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PRACTICE PAPER

Designing Transnational Hydroclimatological Observation Networks and Data Sharing Policies in West Africa

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Surface observations provide ground evidence of climate change to support the scientific guidance paving the way to better adaptation and mitigation actions. The West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) has designed a multi-stakeholder initiative to rescue the deteriorated near-surface weather, climate and hydrological equipment of West African countries. The main goal for this multi-stakeholder framework was to monitor the climate and collect long term and high-quality records of essential climate variables in support of research, education, capacity building, and climate services provision. Proactive and inclusive partnership initiatives were developed to jointly (re)design and (re)implement near surface observatiories with the national meteorological and hydrological services or agencies (NMHS/As) in West Africa. The co-production scheme used by this framework succeeded in evaluating the existing observations networks, to modernizing sensors and field equipment, and densifying the sites in order to improve the quality of data collection, transmission, archiving, processing and sharing policies. After more than four years of community-of-practice, the existing regional basic hydroclimatic was increased/upgraded by 45% with automatic weather observing systems while fifty automatic water level, ten water quality sensors, three mesoscale research catchments, and several pilot sites to benefit countries' services provision, research infrastructure, education, and capacity building. Country-specific data sharing policies were harmonized and signed to support data services delivery. This practice paper exposes the concepts, outcomes, challenges, lessons learned and the ways forward in setting-up the framework and keeping it on working to leverage the co-production of data & information services for better-informed decision-making in the field of sustainable development in West Africa.

Keywords: Transnational Observation Network; Data Sharing Policy; Co-production of Data & Information Services; Climate Monitoring; Climate Change; West Africa

1. Why are hydroclimatic observatories essential for West Africa?

Compared to other regions worldwide, the projection of climate change and its impacts over West Africa are highly uncertain. This high level of uncertainty subsequently affects decision-making on local, national and regional levels and renders the design of efficient adaptation measures much more difficult. These uncertainties are due to a limited scientific understanding of the West African climate drivers and their interactions (Klein et al. 2017), resulting from a lack of high quality, long term observational data, and specific data mining capabilities. Previous analyses by the Climate Risk & Early Warning Systems (CREWS)[1] showed that the West African countries are the most vulnerable to weather extremes because their national hydrological and meteorological services or agencies (NMHS/As, herewith) have limited early warning capabilities (i.e. the low infrastructure, observation systems, and human capacities), weak or non-existent dissemination systems, and a lack of effective emergency planning in case of alerts and warning information (CREWS 2017, Salack et al. 2018). The regional climate is warming faster than the global average (Ly et al. 2013, Salack et al. 2015), causing thereby some complex manifestations of the local climate in many subregions often difficult to handle without an open and integrated bottom-up approach (Salack et al. 2016). Therefore, there is an urgent need to enhance near-surface measurements and observation infrastructure, in West Africa, in order to develop coherent procedures of climate services delivery to national civil protection, humanitarian support agencies, and vulnerable communities. The near-surface observatory networks provide the local evidence to underlying causes of extreme events such as droughts, floods, air pollution, dry spells, etc. (Giannini et al. 2013, Salack et al. 2014, Panthou et al. 2014, Knippertz et al. 2015, Trenberth et al. 2014, Salack et al. 2018), and to underpin climate services for mitigation, adaptation measures and risks assessments (Jones et al. 2015, Salack et al. 2015, Taylor et al. 2017, Ouedraogo et al. 2018).

Recently published studies confirm that the near-surface network of manual stations has substantially deteriorated over the past few decades (Lorenz and Kunstmann 2012, Jones et al. 2015). Many essential climate variables[2] are not observed or not reported (van de Giesen 2014, Knippertz et al. 2015). To improve the availability of high-quality hydro-meteorological measurements, and to increase our understanding of land-atmosphere processes and their interactions, advanced and modern near-surface observational systems are needed in West Africa. Since 2010, The West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) has initiated the establishment of transboundary observatories in close collaboration with its West African member countries (i.e. Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, The Gambia, Ghana, Mali, Niger, Nigeria, Senegal and Togo), Germany and other partners in the Economic Community of West African States (ECOWAS). The main objective of this multi-stakeholder collaboration scheme called the WASCAL observation networks (WASCAL ONs, herewith) is to co-produce high-quality hydro-climatological datasets and information useful for research, climate monitoring, and climate information services (CIS) delivery. By connecting the NMHS/As and other partners around data collection, WASCAL ONs play the leading role of a regional broker for data services, infrastructure, and expertise necessary to improve the quality of CIS and increase the analytical power of national institutions to better serve their customers and the public.

The objective of this paper is to share experience on the concept of tranboundary observatory networks, its outcomes, its challenges, its links to research and services provided to the countries in support of adaptation to climate change and the lessons learned. First, the conceptual framework of the WASCAL ONs is described, followed by the outcomes of the process in section 3. The lessons learned, the challenges and the ways forward are presented in section 4.

2. Methodology

2.1. The Basic concept of the transboundary observatory networks

WASCAL is a non-profit, a regional trans-disciplinary research and capacity building organization providing climate and data services for adaptation to and mitigation of climate change, including land use and management advice to policymakers in West Africa. It was established as an International Organisation under Public International Law grounded on three pillars: research and services provision conducted at its regional center called the "Competence Centre (CoC)", and the capacity building program run under Doctoral/Master Studies Programs (DSP) hosted at 12 different West African Universities. Further information about WASCAL can be found on its official website.[3]

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[1] https://www.crews-initiative.org/.

[2] https://gcos.wmo.int/en/essential-climate-variables.

[3] www.wascal.org.

The conceptual framework of observatories "baobab tree" at WASCAL or WASCAL ONs (**Figure 1**), includes a transboundary weather/climate observation network, a regional hydrological observation network, a biodiversity observation network, a regional socio-economics observation network and a land surveys observation network. From the central coordination unit at the CoC, each observation network is led by a focal point (**Figure 1**). The responsibility of the focal point includes the successful execution of activities, monitoring the equipment, reporting to and providing the central coordination unit with technical and scientific expertise on data quality assurance and quality control. The coordination unit is responsible for initiating the activities, developing the technical specifications for procurement, testing newly acquired sensors, training, and dissemination, as well as conceiving and harmonizing the work plans and the data sharing protocols for research, education and capacity building.

The first component of WASCAL ONs are the mesoscale observation networks which are established in selected "*watersheds and pilot sites*" across the West African Sahel (Salack et al. 2018, Bliefernicht et al. 2018). These novel research testbeds and services development assets are used to monitor hydrometeorological processes, land-atmosphere exchange processes using *in-situ* measurement devices (Berger et al., 2019) and other observation technics. The collected panel data is a fundamental asset to improve our understanding of observational uncertainties (Salack et al. 2018), useful for the calibration and validation of biophysical models (Quansah et al. 2015, Dieng et al. 2017, Heinzeller et al. 2018) and many other research issues. The data ownership and sharing is directly linked to WASCAL data infrastructure (WADI) and data management geoportals (WADI) and governed by an internal data sharing policy (section 3.3).

The second component of WASCAL ONs consists of large scale observatory networks (also called the regional observation networks). The latter are sets of near-ground sensors for monitoring essential climate variables at further locations. The large scale observatory network belongs to the observations grid of each country. The data collection and sharing for research are governed by a harmonized bilateral memorandum of understanding (MoU), signed by WASCAL and a contracting institution in each country. WASCAL data infrastructure and management portal (WADI) is mainly used as a dissemination platform for the metadata of the observational data provided by the transnational observation networks following the terms of use provided by the contracting partners (section 3.3).

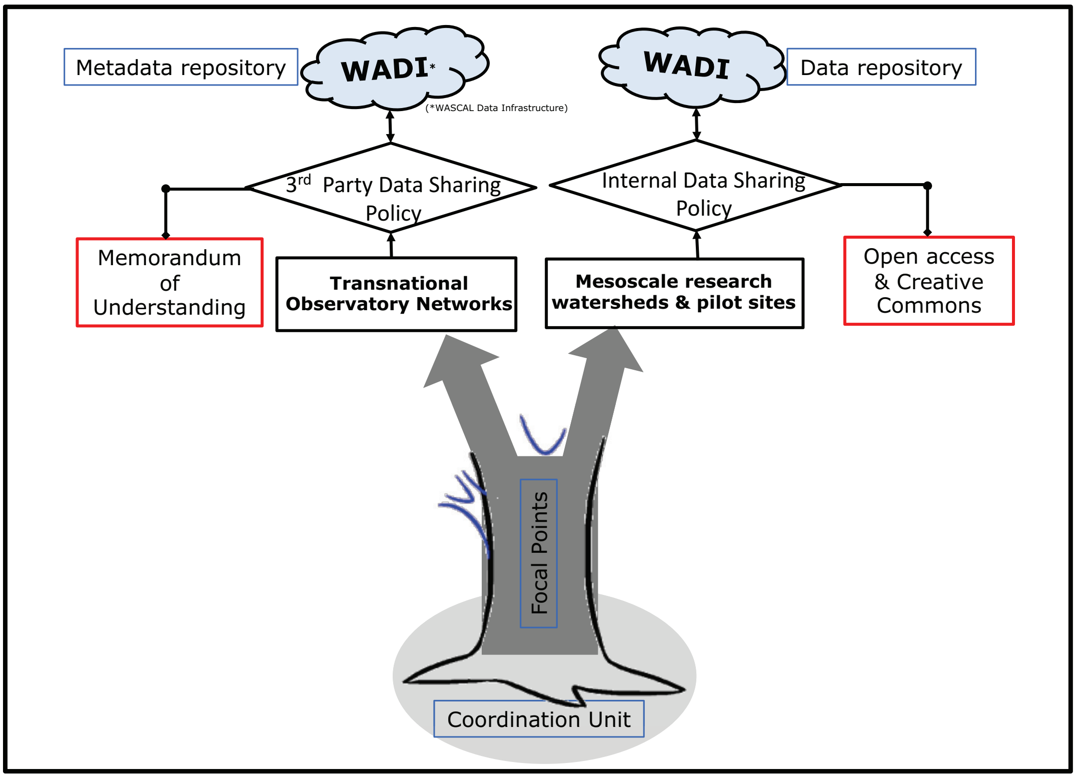

Figure 1: Components and governing principles of the transboundary observation networks (Observations "Boabab tree") at the West African Science Service Centre on Climate Change and Adapted Land use (www.wascal.org).

2.2. Solutions to rescue hydrometeorological observatories in West Africa

To assess country-specific needs for hydrometeorological observatories, WASCAL organized in 2010, 20015, 2016 & 2017 a series of high-level consultations with the directors of NMHS/As, experts from ACMAD,[4] AGRHYMET,[5] West African River Basin Authorities, TAHMO,[6] WMO/GCOS,[7] and funding organizations. These stakeholder dialogues were conducted with the purpose of diagnosing the current problems and limitations and devising practical solutions to improve hydrological and meteorological observations of the region. They led to a deeper insight into the current state-of-the-art in terms of network density, personnel resources, data collection, communication, management, and archieving infrastructure. These consultations also provided the history as well as the transformations needed for the surface observatories owned by countries to regain its WMO standards (WMO, 2010) and better fulfill the Global Climate Observation System (GCOS) principles[8] (WMO 2013). Various activities were jointly designed and implemented with all involved partners.

2.2.1. Evaluation of existing networks

In this activity working groups conduct institutional mapping and cataloging of obsolete, broken equipment and long-term uninterrupted sites. The assessment was based on presentations and group discussions at regular workshops, the compilation of data through focus group survey questionnaires and information collected from field visits of selected observatories. This activity provided the *status-quo*, upgraded the metadata, identified countries least represented in the regional observing systems coverage. It also led to a comparative evaluation of costs for repairs and/or replacement and helped to estimate the contribution of all stakeholders (in-kind or in-cash co-funding).

2.2.2. Rehabilitation of disfunctional instruments or observatories

This activity was directed toward long term uninterrupted sites or observatories. It consisted of providing advanced maintenance, restoring or replacing components in an observatory with relatively modest costs to increase its functionalities. The maintenance was ensured for instruments needing regular recalibration and mechanical or electronic upgrades. The replacement or re-equipment mainly concerned sensors easy to change or to be added to the existing system in order to increase the number of variables. A cost comparison was completed between rehabilitation and the installation a new electronic observing system.

2.2.3. Densification & modernization of equipment

This activity added new locations and upgraded data collection and transmission. Its objective was to measure additional variables and tackle the challenges of data access in remote areas. The number of new locations and other issues warranting, WMO standards and/or GCOS principles (i.e. equipment type, land acquisition, and site clearance works and data transmission protocols, etc.) were identified and processed.

2.2.4. Training of operational and technical staff

Operational staff involved in observations were trained on the use and maintenance of the new observational equipment including related tools such as software, data quality control technics, etc. This activity was used to further disseminate by-products derived from the analysis of the collected data (e.g. software, analytical technics & methods) through in-service training, climate field schools, workshops, and conferences.

3. Results and discussion

3.1. The status-quo

A functional basic weather/climate observatory is a park of sensors for measuring standard meteorological variables, the observers' office and a system of manual data transmission (**Photo 1**). Besides, these instruments, at least five observers are needed to run a WMO standard primary station. Many field visits confirmed the necessity to replace, repair or restore many instruments of the basic manual stations. The cost estimates for such advanced maintenances of a synoptic station could cost approximately 32,855 Euros per highly damaged cases in all the countries. Therefore, setting-up and maintaining a manual observatory was often too expensive for national services.

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[4] www.acmad.net.

[5] https://agrhymet.cilss.int/.

[6] https://tahmo.org/.

[7] https://public.wmo.int/en/programmes/global-climate-observing-system.

[8] https://www.wmo.int/pages/prog/gcos/index.php?name=ClimateMonitoringPrinciples.

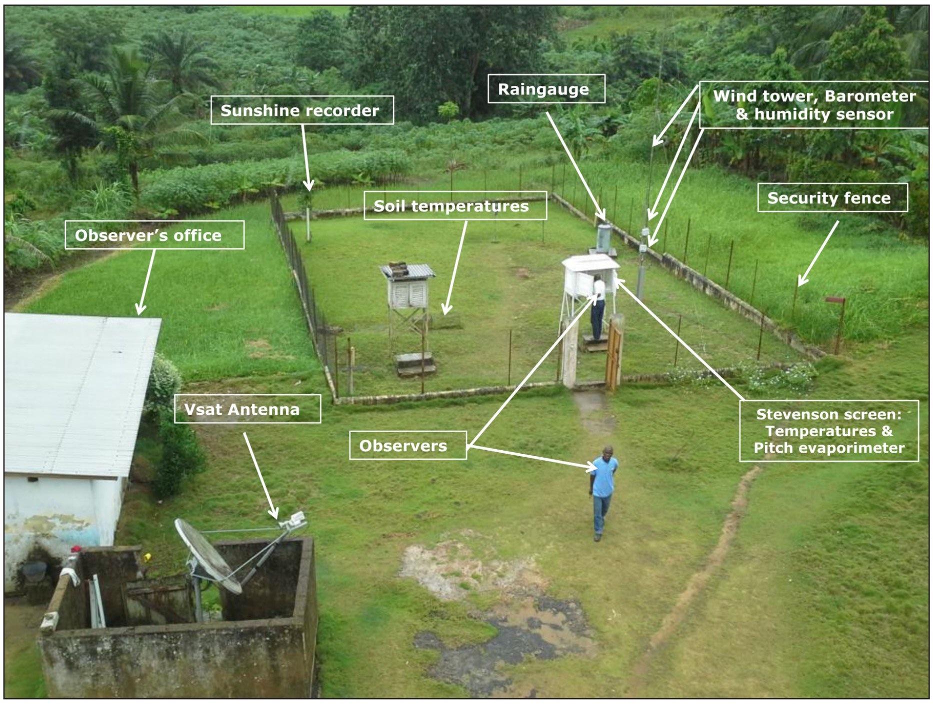

Photo 1: A typical primary synoptic station: A park of sensors in an enclosure near observers' office, a transmission system with an 8-hour shift of five operational observers.

In 11 countries of WASCAL, a total of 115 stations were identified in 2015 by WMO/GCOS as part of its Regional Basic Synoptic Network (RBSN). Many of these synoptic stations lost their basic WMO standards conditions partly because they had been overcome by urbanization, others were not transmitting to the GTS[9] because they are located in conflicts zones (e.g. Northern Mali, North-Eastern Nigeria, Northern Côte d'Ivoire, North-Western Niger, etc.). Many essential climate variables were not measured nor reported due to defective or incomplete sensors. In some cases, the climate or rain gauge stations were simply abandoned due to the retirement of staff manning it or death of the voluntary observers. **Photo 2** illustrates some typical problems of primary weather/climate stations across West African locations. The spatially loose and unevenly distributed observatories that are still functional contain obsolete, damaged and non-calibrated instruments. The systems' data transmission, typesetting and archiving of datasets were still manual, paper-based while the operational staff was retired and not always replaced by new employees (Jones et al. 2015, Salack et al. 2018). Meanwhile, countrywide surveys have also pointed out that up to 70% of the hydrological observation network, owned by some of the countries, were not functional and the metadata was not regularly updated (**Figure 2**).

The challenges identified since the initiation of WASCAL ONs in 2010 are the same today. However, individual NMHS/As are making efforts to modernize their observation networks by developing and conducting own initiatives to restore, relocate and upgrade surface observation networks through external funding mechanisms e.g. Green climate fund,[10] Tahmo (van de Giesen 2014), the WMO Hydrohub project (HYCOS in West Africa)[11] and the hydromet project of the World Bank.[12] The concepts and solutions provided by WASCAL ONs complement these new initiatives and better guarantees the long term sustainability of the networks based on co-ownerships, co-production of services, and the joint security and maintenance of the equipment.

3.2. Setting-up the transboundary observatories

3.2.1. Acquisition and distribution of the equipment

The costs for restoring a single manual observatory were much higher in comparison to electronic data acquisition system such as automatic weather observing systems (AWOSs). Nowadays, the performance of electronic sensors is not the limiting factor to achieve the accuracy required by the WMO standards (WMO

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[9] https://public.wmo.int/en/programmes/global-telecommunication-system.

[10] https://www.greenclimate.fund/.

[11] https://hydrohub.wmo.int/en/projects.

[12] https://www.worldbank.org/en/results/2017/12/01/hydromet.

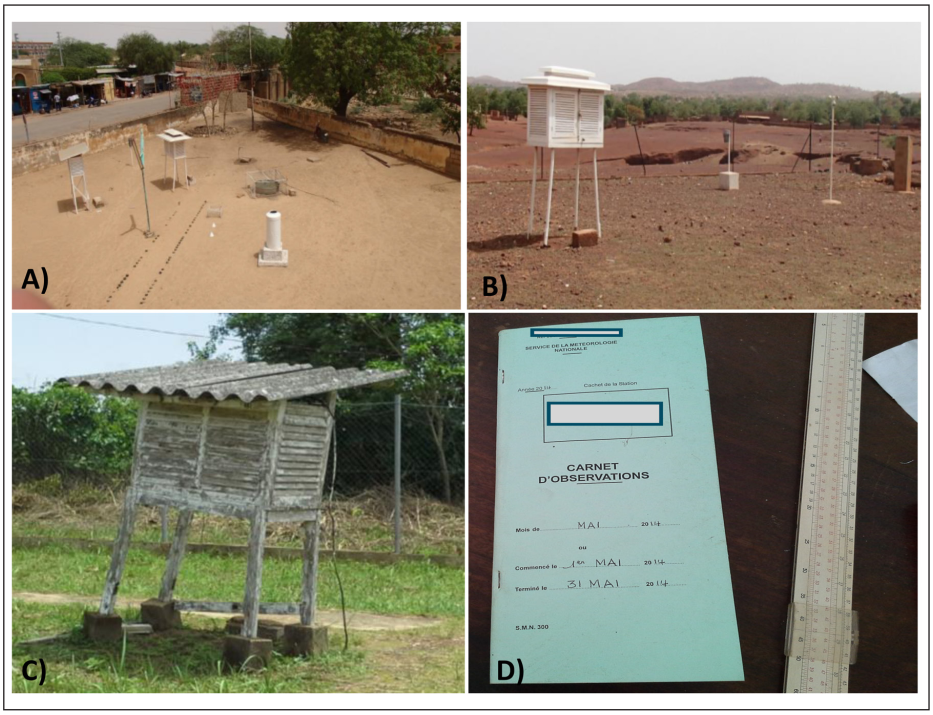

Photo 2: Status-quo of selected primary weather stations in West Africa and its basic components. **A)** A synoptic station overcome by urbanization in Burkina Faso. **B)** A climate station with defective and missing sensors in Burkina Faso. **C)** A tilted Stevenson screen hosting maximum, minimum, dry and wet bulb temperatures, and a pitch evaporimeter in Togo. **D)** The observer's logbook for recording data and a manual slide rule still in use to derive some additional variables in most of the observatories.

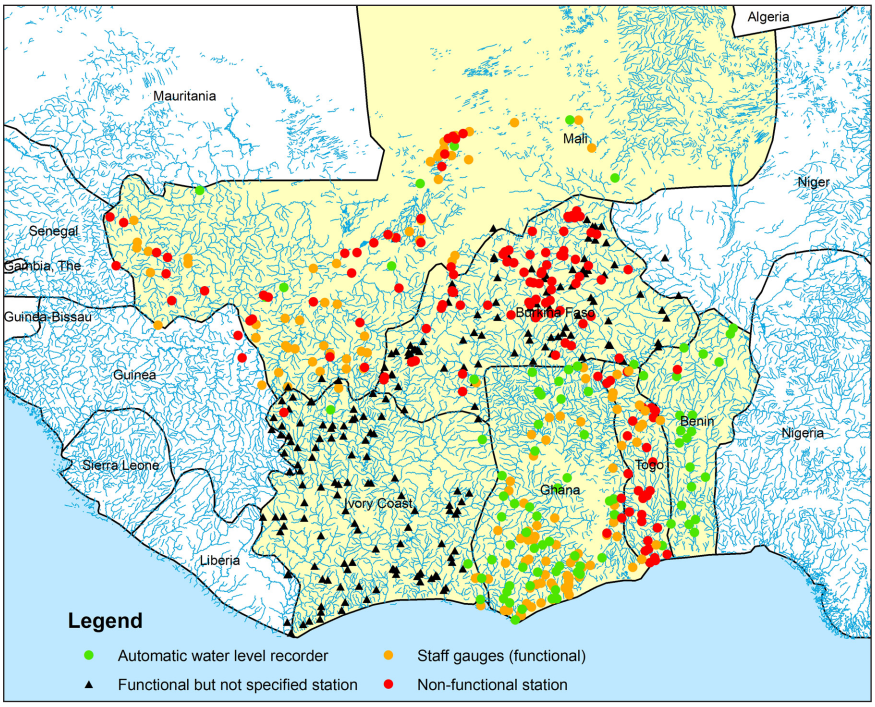

Figure 2: Existing surface water observatories of the six riparian countries of the Volta Basin according to survey questionnaires delivered to the National Hydrological Services. The majority of the functional stream flow stations are equipped with staff gauges where the water level is usually read manually once a day. Although, the metadata of the equipment in Cote d'Ivoire is updated, some countries are better equipped than others. Ghana has more than 50 functional automatic water level recorders; Burkina Faso has reported twenty-four and Mali reported only eight. Togo had none until 2016 when six OTT Radar Level Sensors equipped with automatic transmission systems were installed on the Mono River Basin with the support of external funding.

2010). Investigations into the international markets revealed that buying these electronic devices in bulk makes each set usually much cheaper than a single purchasing of equipment for individual countries. Centralized procurement and supply reduce the complexity of international commercial terms (INCOTERMS),[13] the shipment insurances and port transit forwarding services costs, and can provide quality assurance and warranty for equipment. With WASCAL enjoying tax exemption in member countries, shipment and dispatch costs are also subsidized. Therefore, all equipment was purchased in bulk and centralized at the WASCAL Competence Centre before dispatching to individual countries.

During technical working sessions, the exact locations of the new equipment were discussed with the staff of the NMHS/A prior to dispatching and installations. Special considerations were given to sites where the NMHS/A has already secured land where security, routine maintenance of and accessibility to the equipment could be provided easily. The distribution of the new equipment was preceded also by negotiations with each country to i) sign a memorandum of understanding (MoU) on the "data sharing policy", ii) provide a legal plot of land of at least 200 m2 fulfilling WMO standards, iii) appoint national staff to man the sites and conduct routine maintenance of the equipment, iv) handle the country's customs paperwork, and v) support and contribute to field works for installations.

The equipment is co-owned, observations and maintenance activities are jointly designed and implemented, and the data is shared with the NMHS/As of each WASCAL member country. All newly acquired hydrometeorological set of sensors were installed at existing observatories, in or near public schools, town halls of municipalities, etc. They were well fenced and secured and the technicians of the local NMHS/As guards and conducted routine maintenance. **Figure 3** illustrates the current distribution of the newly

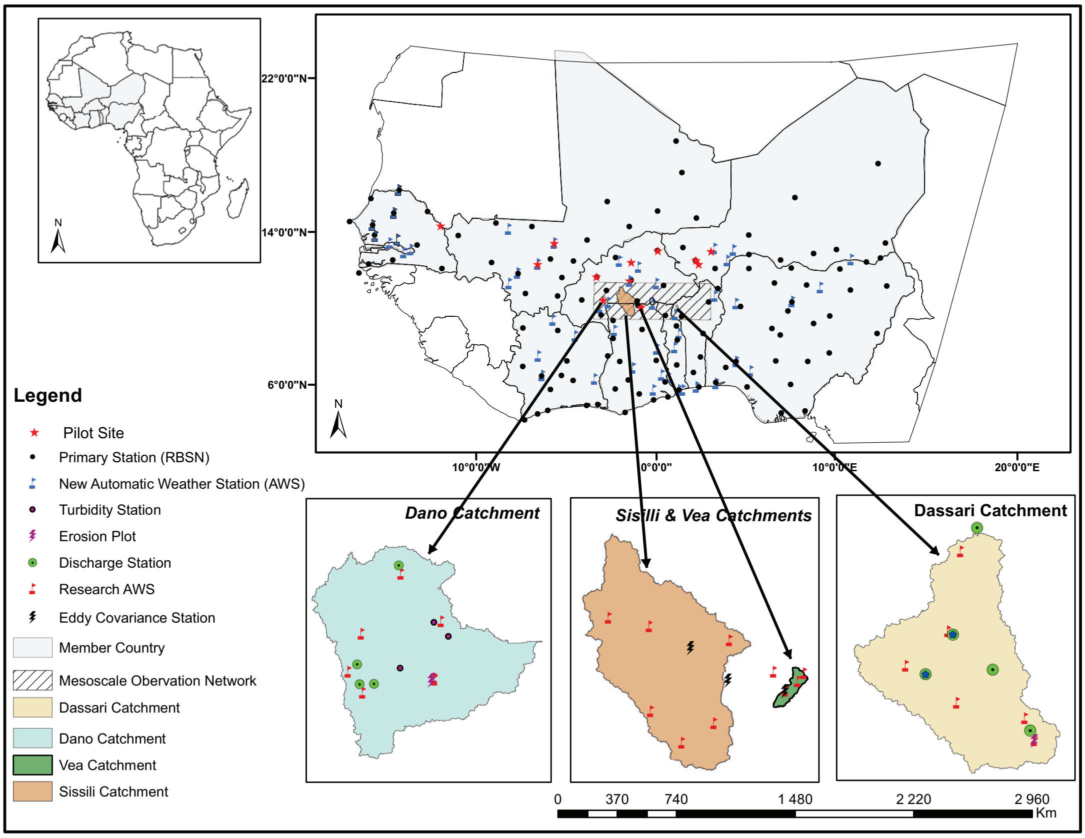

Figure 3: Current distribution of newly installed automatic weather observing systems (AWOS) (blue flag) relative to existing regional basic synoptic network (RBSN) owned by national meteorological services/agencies of countries. In cases of upgrading, the AWOS are installed inside the fenced area of a synoptic station to stay in parallel with manual sensors (black dots are overlaid on blue flags). In addition, the area of the mesoscale research observatories are shown established for the three georeferenced catchments (Dano, Sissili/Vea & Dassari catchments) and further pilot sites (red star) where state-of-the art and cutting-edge hydro-meteorological sensors and field experiments are running and science-based services are being tested and developed.

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[13] https://en.wikipedia.org/wiki/Incoterms.

sponsored automatic weather observing systems (AWOSs) relative to the existing regional basic synoptic stations (RBSN) identified by GCOS in the region. These AWOSs provide atmospheric and terrestrial variables typical of a primary synoptic station under WMO standards.

3.2.2. Technical specifications of the equipment

The mesoscale research catchments and pilot sites (**Figure 3**) were established to monitor biophysical processes at the land surface, their integration across scales (i.e. from point measurements to areal measurements at the basin scale and beyond) and interactions with humans and society based on in-situ measurements devices, socio-economics' surveys and remote sensing. They have been equipped with field laboratories and hydro-meteorological sensors comprising AWOSs (**Photo 3a**), eddy-covariance stations (**Photo 3b**) manual and standalone automatic rain gauges, and much other cutting-edge research equipment (Salack et al. 2018). The pilot sites are used for real-life testing of newly developed climate services and as case studies. Other unique tools of micrometeorology research in this region are the three eddy-covariance stations (EC-stations) installed at locations with different land use practices allowing detailed analyses between land use and climate parameters Further technical specifications, data collection sensors, data type and use of these EC stations are provided by Bliefernicht et al. (2013), Bliefernicht et al. (2018) and Berger et al. (2019).

Each of the hydrological (e.g. water level and quality recorders) and weather/climate observing systems of the transnational observation networks is equipped with a global positioning System (GPS), a GPRS/GSM[14] communication link, a solar panel and battery, a lightning/grounding rod, a data logger and an internal data storage capacity capable of keeping data files up to 5 years. An AWOS consists of a pyranometer for measuring the solar radiation and sunshine hours, a sonic anemometer for measuring horizontal wind speed and

Photo 3: (Left) A typical automatic weather observing system (AWOS) provided to the countries to upgrade, replace or add new locations to the observatory networks of the national meteorological and hydrological services or agencies (NMHS/As) in West Africa (e.g. Installation completed at Kangaba station for the benefit of Mali-Meteo, Mali). (Right) Typical high resolution eddy-covariance station installed in the mesoscale watersheds and pilot sites (e.g. Nazinga Range Land) for research activities.

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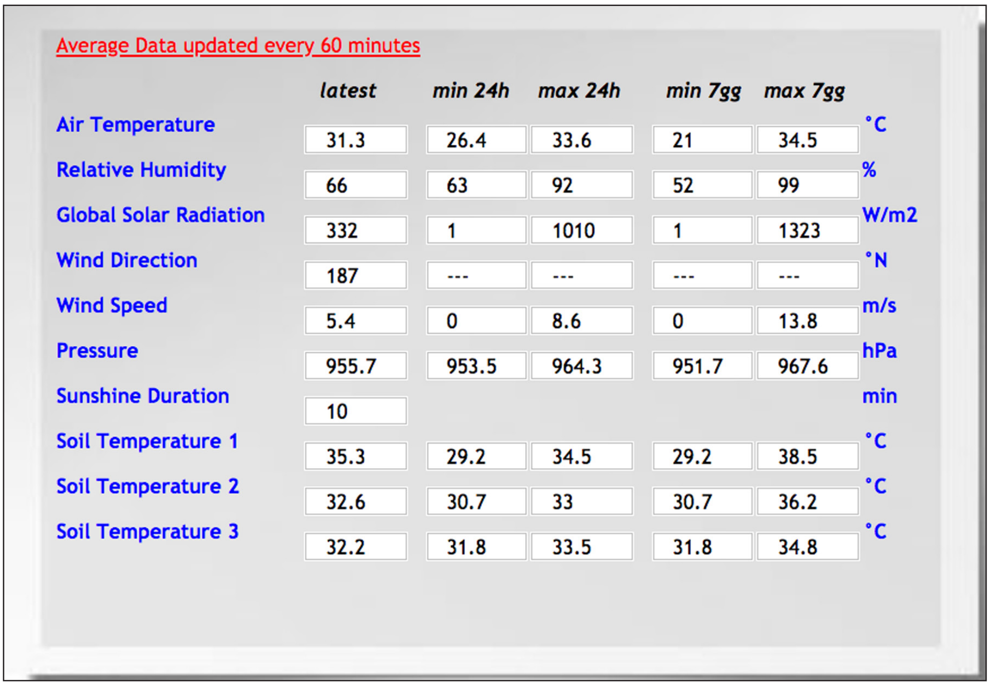
[14] General Packet Radio Service (GPRS)/Global System for Mobile communications (GSM) (https://en.wikipedia.org/).

wind direction. A silicon bandgap and a capacity humidity sensors, protected by a radiation shield, are used to determine air temperatures and relative humidity and derived variables such as minimum, maximum and dew point temperatures. The air pressure is measured using a capacity pressure sensor. All sensors are set-up at 2 meters height except for the EC-stations where some sensors are at heights above 2 meters and the sonic anemometer at 10 meters above the ground. There are also soil temperature probes at 3 depths (5 cm, 20 cm, and 50 cm). The total precipitation amount is recorded by a tipping bucket rain gauge with a sampling resolution of 0.2 mm. In the mesoscale research catchments and pilot sites, disdrometers, weighing and tipping bucket gauges are available to measure rainfall. In some cases, two rain gauges, in the same enclosure, are providing simultaneous records of rainfall, useful for rating observational uncertainties and supporting operational monitoring of extreme events (Salack et al. 2018). The automatic water level gauges and water quality sensors are deepened into rivers and streams at a maximum of 20 m depth to provide water temperatures, water level, pH, and turbidity. All the newly installed sensors have compatible interfaces with the existing systems and data are remotely transmitted to WASCAL and NMHS/A servers simultaneously.

3.2.3. Data type, quality assurance and quality control

In the mesoscale "*watersheds and pilot sites*" network, fieldworks for equipment monitoring and advanced maintenance are conducted single-handedly by WASCAL staff. In each of the mesoscale research sites, the equipment is maintained every two weeks for all rain gauges and twice a month for other sensors. Standard maintenance consists of checking the filters, removing any debris that may obstruct normal water flow in tipping bucket gauges, and cleaning other sensors. Water level and quality sensors are (re)calibrated before and after the rainy season. Fieldworks for advanced maintenance of sensors are organized only when necessary and consists of re-calibration, replacement and repairing non-functional sensors. On the largescale observatories network, shared with the countries, monitoring of the equipment (routine and advance maintenance) is undertaken in a joint effort with the staff of the NMHS/As. In both types of observatory networks, data are recorded subhourly (e.g. every 5-min and 10-min interval) and daily depending on the variable. The records started since 2012/2013 in the three mesoscale research catchments on **Figure 3**. For the largescale observatories, the earliest records started only in November 2017 in some countries. **Photo 4** provides a summary of the variables displayed online by the AWOSs installed for the countries. The automatic hydrological sensors (AHS) (i.e. Automatic water level and water quality) transmit every six hours, data recorded of every 10 minutes for water level, water temperature, pH, turbidity.



Average Data updated every 60 minutes

	latest	min 24h	max 24h	min 7gg	max 7gg	
Air Temperature	31.3	26.4	33.6	21	34.5	°C
Relative Humidity	66	63	92	52	99	%
Global Solar Radiation	332	1	1010	1	1323	W/m2
Wind Direction	187	---	---	---	---	°N
Wind Speed	5.4	0	8.6	0	13.8	m/s
Pressure	955.7	953.5	964.3	951.7	967.6	hPa
Sunshine Duration	10					min
Soil Temperature 1	35.3	29.2	34.5	29.2	38.5	°C
Soil Temperature 2	32.6	30.7	33	30.7	36.2	°C
Soil Temperature 3	32.2	31.8	33.5	31.8	34.8	°C

Photo 4: A screenshot of the user-friendly display table of observed data statistics provided by the AWOS for some essential climate variables.

All datasets are subjected to pre-processing and post-processing quality controls, following standard procedures (**Figure 4**) and standard methods (Mauder et al. 2013, Salack et al. 2018, Berger et al. 2018, Bliefernicht et al. 2018). Some datasets are pre-processed on-site for quality checks, quality assurance by the focal points in the countries, and the technicians in the "*watersheds and pilot sites*". Further quality control assessments are conducted (post-processing), when the datasets reach the WASCAL ONs coordination unit based at the competence Centre, before data is stored or released to end-users (**Figure 4**). Data gaps are infilled using straightforward approaches like replacement (e.g. Nearest neighbor) or by linear interpolation. Linear interpolation is used mostly for cases where the gap does not exceed three hours for variables like air temperature. Replacement mainly concerns the datasets from the locations with two raingauges when e.g. one tipping bucket was blocked. At the eddy covariance stations on-site flux processing is done using the TK3 software[15] including state-of-the-art corrections, quality tests and uncertainty assessment (Mauder et al. 2015). The infilling approach uses information from the neighboring sites and the nearby time steps (spatio-temporal infilling) for sub-daily measurements. More than twenty essential variables can be generated which are useful for land surface modelling (Bliefernicht et al. 2018). **Table 1** shows the current metadata of these AWOSs in each country.

3.3. Data sharing protocols

Transnational hydroclimatic data and information sharing among countries can be one of the solutions to leverage climate change data and to ensure that climate actions are better implemented for sustainable development. However, it is well known that intellectual property and copyright are defined differently in West African countries. Generally, the NMHS/As adher to the policy and practice for the exchange of meteorological, hydrological and related data and products of WMO Resolution 40[16] as the only existing internationally valid legislation for copyright and data privacy protection. It is stated therein that "data and products from the Regional Basic Synoptic Network (RBSN) should be exchanged without charge and with no conditions on use" for research, education, and climate services. The complexity of the technical and political implementation of this WMO resolution, rather, has led to a commercial access to the hydrometeorological datasets in most West African countries even when the use is for research and education purposes. Therefore, to reach transnational cooperation around data, key concepts of the management of data rights, data access, and re-use, and the role of data policy documents have to be defined, agreed upon and accepted by all involved parties.

At WASCAL, in the current setting of the transboundary observation networks, biophysical and socioeconomic panel data, generated from the research watersheds, pilot sites and other research assets set-up in the mesoscale observation networks, are governed by internal data sharing policy. The latter contains the rights and commitments of staff members regarding storage, access and re-use of their data, data standardization, integration, and metadata cataloging. Time series, maps, and further information are made publicly available and open access through a central data portal application (e.g. WADI). The internal data sharing policy also suggests the establishment of agreements (e.g. Memorandum of understanding, MoU) defining

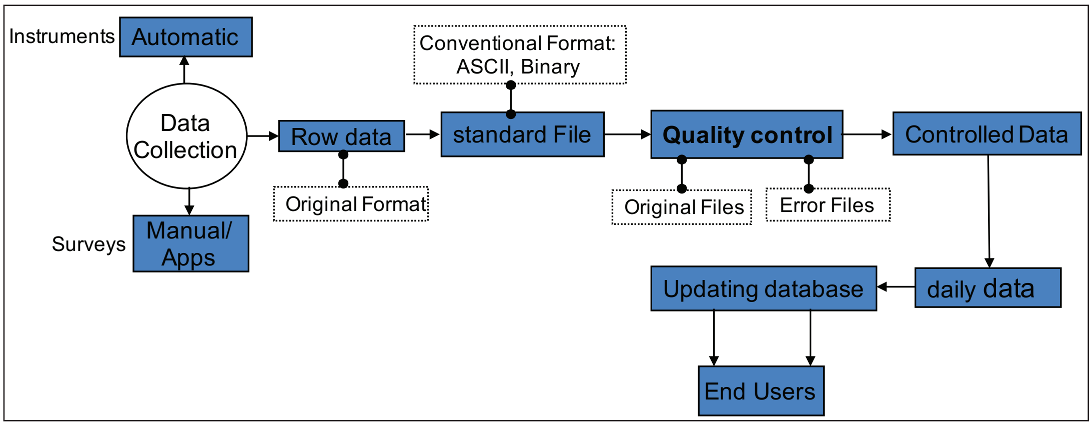


Figure 4: Conceptual work flow on data processing for quality control applied to the transboundary observatory networks datasets.

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[15] Eddy-Covariance Software TK3: https://zenodo.org/record/20349.

[16] https://www.wmo.int/pages/prog/hwrp/documents/wmo_827_enCG-XII-Res40.pdf.

Table 1: Updated metadata of the transnational observatory network sponsored fort the benefit of national meteorological and hydrological services or agencies (NMHS/As) of ten West African countries.

Country	WASCAL ID	Name	Latitude	Longitude	Type (Previous)	Current Status	First record
Benin	2917020	Garou	11.4766	3.2856	Unknown	New	Oct-2018
	2917019	Materi	10.4216	1.0288	Unknown	New	Jan-2018
	2917023	So-ava	6.3383	2.246	Unknown	New	Jan-2018
	2917024	Grand-Popo	6.1636	1.4754	Climate	Upgrade	Jan-2018
Burkina Faso	2617036	Boassa, Ouaga	12.291944	–1.607222	Unknown	New	Mar-2018
	2617009	Gounghin	12.1449	–0.0201	Raingauge	New	Mar-2018
	2617047	Kaya	13.091	–1.0873	Climate	Upgrade	Mar-2018
	2617048	Leba	13.2339	–2.212	Unknown	New	Mar-2018
	2617031	Ouessa	11.0294	–2.4693	Unknown	New	Mar-2018
	2617032	Tiankoura	10.4603	–3.1549	Raingauge	Upgrade	Mar-2018
Cote d'Ivoire	2517028	Mbengue	10.001	–5.5391	Raingauge	Upgrade	Mar-2018
	2517027	Kong	9.0941	–4.3691	Raingauge	Upgrade	Mar-2018
	2517012	Seguela	7.9772	–6.6738	Climate	Upgrade	Mar-2018
	2517011	Daloa*	6.9089	–6.4383	Synoptic	Upgrade	Mar-2018
	2517007	Abengourou	6.7352	–3.493	AgroMet	Upgrade	Mar-2018
	2517008	Grand-Bassam	5.2	–3.733333	Climate	Upgrade	Mar-2018
Ghana	3317029	Kpando	7.036329	0.300661	Climate	Upgrade	Nov-2017
	3317030	Hunhunya	6.1015	–0.1064	Unknown	New	Nov-2017
	3317046	Ejura	7.382555	–1.368206	Climate	Upgrade	Nov-2017
	3317037	Manga-Bawku	11.016165	–0.26589	Climate	Upgrade	Nov-2017
	3317038	Kpandai	8.4705	–0.0116	Unknown	New	Nov-2017
	3317045	Tuna	9.2965	–2.2548	Unknown	New	Nov-2017
Mali	2317042	Bamako*	12.555278	–7.973056	Synoptic	Upgrade	Mar-2018
	2317003	Kangaba	11.953333	–8.431389	Climate	Upgrade	Mar-2018
	2317041	Baroueli	13.088611	–6.858056	Climate	Upgrade	Mar-2018
	2317035	Niono	14.291111	–5.970278	AgroMet	Upgrade	Mar-2018
	2317004	Yanfolila	14.952778	–8.614722	Climate	Upgrade	Mar-2018
Niger	2717014	Chical	14.1509	3.2649	Climate	Upgrade	Apr-2018
	2717040	Matankari	13.4626	4.003å	Climate	Upgrade	Apr-2018
	2717039	Goudoumaria	13.4209	11.1178	Climate	Upgrade	Apr-2018
	2717010	Dogon Kiria	14.058	4.3658	Climate	Upgrade	Apr-2018
	2717013	Sekoukou	13.2717	2.36556	Unknown	New	Apr-2018
Nigeria	3417006	Zaria*	11.13603	7.68945	Synoptic	Upgrade	Jul-2018
	3417022	Dutse*	11.89166	9.3166	Synoptic	Upgrade	Jul-2018
	3417021	Yelwa*	11.0386	4.5	Synoptic	Upgrade	Jul-2018
	3417005	Akure	7.24754	5.29976	Synoptic	Upgrade	Jul-2018
	3417002	Osogbo*	7.77085	4.4811	Synoptic	Upgrade	Jul-2018
	3417001	Oshodi*, Lagos	6.5454	3.34702	Synoptic	Upgrade	Aug-2018

(Contd.)

Country	WASCAL ID	Name	Latitude	Longitude	Type (Previous)	Current Status	First record
Senegal	2117043	Diourbel*	14.6691667	−16.243054	Synoptic	Upgrade	Mar-2019
	2117026	Linguere*	15.4030556	−15.0925	Synoptic	Upgrade	Mar-2019
	2117044	Podor*	16.6563889	−14.95861	Synoptic	Upgrade	Mar-2019
	2117025	Kaolack*	14.150	−16.058055	Synoptic	Upgrade	Mar-2019
	2117047	Koungheul	13.970	−14.830	Climate	Upgrade	Mar-2019
The Gambia	2017017	Njau	13.754166	−15.221388	Unknown	New	Dec-2018
	2017018	Bakadagi	13.312778	−14.401111	Unknown	New	Dec-2018
	2017050	Sutukoba	13.5001	−14.0145	Unknown	New	Dec-2018
Togo	2817033	Kpalime	6.8823	0.6467	Synoptic	Upgrade	Dec-2017
	2817034	Lome*	6.1049	1.152	Synoptic	Upgrade	Dec-2017
	2817016	Sotouboua	6.410	1.20	Raingauge	Upgrade	Dec-2017
	2817015	Bafilo	9.363	1.25	Raingauge	Upgrade	Dec-2017

* Station belonging to the regional basic synoptic and/or climatic observation networks of the WMO/global observing system (GCOS).

the terms of use for all data and metadata accessed and/or hosted by WASCAL and owned by the member countries or any other partners.

The transboundary hydrometeorological observatory networks is a regional framework in which the instruments and the knowledge are transferred to the NMHS/As of the countries. In return, the NMHS/As share historical and near-real-time data with WASCAL for research, education and climate services. Before the deployment and installations of WASCAL sponsored equipment, country-specific MoUs were signed. This is the legal document which elaborates on all terms of use and conditions for sharing both historical, near-real-time data, co-ownership of the equipment, intellectual property protection, the co-production of derived datasets and services in support of research, education and capacity building. The process of signing the MoUs involved many round tables of negotiations with directors, technician, lawyers and the administration of the participating parties. The signed MoUs had a duration of at least 10 years starting with a 5-year review and renewal by tacit consent (if modifications were not sought by either party). Each data sharing policy guarantees a decentralized archiving scheme of own datasets and the use of the WASCAL data infrastructure as centralized dissemination platform of the metadata of the partner. Data publication and exchange is facilitated predominantly through standard web services.[17]

4. Lessons Learned, Challenges and Ways Forward

The process of establishing novel transboundary hydrometeorological observation networks is improving the art of data collection, transmission, archiving and analyses in West Africa. The currently existing regional basic synoptic (climatic) networks (i.e. Countries' stations identified by WMO/GCOS as part of its global weather/climate observation networks) has been increased and upgraded by 45% with fifty automatic weather stations (**Table 1**) while fifty automatic water level gauges and ten water quality sensors are added to improve the hydrological network of the countries. However, without external support, keeping an operational observatory beyond the lifetime of projects and programs is not possible for the NMHS/As in West Africa. In the past, many instrumented observatories were established for field experiments or international research observation campaigns (Kahan et al. 2006, Lebel et al. 2009) but they could not be maintained and sustained by the NMHS/As after the funding time of the project. The modernization of the near-surface observation networks can only be sustained in a proactive/participative collaboration and inclusive cooperation of all partners in co-production of data & services and co-ownership responsibility schemes rather than mere interventionism. In the case of WASCAL ONs, equipment monitoring and advanced maintenance fieldworks are conducted as a joint effort of WASCAL staff, the NMHS/As staff and other partners, and data are shared for research, education, capacity building and climate services delivery.

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[17] https://www.opengeospatial.org/.

The deployment and installation of the equipment, for the large scale observatory network, were hampered by the slow and often complicated bureaucracy in the WASCAL countries (e.g. The in-kind contributions provided by countries such as Customs' tax waiver documents, administrative paperwork, and other local logics). Nevertheless, inherent costs to its establishement were reduced and technical specifications were harmonized. The consequences of epidemic diseases outbreaks (e.g. Ebola disease in 2014), terrorism, dramatic changes of governments, political instability in the region, vandalism and armed robbery (e.g. damages dues to wildfire, theft of solar panel or batteries, etc) often affect scheduled trips for maintenance and the equipment. The contribution of the local staff of the NMHS/As has been of curcial importance in preventing of the vandals. Fluctuating GPRS/GSM networks, slow internet connections, and rough road conditions are circumvented by the tremendous internal storage capacity of the new equipment. Increasing the number of similar equipment will help cover remote areas and the funding for such solutions should be diversified with both public, private and foreign investments. The management of such infrastructure, its maintenance and the proper use of the data generated to improve the daily work of the NMHS/As is the next level of challenges which should be addressed through in-service training for the operational staff in charge of observation and climate information services.

The process of drafting and signing country-specific data sharing policy and MoU documents began in 2014, and was not completed until 2018. This was a long, tough and tedious chain of negotiations mixing technical expertise, scientific consistency, diplomatic endeavors, advocacy, and sometimes political interventions. The country-specific MoU for sharing data is completed for all the concerned countries. They constitute a solid foundation of federating regional data providers and harmonizing data sharing protocols for the benefit of research, education capacity building, and climate services development in West Africa. They also pave the way to building archives and data rescue through digitization of paper-based data records, micro-fiche tables, etc. The data rescue of historical solid archives & records (e.g. micri-fiche tables, observers booklets, etc.) can provide unprecedented opportunity to improve the understanding of the West African climate system and in turn, help to prepare better for the future. The strong commitment of WASCAL to ensure the sustainability and continuation of the transnational observation networks will empower West African scientists as well as national meteorological and hydrological agencies to conduct climate research and deliver climate services at a high level of excellence.

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

S. Salack, H. Kunstmann, B. Diekkrüger, G. Steup, A. Rogmann, R. Kunkel, A. Bossa, J. Bliefernicht, Y. Yira, S. Berger, D. Heinzeller, M. Waongo, J. P. A. Larmers, Christian Jaminon, M. B. Sylla, B. Barry, L. Sedogo, J. Adegoke, and Paul Vlek developed the concept. S. Salack, A. Bossa, J. Bliefernicht, S. Berger, Y. Yira, B. A. Diallo, S. Sanfo, M. B. Sylla, H. Kunstmann, M. Savadogo conceived the paper. All authors contributed to writing the manuscript.

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