist20140727_ir_108.mpl, "iff((##)<260, 4.3505278e–005 *(exp(2550.0127/(##))), 0)") (Eq. 4.1)

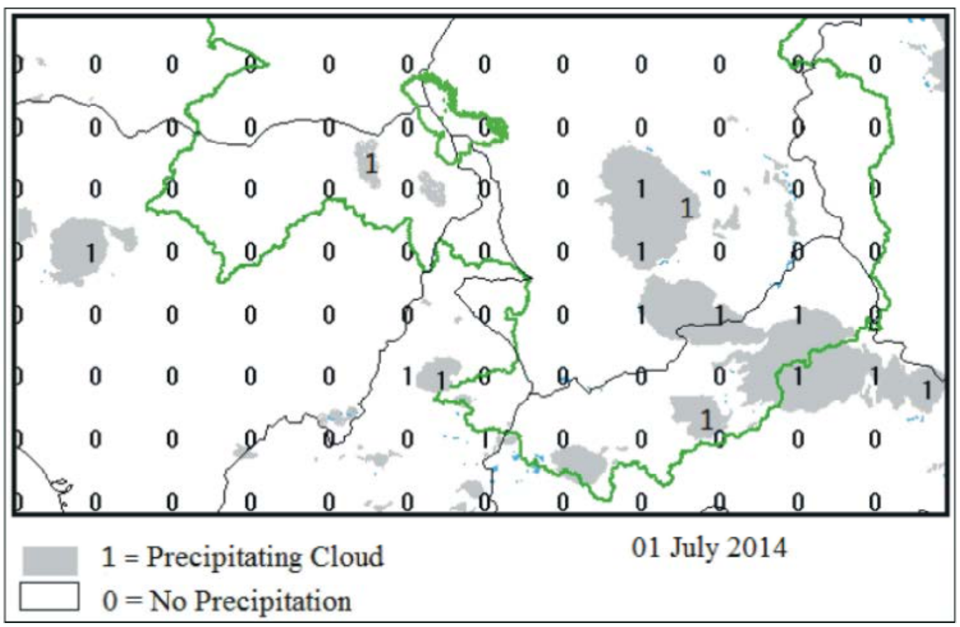

Fig. 4.1: Extraction of Precipitation from Space, 2014 07 27 00:15min.
Source: GEONETCast, University of Maiduguri, 2014.

Determination of Rainfall Intensity: From equation 4.1 holds on 27^{th} June 2014 at latitude 08° 41’30.97”N and longitude 19°47’42.92”E, extraction of precipitation for 12 hours at 15 min interval produces

(0.00, 0.00 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 1.39, 10.37, 10.37, 13.86, 14.78, 14.78, 13.04, 17.50, 16.33, 14.78, 14.78, 14.31, 12.65, 11.59, 9.59, 8.07, 6.89, 4.35, 3.09, 5.40, 7.53, 7.70, 7.70, 6.89, 6.60, 6.07, 5.01, 4.58, 4.06, 3.64, 3.47, 3.04, 2.88, 2.49, 2.20, 2.15, 2.01, 2.34, 2.05,

1.40 mm of rain) results, amounting to $\frac{301.73}{12}$ mm or 25.14 mm of rain;

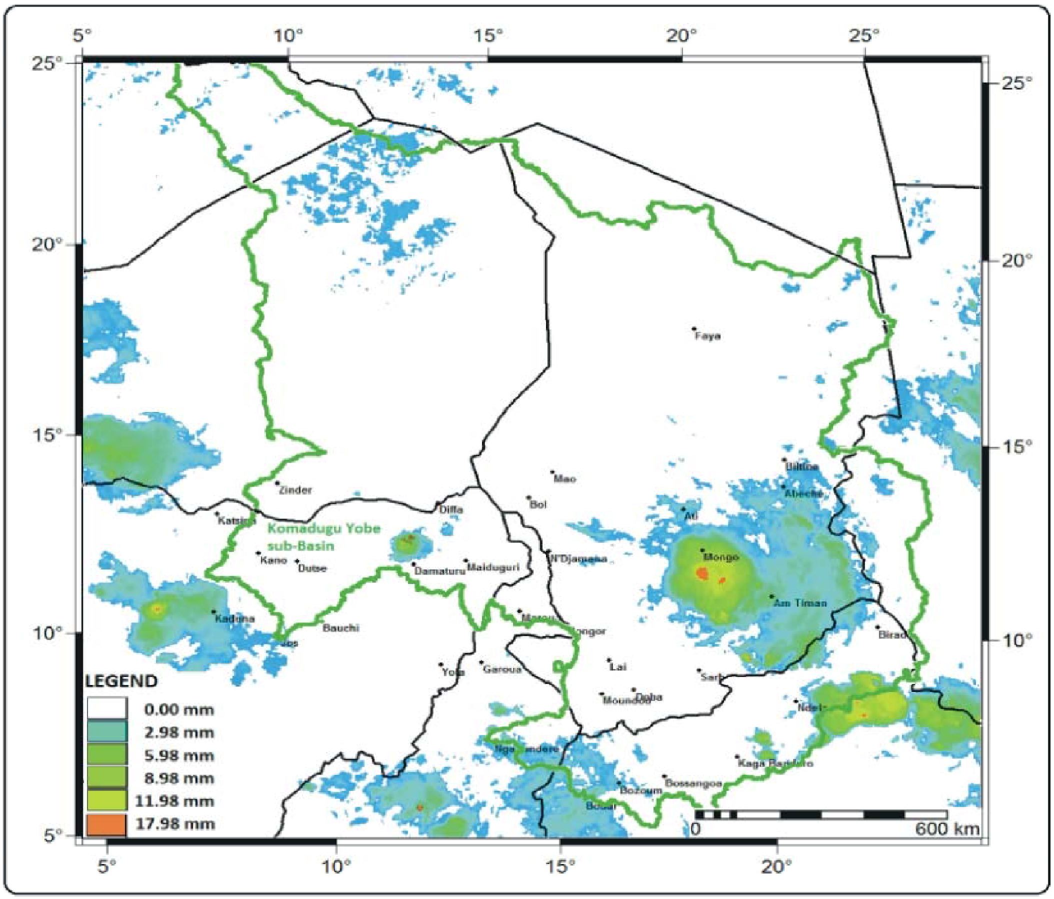

Fig. 4.2: Extracted Precipitation from cloud, MPE for 27 June 2014
Source: GEONETCast University of Maiduguri 2014.

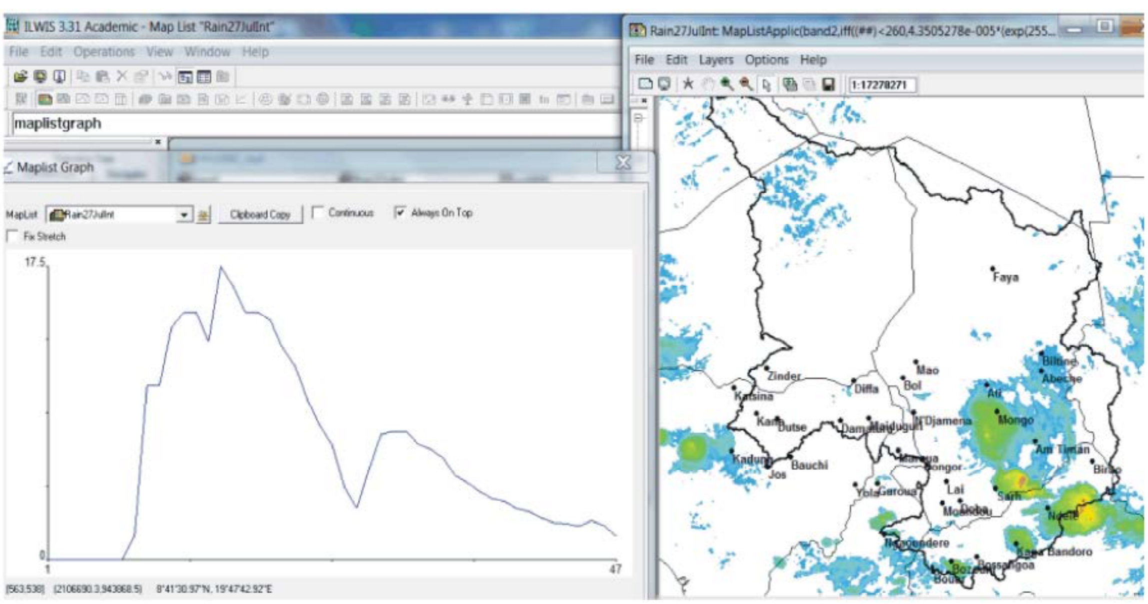

Fig. 4.3: Accumulated 12-hour rainfall at 8° 41’ 31”, 19° 47’43”
Source: GEONETCast University of Maiduguri 2014.

Table 4.1: Onset of rain at major towns in Komadugu Yobe sub-basin of Lake Chad

Name	Location	Onset 2011	Onset 2012	Onset 2013	Onset 2014
Diffa	13°25'12.0"N, 12°46'48.00"E	01 July	07 June	6 July	01 Aug
Kano	12°03'00.0"N, 08°31'48.00"E	08 June	16 April	10 June	01 June
Magaria	12°58'48.0"N, 08°55'48.00"E	10 June	24 May	14 June	08 July
Maiduguri	11°51'00.0"N, 13°04'48.00"E	06 June	20 May	06 June	27 May
Maine Soroa	13°13'48.0"N, 11°58'48.00"E	17 June	10 June	08 July	07 July
Nguru	12°52'48.0"N, 10°28'12.00"E	01 July	02 June	24 June	06 July
Potiskum	11°42'00.0"N, 11°01'48.00"E	06 June	17 May	10 June	04 June
Zinder	13°46'48.0"N, 08°58'48.00"E	18 June	25 May	28 June	01 July

Source: GEONETCast, Department of Geography University of Maiduguri 2014.

Therefore, with this Geospatial technology at 15 minutes and 3 km temporal and spatial resolutions respectively, daily precipitations are being monitored spatially, see Figures 4.2 and 4.3. Thus, Figure 4.2 shows rain at particular location as extracted precipitation from cloud, using Multi Sensor Precipitation Estimate (MPE) for 27 June 2014; and Figure 3.3 shows trends as a result of cumulative 12-hour rainfall at Latitude 8° 41' 31"N, Longitude 19° 47'43"E location. This is a good potential for determination of precipitation intensity, onset and retreat of rain at location of interest in the entire Lake Chad Basin. When put in animation, therefore, when and where is likely to rain can be estimated.

While Figure 4.2 shows visual monitoring of precipitation at entire Lake Chad Basin, Figure 4.3 indicates the effectiveness of the Geospatial systems for statistical display of the hourly rains. Specific sites can be intensively monitored for informed decisions particularly on onsets and retreat of rainfall as well as for drought prediction if the extracted rainfall is below normal and/or critical quantity.

Determination of Onset of Rainfall for Agricultural Planning: While Stern *et al.* [22] considered onset of rainfall of at least 20mm in 2 days, Sivakumar's [23] criterion deems at least 20 mm of rain in 3 days. However, Kowal and Kassam [24] believe that onset of rainfall to be at least 25mm in 10 days. Kowal and Kassam criterion suites the arid ecological zone and therefore considered in this study. In determination of onset of rainfall at the Lake Chad Basin, particularly Komadugu Yobe sub-basin of Lake Chad, the criteria from Stern *et al.* [22]; Sivakumar [23]; Benoit [25]; Kowal and Kassam [24] criteria were reviewed.

MSG data streams with15 minutes temporal resolution are used to transform temperature time series to rainfall by single statement – equation 4.1 and the quantity of rain is used to determine onset of rainfall at different parts of the basin, see Table 4.1, for four years period of the study:

In Komadugu Yobe sub-basin of Lake Chad, all the studied towns (Table 3.1) experience different rainfall onset. As being practice officially and locally, the same date is being used as start of planting/farming, as is considered as same region irrespective of their spatial differences. For example, when decision is taken such as in Diffa, Magaria, Maine Soroa and Zinder (Niger Republic) there is likelihood to affect their farming system. Even though the towns in Niger Republic in 2011 with exception of Diffa, they experienced similar onset, from 2012 through 2014 the situation were different. In Nigerian part of the sub-basin, in 2011, Kano, Maiduguri and Potiskum their onset was similar (6 – 8 June) but Nguru almost a month late. A year after, the onset changed with Kano's onset being eelier (mid April) while Potiskum and Maiduguri started 17 – 20 May 2012. Although Kano and Potiskum had in 2013 and 2014 similar onset (between 01 – 10 June), Maiduguri and Nguru's onset was late (6 – 8 July).

Validation of Rainfall Data: Comparison and validation of the extracted precipitation was made with in-situ weather station records at different locations (Table 4.2). This table is linked with Table 4.1 Though, this required long-term records to finalise. The study used 4-year records to compare. The Meteosat Second Generation Multi-Sensor Precipitation Estimate (MSG – MPE) records were summed into monthly data as most meteorological stations record into monthly total.

Table 4.2 shows a comparative 2-year study (2013 – 2014) for some locations in Nigerian part of the sub-basin. The actual location of the in-situ weather stations were used to extract MSG – MPE rainfall. The study is still ongoing as it is planned to validate the results from MSG – MPE.

Table 4.2: Validation of Rainfall data, In-situ and MSG – MPE

Name	WMO Code	Month	2013 In-situ	2013 MSG	2014 In-situ	2014 MSG
Kano	65046	May	0	16.363	15	46.406
		June	60	111.802	124	142.884
		July	150	92.385	149	101.152
		August	200	135.814	245	141.056
		September	100	27.103	142	84.57
		October	28	19.145	2	8.956
		Total	538	402.612	677	525.024
Maiduguri		May	13	35.86	34	56.572
		June	61	74.093	62	72.385
		July	130	154.876	109	121.859
		August	209	213.727	181	191.548
		September	128	136.828	80	92.679
		October	28	45.423	16	30.656
		Total	541	660.801	466	565.699
Nguru		May	0	9.233	0	9.801
		June	40	53.241	9	25.982
		July	79	96.979	65	78.555
		August	158	180.062	164	187.066
		September	55	64.322	95	101.243
		October	0	0.437	11	26.897
		Total	332	404.274	333	429.544
Potiskum		May	0	22.405	19	37.973
		June	63	89.698	85	96.309
		July	166	182.331	87	106.762
		August	173	182.673	171	199.890
		September	58	86.664	149	169.439
		October	19	36.15	10	34.555
		Total	460	599.921	511	610.400

Source: WMO 2010, NIMET – Nigeria and MSG – MPE data 2014

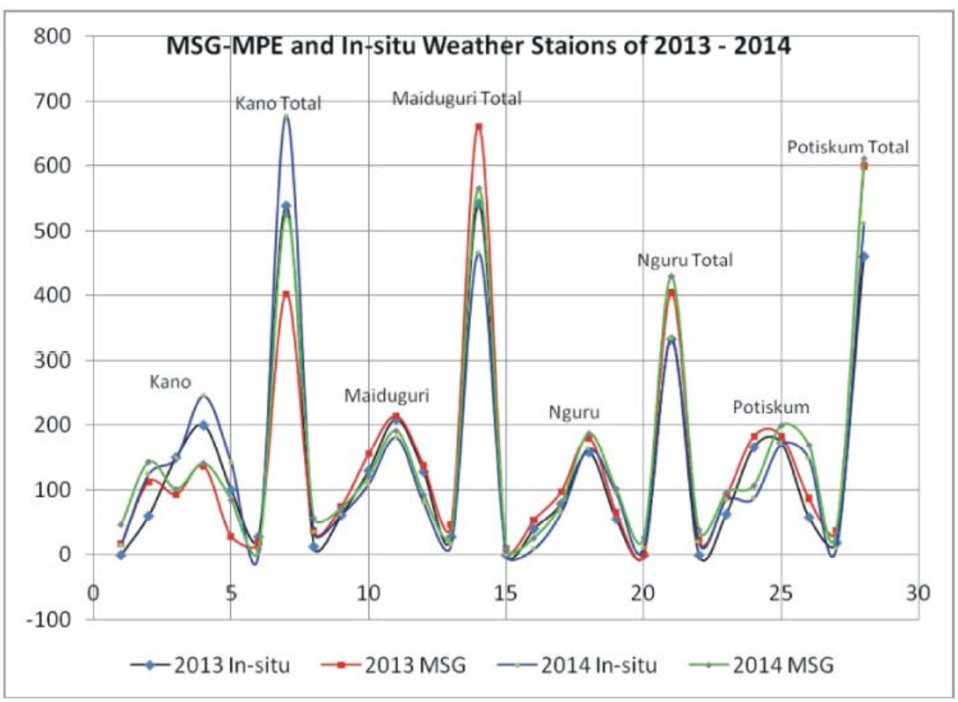

Fig. 4.4: Estimated rainfall from MSG-MPE and In-situ rainfall records
Source: Researchers 2014.

The analysis from Table 4.2 was further displayed graphically shown in Figure 4.4. There are significant variations in terms of quantity between records from in-situ weather stations and MSG-MPE. This could be due to time lag (delay) to reach from the space and ground. During the time, change in temperature can cause some precipitating cloud to return to the atmosphere.

However, Figure 4.4 displays perfect fitness of the two records but differed in quantity. In all the records, MSG-MPE is higher than the in-situ weather data. In this situation, since the records are matching, relationship needs to be established and validated whereby any difference can be estimated and/or projected.

Conclusions and Recommendations Benefits for Agricultural Planning: The potentials of Geospatial technology (GEONETCast with its 15-mins temporal and 3-km spatial resolutions) in terms of computing onset, retreat, crop duration and monitoring crops are immense. Nowadays, rainfall records right from sources in space are being monitored and calculated. Coupling the potentials of Geospatial technology, spatially (especially in animation) and graphically, rainfall assessment can be made effectively and efficiently.

Tropical Rainfall Monsoon Mission (TRMM) is planned as part of the continuation of the project to be used for MSG-IR calibration but with cloud type determination and masking;

GEONETCast technology covers entire Africa and free software sources make such a near real-time system suitable for monitoring climate, strongly recommends the replication of the research in other parts of Africa.

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