Weather and Climate Extremes 3 (2014) 22–30

Contents lists available at ScienceDirect

Weather and Climate Extremes

journal homepage: www.elsevier.com/locate/wace

AGRHYMET: A drought monitoring and capacity building center in the West Africa Region

Seydou B. Traore *, Abdou Ali, Seydou H. Tinni, Mamadou Samake, Issa Garba, Issoufou Maigari, Agali Alhassane, Abdallah Samba, Maty Ba Diao, Sanoussi Atta, Pape Oumar Dieye, Hassan B. Nacro, Kouamé G.M. Bouafou

Centre Régional AGRHYMET, P.O. Box 11011, Niamey, Niger

ARTICLE INFO

Article history:
Received 5 January 2014
Received in revised form
27 March 2014
Accepted 30 March 2014
Available online 23 May 2014

Keywords:
Drought monitoring center
Environmental monitoring
Food security early warning
Human resources development
Sahel
West Africa

ABSTRACT

The AGRHYMET Regional Center, a specialized institution of the Permanent Interstates Committee for Drought Control in the Sahel (CILSS), was created in 1974 at the aftermaths of the severe droughts that affected this region in the early 1970s. The mission assigned to the Center was to train personnel, provide adequate equipment for the meteorological and hydrological stations networks, and set up regional and national multidisciplinary working groups to monitor the meteorological, hydrological, crops and pastures conditions during the rainy season. As such, it can be considered as the West Africa drought monitoring center, similarly to its younger counterparts in Eastern and Southern Africa. After 40 years of existence, AGRHYMET's scope of activities expend now beyond the geographical boundaries of CILSS member states, to include the whole West Africa thanks to several initiatives it has been implementing on behalf of the Economic Commission of West African States (ECOWAS) on food security and environmental issues, including climate change. Throughout the years, AGRHYMET developed, in collaboration with international research organizations, models and methodologies based on ground and satellite observations to monitor rainfall, food crop water requirements satisfaction and prospective yields, the progress of vegetation front and its seasonal and interannual variations. It has trained about 1200 new experts in agrometeorology, hydrology, equipment maintenance, and plant protection, and more than 6000 professionals on topics related to food security, climate change, and sustainable natural resources (land and water) management. As of now, AGRHYMET staff is involved in several international initiatives on climate change, food security, and environmental monitoring that allow them keep abreast of the best available technologies and methods, and also contribute to generating knowledge on those issues.

© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

1. Introduction

The drought that occurred in the West African Sahel during the early 1970s is considered to be unique not only by its severity, but also by its spatial extent (Hulme, 1996). Some of the striking illustrations of this are the southward displacement of isohyets by about 200 km over the whole region, and the dramatic shrinking of the area occupied by free waters in Lake Chad (Lebel and Ali, 2009; Diouf et al., 2000). This resulted in massive socioeconomic and environmental disruptions in the region, whereby the local populations suffered severe food shortages and loss of assets, and the natural resources such as pastures and water bodies were largely depleted. This shock lead the decision makers of the region to put in place some institutional mechanisms that may help prevent or reduce the negative socioeconomic impacts of such events, if they were to occur in the future. CILSS, French acronym for Permanent Interstates Committee for Drought Control in the Sahel, was thus created in 1973, initially by six West and Central African states (Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal). Those were later joined by The Gambia in 1974, Cape Verde Islands in 1975, and Guinea Bissau in 1986. More recently, Guinea (in 2011) Coted'Ivoire, Togo and Benin (in 2012) also joined CILSS to make it a 13 member state regional institution in West Africa. The current mandate of the CILSS is to undertake actions towards food security and combat the effects of drought and desertification for a new ecological balance (www.cilss.bf). Its work is implemented by an executive secretariat (headquarters) based in Ouagadougou, Burkina Faso, and two specialized institutions: the AGRHYMET Regional Center in Niamey, Niger, and the Institute du Sahel (INSAH) in Bamako, Mali.

* Corresponding author. Tel.: +227 20315316.
E-mail address: s.traore@agrhymet.ne (S.B. Traore).

http://dx.doi.org/10.1016/j.wace.2014.03.008
2212-0947/© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

The INSAH was created in 1976 to coordinate, harmonize and promote scientific and technological research in member states (www.insah.org). As for the AGRHYMET Regional Center (www.agrhymet.ne), it was created in 1974 with the mission to train personnel, provide adequate equipment for the meteorological and hydrological stations networks, and set up regional and national multidisciplinary working groups to monitor the meteorological, hydrological, crops and pasture conditions during the rainy season. The Executive Secretary of CILSS and the Directors of AGRHYMET and INSAH are all appointed by the Council of Ministers of CILSS for 3-year terms renewable only once. This turnover of leadership allows the member states make sure that new ideas are always coming in for their common benefit.

Based on the mission assigned to it by the CILSS authorities, AGRHYMET can be considered as the West Africa drought monitoring center, similarly to its younger counterparts in Eastern and Southern Africa. Although there was no generalized drought in the Sahel since 1985, this extreme climatic phenomenon continues to be a permanent threat, and the great spatio-temporal variability of rainfall remains. For example, the years 2009, 2011 and 2013 were characterized by very poor spatial and temporal distribution of rains, resulting in either late installation of crops, and thus the reduction of their production potential, or in their total failure in some regions due to the lack of rains during the most critical growth stages (flowering and maturation) of rainfed crops (www.agrhymet/ne/bulletin.html). After nearly four decades of existence, the AGRHYMET Center can now be defined as a regional institution, specialized in the sciences and technologies related to agricultural development and natural resources management, and promoting information and training in the area of agroecology.

In recent years, AGRHYMET's scope of activities expended beyond the geographical boundaries of CILSS member states, to include the whole West Africa following an agreement between CILSS and the Economic Commission of West African States (ECOWAS) in December 2009, supported by a recommendation of the CILSS Council of Ministers and a decision of the Summit of CILSS Heads of States held in N'Djamena, Chad, in March 2010. AGRHYMET is currently implementing several projects in West Africa on behalf of ECOWAS on food security and environmental issues, including climate change. This paper describes the achievements of AGRHYMET regarding drought monitoring and early warning and related capacity building activities in West Africa and beyond.

2. Assistance to member states

The overall objective assigned to AGRHYMET at its creation is to develop mechanisms for large-scale diagnosis of the Sahelian environment and integrate them into a coherent plan of spatial and statistical information to detect, track and help understand the nature and speed of changes in the Sahelian environment on the one hand, to train national experts in the areas of agrometeorology, hydrology and crop protection, on the other hand. The system put in place works as an observation network of climate variables in different ecological zones to cover the spatial diversity of agro-hydro-meteorological phenomena and their temporal variability. Gathering ground biophysical data by national meteorological, hydrological and agricultural agencies is complemented by the use of remotely sensed satellite data through receiving stations installed at the Centre and some national agencies. All data are then processed and analyzed in an information system that allows issuing early warnings and management of natural resources (Fig. 1). Models have been developed to monitor rainfall, food crop water requirements satisfaction and prospective yields, the progress of vegetation front and its different seasonal and interannual variations. Starting from May each year, a monitoring is implemented every 10 day at both regional and national levels by the multidisciplinary working groups that issue decadal and/or monthly bulletins to inform decision makers on the evolving agropastoral and hydrological situations. Those bulletins contain several chapters, going from the interpretation of the results of the regional seasonal outlook forum (PRESAO) on rainfall and hydrological forecasts, to the analysis of the rainfall and hydrological situations, the progress of sowing, the assessment of crop water requirements satisfaction and potential yields using field data and agrometeorological models, the status of pastures using vegetation indices, and the estimation of regional cereal/food balance. In addition to producing and disseminating information to decision makers, an important component of AGRHYMET's assistance to member states is the training it provides to reinforce the human resource capacity of national meteorological, hydrological and agricultural services, civil society, through diploma and on the job trainings it organizes at both regional and national levels.

3. Achievements and discussion

3.1. Seasonal rainfall and hydrological forecasts

Since the inception of the West Africa seasonal climate outlook forums (PRESAO) in 1998, the AGRHYMET Regional Centre has been an active member of the consortium composed by the African Center for Meteorological Applications to Development (ACMAD) and the Niger river Basin Authority (NBA). The outcome of these forums consists in issuing, at the end of May, forecasts for the July–August–September (JAS) cumulative rainfall for countries in West Africa, Cameroon and Chad. These forecasts are based on outputs of coupled atmosphere–ocean dynamic models and of national statistical models. Each year, scientists from all these countries meet together in a pre-forum during which they come up with a consensual forecast for different zones. For each of these zones, the seasonal forecast gives the probabilities of the seasonal rainfall (Fig. 2) or maximum river flows (Fig. 3) being within the lowest, middle, or top third of the available time series, usually the last 30-year standard normal period. These forecasts are updated at the end of June and July.

Since 2012, efforts are being made by AGRHYMET to forecast other characteristics of the rainy season that are more relevant for rainfed agriculture such as the onset and cessation dates of the season, and the potential duration of dry spells during the critical growth stages of the major cereal crops (www.agrhymet/ne/bulletin.html). Those forecasts are based on statistical relationships established between the forecasted variables and the outputs of coupled atmospheric and ocean models using the CPT tool (Mason et al., 2011). Also, a special session for guinea cost countries was initiated in 2013 by AGRHYMET to issue forecasts for the March–April–May, April–May–June and June–July–August periods that corresponds to the greater rainy season in those countries (www.agrhymet/ne/bulletin.html). This lead to the organization, together with ACMAD, the meteorologists and agrometeorologists of the Guinea Golf countries, of the 1st PRESA-GG outlook forum in Abidjan, from 10 to 14 March 2014.

3.2. Rainfall monitoring

The analysis of the rainfall situation consists in mapping the cumulative decadal, monthly and seasonal amounts observed throughout West Africa and commenting on them with regards to the 30-year average and the previous year. Rainfall data can come from the regular raingauge networks of member countries and/or estimates made using meteorological satellite (METEOSAT) infrared images (Fig. 4). Particular attention is paid to zones with

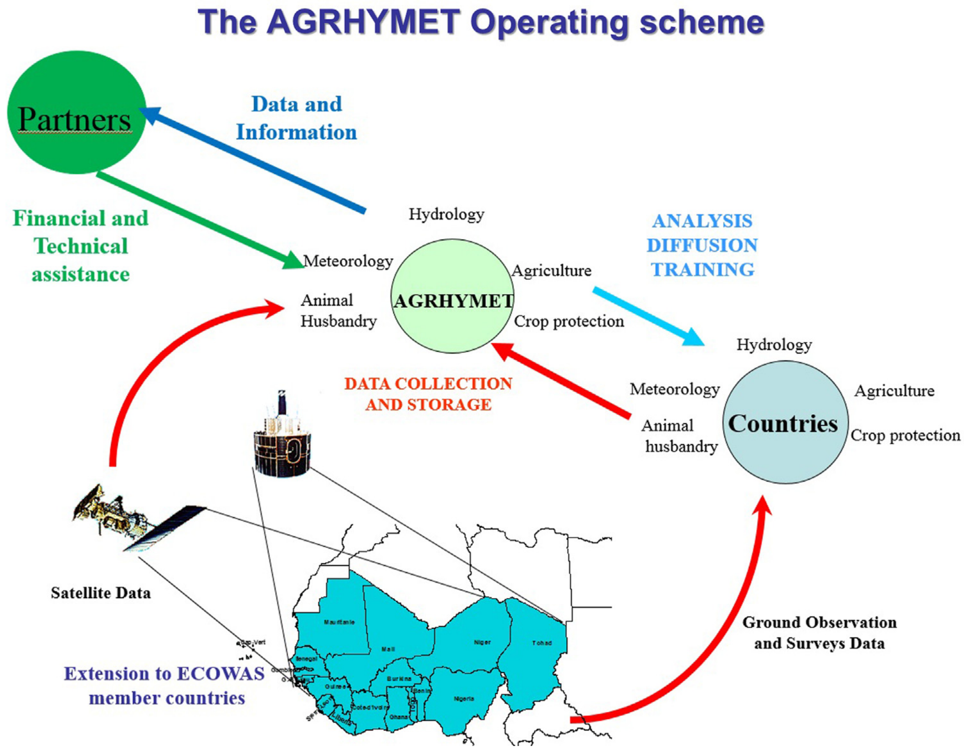

Fig. 1. The AGRHYMET information production system.

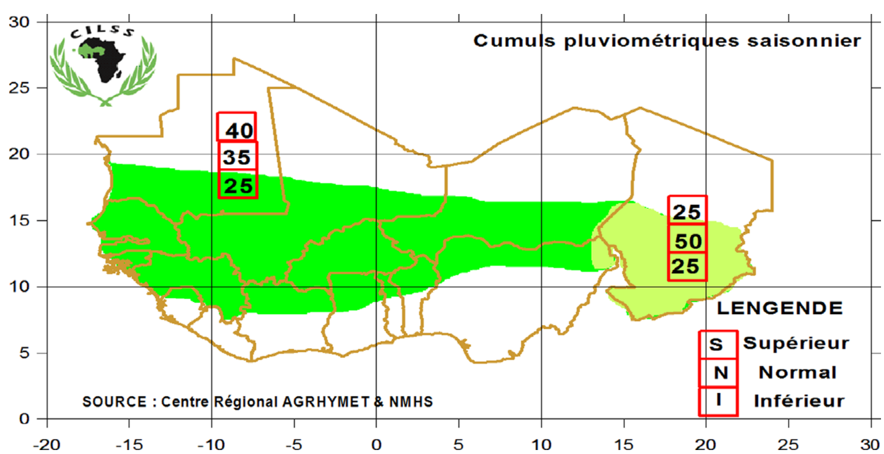

Fig. 2. Forecast of the seasonal cumulative rainfall in West Africa (figures in small rectangles at the top, middle and bottom indicate the probability of the cumulative rainfall to be higher, equivalent or lower, respectively, compared to the average of the 1981–2010 period).
Source: AGRHYMET monthly bulletin, May 2013.

exceptional events, such as those with deficit or excess cumulative rainfall during consecutive decades.

3.3. *Surface waters monitoring*

Surface waters are monitored using data collected and transmitted by the national hydrological offices and regional river basin authorities. Water levels and river flows are analyzed and compared to reference values (average, maximum, minimum, etc.) (Fig. 5).

3.4. *Crop monitoring*

Crop monitoring at the AGRHYMET Center is done by combining information from national meteorological offices on sowing dates, phenology and water requirements satisfaction, and also results from crop simulation models. The outputs of these models are used to map the onset dates of the season throughout the region, the water requirements satisfaction indices and the potential yields (Dingkuhn et al., 2003) (Fig. 6). Since the early 1990s, the diagnostic hydrique des cultures (DHC) model, based on soil water balance simulation, was used to simulate the above mentioned parameters. This model uses as input data the daily rainfall from the regular network of CILSS member countries or rainfall estimates from METEOSAT infrared images, the average decadal values of potential evapotranspiration (PET), and the soil potential water storage above the wilting point in the first meter layer. The DHC model has now been upgraded to include, in addition to simple water balance, carbon balance and also modules accounting for photoperiod sensitivity, a character still dominant in crop varieties sown by West African farmers (Traore et al., 2004, 2010). The new model, named Système d'Analyse Régional des Risques

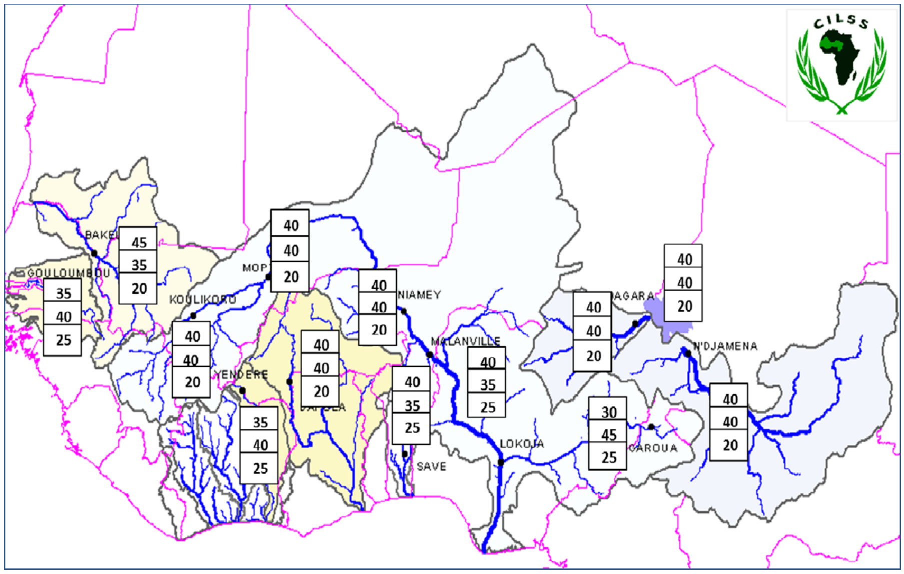

Fig. 3. Forecast of the maximum discharges in the major rivers systems in West Africa (figures in small rectangles at the top, middle and bottom indicate the probability of the maximum discharges to be higher, equivalent or lower, respectively, compared to the average of the 1981–2010 period).
Source: AGRHYMET monthly bulletin, May 2013.

Agroclimatiques, version H (SARRA-H) (http://sarra-h.teledetection.fr/SARRAH_Home.html), is currently being adapted to the operational needs of agrometeorological monitoring in West Africa.

In addition to the results from crop simulations models, vegetation indices derived from satellite observations, such as those described below for the pastoral monitoring, also serve as indicators of crop growing conditions.

3.5. Pastoral monitoring

Pastures situation is assessed mostly indirectly through vegetation indices derived from satellite images. Since 1980s, the normalized difference vegetation index (NDVI) from the NOAA satellites was used by AGRHYMET and its member states to monitor the emergence and the advance of the vegetation front throughout the growing season. Comparisons of the current decadal values with those of the previous one and the average for the same decade allowed seeing where conditions were favorable or unfavorable to vegetation growth. With time, some imperfections were observed with the use of NDVI, such as the effects of clouds, dust and water vapor on this index. New indicators were therefore suggested to separate meteorological and ecological signals in characterizing ecosystems. The vegetation condition index (VCI), which is the ratio of the difference between the NDVI value observed at a given time and its minimum historical value to the maximum historical difference (maximum minus minimum), was suggested (Kogan, 1988, 1995; Unganai and Kogan, 1998). A somewhat similar index, the normalized vegetation growth index (ICN in French), which is the same ratio, but where the maximum and minimum values of NDVI are for the whole growing season and not just for the period (decade or month) being examined. VCI and ICN values are comprised between 1 and 100, and VCI values below 35 indicate drought conditions (Kogan, 1995).

$$\mathrm{VCI} = (\mathrm{NDVI\_}x - \mathrm{NDVImin\_}x)/(\mathrm{NDVImax\_}x - \mathrm{NDVImin\_}x) \times 100$$

where NDVI_x is the NDVI value for a given period x, while NDVImin_x and NDVImax_x are maximum and minimum historical NDVI values for the same period.

$$\mathrm{ICN} = (\mathrm{NDVI\_}x - \mathrm{NDVImin})/(\mathrm{NDVImax} - \mathrm{NDVImin}) \times 100$$

where NDVI_x is the NDVI value for a given period x, while NDVImin_x and NDVImax_x are absolute maximum and minimum historical NDVI values for the whole growing season.

Another index, also derived from the initial NDVI, is the standardized NDVI, which is the ratio of the difference between the NDVI value observed at a given time and its historical average, to its standard deviation for the same historical period. sNDVI also helps identify locations where conditions were favorable or unfavorable to vegetation growth, and makes decisions in conjunction with other indicators.

$$\mathrm{sNDVI} = (\mathrm{NDVI\_}x - \mathrm{NDVIavg\_}x)/\mathrm{StdNDVI\_}x$$

where NDVI_x is the NDVI value for a given period x, while NDVIavg_x and StdNDVI_x are the average and the standard deviation of NDVI values for the same period.

In the framework of the African Monitoring of Environment for Sustainable Development (AMESD) project, which the AGRHYMET Center has been implementing since 2009 on behalf of ECOWAS and African Union in West Africa, these new indicators were adopted for monitoring crop and vegetation status. AMESD products are derived from the SPOT VEGETATION satellite with a spatial resolution of 1 km/1 km. The processed images are made available through the AMESD e-stations installed in all West African countries, and used in the AGRHYMET monthly and special environmental monitoring bulletins (Fig. 7).

All the above mentioned indicators are used to decide whether a zone is "at risk" or not. The first signal is given by the seasonal forecast map (Figs. 2 and 3), which helps identify where water shortages are expected for the incoming season. Then a delay of more than two decades in the current year's starting date relative to the average (Fig. 6a) indicates that crops are likely to have less time to develop and give adequate yields, because of a shortened season. This is based on the observation that the starting date of the rainy season in the Sahel is much more variable than its ending date (Sivakumar, 1988), and that a season starting late does not necessarily mean that it will also end late (Traore et al., 2000). Once the season is installed, other indicators are used to determine risk zones, namely, if the crop water satisfaction index falls below 50 percent for two consecutive decades (Fig. 6b), or if the potential millet yields are below 90% of the average (Fig. 6c). Also, negative values of the standardized NDVI (Fig. 7a), or vegetation

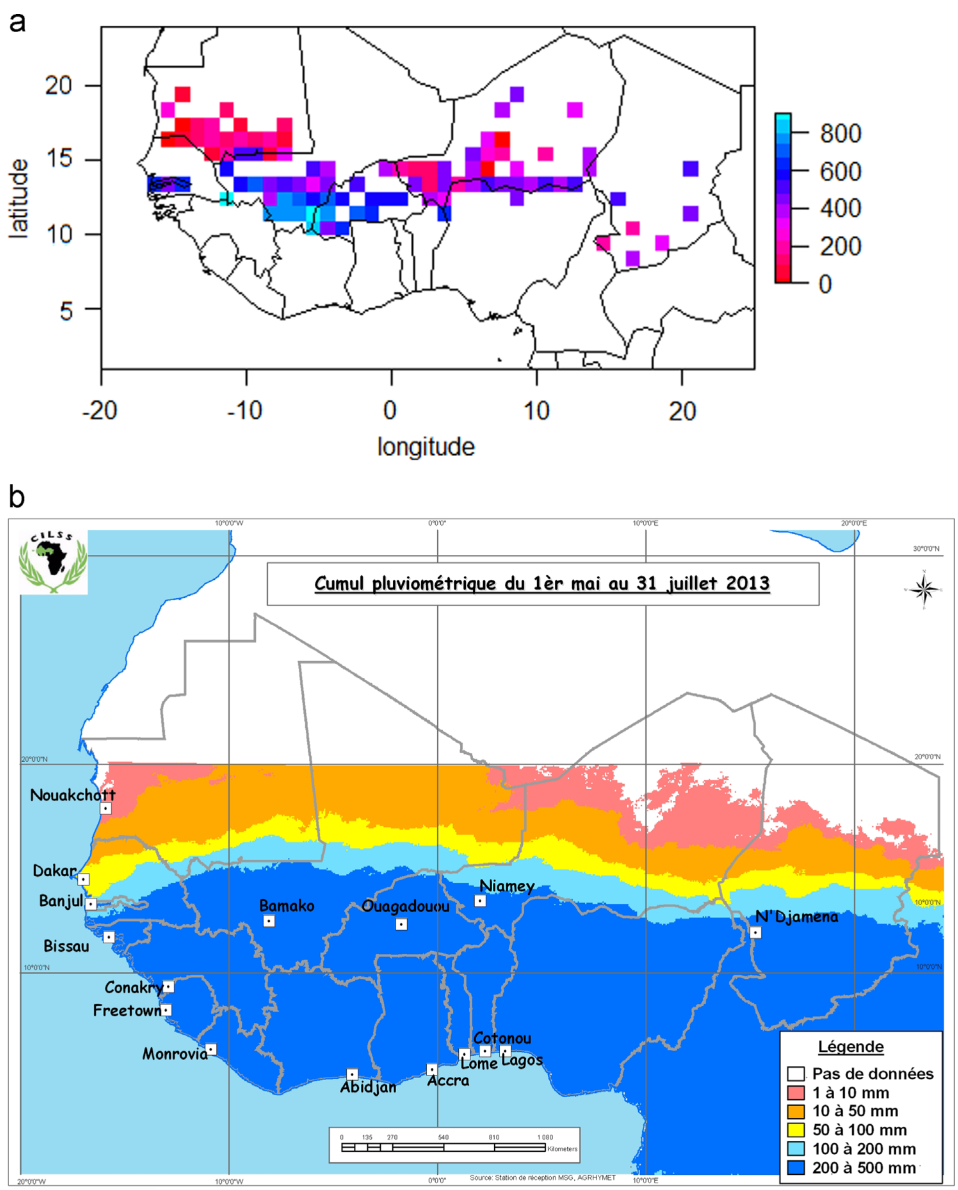

Fig. 4. Maps of cumulative rainfall from 1st May to 31st July 2013 in West Africa. (a) Data transmitted by national meteorological services. (b) Estimations from METEOSAT satellite.
Source: AGRHYMET monthly bulletin, August 2013.

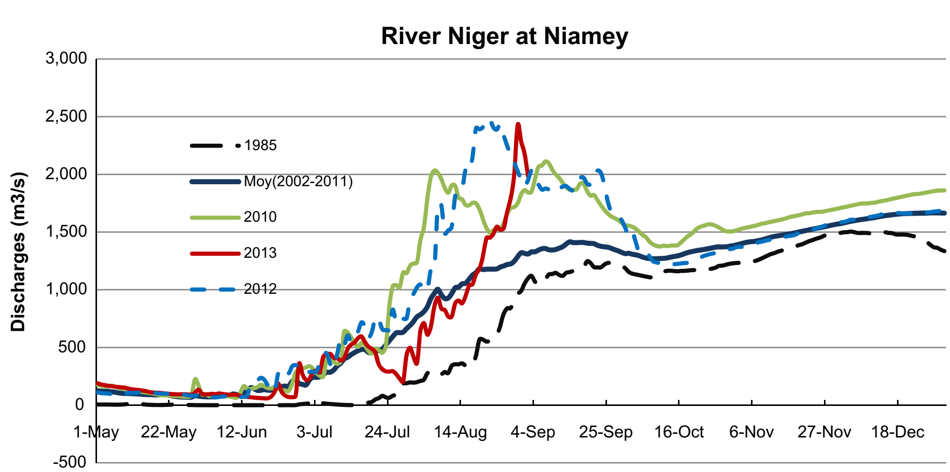

Fig. 5. River Niger 2013 discharges in Niamey, Niger Republic, compared to reference years.
Source: AGRHYMET monthly bulletin, August 2013.

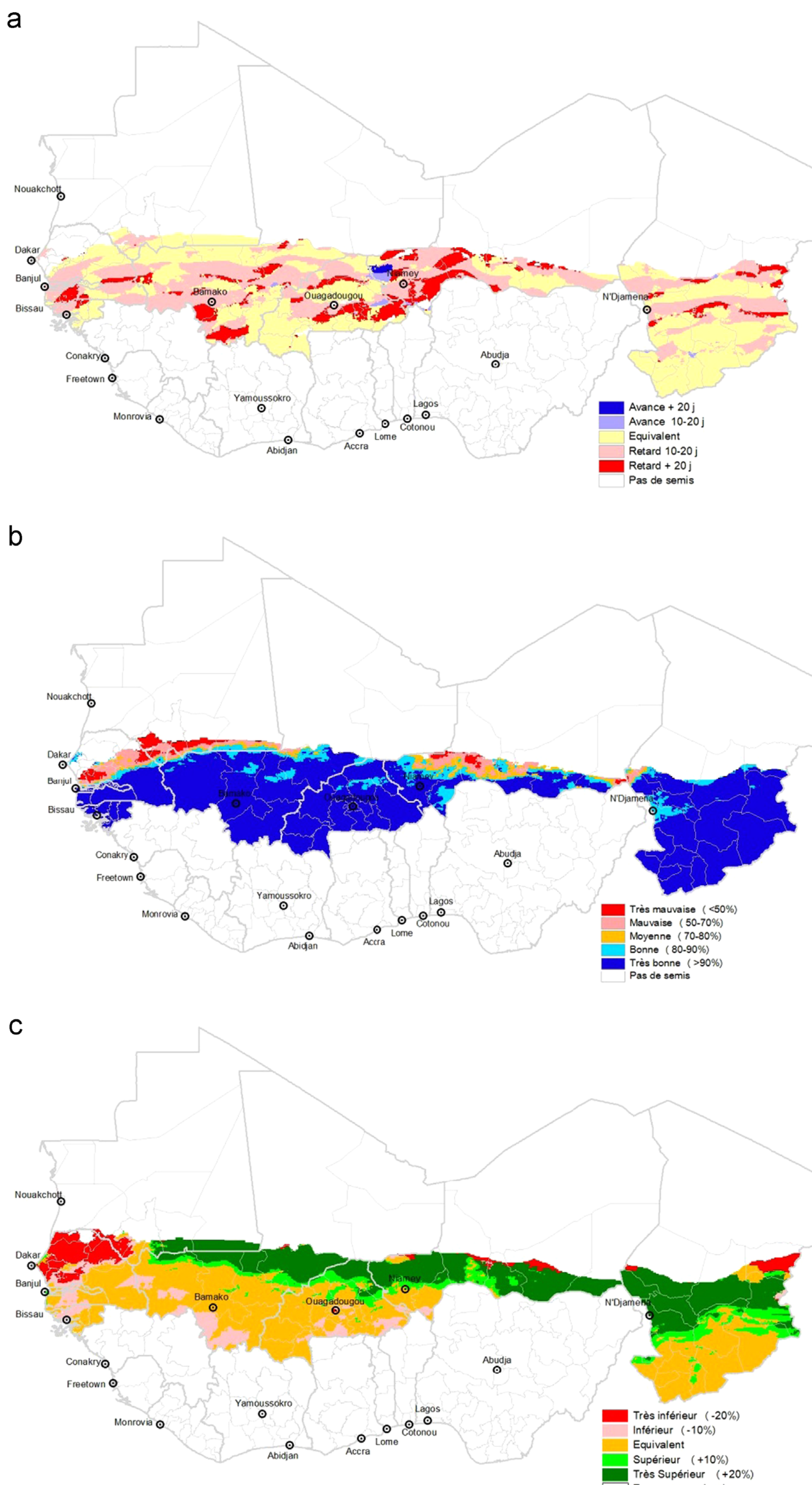

Fig. 6. Maps of crops situations in the West African Sahel derived from the outputs of the DHC crop water balance model. (a) Onset dates of the cropping season as compared to the 1971–2000 averages. (b) Pearl millet crop water requirement satisfaction levels during the 3rd decade of July 2013. (c) Potential pearl millet yields as compared to the 1971–2000 averages.
Source: AGRHYMET monthly bulletin, July and August 2013.

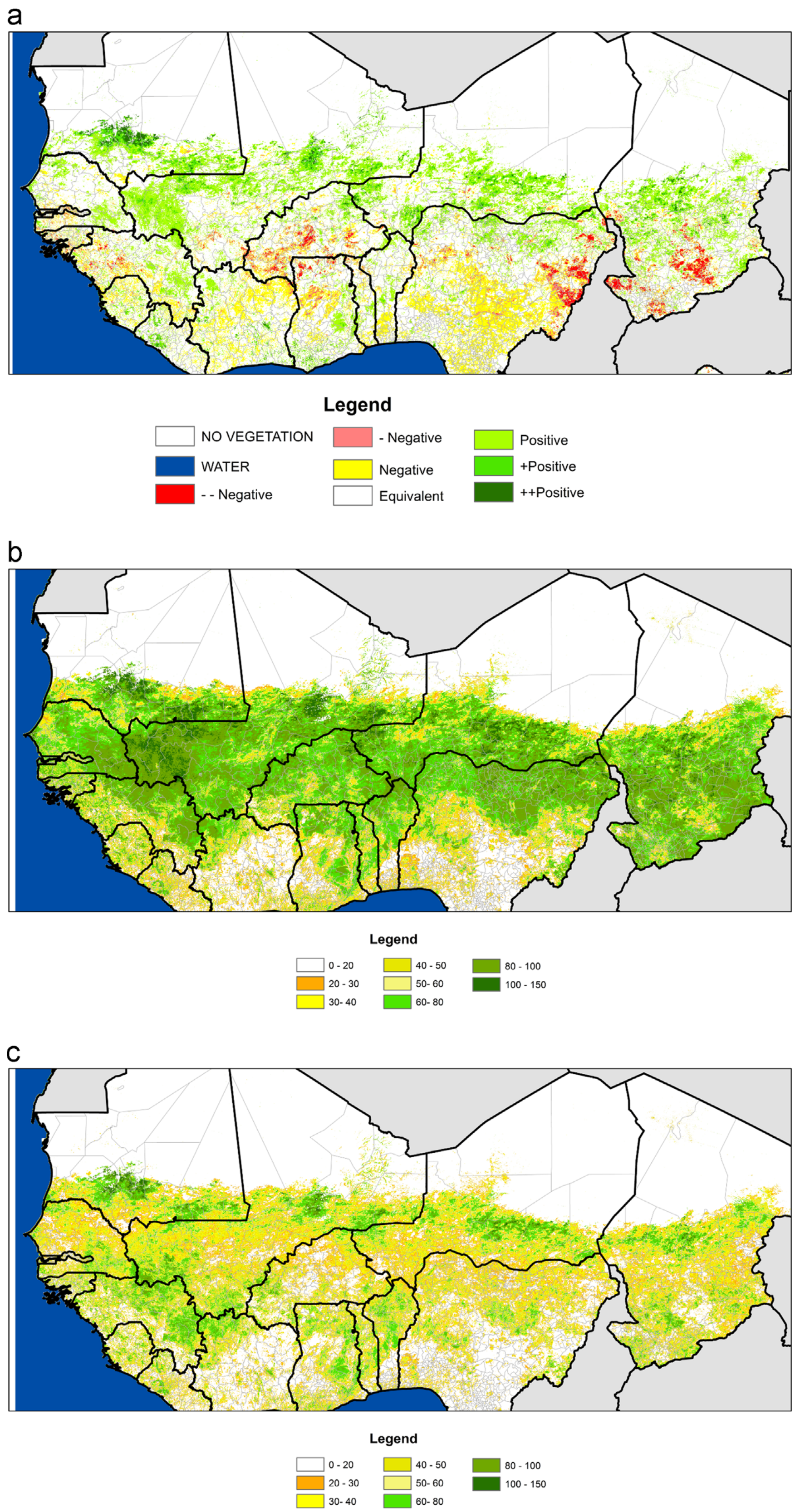

Fig. 7. Indicators of vegetation status in West Africa as at 31st July 2013. (a) Standardized Normalized Difference Vegetation Index (sNDVI). (b) Normalized growth index (Indice de Croissance Normalisé, ICN) (c) Vegetation condition index (VCI).
Source: AGRHYMET monthly bulletin, August 2013.

Table 1
Number of AGRHYMET graduates from 1975 to 2013.

Degree	Discipline				Total
	Agricultural meteorology	Plant protection	Hydrology	Instrument maintenance and microcomputing	
Higher technician	201	381	118	104	804
Engineers	120	55	57	22	254
Sub-total 1	*321*	*436*	*175*	*126*	*1058*
Masters	Concerted management of natural resources	Climate change and sustainable development	Sustainable protection of crops and environment	Sustainable land management	
Sub-total 2	*52*	*19*	*18*	*20*	*109*
Grand total					1167

condition indices below 60% (Fig. 7b and c) are used to alert on possible reduction of food crops and pastures productions in particular areas. This gives basis for decision makers to focus their attention on those areas by closely monitoring not only rainfall conditions, but also socioeconomic activities and taking adequate measures to prevent food and fodder shortages there.

3.6. Human resources development

AGRHYMET is a center of excellence recognized by the African and Malagasy Council for Higher Education (CAMES) and the World Meteorological Organization (WMO) as an institution of higher education. It is also a full member of the Agence Universitaire de la Francophonie (AUF). In May 2012, AGRHYMET was labeled “Centre of Excellence” by the Council of Ministers of UEMOA (West African Economic and Monetary Union). The training courses organized at AGRHYMET aim at strengthening the capacities of African professionals with the added benefit of taking into account the social and professional realities of the West Africa region. From 1975 to 2013, AGRHYMET has trained more than 1200 new experts in agrometeorology, hydrology, equipment maintenance, and plant protection, and more than 6000 professionals on topics related to food security, climate change, and sustainable natural resources (land and water) management (Table 1). The Centre also organizes in-country training workshops to strengthen the capacity of national experts in the use of tools and methods to assess the status of food security and of environmental indicators. The impact of these trainings is noticeable as more than 60% of the staff from national meteorological and hydrological services of CILSS member countries graduated from AGRHYMET. Most of those graduates have undergone additional training through refresher courses and Master's degree programs at AGRHYMET. A number of them became heads of departments and directors at their National Meteorological or Hydrological Services, experts at AGRHYMET, and occupied managerial positions in sub-regional organizations. In those various positions, they have had the opportunity to express their needs and orient the training and information production activities implemented by the Center. A liaison bulletin was initiated by the AGRHYMET Training and Research Department to keep track of all the graduates, and national AGRHYMET graduates associations have been promoted in several countries.

4. Conclusions and perspectives

The above described activities allowed AGRHYMET fulfill the mandate assigned to it by the heads of states of CILSS member countries and serve as a drought monitoring and capacity building center in West Africa since 1974. This was possible thanks to the active involvement of several technical and financial partners throughout the years. Among those technical partners, it is worth mentioning the platform of regional institutions on environment and meteorology based in Niamey (PIREM) consortium, composed of ACMAD, AGRHYMET, CERMES, CRESA, EAMAC, ICRISAT, and NBA, that not only contributes to the teachings and supervisions of AGRHYMET students, but also makes use of its expertise and facilities. Moreover, they conduct joint projects such as the IDRC funded FACE project involving ACMAD, AGRHYMET, CERMES, and the Niamey University, the African Development Bank funded CLIMDEV/ISACIP project involving ACMAD and AGRHYMET, the AgMIP and CCAFS projects involving AGRHYMET and ICRISAT, etc. ACMAD, AGRHYMET and NBA are currently involved, together with OSS and the CILSS executive secretariat, in the World Bank PRECA-Sahel initiative. AGRHYMET faced and continues to face several challenges, some of which are related to data acquisition in member countries, their timely transmission to the processing centers and the small number of observation points. Efforts have continuously been deployed to solve those issues by adopting new technologies and broadening scientific and technical collaboration with international research centers. These efforts are still ongoing at the Center to improve the various information products, by for example upgrading and coupling crop simulation models with satellite derived climate data and climate forecast models at short and medium time scales, by blending satellite and ground based climate data to fill spatial and temporal gaps.

The extension of activities to the whole West Africa, and also the increased occurrence of climate extremes throughout the region made CILSS and AGRHYMET evolve from tackling only drought related issues to address all climate hazards, including climate change impacts assessment on agriculture and water resources, as well as adaptation studies. AGRHYMET staff is currently involved in several international initiatives on climate change, food security and environmental monitoring that allow them keep abreast of the best available technologies and methods, and also contribute to generating knowledge on those issues.

An important perspective for AGRHYMET is the implementation, jointly with ACMAD, of the WMO designated West Africa Regional Climate Center Network (ECOWAS RCC-Network) whereby it will be generating regional tailored climate products, providing online access to those products, and coordinating training for users, among other tasks.

The recent initiatives involving CILSS, the World Bank, the African Development Bank, The Islamic Development Bank, USAID, EU and many other financial partners on irrigation, pastoralism, as well as the various resilience projects (PRECA-Sahel on resilience to disasters, BRICKS on building resilience through innovation, communication and knowledge services, P2RS on resilience to food insecurity and floods, etc.), constitute new frontiers for AGRHYMET and its staff, alongside with their colleagues of the CILSS Executive secretariat, INSAH, and other partner organizations in the subregion.

References

Dingkuhn, M., Baron, C., Bonnal, V., Maraux, F., Sarr, B., Sultan, B., Clopes, A., Forest, F., 2003. Decision support tools for rainfed crops in the Sahel at the plot and regional. In: Struif Bontkes, T.E., Wopereis, M.C.S. (Eds.), Decision support tools for smallholder agriculture in sub-Saharan Africa: a practical guide. IFDC, Muscle Shoals, USA, pp. 127–139.

Diouf, M., Nonguierma, A., Royer, A., et Somé, B., 2000. Lutte contre la sécheresse au Sahel: résultats, acquis et perspectives au Centre régional AGRHYMET. Sécheresse 11, 257–266.

Hulme, M., 1996. Recent climatic change in the world's drylands. Geophys. Res. Lett. 23, 61–94.

Kogan, F.N., 1988. Remote sensing of weather impacts on vegetation in non-homogeneous areas. Int. J. Remote Sens. 11, 1405–1419.

Kogan, F.N., 1995. Droughts in the late 80s in the United States as derived from NOAA polar orbiting satellite data. Bull. Am. Meteorol. Soc. 76, 655–668.

Lebel, T., Ali, A., 2009. Recent trends in the Central and Western Sahel rainfall regime (1990–2007). J. Hydrol. 375, 52–64.

Mason, S.J., Tipett, M.K., Son, L., 2011. The Climate Predictability Tool (CPT). International Research Institute for Climate and Society. The Earth Institute of Columbia University, New York.

Sivakumar, M.V.K., 1988. Predicting rainy season potential from the onset of rains in southern sahelian and sudanian climatic zones of West Africa. Agric. For. Meteorol. 42, 295–305.

Traore, S.B., Reyniers, F.N., Vaksmann, M., Kouressy, M., Yattara, K., Yoroté, A., Sidibé, A., Koné, B., 2000. Adaptation à la sécheresse des écotypes locaux de sorgho du Mali. Sécheresse 11, 227–237.

Traore, S.B., Alhassane, A., Muller, B., Kouressy, M., Somé, L., Sultan, B., Oettli, P., Siéné Laopé, A.C., Sangaré, S., Vaksmann, M., Diop, M., Dingkhun, M., Baron, C., 2010. Characterizing and modelling the diversity of cropping situations under climatic constraints in West Africa. Atmos. Sci. Lett. 12, 89–95, http://dx.doi.org/10.1002/asl.295.

Traore, S.B., Sidibe, B., Djaby, B., Samba, A., Kaba, A.B., Sarr, B., Amani, A., Some, B., Andigue, J., 2004. A review of agrometeorological monitoring tools and methods used in the West African Sahel. In: Motha, R., Sivakumar, M.V.K., Bernadi, M. (Eds.), Proceedings of the Inter-Regional Workshop on Strengthening Operational Agrometeorological Services at the National Level, 22–26 March, 2004. Manila, Philippines, pp. 209–221.

Unganai, L.S., Kogan, F.N., 1998. Drought monitoring and corn yield estimation in Southern Africa from AVHRR data. Remote Sens. Environ. 63, 219–232.