

CTCN assistance in Ghana

Improving Resiliency of Crops to Drought through
Strengthened Early Warning within Ghana

Technology validation (activity 2.2)





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Approved by

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Improving resiliency of crops to drought through strengthened early warning within Ghana Needs Assessment report

Technology validation (activity 2.2)

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LIST OF ABBREVIATIONS

CRU	Climate Research Unit
CHIRPS	Climate Hazards Group Infrared Precipitation with Station Data
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GHCN	Global Historical Climatology Network
GIDA	Ghana Irrigation Development Authority
GIS	Geographical Information System
GMeT	Ghana Meteorological Agency
GPM	Global Precipitation Measurement
HSD	Hydrological Services Department
MOF	Ministry of Finance
MOFA	Ministry of Food and Agriculture
NADMO	National Disaster Management Organization
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organizations
TRMM	Tropical Rainfall Measuring Mission
WRC	Water Resources Commission

1 Introduction

1.1 Background

The CTCN funded technical assistance relates to improving resiliency of crops to drought through strengthened early warning within Ghana. The objective is to facilitate transfer and capacity building for climate change adaptation focusing on dry season management and planning. The proposed support will utilise existing knowledge and capacity and further develop and validate these for applications to local issues within Ghana.

The technical assistance was initiated in October 2016 by a national workshop held in Accra. Based on feedback and discussions from stakeholder consultations and a Needs Assessment report prepared to present the objectives and requirements for the CTCN assistance. The recommendations have then been taken into consideration to draft a more detailed description of the proposed outcome in the Technology specification report delivered in February 2017.

Based on the outlined requirement the Drought Monitoring and Early warning system for Ghana has been developed and a first version was presented at the second the national workshop held in Accra in October 2017. This was the opportunity to give insight into the developed system and get feedback from the key stakeholders.

Following this workshop, the main applicant (Water Resources Commission) has carried out a thorough review of the system followed by a validation of the performance of the portal described in the Review report delivered in January 2018. Methodology of the validation of the technical tool was detailed in Methodology for validation and testing report submitted in July 2017. Finally all the technical tools developed as part of this technical assistance have been documented in the Technology description and User guide (January 2018) and the outcomes of the validation processes are described in this following report.

1.2 Drought Early Warning System developed as part of the CTCN assistance

The drought early warning system, developed as part of the CTCN assistance, enables decision makers and stakeholders to use the transferred knowledge, practices and technologies actively in the dry season planning. The solution focuses on **improving the adaptation** to upcoming drought events by supporting elements within the **risk management** part of the drought management process. The crisis management or the response to an already occurred drought event or disaster will not as such be included in the outcomes of the CTCN assistance.

The Web-based drought early warning and forecasting portal (www.flooddroughtmonitor.com) covers the following main topics:

- **Web-based drought early warning and forecasting portal** providing access to the technical functionalities, and enable stakeholders to view and download data and information;
- **Data and information** to avail near real-time satellite products related to drought warning and forecasting, and provide the required data input for the drought warning and forecasting system

- **Risk management components** supporting the risk-based drought management through drought early warning and detection for increased adaptation and preparedness to upcoming drought events
- **Dissemination** relating to how the technical information is conveyed from the web-based system to the end-users in form of reports, messages or warnings.
- **Issue analysis:** Analysis of the underlying cases behind drought issues. Supports a Causal Chain Analysis (CCA)
- **Water indicator selection:** selection of relevant indicators for measuring the state of the key impacts and issues related to drought in Ghana

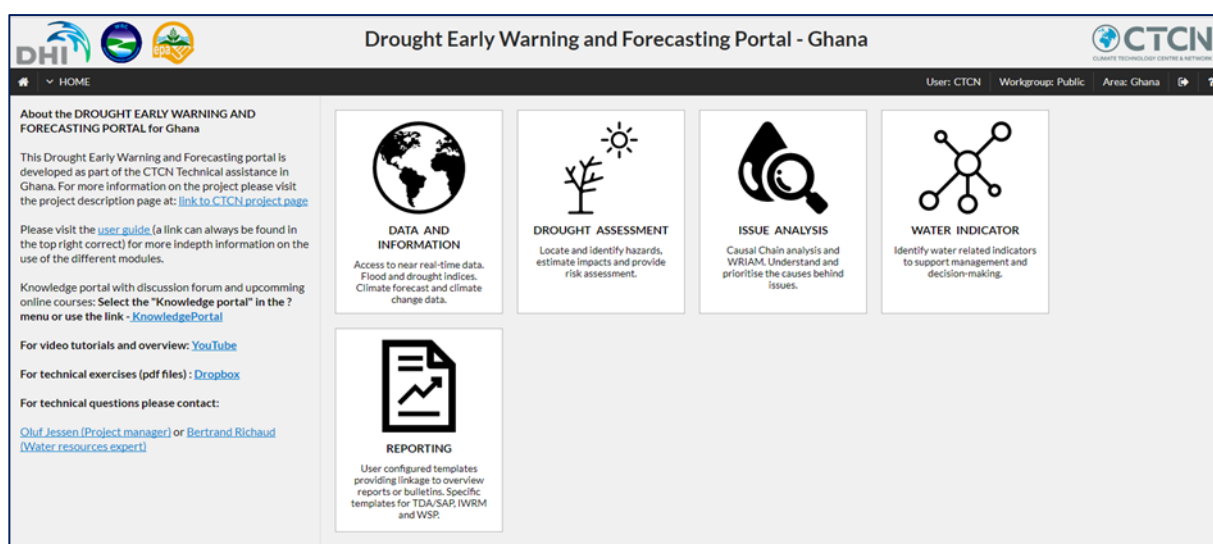


Figure 1 Web based drought early warning portal (www.flooddroughtmonitor.com)

1.3 Objective

The review and validation of the system developed as part of the technical assistance is an important step to ensure the developed technical tools are in line with the specifications that were drawn upon the stakeholder consultation.

A successful review and validation will ensure that the tools can efficiently be used by the key stakeholders, in addition it will provide solid basis to bring trust around the potential of these technical tools.

The validation is partly done by one of the national experts within the project (Mr. James Aggrey, Water Resources Commission) and partly by the CTCN assistance team.

2 Method for validation

The overall objective with the validation of the technical outcomes is to ensure that the developed technology provides results, which are representing the actual conditions in

Ghana, and therefore can be used for decisions aiming at increasing the adaptation capacity towards drought hazards. The use of a national expert in the validation process ensured that the national requirements and objectives were included in the validation.

The details of the validation methodology has been outlined in the Validation Methodology report submitted in July 2017. The validation of the outcomes will be done on historical data, hence evaluating how the early warning system is able to reproduce events, which have already occurred.

The steps followed in the validation phase are:

1. **Identification phase:** Identify the outcomes of the early warning system to be validated. *This was completed as part of activity 2.1 (Methodology for validation and testing)*
2. **Data collection:** Collect data and information for the validation e.g. observed data or historical information describing drought hazards, impacts or risks in the selected area (upper east region).
3. **Assessment:** comparison of the early warning system outcomes with collected data. Correlation between the information provided by the early warning system and the observation on past events will be assessed.
4. **Adjustment:** based on the finding of the assessment, some adjustments of the system outputs will be modified with the objective to better describe the actual conditions. Then step 2 for collection of additional information and step 3 for updated comparison between CTCN outcomes and collected information will be carried out, until the assessment is satisfactory.

2.1 Identification

The identification of the elements to be validated have been outlined in the report related to Activity 2.1 (Methodology for validation and testing).

Table 1 and Table 2 list respectively the outcomes related to hazard identification and risk assessment which will be prone to validation as part of the CTCN assistance.

Table 1 Validation related to hazard identification

Hazard identification		
Outcome	Means of validation	Purpose
Drought indices	Compare index values with historic information in the form of records of drought impacted areas or recorded hazards in the upper east region. Evaluate the need for adjustment of the selected indices.	Ensure that the most appropriate indices are used for hazard identification.
Drought warning	Compare early warning index values with observed climate and drought hazard information. The drought warning will mainly be validated on historic information.	Ensure proper warnings for the early warning part.

Exposure	Compare collected and available information with historic records of relevant exposure types.	Ensure that relevant exposure categories are included as part of the CTCN assistance.
Hazard categories	Assess the current hazard categories used by NADMO and MOFA with international standards for hazard categories and propose adjustment.	Ensure relevant hazard categories for the hazard identification and dissemination within Ghana
Impact assessment	Compare crop based impact analysis with available information regarding crop production and losses in the upper east region.	Correct and validate the tools used for impact assessment in relation to crop production.
Dissemination	Validate that the dissemination format from the CTCN assistance is compatible with the existing national dissemination from MOFA and NADMO.	Ensure that the dissemination format is compatible with the current dissemination from MOFA and NADMO.

Table 2 Validation related to risk assessment

Risk assessment		
Outcome	Means of validation	Purpose
Vulnerability	Validate the vulnerability approach and analysis based on earlier studies and relevant information from the upper east region.	Ensure proper and relevant vulnerability assessment.
Risk assessment	Evaluate the risk assessment based on existing information or records related to economic or agricultural related drought risk.	Ensure that the risk assessment provides relevant information for linkage with adaptation measures and drought related action plans and investments.
Dissemination	Validate that the dissemination format from the CTCN assistance is compatible with the existing national dissemination.	Ensure that the dissemination format is compatible with the current national dissemination.

2.2 Collection

The information used for the validation is collected during a number of visits and meetings in Ghana, where the most important ones are:

- **MOFA regional office** in Bolgatanga: information related to the climate conditions, food production data from the different districts in the area and marked prices of the main crops
- **GMET** office in Accra: information related to the current workflow and dissemination from the meteorological office to the relevant ministries

- **MOFA** office in Accra: information regarding the dissemination of information from the national ministries to the regional offices.
- **WRC** office in Accra and in Bolgatanga: the Water Resources Commission is the main applicant and is providing essential help and assistance for setting up meetings and connections with stakeholders.

The stakeholder consultations have been reported in Technology Specification report.

The data received from WRC has been listed in Appendix A. and consist of the following type of information:

- **Crop yield and crop prices:** this information is given per crop types at the district level. Due to the change of currency in Ghana in 2007, the crop price is slightly difficult to interpret across this period.
- **Crop calendar:** the crop pattern per district is reported in a form of tables. However, it must be noted that the crop pattern does not distinguish the crop types.
- **Rainfall data:** Monthly rainfall from 1991 to 2016 averaged for each region.

The data received from WRC constitutes a good basis for validating remote sensing data in the Upper East region of Ghana.

2.3 Assessment

The assessment of the performance is based on the tasks listed in the identification phase (c.f. section 2.1). The performance of each task is documented and recommendations will be given when relevant.

In order to validate the early warning system, two events have been identified in the Upper East region and the Volta region (see map in Figure 2). The first region (Upper East) is known to be prone to high crop failure, however the second one (Volta region) is categorized as being less prone to crop failure. Assessment of the performance in both regions will be relevant for future upscaling of the system.

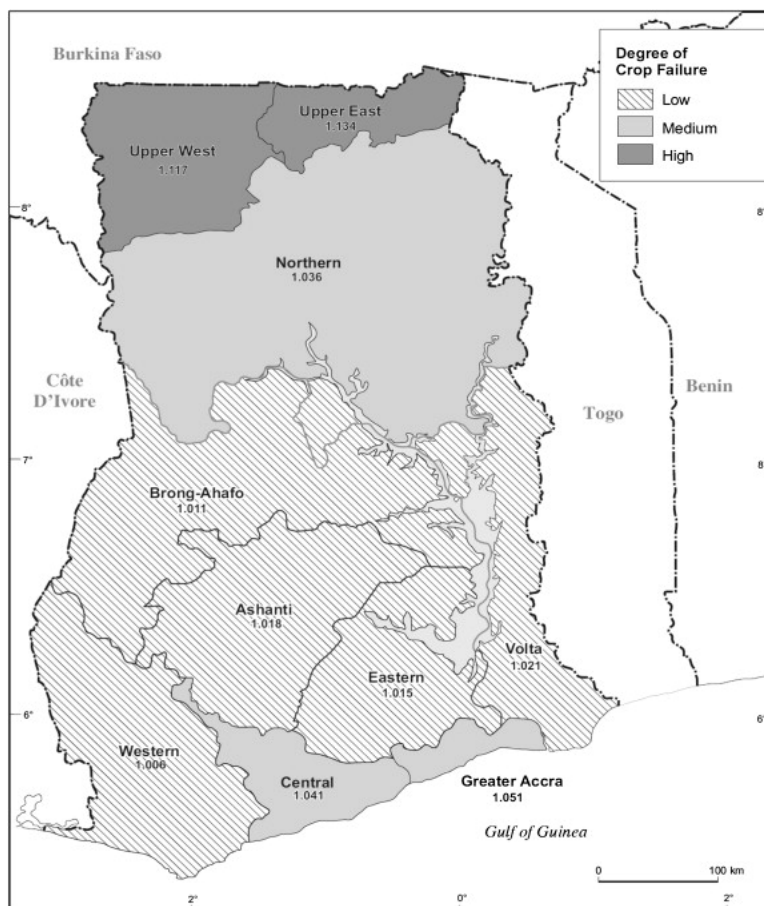


Figure 2 Map of the regions in Ghana (Source: Philip Antwi-Agyei et al.)

2.3.1 Upper East region

According to Figure 2, the Upper East region has a high degree of crop failure. The main crops planted in this region are millet, sorghum and maize (see Kasei & Afuakwa, 1991). The main objective of the validation will be to evaluate how the early warning system is able to reproduce events, which have already occurred in the region. Evaluation of the performance on the actual events will be collected by the applicant as the system is used over the coming seasons.

2.3.2 Validation of the monthly rainfall (Upper East)

Ground data collected and verified by WRC technical staff has been received. The validation consists of comparing this data with satellite based rainfall products available through the web based drought portal. The portal offers an access to several products that have the advantage of being available in near real-time and covering the entire national territory. However not all this products might be able to reflect accurately the rainfall events in Ghana.

The main purpose of the validation is to identify which rainfall product reflects with most accuracy the local conditions in Ghana using observed data as a reference.

- **Observed data:** The rainfall data received WRC covers the period 1991-2016 in a form of monthly average for each regions. No details has been given on the calculation method for producing the area weighted rainfall averages.

AVERAGE RAINFALL FIGURES FOR THE UPPER EAST REGION-1991-2015														
YEAR		JAN	FEB	MAR.	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1991	Total	0	0	0	34.7	131.2	151.8	195.5	169.7	172.4	51.6	2.7	0.0	909.5
	Raindays	0	0	0	5	9	10	11	13	13	5	2	0	68
1992	Total	0	6.8	39.2	64.9	187.8	86.2	196.9	326	64.1	73.1	0.0	0.0	1045
	Raindays	0	1	2	7	14	8	13	18	8	10	0	0	81
1993	Total	0	0.5	34.3	34.4	57.8	143.4	199.1	222.4	149.5	26.1	0.0	0.0	867.5
	Raindays	0	1	2	4	5	10	12	13	13	6	0	0	66
1994	Total	0	0	18.8	23.8	114.4	81.4	134.8	346.7	208.9	120	0.0	0.0	1049
	Raindays	0	0	2	3	6	8	10	15	15	14	0.0	0.0	73
1995	Total	0	1.3	7.7	38.3	93.7	150.4	179.1	277.3	91.1	80.8	0.4	3.1	923.4
	Raindays	0	1	2	4	6	7	12	17	11	7	1	1	69
1996	Total	0	0	8.7	57.1	118.1	161.5	104.2	310.9	244.3	74.5	0.0	0.0	1078.7
	Raindays	0	0	1	5	8	12	7	16	15	5	0	0	69
	Total	0	0	11.5	53.2	112.8	184.9	97.9	178.9	193.7	51.4	0.5	0.0	884

Figure 3 Extract of the rainfall data received from WRC

For purpose of validating the rainfall dataset available from the web based drought portal, the monthly average of the observed data are compared with different remote sensing products.

- **TRMM:** The Tropical Rainfall Measuring Mission (TRMM) is the first Earth Science mission dedicated to studying tropical and subtropical rainfall¹. With a spatial resolution of 0.25 degree, the data is available in near real-time for the period from 2000 to present with a daily time step (original data is 3-hourly but resampled to daily).
- **CHIRPS:** Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 30+ year quasi-global rainfall dataset². Starting in 1981 to near-present, CHIRPS incorporates 0.05 degree resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.
- **PERSIANN:** PERSIANN-Cloud Classification System (PERSIANN-CCS) is a real-time global high-resolution (0.04 deg x 0.04 deg) satellite precipitation product developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI)³. PERSIANN-CCS system enables the categorization of cloud-patch features based on cloud height, areal extent, and variability of texture estimated from satellite imagery.

A detailed description of these rainfall products is given in the Technical description and User guide report, January 2018.

For the purpose of the comparison, three periods have been selected:

- Period: 2003-2016 (longest common period for the selected products)

¹ More information about TRMM rainfall data available at: <http://trmm.gsfc.nasa.gov>

² More information about CHIRPS rainfall data available at: <http://chg.geog.ucsb.edu/data/chirps/>

³ More information about PERSIANN rainfall data available at: <http://chrdata.eng.uci.edu/>

- Year 2014 (recent year with overlap between the different data sources)
- Year 2015 (recent year with overlap between the different data sources)

The results of the comparison are given in the plots in Figure 4, Figure 5 and Figure 6. The comparison for the entire period (2003-2016) shows consistent results with years 2014 and 2015.

The conclusions from these graphics are:

- PERSIANN data is indicating very high rainfall and is an outlier of all months, especially for the start of the rainy season April-May. This is actually a critical period, when the high rainfall reported by PERSIANN data set could be misleading for management of the cropping season. This trend of high PERSIANN rainfall has been described by other studies in the Volta region (Moctar Dembele and Sander Zwart, 2016).
- TRMM and CHIRPS are able to estimate relatively well the monthly rainfall and the seasonal variability. CHIRPS shows slightly better performance, while TRMM tends to over estimate the amount of rainfall. This difference of performance can be explained by the fact that CHIRPS data is actually corrected with ground data, with the drawback that the correction implied delay in releasing the data. CHIRPS data is available on the monthly basis, while TRMM is available on the daily basis with only a few days of delay.

The recommendation will be to use TRMM or CHIRPS rainfall data for drought analysis in Ghana as these data sets, at this stage, has an acceptable representation of the actual rainfall events in Ghana. Please note that the quality of the rainfall products increases as the data providers include more sophisticated correction methods. The GPM (Global Precipitation Measurement, NASA) is another rainfall product which might be applicable but which we did not include in the validation as the data is only available since 2015.

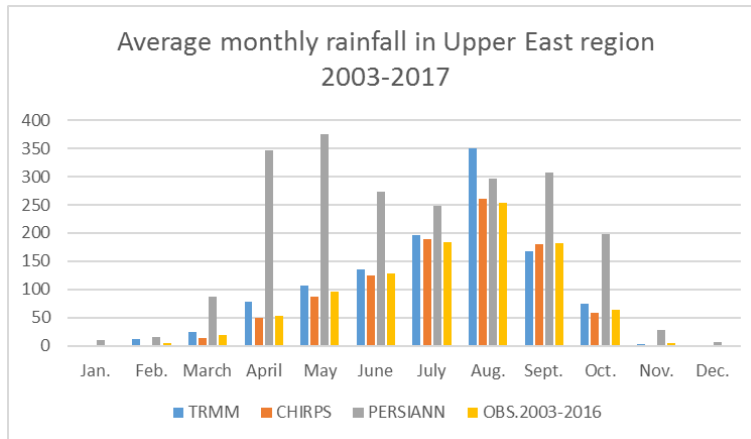


Figure 4 Average monthly rainfall in the Upper East region (TRMM, CHIRPS, PERSIANN and observed rainfall)

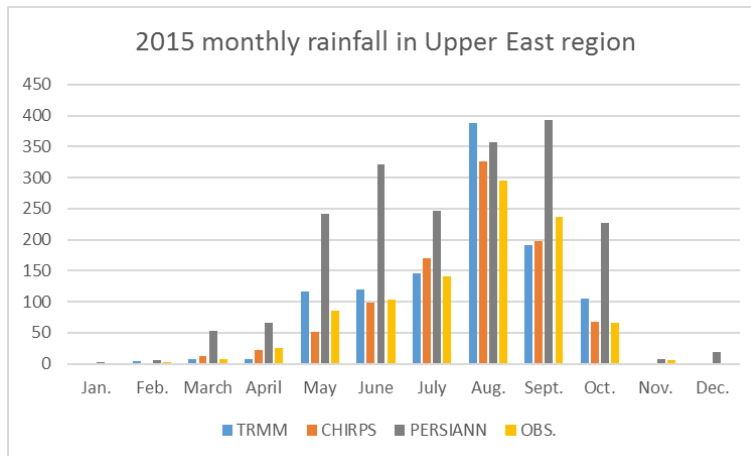


Figure 5 Monthly rainfall in 2015 in the Upper East region (TRMM, CHIRPS, PERSIANN and observed rainfall)

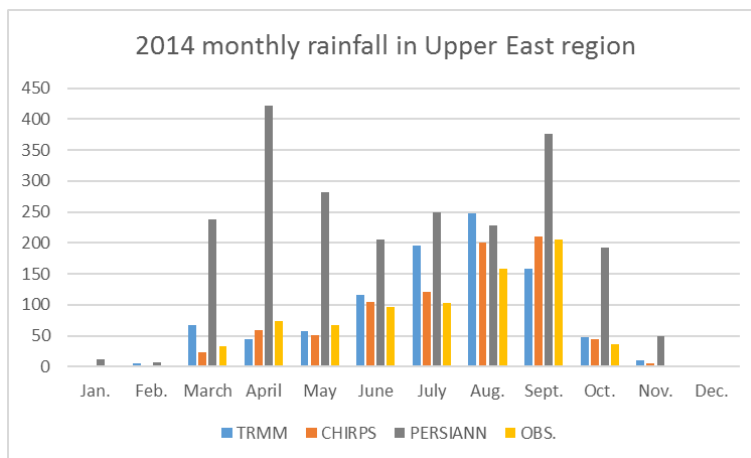


Figure 6 Monthly rainfall in 2015 in the Upper East region (TRMM, CHIRPS, PERSIANN and observed rainfall)

2.3.2.1 Crop yield and rainfall analysis

WRC has provided records of annual crop yields (in tons/year) in all the regions of Ghana. This information is a reliable source to identify year(s) when the crop yield has been significantly different from an averaged year and thus identify year(s) with crop failure.

To compare crop yield between different crops, the yield has been normalised: this corresponds to the annual crop yield divided by the long-term average yield for a given crop.

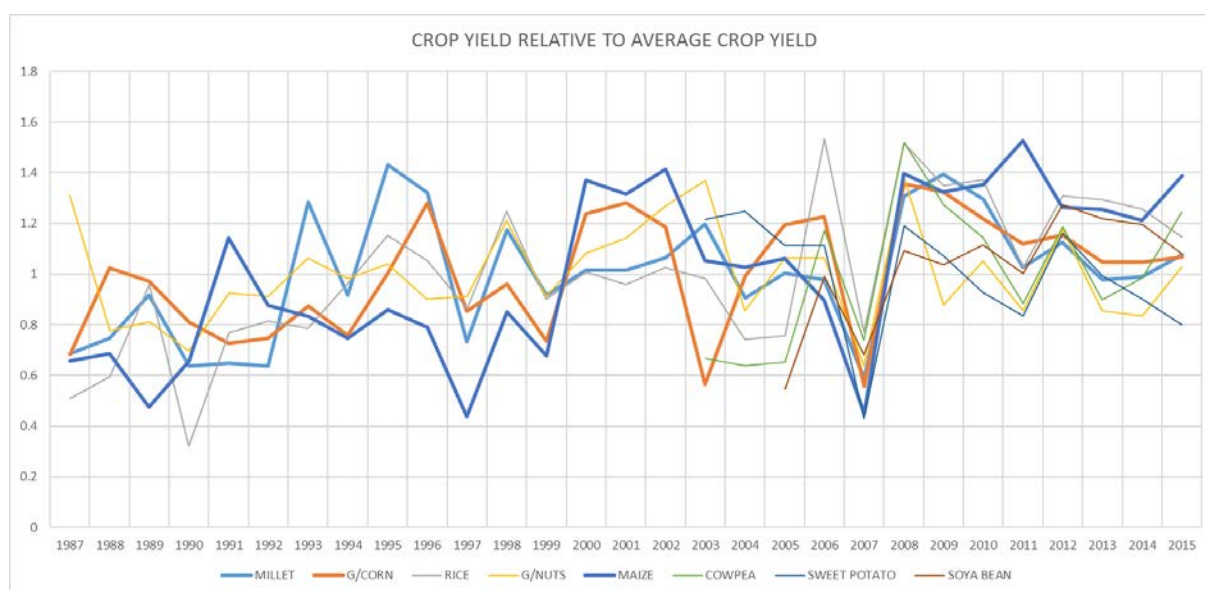


Figure 7 Normalised crop yield for major crop in the Upper East region.

Figure 7 shows the annual normalised crop yields for all crops, where major crops (Millet, Maize, G/Corn) have been highlighted with a thicker line. Apart from year 2007, when the crop yield was very low for all crops, no other year seems to show a general crop failure.

Interestingly, several local papers have published articles mentioning extreme droughts in the three northern regions in Ghana (see two extracts below mentioning the severity of the drought in northern Ghana):

“The region had never experienced drought such as this year's, apart from the 1983 "national drought" that affected cocoa and food crop farms throughout the country.” published on 18 July 2007 accessible at <http://www.africanagriculture.co.zw/2007/07/northern-ghana-facing-catastrophic-crop.html>)

“The farmers said their crops failed due to inadequate rains and asked for government assistance to re-crop because all their monies had been invested in the first farming season and it had failed.” Extract from news published on 23 July 2007 <https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Government-to-support-farmers-to-re-crop-127682>

In the north of Ghana, a unimodal rainfall pattern is normally observed, which means only one growing season per year is possible. Long-term average of the monthly rainfall with the distribution in form of the median, 25 percentile and 75 percentile is displayed in Figure 8 for the Upper East region. It can be seen that the rainy season is normally in

July and goes until September, and that there is only one distinct rainy season in this area.

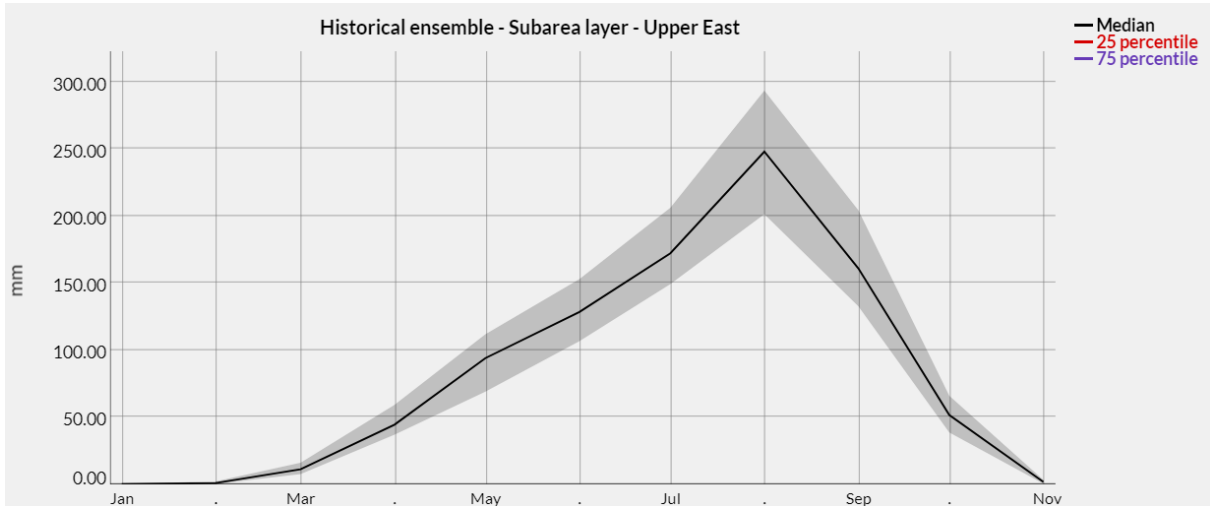


Figure 8 Historical monthly rainfall data (CHIRPS dataset) extracted from the web based drought portal for the Upper East region. The black line is the median of the historical ensemble, which consists of the years 1981 to 2017. The envelope (grey area) is delimited by the 25th and 75th percentile of the historical ensemble.

Monthly rainfall from CHIRPS in the Upper East region has been extracted from the web based drought portal (see Figure 9). The year 2007 clearly stands out of the record with the peak value (411 mm) observed in August 2007. This is the highest monthly rainfall recorded in the region by the CHIRPS dataset.

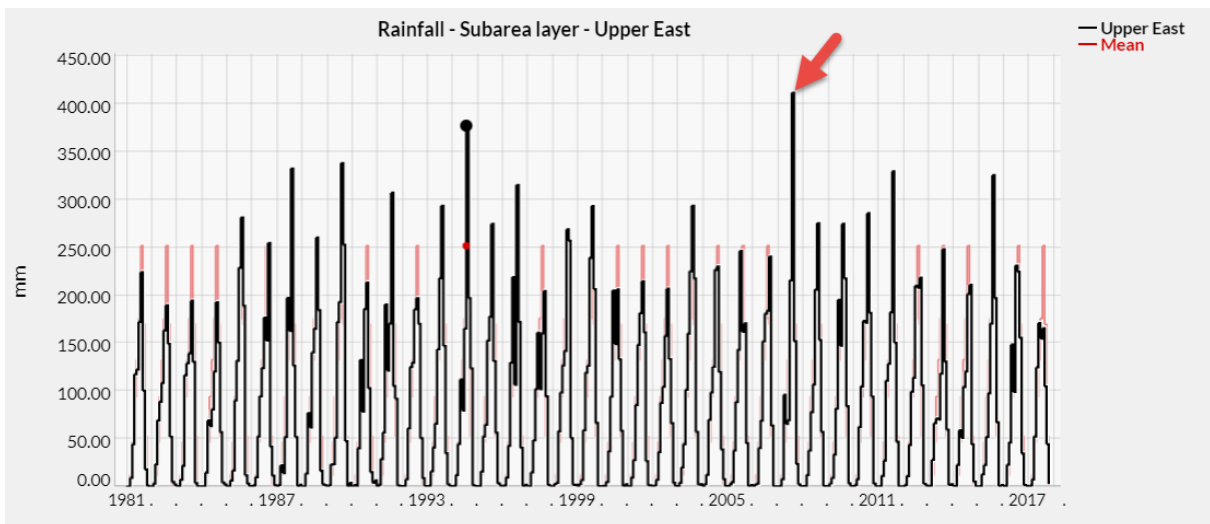


Figure 9 CHIRPS rainfall for the Upper East region for period 1981-2017

The analysis of the monthly rainfall of the 2007 (in Figure 10) reveals that this very wet month (August 2007) was preceded by a late and dry start of the rainy season. In Figure 10, the monthly rainfall shown in black can be compared with the long-term average in red. It can be seen that the months of May and June have been drier than average, moreover it can be expected that the start of July was also drier and the rainfall onset started only mid-July. This late rainfall onset, followed by an extremely wet August has been critical for the rainfed-agriculture in the region, resulting in a dramatic decrease in the crop production that year.

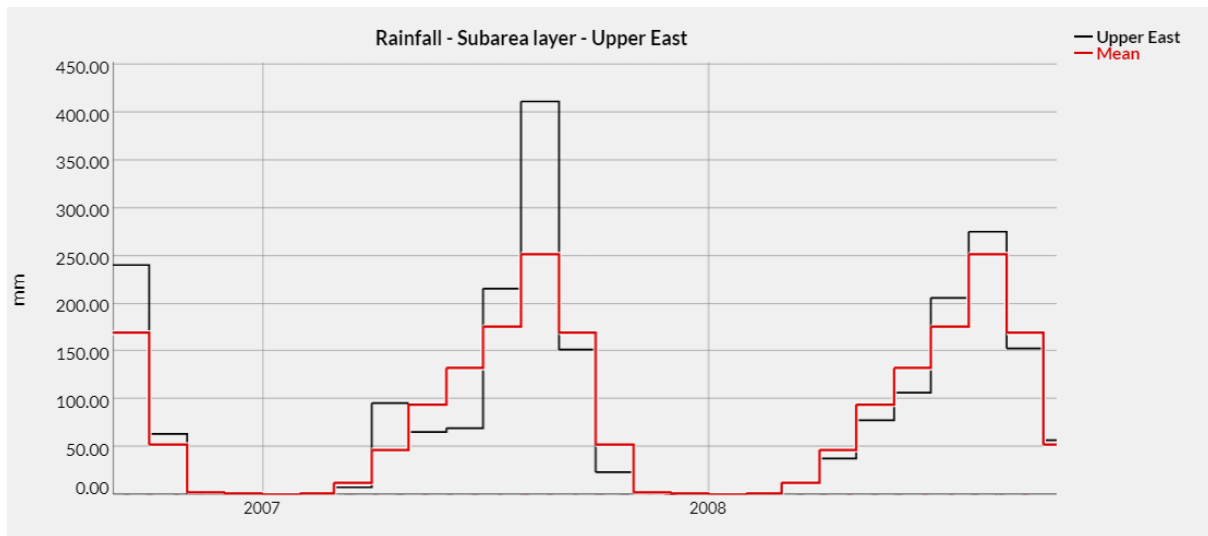


Figure 10 CHIRPS rainfall in the upper east for period 2007-2007

The use of rainfall-based drought indices, such as SPI-1month, is commonly used to highlight the severity of the meteorological drought. In Figure 11, the map extracted directly from the web based drought portal shows the spatial distribution of SPI-1 month in the entire country at the beginning of July. The three northern regions are patched areas under “extreme drought” meaning that the SPI value has fallen below the critical limit of -2 (see text box about SPI below).

Overview: Standardised Precipitation Index (SPI)

The SPI is based on the probability of precipitation for any time scale. The probability of observed precipitation is then transformed into an index. It is being used in research or operational mode in more than 70 countries.

Strengths: Precipitation is the only input parameter. The SPI can be computed for different time scales, provide early warning of drought and help assess drought severity.

Weaknesses: It can only quantify the precipitation deficit.

A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and an intensity for each month that the event continues.

Source: Standardized Precipitation Index User Guide, WMO no. 1090

Figure 11 shows the SPI index for July 10th 2007, where all the red areas indicates that the rainfall is much less than expected for that time of the year. This indicates that the rainfall for month of July was much dryer than normal as the start of the rainy season was delayed. The SPI index is available in the web based drought portal and could be viewed for different months and the data could be downloaded for further analysis by the user. The SPI is also available in forecast mode so the user is able to evaluate how the current situation will evolve over the coming months. Figure 11 highlights how a drought index could be used to identify areas with a severe rainfall deficit, which is often the first indication of an upcoming drought event.

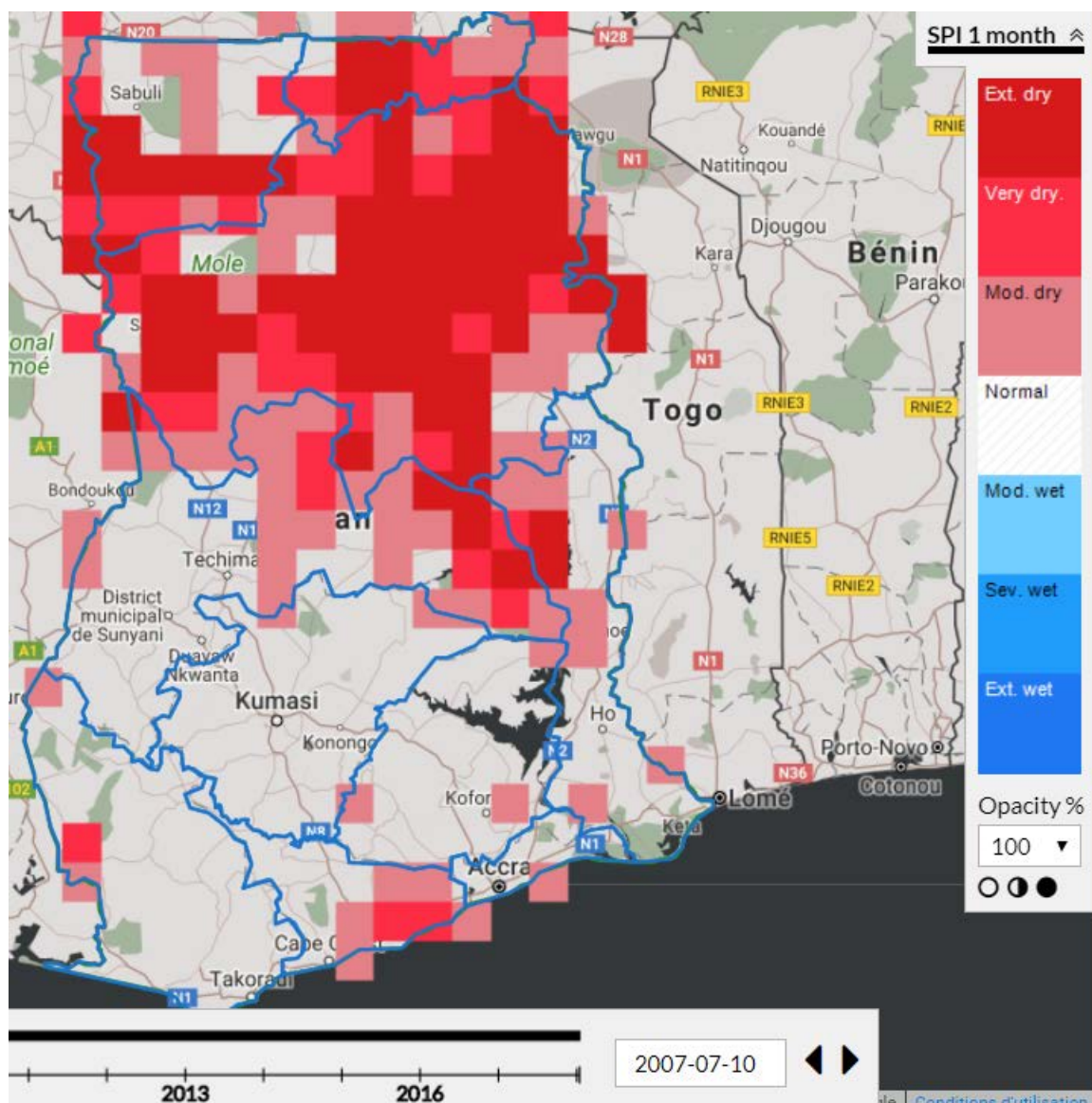


Figure 11 SPI 1 month on 10 July 2017 showing the extent of the drought or rainfall deficit. This corresponds to the period from 10 June 2017 to 10 July 2017.

Finally, an analysis of the vegetation based drought index (Vegetation Condition index) represented in Figure 12 confirmed that the meteorological drought (rainfall deficit) has been followed by a significant reduction of the vegetation cover. The areas marked with meteorological drought (Figure 11) are also impacted with low value of Vegetation Condition index (Figure 12) representing drought impacted areas (see text box below on VCI).

Overview: Vegetation Condition Index (VCI)

The Vegetation Condition Index (VCI) compares the current NDVI to the range of values observed in the same period in previous years.

The VCI is expressed in percent and gives an idea where the observed value is situated between the extreme values (minimum and maximum) in the previous years.

$$VCI = \frac{NDVI - NDVimin}{NDVImax - NDVimin}$$

- High VCI -> NDVI close to historic maximum
- Low VCI -> NDVI close to historic minimum

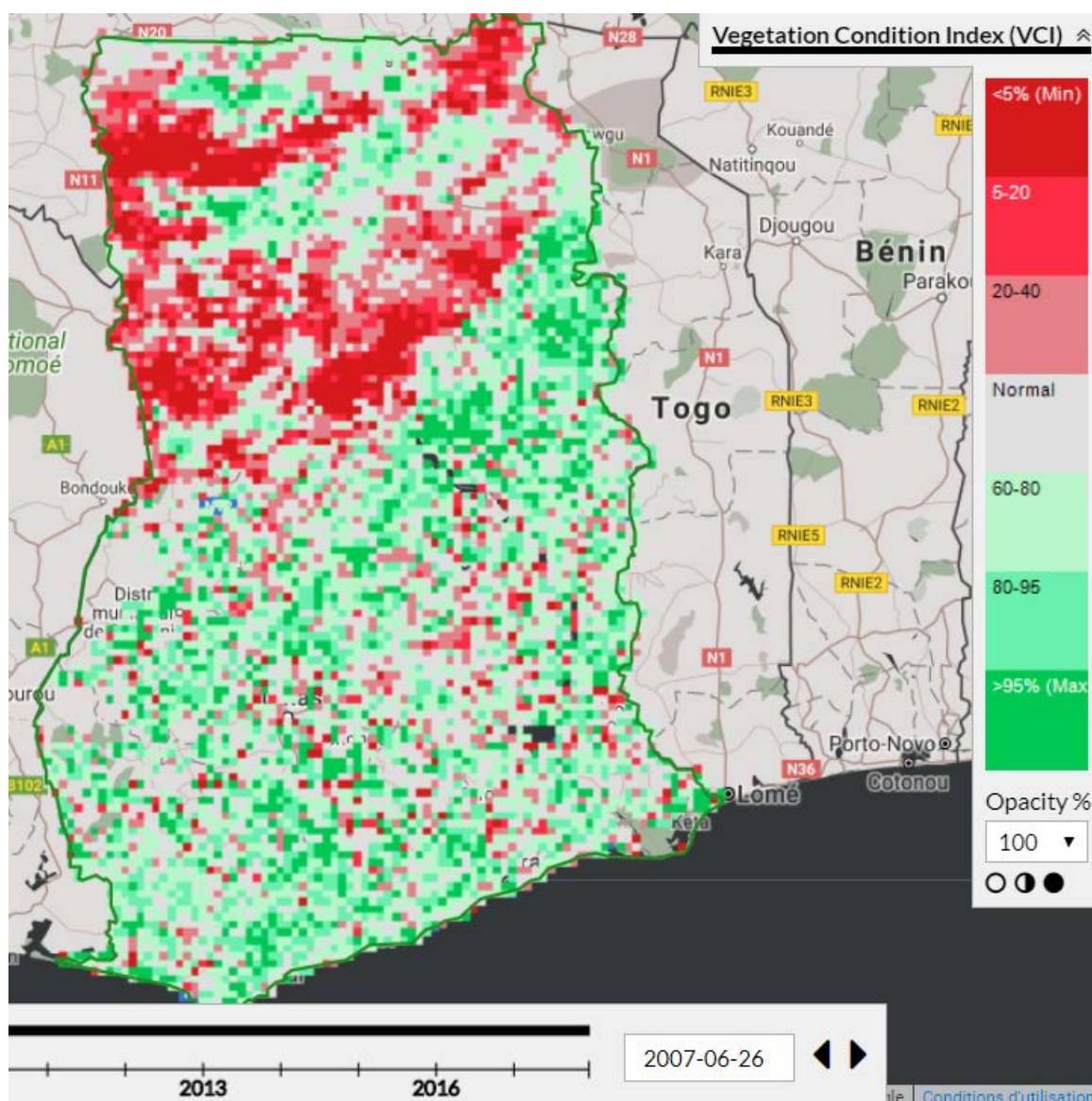


Figure 12 VCI for the period 26-06-2017 to 11-07-2017.

Figure 12 highlights that the vegetation development in the Upper East region of Ghana also was impacted during the event in 2007, as the drought index (VCI) indicated that the vegetation was close to the historic minimum values).

The analysis of rainfall data, rainfall-based index as well as vegetation based index confirm the evidence of severe a drought event affecting some parts of the three northern regions in Ghana. The late rainfall onset, followed by an extremely wet August 2007 has caused crop failure and therefore a low crop yield for the main crops. The use of remotely sensed data is able to clearly identify the parts of the country that was mostly impacted by the drought event.

2.3.3 Volta region

Another region that has been used for validation is the Volta region located in the southern part to the country (Figure 2). The region covers a total land mass of 20,570 km² and has a population of about 2 million.

As opposed to the northern region where a unimodal rainfall pattern is observed (Figure 8), in the southern part of the country a bimodal rainfall pattern. Two rainfall seasons (Figure 13). In the south, the rainy season occurs a few months earlier than in the north and is followed by a second rainy season in September.

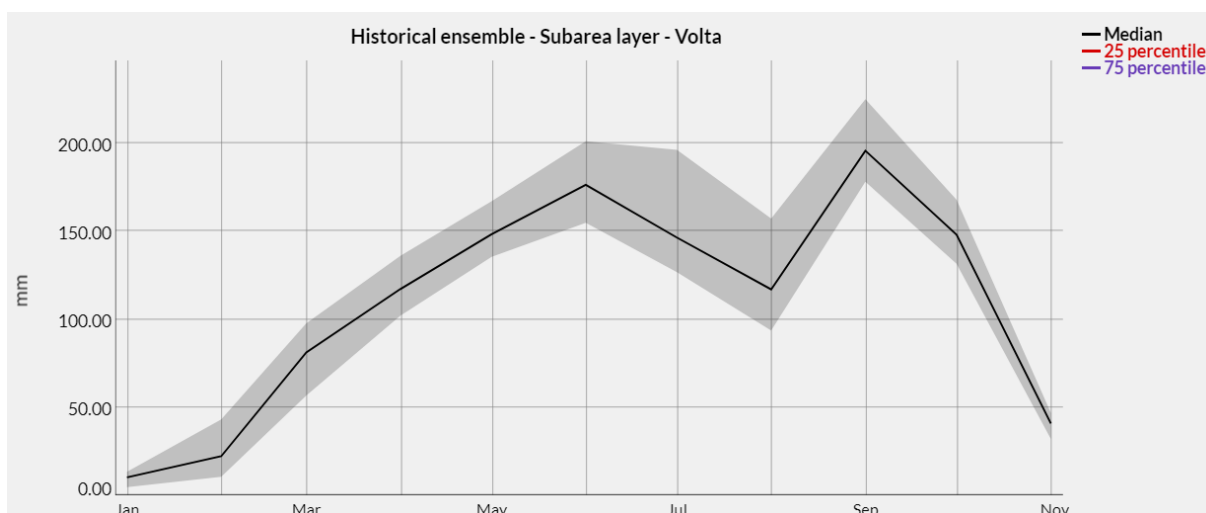


Figure 13 Historical monthly rainfall data (CHIRPS dataset) extracted from the web based drought portal for the Volta region. The black line is the median of the historical ensemble, which consists of the years 1981 to 2017. The envelope (grey area) is delimited by the 25th and 75th percentile of the historical ensemble.

In this region, drought conditions were also reported during the season 2006-2007. This event led to the drying up of the Keta Lagoon a case confirmed by officers of NADMO (source: WRC local staff). This drought condition affected many households and caused the execution of the intervention plan by the National Disaster Management Organization (NADMO). NADMO distributed food and other livelihood items to the affected communities.

This agrees with Figure 14 showing that the rainfall occurred (black line is the observed rainfall) later than expected (red line is the long-term average). In addition, the rainfall during the last months of 2006 and early 2007 is lower than the long-term average (black line is below the red line in Figure 14).

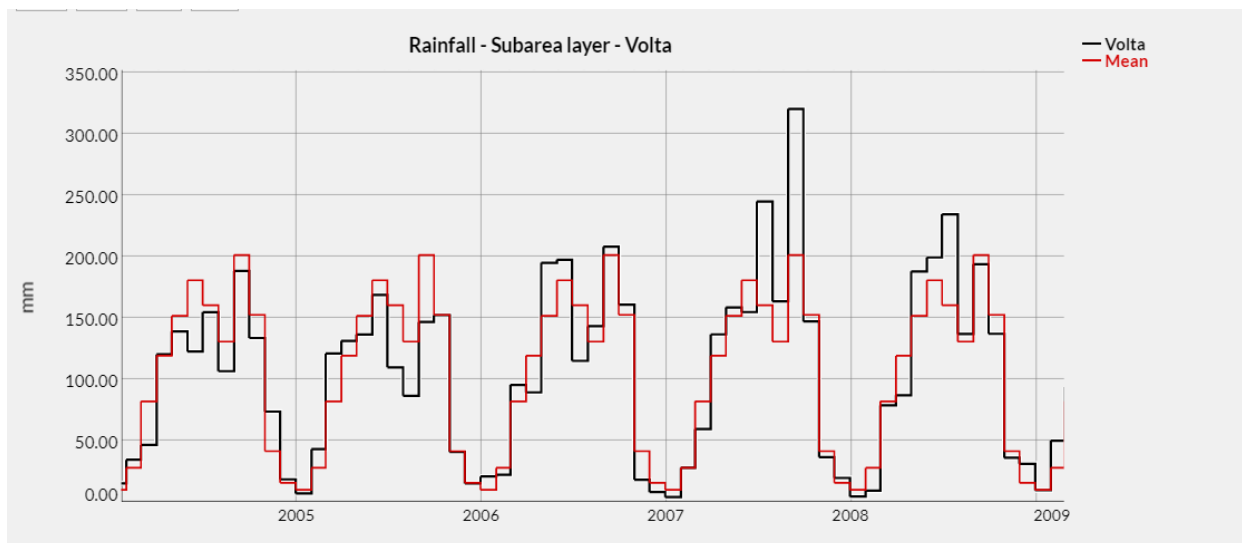


Figure 14 Rainfall data from CHIRPS for the years 2004 to 2009 for the Volta Region

As seen previously in the Upper East region, the VCI is a vegetation based drought index that can be used to monitor the vegetation cover at a given time of the year relatively to the extreme conditions observed in the past (comparison with the historical min and max values).

Figure 15 illustrates the variation over time of the percentage of the Volta region under each drought categories related to the VCI. For each time step, representing a 16-day period the plot indicates how much of the area is under each drought category (VCI percentage). At the start of 2017, more than 80% of the Volta region is classified with a VCI value below 5%, which can be interpreted as extremely low value of vegetation (Low VCI value is observed when NDVI is close to historical minimum).

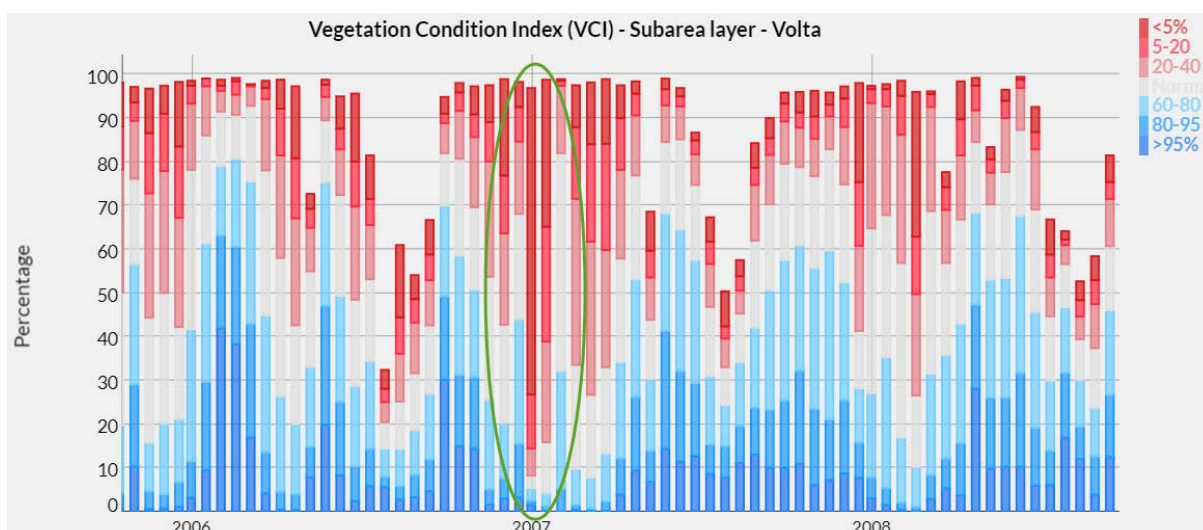


Figure 15 Variation in time of the percentage of the Volta region under each VCI categories. The start of 2017 is highlighted with a green mark.

As observed in the northern region, the drought index based on vegetation is in agreement with observation on the ground that indicated a drought affecting crops.

The meteorological drought (observed in rainfall deficit) is followed by the agricultural drought (observed in vegetation cover deficit) and is often followed by the hydrological drought (stream flow deficit). The developed system also provides near-real time access to the Lake Volta water level based on satellite altimetry JASON data⁴. The data set contains time-series of water level variations for some of the world's largest lakes and reservoirs. Currently, large (>100 km²) lakes in important agricultural regions are the main targets.

The historical record of the lake level does also confirm that the inflow to the lake have decreased at the start of the year 2007. Figure 16 shows the water level of Lake Volta and the very low level recorded during 2007. The low levels indicate a low inflow, which could be caused by reduced inflow from within Ghana or in the release from Burkina Faso.

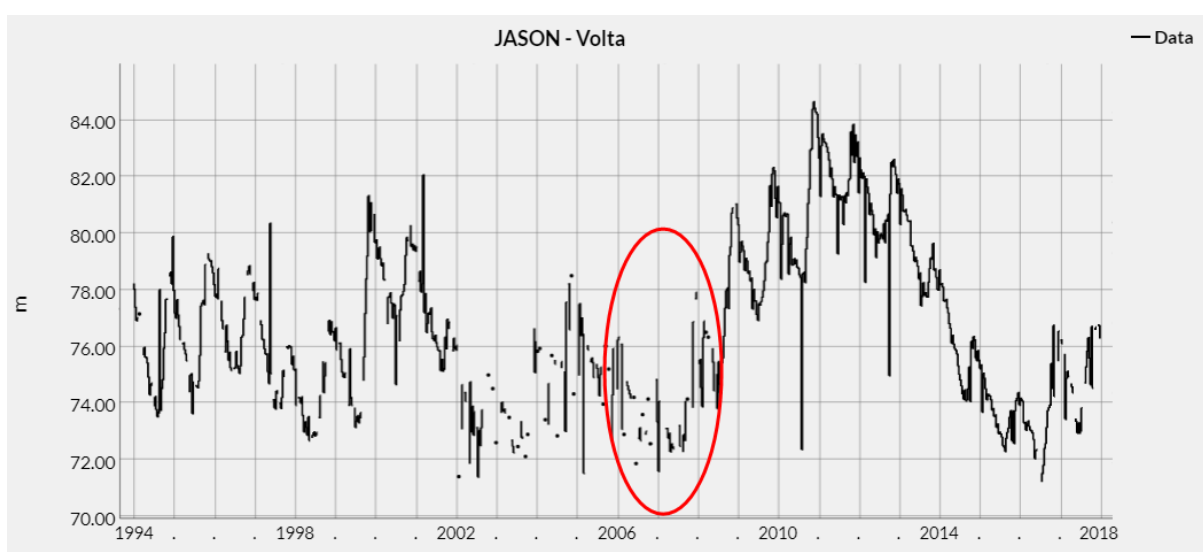


Figure 16 Record of the JASON altimetry water level in the Lake Volta from 1994 to present (data accessible in near real-time from the portal)

The use of data and information from the web based drought portal is in agreement with the local observation in the Volta region of Ghana. In addition, it allows an accurate identification of the area impacted by the meteorological, agricultural and hydrological drought.

2.3.4 Summary of the assessment

The following tables list respectively the outcomes related to hazard identification and risk assessment, which have been prone to validation as part of the CTCN assistance. The last column summarise the outcome of the assessment.

⁴ See more at http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/Default.aspx

Table 3 Outcomes of the validation related to hazard identification

Hazard identification			
Outcome	Means of validation	Purpose	Outcome
Drought indices	<p>Compare index values with historic information in the form of records of drought impacted areas or recorded hazards in the upper east region.</p> <p>Evaluate the need for adjustment of the selected indices.</p>	<p>Ensure that the most appropriate indices are used for hazard identification.</p>	<p>This comparison has been performed in the Upper East and Volta regions of Ghana based on the SPI-1 month and VCI drought indices. Both drought indices were in agreement with local conditions during the 2007 drought event. The use of indices allows an accurate identification of the timing and location of the impact of the drought [cf. chapters 2.3.1 and 2.3.2]</p>
Drought warning	<p>Compare early warning index values with observed climate and drought hazard information. The drought warning will mainly be validated on historic information.</p>	<p>Ensure proper warnings for the early warning part.</p>	<p>Drought indices warning levels (through the drought categories) have been checked against historical events. SPI-1 month and VCI drought indices have shown good agreement with local conditions during the 2007 drought event. [cf. chapters 2.3.1 and 2.3.2]</p>
Exposure	<p>Compare collected and available information with historic records of relevant exposure types.</p>	<p>Ensure that relevant exposure categories are included as part of the CTCN assistance.</p>	<p>The review of the system by the main applicant addressed this point, which appeared to be in line with their expectations [cf. Technology Review report, January 2018]</p>
Hazard categories	<p>Assess the current hazard categories used by NADMO and MOFA with international standards for hazard categories and propose adjustment.</p>	<p>Ensure relevant hazard categories for the hazard identification and dissemination within Ghana</p>	<p>It appeared that NADMO and MOFA do not have any drought warning levels.</p> <p>It was therefore agreed to use the internationally recognised drought categories such as the ones used in US drought monitoring system and adapt them where necessary [cf. Technology</p>

			description report, January 2018]
Impact assessment	Compare crop based impact analysis with available information regarding crop production and losses in the upper east region.	Correct and validate the tools used for impact assessment in relation to crop production.	This assessment has been performed as part of the validation in the Upper East region. Vegetation-based drought index such as VCI is in agreement with the reported crop yields of the 3 main crops indicating an extremely low production level in 2007 [cf. chapter 2.3.1]
Dissemination	Validate that the dissemination format from the CTCN assistance is compatible with the existing national dissemination from MOFA and NADMO.	Ensure that the dissemination format is compatible with the current dissemination from MOFA and NADMO.	The main applicant (WRC) together with other key stakeholders have reviewed the format of the drought report during the workshop held in October 2017 and also during the review process [cf. Summary report of the technical training, November 2017 and Technology Review report, January 2018]

Table 4 Outcomes of the validation related to risk assessment

Risk assessment			
Outcome	Means of validation	Purpose	Outcome
Vulnerability	Validate the vulnerability approach and analysis based on earlier studies and relevant information from the upper east region.	Ensure proper and relevant vulnerability assessment.	This assessment has been performed in the Upper East region, where vulnerable rainfed crop lands have been affected by the drought conditions during the 2007 event [cf. chapter 2.3.1]
Risk assessment	Evaluate the risk assessment based on existing information or records related to economic or agricultural related drought risk.	Ensure that the risk assessment provides relevant information for linkage with adaptation measures and	This assessment has been performed in the Upper East region, where the economic losses due to crop yield reduction are in

		drought related action plans and investments.	correlation with the drought indices values (SPI-1 month and VCI). [cf. chapter 2.3.1]
Dissemination	Validate that the dissemination format from the CTCN assistance is compatible with the existing national dissemination.	Ensure that the dissemination format is compatible with the current national dissemination.	The main applicant (WRC) together with other key stakeholders have reviewed the format of the drought report during the workshop held in October 2017 and also during the review process [cf. Summary report of the technical training, November 2017 and Technology Review report, January 2018]

2.4 Drought early warning system

A drought early warning application is developed as part of the developed web based drought early warning system. The drought early warning system allows users to evaluate the current drought level and assess the risk of drought impact towards different sectors. The drought early warning application is described in the user guide and is used to describe the current state, hence it does not store information of drought conditions in the past and for that reason this application is not included in the current validation. The main applicant (WRC) will evaluate the drought early warning system over the coming season and provide feedback when feedback from the system is collected.

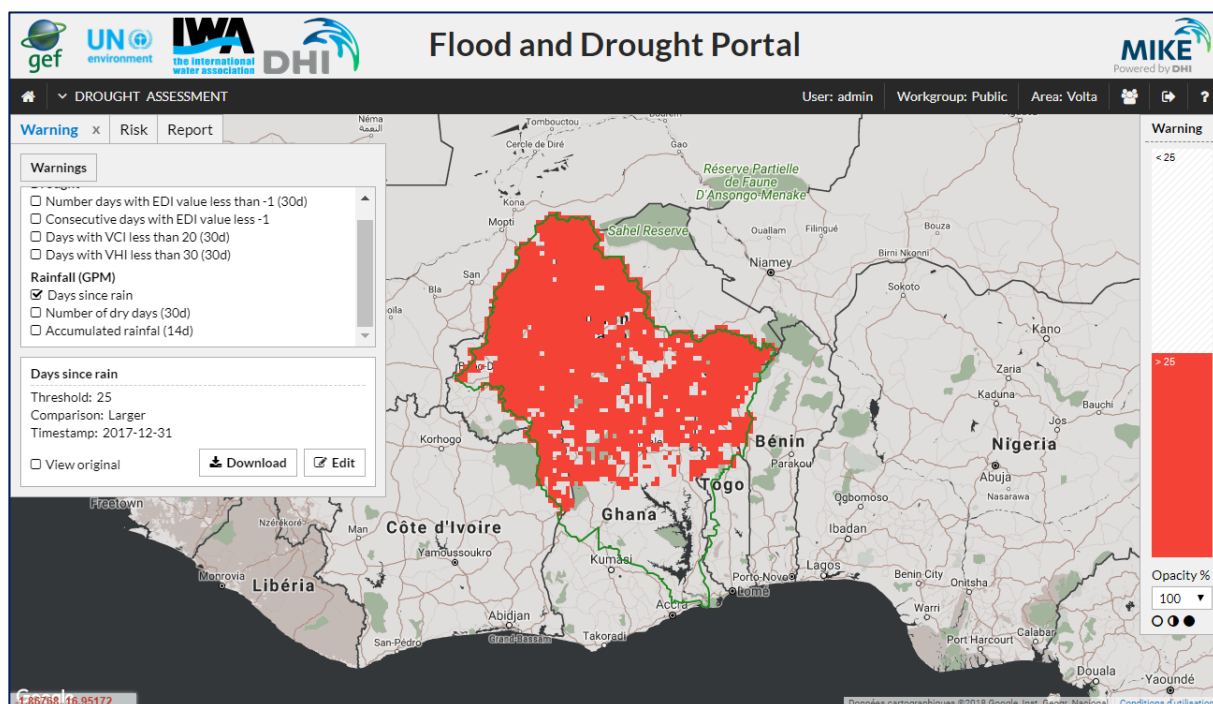


Figure 17 Drought early warning system within the web based drought portal developed as part of the CTCN assistance

The drought early warning system is based on the data and information part, used for the validation, and contains the following functionality:

- **Drought warning:** based on user specified thresholds the users are able to identify drought prone areas as areas where specific drought indices exceeds the specified threshold. The drought warning is specified based on current drought indices (eg. rainfall over the past 20 days, forecasted rainfall for the coming 10 days, number of consecutive dry days for the past 20 days etc.)
- **Drought risk:** the risk is calculated by overlaying the drought hazard (from drought indices) with different vulnerability maps (e.g. drought mortality risk, urban expansion, population density etc.) providing an assessment of the drought risk for a specific hazard towards vulnerable sectors or areas.
- **Drought reporting:** Automated reports submitted when a drought index is exceeded and reports summarising the drought status in the country. The drought reports are to be further developed during the final part of the project based on feedback from the national experts.

2.5 Adjustment

Based on the finding of the validation the following conclusions can be taken:

- The rainfall products that are availed via the web based drought portal agree relatively well at the monthly scale with ground data collected by WRC, with one exception for the PERSIANN dataset. Since this behaviour is confirmed by other sources, it has been decided to keep the dataset but not too include it neither in the validation nor in the drought reporting.

- Temperature and Vegetation datasets from MODIS are cloud sensitive and therefore are not so reliable during the rainy season due to frequent gaps in the datasets. The phenomena is more frequent for Temperature which is an 8-day composite product compared to vegetation (NDVI), which is a 16-day composite product. This led to the introduction of another Temperature based dataset (CRU), which unfortunately is not a real time product but offers more accurate historical records of temperature.
- For the purpose of the validation, it would have been very valuable to be able to compare different dataset directly in the web based drought portal (plot several time series from different sources together). To remediate to this limitation, a new functionality will be added to the web based drought portal to be able to compare multiple time series (available after the submission of this report).

3 Conclusions

The validation of the developed drought early warning system is done by one of the national experts, Mr James Aggrey, and the CTCN technical assistance team. The inclusion of the national expert in the validation process was essential, as the national requirements and needs had to be included in the validation.

The validation have focused on the ability to describe previous drought events using the available data and information provided as part of the CTCN based drought early warning system. The validation on past events ensures that the system is applicable in Ghana and it provides confidence that future events will be captured by the system.

The validation report described how the available satellite based data describing climate (rainfall and temperature) and vegetation could be used to identify past drought events in the northern and southern part of Ghana. In both cases, the available data provided an accurate and precise description of the previous event, and was able to identify the timing and location of drought related impacts from climate and vegetation. It was also demonstrated how the water level in Lake Volta could be used to further validate the drought impact in Ghana.

The system will over the coming seasons be used by the main applicant and feedback on the ability to capture future drought events will be compiled based on feedback from the use in the different parts of Ghana.

4 References

Philip Antwi-Agyei, Evan D.G. Fraser, Andrew J. Dougill, Lindsay C. Stringer, Elisabeth Simelton (2012) Mapping the vulnerability of crop production to drought in Ghana using rainfall, yield and socioeconomic data, *Applied Geography*, Volume 32, Issue 2, 2012, Pages 324-334, ISSN 0143-6228, <https://doi.org/10.1016/j.apgeog.2011.06.010>.

Moctar Dembélé & Sander J. Zwart (2016) Evaluation and comparison of satellite-based rainfall products in Burkina Faso, West Africa. *International Journal of Remote Sensing* Vol. 37, Iss. 17, 2016

Kasei, C. N., & Afuakwa, J. J. (1991). Determination of optimum planting date and growing season of maize in the northern savannah zone of Ghana. Soil Water Balance in the Sudano-Sahelian Zone (Proceedings of the Niamey Workshop). IAHS Publ. no. 199, 1991.

Appendix A

List of data received by WRC.

Cropping Calendar for 2011 Agricultural Season

- Navrongo
- Builsa Using Navrongo Data
- Bolgatanga
- Using Manga Data, Bawku

Cropping Calendar for 2014 Agricultural Season

- Using Manga Data, Bawku

Yearly cropping calendar around Navrongo in the Upper East Region of Ghana

Monthly rainfall from 1991 to 2016

- 6 districts
- REGIONAL AVERAGE

AVERAGE WHOLESALE PRICES 1970 to 2016

- MAIZE
- MILLET
- G/CORN
- RICE
- YAM (WHITE)
- GARI
- TOMATOES
- ONIONS
- DRIED PEPPER
- G/NUTS(RED)
- COWPEA (WHITE)
- SOYABEAN
- PADDY RICE

Crop area and yield for 2015

- MAIZE
- RICE
- MILLET
- SORGHUM
- G/NUTS
- COWPEA

AREA, YIELD AND PROD. OF SELECTED FOOD CROPS 1991-2015

- Per districts
- Regional overview