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Constraints and opportunities for Water Resources Monitoring and Forecasting using the Triple Sensor approach
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Constraints and opportunities for Water Resources M&Fusing the Triple Sensor approach
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Acronym List

AKVO  Foundation (The Netherlands)
AMCOMET  African Ministerial Conference on Meteorology
AMCOW  African Ministerial Conference on Water
AU  African Union
BOM  Australian Bureau of Meteorology
CPTEC  Centro de Previsão do Tempo e Estudos Climáticos (Brasil)
ECMWF  European Centre for Midrange Weather Forecasting (Reading, UK)
ECOWAS  UN Economic Commission – Western Africa
EIP  European Innovation Partnership
ESA  European Space Agency
EUMETSAT  European Agency for Meteorological Satellites
FAO  Food & Agricultural Organization of the UN
GCOS  WMO - Global Climate Observing System
GEOSS  Global Earth Observation System of Systems
GFCS  Global Framework of Climate Services
GMES  Global Monitoring & Environmental Security
GPRS  General Packet Radio Service for GSM (Global System for Mobile phones)
ICOLD  Int’l Commission on Large Dams
IHE  UN - Institute for Water Education (Delft, NL)
IPCC  Intergovernmental Panel on Climate Change
ITC  Faculty of Geo-information Sciences & Earth Observation – Univ. of Twente (NL)
JAES  Joint Africa-EU Strategy
KS  Knowledge Sharing
M&F  Monitoring and Forecasting
MOOC  Massive Open Online Course
MoU  Memorandum of Understanding
NASA  National Aeronautics & Space Administration (USA)
NCDC  National Climate Date Centre(s) / NOAA
NOAA  National Oceanic and Atmospheric Administration – US Department of Commerce
NCEP  National Centres for Environmental Prediction / NOAA
RBO  River basin organization
RCOF  Regional Climate Outlook Forum
SDG  Sustainable Development Goals
ToR  Terms of Reference
UNECA  UN Economic Commission of Africa
W&C  Water and Climate
WATER JPI  Joint Programming Initiative on Water
WMO  World Meteorological Organization
1 Introduction and background

1.1 Background

The AfriAlliance project aims to prepare Africa for future climate change challenges by creating the opportunity for African and European stakeholders to work together in the areas of water innovation, research, policy, and capacity development.

Rather than creating new networks, the 16 EU and African partners in this project are consolidating existing ones, consisting of scientists, decision makers, practitioners, citizens and other key stakeholders, into an effective, problem-focused knowledge sharing mechanism. This will be coordinated by means of an innovation platform: the Africa-EU Innovation Alliance for Water and Climate.

AfriAlliance will support the existing networks in identifying appropriate social innovation and technological solutions for key water and climate change challenges. It will capitalise on the knowledge and innovation base and the potential in Africa and the EU. The project will support effective means of knowledge sharing and technology transfer within Africa and between Africa and the EU, with the aim of increasing African preparedness to address the vulnerability of water and climate change-related challenges. The project makes extensive use of existing/emerging communication channels and events (EU/African platforms, conferences and social media) to streamline climate change issues into water-related networks, thereby raising awareness about their impacts and to propose adaptation measures.

1.2 Use of multiple Sensors for improving Water Resource Monitoring & Forecasting

One of the innovative aspects of AfriAlliance and more specifically of WP4 is the multiple information source gathering approach. The inventory is based on a triple-sensor approach, looking into the capacity and efforts on human sensors (citizens, geo-crowdsourcing and communications), physical in-situ sensors (like weather station-based meteorological and ground-based water resource and hydrological networks such as stream gauging, groundwater, etc.) and space-based satellite sensors.

![Figure 1](image.png)  
**Figure 1** The AfriAlliance Triple Sensor approach for improved water resources Monitoring & Forecasting
A major challenge in climate and water information analysis for decision-making at different spatial levels and stakeholders (i.e. ranging from governments at country level to local populations at village level) lies in the accessibility of the information sources, as well as the reliability and accuracy associated with the different data. Some people may rely heavily (or solely) on rain gauge network information, whereas others typically use satellite observations. Yet others, and especially local communities, may find crowdsourcing and citizen observatories the best choice.

In AfriAlliance, an information merging or collocation approach is proposed to support African stakeholders in their analysis of climate and weather challenges related to water resources management. This approach is derived from the principle that a single observation (e.g. on weather or water availability) at a certain location and time will be much more reliable and generally accepted if it is compared to other independent observation data sources (of the same location and time period). And as typically done in the weather forecasting and prediction world (who were the first do adopt this technique), to merge data sources and derive optimal estimates and information. This triple sensor approach launched by AA is under development within WP4, and some more information is given in later sections of this report. After the inventories of constraints and opportunities of the three different sensor approaches (in-situ, citizen and satellites) in sections 3, 4, and 5, the current barriers and opportunities of collocating the three data and information sources using the triple sensor approach will also be investigated (Chapter 6). It is acknowledged that triple collocation of data sources is also subject to constraints, and these will be visited in Section 6. Section 7 draws conclusions and the way forward.

1.3 Purpose of the Report

Within the AfriAlliance project, WP4 is an activity geared towards inventorying and providing a comprehensive overview of current Monitoring and Forecasting (M&F) efforts on water resources in relation to climate in Africa, and provide input on barriers, constraints and opportunities into the WP2 agenda on research and innovation opportunities.

A triple sensor approach for improved water resources monitoring and forecasting is proposed, developed and will be evaluated during the project (2016-2020). This M&F approach encompasses a combination of newly emerging (i) citizen-based geo-information gathering and communication on water resources (e.g. crowdsourcing, citizen science), connected to (ii) in-situ sensor and physical surface observation networks and further to (iii) space-borne satellite observations on water cycle and resource monitoring, assessment and forecasting. The various data and information sources, gathered throughout the project duration, will be reported using an interoperable web-based service and visualization application tool, under development in the project, and made available through the coordination platform web portal. The inventory and analysis will set out new needs and opportunities for research, innovation and service building which will be fed into the agenda developed in WP2.

The objective of this task and report is therefore:

- To identify constraints, barriers and opportunities for improved water resources monitoring using the triple sensor approach;

These findings will be fed into the demand-driven agenda on water and climate related research and operationalization opportunities developed in AfriAlliance WP2.
In this context, a number of aspects will receive more attention:

- Mapping of int’l initiatives and actors of weather, climate and water information provision in Africa;
- Constraints and opportunities of *in-situ* station, satellite and citizens data & information sources;
- Challenges and opportunities of triple sensor collocation of data and information sources applied to water resource monitoring and forecasting.

### 1.4 Structure of the Report

This introductory, section 1, generally describes the role of the AfriAlliance project as a mechanism for technological Innovation and exchange for Water and Climate (W&C) challenges between Africa and Europe. It also describes the context and role of Work Package (WP) 4, dedicated to Monitoring and Forecasting (M&F) for W&C challenges in the overall project. The major aspect i.e., the triple sensor collocated information gathering and analysis approach for water, weather and climate monitoring and forecasting is also briefly introduced.

In Section 2, the concept of the information value chain related to weather and climate and the actors involved are introduced. Then, a succinct inventory of international initiatives and research agendas directly related to Monitoring & Forecasting of Water and Climate challenges across Africa is done and relationships to the information value chain and actors are drawn.

Sections 3, 4, and 5 consecutively make an inventory of the constraints, challenges and opportunities of the three different types of observations, i.e. surface (*in-situ*) observations, satellite (space, airborne) observations and the more recently emerging citizen science-based, crowdsourced and human sensor observations on water resources and weather or climate phenomena.

The inventory of constraints and barriers focuses on all issues in the M&F process chain (in relation to the actors) that have affected Africa with respect to developing sustainable solutions for monitoring and forecasting of water and climate challenges across the continent.

In section 6, the constraints and opportunities for combining (collocating) the three independent data sources are analysed and reviewed.

Section 7 draws conclusions from the constraints, barriers and opportunities analysis for using the triple sensor approach. This is done by looking at three data dimensions, and mapping the main constraints and opportunities for collocating information sources to realize improved water resource monitoring.
2 Climate and water information value chains, international initiatives and actors

2.1 Weather and climate Information value chains and actors

An important aspect underlying the socio-economics of monitoring & forecasting (M&F) practice is the economic valuation of weather, climate and water observations. Lazo (2016) mentions that “far too many research and operational programs justify themselves as ‘providing benefits to society’ without actually measuring or even characterizing that value or how the new products and services will be created, communicated, understood, or used”.

A value chain for information can be described as a process to make the societal benefits of M&F products and services explicit. If this process is not adequately mapped, the resulting value for different societies and citizens and public may not be tangible. Value chain models are in fact economic approach to more explicit mapping and valuing of the different work processes in the whole chain of information production for societal benefit.

![Value Chain Linking Climate Knowledge to Action](image)

Figure 2 Value chain linking Climate knowledge generation to action


Figure 2 shows the value chain linking climate knowledge generation by the different societal actors, to action as described in the WMO Global Framework for Climate Services (GFCS) Regional Stakeholder Coordination Workshop report (WMO-GFCS, 2017). These analyses clearly illustrate the importance of considering common value chain aspects and actors in the whole process of M&F.
<table>
<thead>
<tr>
<th>Actors</th>
<th>Political actors</th>
<th>International data providers</th>
<th>National data providers</th>
<th>Sector experts</th>
<th>Boundary organisations</th>
<th>Professional data users</th>
<th>Community level users</th>
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<td>International, national, regional or local politicians</td>
<td>GPCs, Climate Data Providers, RCCs IPCC, RCOF, AC-MAD, etc.</td>
<td>National Meteorological &amp; Hydrological Services (NMHS)</td>
<td>Ministerial departments Agriculture, DRR, Water, health, energy,</td>
<td>Media, ICTs, Rural Radio, Telecom Co, Agric. Extension Agents, NGOs, CBOs,</td>
<td>Rural Development Planners, Disaster Managers, Public Health, Dam Builders, Private Sector</td>
<td>Farmers, Pastoralists, Vulnerable Communities, general public</td>
</tr>
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<td>M&amp;F Processes (*)</td>
<td>Monitoring &amp; observation networks</td>
<td>+++ Policy, resource allocation</td>
<td>+++ Global Networks, GCOS, GOOS</td>
<td>+++ Synoptic and secondary networks, ...</td>
<td>++ Other sec. networks</td>
<td>++ Local observations, project based networks</td>
<td>++ dedicated networks; private prof. associations, ++ private stations, Community-based</td>
</tr>
<tr>
<td></td>
<td>Data aggregation, integration, databases</td>
<td>0</td>
<td>+++ int’l mandate</td>
<td>+++ government mandate</td>
<td>++ Mandated by sector</td>
<td>0</td>
<td>+ emerging private sector e.g. Google</td>
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<td>Modelling &amp; forecasting (early warning)</td>
<td>0</td>
<td>+++ Done by Int’l Centres: ECMWF, NCAR, ...</td>
<td>+ some Nat.Centres e.g. SAWS (SA),...</td>
<td>+ Specific M&amp;F e.g. agric., diseases,...</td>
<td>+ ++ emerging private sector (icloud...)</td>
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<td>Dissemination, communication</td>
<td>+ rely on NMHS Nat.data prov.</td>
<td>++ passive through open websites</td>
<td>+++ using official media channels</td>
<td>+ +++ active (web, new apps..)</td>
<td>+ to local, regional network</td>
<td>+ local</td>
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<td>Perception, Interpretation</td>
<td>+ Rely on NMHS</td>
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<td>+ ++ own sector</td>
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<td></td>
<td>Information use, decision making</td>
<td>++ emergencies, extremes</td>
<td>++ int’l level e.g. IPCC</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++ (e.g. sub-daily...,v.regular)</td>
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(*) M&F processes: i) Monitoring & Observation Networks: setup, maintenance and data collection, ii) Data aggregation, integration: storage, data control and integration, database holder (e.g. monthly reports...), iii) Modelling & Forecasting: large scale weather (climate) prediction - forecasting done by int’l centers, regional and large country national services, iv) Dissemination and Communication: Relaying data to public by Official Media, but also private, telcom, internet providers, apps,..., v) Perception and data interpretation: get info, analyze and judge situation, vi) Information Use and decision making: act, mitigate upon information provision. Importance of actor involvement: (+++) very important; (+++ important); (+) involved; (0) not
The six actors (stakeholders) are typical for the weather, climate and water resources monitoring sector and agreed upon by the int’l community. We will adopt the same stakeholder (actor) sequence in this analysis.

Table 1 describes the actors involved in the different M&F processes for Water & Climate in Africa. Table 1 and Figure 2 clearly illustrate the role and interactions of the many stakeholders (actors) involved at the different (spatial) scales of operation in the M&F processes, needed to inform decision makers and the public on weather, climate and water issues, and influencing their daily lives. The stakeholders and actors will be made visible throughout the constraints and opportunity analysis made in the report.

2.1.1 Mapping of international initiatives on climate and water Monitoring & Forecasting in Africa

We have no intention here to expose all on-going initiatives and research agendas on climate and water resources in Africa (which would be sheer impossible), but expose some more important global and current international initiatives and bodies (actors), implicated in the Weather, Climate and Water M&F sector in Africa. We also describe some major issues (i.e. climate change) and concepts (ECVs) used in the framework of climate adaptation, resilience building and disaster risk reduction.

Climate Change (CC) and variability and the IPCC

Since several decades, due to climatic events such as the prolonged Sahel drought from 1968 to 1984, the major droughts in the Horn of Africa from 1982 to 1985 and later, strong ENSO or El Niño Southern Oscillation signals across Africa from 1992 to 1994 and other weather and climate hazards, much more attention has been given to increasing climate M&F operations and research across Africa.

The IPCC Assessment reports (IPCC AR5, 2014) integrate the findings of the Intergovernmental Panel on Climate Change on the state of global climate change, and the analysis of past and future trends. These synthesis or assessment reports (e.g. AR5) confirm that human influence on climate is detectable and growing across all continents and world ocean regions since the last century and especially since recent decades. Changes observed in global temperature, sea level rise and greenhouse gases have now been confirmed and shown in Figures 3 below.
Impacts of global CC are however different and variable per continent and world regions. Countries therefore may experience different net impacts of climate trends related to water, agriculture, energy and health. Also, climate model predictions show a variable picture of impacts (e.g. air temperature rise, precipitation decline or increase, etc.) across the African continent.

The **Intergovernmental Panel on Climate Change (IPCC)** is a scientific and intergovernmental body under the auspices of the United Nations, set up at the request of member governments, dedicated to the task of providing the world with an objective, scientific view on climate change and its political and economic impacts. It was first established in 1988 by two United Nations organizations, the World Meteorological Organization (WMO) and the United Nations Environment Program me (UNEP), and endorsed by the United Nations General Assembly through Resolution 43/53. The IPCC produces reports that support the United Nations Framework Convention on Climate Change (UNFCCC), which is the main international treaty on climate change. The ultimate objective of the UNFCCC is to "stabilize
greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [i.e., human-induced] interference with the climate system”. IPCC reports cover “the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation” (http://www.ipcc.ch/).

**UNEA – ACPC African Climate Policy Centre** is a direct pan-African connection to the global IPCC activities, located in Addis Ababa (Ethiopia). ACPC, residing under the UN Economic Commission for Africa or UNECA, is a hub for demand-led knowledge generation on climate change in Africa. It is an African centre addressing the need for greatly improved climate information for Africa and strengthening the use of such information for decision making related to climate impacts across Africa (https://www.uneca.org/acpc).

The **World Meteorological Organisation (WMO)** is the global overarching UN organisation dealing with weather, climate and hydrological observations. It provides the international cooperation framework for these transboundary phenomena. As a specialized agency of the UN, WMO is dedicated to international cooperation and coordination on the state and behaviour of the Earth’s atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources (https://public.wmo.int/en/our-mandate).

**GCOS: the Global Climate Observing System**

**Observations** remain crucial for monitoring, understanding and predicting the variations and changes of the climate system. They need to be collected over substantial timescales with a high degree of accuracy and consistency to observe directly long-term trends in climate. Informed decisions can only be made on prevention, mitigation, and adaptation strategies based on sustained, local and comparable observations. Language on research and systematic observations was defined in the original 1991 report of the International Negotiating Committee for the United Nations Framework Convention on Climate Change (UNFCCC) and was included in the text of the Convention in 1992 in Articles 4 and 5 (Box 1) where Parties to the Convention agree to support and develop mechanisms for the collection and sharing of climate data.

GCOS has been recognised by the UNFCCC since 1997 as the programme that leads the improvement of systematic observations to meet the needs of the convention.

**Essential Climate Variables (ECV)**

All the large international (research) initiatives on climate change (IPCC, GCOS, GFCS, and many more) apply the ECV concept in their analysis and reporting on observations. We therefore briefly mention it here.

The collection and analysis of (long-term) global data time series and datasets is essential for the interpretation and detection of trends and signals of climate change. Precipitation and air/ocean temperatures are the essential climate variables (ECV) most commonly used, although a multitude of ECVs has been defined and shown in the GCOS or Global Climate Observing System Essential Climate Variable (ECV) Data Access Matrix accessible on: https://www.ncdc.noaa.gov/gosic/gcos-essential-climate-variable-ecv-data-access-matrix. Although many climate variables can be considered as playing a role in water resources from the listing above, we can initially retain about 7 important environmental hydrological variables for monitoring water resources: precipitation, temperature, soil moisture, surface and groundwater water storage, evapotranspiration, and runoff and water quality.
The Global Framework for Climate Services (GFCS) and the Climate Services Information System (CSIS)

For delivering climate information effectively it is imperative that appropriate operational institutional mechanisms are in place to generate, exchange and disseminate information nationally, regionally and globally. The Climate Services Information System (CSIS) is the principal GFCS mechanism that will routinely archive, analyse, model and process information about past, present and future climate. The CSIS will comprise a physical infrastructure of institutes, centres and computer capabilities that, together with professional human resources, will develop, generate and distribute a wide range of climate information products and services to inform complex decision-making processes across a wide range of climate-sensitive activities and enterprises. The WMO World Climate Services Programme will be the principal mechanism for implementing the CSIS, a substantial part of which already exists. The implementation strategy of the CSIS is based on a three-tiered structure of collaborating institutions (CSIS ‘entities’) that will ensure climate information and products are generated, exchanged and disseminated:

a) Globally through a range of advanced centres;
b) Regionally through a network of entities with regional responsibilities;
c) Nationally and locally by National Meteorological and Hydrological Services (NMHSs) and, through national institutional arrangements, with partners.

At the regional level, Regional Climate Outlook Forums (RCOFs) are one effective mechanism for stimulating the development of such collaboration and consensus. Users of climate information can benefit from access to products reflecting collaborative expert assessment and consensus along with information derived from a variety of individual sources. Climate Outlook Forums on a national scale may also serve useful purposes, with similar roles to those seen in RCOFs (such as the technical development and enhancement of the outlook products for national context, the professional development of information providers and, most importantly, the enhancement of user-provider interactions). In Africa, 6 RCOFs operate to support the seasonal and other weather- and climate-related forecasting processes (see Figure 4). More information can be found on the WMO – RCOF webpages (http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html).
A number of centres in Africa operate closely with the WMO and other organizations related to weather and climate, such as:

**ACMAD or African Centre for Climatological Applications Development**, based in Niamey (Niger), is the Weather and Climate Centre with African continental competence. It was created in 1987 by the Conference of Ministers of the United Nations Economic Commission for Africa (UNECA) and the WMO. ACMAD has been operational in Niamey since 1992. ACMAD is composed of 54 Member States, the 54 countries of the African continent. To ensure its mission, ACMAD functions primarily with meteorologists detached by its Member States.

ACMAD is the African core node for WMO Meteorological Data Dissemination (MDD) across Africa and the world. Data that comprise the MDD are real-time surface observations, supplied by the various National Meteorological & Hydrological Services (NMHS) through the WMO-GTS, and weather forecast data from the large global weather forecasting modelling centres (i.e., ECMWF, NOAA/NCEP, CPTEC, BOM, etc.).

For more information, please visit the webpage at [http://www.acmad.net/new/?q=en/pages/about-us](http://www.acmad.net/new/?q=en/pages/about-us).

Two regional Climate centres closely related to ACMAD and WMO are the **ICPAC** (Nairobi) and the **SADC-CSC** in Gaborone. The ICPAC or IGAD Climate Prediction & Applications Centre in Nairobi works more specifically towards weather and climate issues in the Greater Horn of (Eastern) Africa countries, whereas the Southern African Development Community Climate Services Centre, operating from the Botswana Meteorological Department or BDMS in Gaborone, deals with the regional Southern African drought and climate watch issues. For more information, please visit the webpages at [http://www.icpac.net/](http://www.icpac.net/) and [http://www.sadc.int/sadc-secretariat/services-centres/climate-services-centre/](http://www.sadc.int/sadc-secretariat/services-centres/climate-services-centre/).

Furthermore, there are several other related regional centres with weather, climate and other (i.e., water resources) mandates such as the “Observatoire du Sahara et Sahel” or **OSS** in Tunis, the **WMO-RCOF** regional climate outlook forums – Africa.
related agro-hydro meteorological or AGRHYMET Centre in Niamey, and Centers in Morocco (Casablanca). The WMO Hydrological Observation Networks like WHYCOS will be discussed in Chapter 3.

Other UN agencies focusing on water resources are for example the Food and Agriculture Organization (FAO) with its large FAOSTAT database. It’s Geodata Portal and other information sources on water, agriculture and related subjects give important global and regional information on water, agriculture and climate. Recently (April, 2017), new mapping efforts in monitoring agricultural water productivity across Africa and Middle East became available (see also Chapter 4 on Constraints and Opportunities of Satellite data and the new agricultural water productivity or WaPOR database initiative for Africa and the Middle East). For more information please visit the webpage at http://www.fao.org/geonet-work/srv/en/main.home.

For water and (human) health, the World Health Organization (WHO) holds the primary mandate. Huge efforts concerning health and water quality, epidemiology, sanitation, etc. exist across Africa. In this context, large initiatives undertaken by international foundations such as the Bill & Melinda Gates Foundation (BMG) should be mentioned. These funding mechanisms play an ever increasing role in many parts of the society.

The UN Environmental Program or UNEP (and its main African Hub in Nairobi and division of Early Warning and Assessment (DEWA) was the core author of the valuable African Water Atlas (see UNEP, 2010). This atlas gives a comprehensive picture of the water challenges that Africa is currently facing.

Hosted and led by UNESCO, the United Nations World Water Assessment Programme (WWAP) coordinates the work of 31 UN-Water members and partners in the World Water Development Report (WWDR).

This key UN Water report is an annual review providing an authoritative picture of the state, use and management of the world’s freshwater resources. In addition to coordinating this significant UN report, WWAP monitors freshwater issues in order to provide recommendations, develop case studies, enhance assessment capacity at a national level and inform the decision-making process. WWAP seeks to equip water managers and key decision-makers with the information, data, tools and skills necessary to enable them to effectively participate in the development of policies.

The Water and Climate Agenda of the African Union (AU) is set for a large part by the AMCOW and AMCOMET mechanisms. The African Ministerial Conferences on Water and Meteorology are the most important political actions and decision making for M&F. A very recent action of the AU and AMCOMET is the setup of Hydromet Forum Africa (inauguration in Sep, 2017).

Another AU initiative and real action example of climate adaptation is the “Great Green Wall initiative” (http://www.greatgreenwallinitiative.org/). The Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI) is a pan-African programme launched in 2007 by the African Union (AU). Its goal is to reverse land degradation and desertification in the Sahel and Sahara, boost food security and support local communities to adapt to climate change.

An interesting human capacity development initiative of the AU is the Pan African University Network, encompassing 5 large universities (in Kenya, Cameroun, Nigeria, Algeria and South Africa). The PAU network node of Tlemcen hosts the water and energy and also climate change education and research portfolio, together with the PAU node in South Africa (Stellenbosch) for the space sciences.

For water resources in the African regions, also regional coordination centres exist such as the WRCC (Water Resources Coordination Center) of ECOWAS. This unit coordinates water resource information
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from all 15 ECOWAS countries of Western Africa, incl. information from the RBOs or river basin organizations (i.e., the Niger, Volta, Senegal and Chad lake basin authorities).

It would be unfeasible to list all European initiatives and project cooperation between Europe and Africa. A number of important EU cooperative actions, programs, and projects directly related to Monitoring & Forecasting of Water & Climate are discussed in Chapters 3, 4 and 5.

We mention here just some important examples of European (EU) cooperative action with the African Union (AU) that is directly related to weather, climate, meteorological observations and environmental M&F. Those are the PUMA, AMESD, MESA and currently the GMES Africa programs, executed through funding of the European Development Fund (EDF). The PUMA, AMESD and MESA projects presented (sequentially from 2005-2017) large EU-AU Pan-African (in all 53 countries) cooperation efforts in the field of satellite meteorology, weather, climate and related environmental monitoring processes (such as land degradation, coastal and marine monitoring using operational satellite constellations (such as METEOSAT MSG, METOP, JASON and others). The most recent MESA project (2013-2017) recently ended and the Africa - EU cooperation efforts in the M&F field are now being integrated in the GMES for Africa initiative ( overseen by the AU).

The Global Monitoring for Environment and Security (GMES), a collaboration initiative of the European Union (EU), the European Space Agency (ESA) and the African Union (AU), is being developed to provide, on a sustained basis, reliable and timely services related to environmental and security issues in support of users and public policy makers’ needs. This EU program is now being taken beyond European borders: in the context of the ‘GMES and Africa’ initiative launched in 2007, African earth-observation capacities are being developed. A draft Action Plan to help Africa harness the benefits of space systems for sustainable development has been outlined and stakeholders were consulted through public consultation. The Plan focuses on applications in the following key areas:

- Natural disasters: risk reduction with regard to floods, fires, cyclones, volcanic eruptions, tsunamis, earthquakes, and so on;
- Food security and rural development: crop monitoring, rangeland monitoring, vulnerability assessment, locusts, water;
- Long-term management of natural resources: forest resources, biodiversity, land resources, land cover change, protected area management;
- Water resource management: integrated basin management, ground water, water scarcity;
- Impacts of climate variability and change: desertification, droughts, water scarcity, health;
- Marine and coastal areas: fisheries, integrated coastal zone management, transport and so on;
- Conflicts and political crises: disputed territory, vulnerable settlements, conflict resources, land mines;
- Infrastructure and territorial development: land planning, urban sprawl, road and water infrastructure, ecological footprint.

The purpose of the EUMETSAT User Forum in Africa is to sustain the well-established dialogue between EUMETSAT and the African user community, in particular the National Meteorological Services and their regional centres. The overall objective is to facilitate the use of EUMETSAT satellite data throughout the continent. The Forum also provides the opportunity to identify actions and initiatives that could be taken by EUMETSAT and its partners to meet the requirements of its African users. The EUMETSAT User Forum in Africa is organised every two years (http://ufa.eumetsat.int/). Further information is given in chapter 4.
A large number of examples of recently conducted, ongoing and potential future research opportunities are available, and these are conducted through:

- Relevant previous and/or current EU Frame Work or FP6 and FP7 Program projects, like DevCo-Cast, AgriCab, SIGMA, DEWFORA, etc.
- Directly conducted or in collaboration with the Joint Research Centre, under current EU Framework Programs like Horizon 2020 (H2020)
- Direct involvement of the European Space Agency, e.g. the TIGER Capacity Building Project, or ESA’s involvement in Copernicus (see also Chapter 4).

In the water resource sector, ACEWATER is an important joint EU - Africa initiative linking the 5 NEPAD Centres of Excellence in Africa and various other research centres in the continent with European partners and stakeholders. Also the large European Framework project “Earth2Observe”, reinforcing the production capacities and use of global and regional water datasets, derived from satellite, in-situ data and models (http://wci.earth2observ.eu) illustrates the efforts of European and African partners in the Water resources and Climate Monitoring and Forecasting sector.

There are also other international initiatives like those under the umbrella of the GEO or Group on Earth Observations, e.g. the GEO Flagships. CGIAR Consultative Group of International Agricultural Research is also conducting water and climate related research in Africa through its thematic centres and sub-offices (e.g., ILRI, IWMI, ICRAF, etc.).

From the USA there are many long standing examples of mutual involvement with African stakeholders in weather, climate and water resources Monitoring and Forecasting. We just mention the larger FEWSNET, SERVIR, MENA int’l cooperation programs and African cooperation initiatives in Monitoring & Forecasting and also the USAID/PEER research cooperation programs, between US and African universities and institutions. The US-based “climatelinks.org” is a global knowledge portal for climate change and development practitioners. Climate links provides a platform to CONNECT, SUPPORT, and GROW the capacity of climate change and development practitioners through systematic learning and knowledge sharing (www.climatelinks.org).

The People’s Republic of China is getting more and more involved in monitoring and mapping African land cover and land use and there are new initiatives from RADI/CAS (Chinese Institute of Remote Sensing & Digital Earth / Chinese Academy of Sciences; Beijing) announced during the AARSE 2016 Kampala conference. This concerns amongst others the new DBAR “Digital Belt and Road” initiative of Chinese cooperation in Earth Observation with in particular North and East African stakeholders. We refer to http://english.radi.cas.cn/News/PN/201611/t20161109_170226.html for more information.

We cannot end this succinct inventory of international initiatives on W&C M&F in Africa without mentioning also the “internet data and information” players and brokers. This concerns the “Big Five”: Google, Apple, Microsoft, Amazon and Facebook. As also shown (in Chapter 4 and Section 4.4.3 on Google Earth Engine), it can be expected that these information society players (currently they are the largest commercial multinationals and companies on the globe), will affect the ways monitoring data, observations, etc. will be stored, used and disseminated. One can anticipate important changes in roles of actors, value chains and M&F processes in the near future from these fast digital society developments.

This succinct inventory focused only on larger int’l initiatives (and actors) in the weather, climate and water resource M&F field in Africa. This small inventory shows clearly the keen interest of larger int’l stakeholders in the M&F sector of Africa. We fully acknowledge the existence of numerous other int’l and national initiatives, sectorial efforts and actors, and also private, boundary organizations, regional
and local community-level actions in this field of M&F of water resources and climate impacts. Their inventory is beyond the present scope of this report, but more actors are being mapped within the AA project and will be duly considered in the near future.
3 Challenges and opportunities of **in-situ** surface observations

3.1 Introduction

Most people and governments in Africa know and understand that a changing climate is posing serious challenges to their nations’ political and social security as well as to their economies and well-being. These impacts will be felt both on the short-term, through changes in occurrence and intensity of severe (dry or wet) weather or extreme water events, as well as on the long-term, through changes in annual rainfall and temperature patterns, among others. Despite this knowledge on the urgency of improving M&F of weather, climate phenomena and water resources, willingness and investments have in many countries not led to sufficient improvements on delivering weather, climate and early warning information. We attempt here to analyse and explore a number of causes and constraints which have led to the delay in progress in regions of Africa in M&F processes and dissemination of information.

Since the signals of global climate variation and change across the African continent were acknowledged by the international communities, most international support and aid programs have focused heavily on the deployment of observation systems and infrastructure. We will therefore first focus here on the constraints and opportunities related to these in-situ (surface and lower atmosphere observation) monitoring efforts.

3.2 Meteorological Surface observations by NMHS (and WMO)

The NMHS or National Meteorological and Hydrological Services are the prime authorities (and actors) mandated with the task of providing weather bulletins and forecasts to policy makers, citizens and the public in general in each country. They are also responsible for the monitoring infrastructure, data collection and preliminary analysis and quality control. NMHS cooperate closely with the WMO regions and provide synoptic station data continuously (usually on a 6-hourly basis) to the WMO-GTS Global Telecommunication System through the WMO regional network system nodes. These **in-situ** station observation data are then ingested by WMO and affiliated international weather forecast centres into Global or Integrated Forecasting Modelling systems, to provide the global weather forecasts. An adequate approach for a constraints and opportunities analysis in this field is the “measures of health” approach applied in the UNDP CIRDA report (Snow & Biagini et al, 2016) on M&F data gathering and dissemination of information to stakeholders and the public in general. The next paragraphs are cited from this report.
“A first measure of the health of a National Hydro Meteorological Service (NHMS) is the number of its synoptic and local Hydromet observing systems that are fully operational and reporting data in real time. Synoptic stations provide meteorological data at the scales of space and time needed to resolve continental-, regional and national-scale weather patterns for periods ranging from one to approximately ten days. The usually much more numerous local stations provide the data at space and time scales needed to better resolve mesoscale and microscale weather systems, complimenting and extending the data from the synoptic observations. In essence, synoptic observations provide the big picture while local observations provide the details. The data from synoptic and local observing systems are essential inputs for all weather and water monitoring and forecasting, and they serve as the foundation for climate services across the region. Local observations are particularly important in regions with complex terrain and/or large urban complexes, and are essential for early warnings of the approach of hazardous weather events. The data from observations taken at synoptic stations and perhaps those from some of the local stations are shared around the world via the Global Telecommunications System operated by the World Meteorological Organization”.

“A second measure of the health of an NHMS is its outputs, that is, the quantity and skill of its local Hydro-met products and services—ones that directly impact critical decision-making in the government, in the local business community, and by individuals in the general population. Success here requires that the NHMS understands and reaches out to its users, and provides the products and services that those users need. This is a challenge because the users are normally very diverse and have very different needs. Many of the Hydromet products and services provided by an NHMS are routine and straightforward, e.g., the daily weather report/forecast covering yesterday, today and tomorrow, and so should not be a challenge to produce with high skill and effective delivery”.

“A third measure of the health of an NHMS is its ability to anticipate the onset of severe weather later in the day, then monitor it in real time and deliver effective warnings for the imminent arrival of hazardous events such as severe thunderstorms and flash flooding. Accomplishing this task requires a well-synchronized forecast center able to blend real-time observations with radar or lightning-locating data, hydrologic data, and satellite imagery to identify the onset of hazardous weather, monitor the developments and movements that are indicative of severe weather, carry out continuous now casting of the future path of the hazard, and communicate warnings to the regions in the path of the storms. This is not a simple task and continuous specialized training is required for it to be done well”.

“Similarly, a fourth measure is the skill of climate information products produced and delivered effectively to various user communities—products such as seasonal information on local planting and harvesting dates, anticipated wet/dry periods, and anticipated soil conditions (the temperature and moisture from surface to depth). Many such climate products require the ability to interpret climate model output; take into consideration global discussions from centers in the United States and Europe; and integrate forecasts of such planetary scale phenomena as the El Niño-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), and other factors; and then downscale the information into a local context”.

Source : Snow & Biagini et al. (2016)
3.2.1 WMO-GTS Synoptic surface observations

The national NMHS services around the world and a number of international global earth monitoring initiatives (e.g. GOOS or Global Ocean Observing System and others) in cooperation with WMO provide the global surface observations such as SYNOP, TEMP and CLIMAT reports. These are typically used for international civil aviation and marine transport purposes and global, regional and national weather forecasting, by the NMHS, WMO and international global weather forecasting centers on the world. Detailed information on the WMO top-level (synoptic) surface observing system around the world and Africa can be found at http://www.wmo.int/pages/prog/www/ois/monitor/index_en.html.

Out of approximately 9000 global synoptic stations shown in Figure 5, 1183 are located in Africa (and outer islands). Examination of the historical weather records shows that there is a large variation in reporting quality among the stations and countries. Usually political, civil strife and unrest have been the major causes of non-reporting. Reasons have been well documented and discussed “ad infinitum” in the development community and will not be further addressed here (see also UNDP, 2016 and the WMO pages above for factual information on reporting stations).

![Global map of WMO-GTS synoptic meteorological stations (as from the GSOD or Global Summary of Day database at the NOAA/NCDC; approx. 9000 stations)](image)

**Challenge and opportunity: station reporting**

WMO-GTS reporting stations are a valid source of scientifically controlled meteorological information and most station data can be accessed (24-hrs after observation) by the public, based on WMO data policy resolution #40, whereby most countries allow public access to these data (after they have been used by the national and Int’l weather services for weather forecasting and prediction. Figure 5 shows the global WMO-GTS station map. This mapping was achieved using the ILWIS ISOD or Ilwis In-Situ and On-line Data Open Toolbox (OTB), which permits users to import the station map as well as direct web-based access to the - global summary of day - station data archive at the NCDC or National Climate Data Centers of the US/NOAA. The open source (OS) software tools, developed by Maathuis, Mannaerts et al, (2012-2016) at ITC, can be freely retrieved from at http://52north.org/downloads, ITC’s cooperation partner in Open Source Geospatial solutions.
We did an “actual status” analysis and verified the station reporting status for a few days in May 2017 (time of redaction of this report) in Figure 6. Although we recognize this is a mere (one day) snapshot of the WMO GTS synoptic station reporting status over Africa, which is highly variable among countries and stations in time. We must further note that station reporting is variable and another picture will be observed on other days, although trends in station GTS reporting activity can be well observed from these data.

![Image: Reporting vs. non-reporting status check of WMO-GTS (GSOD) stations on May, 21 2017 (red: reporting; blank non reporting stations on that day i.e. non 6-hourly reporting)](image_url)

**Figure 6** Reporting vs. non-reporting status check of WMO-GTS (GSOD) stations on May, 21 2017 (red: reporting; blank non reporting stations on that day i.e. non 6-hourly reporting)

**Challenge and opportunity: station network density**

The WMO GTS synoptic station density, although seemingly high on a global map (ref. Figure 6), is low in reality. Areal mapping of meteorological variables from those stations is not very feasible and prone to high estimation and spatial interpolation errors. More surface observations and secondary stations are however available in NMHS services and other organizations within a country. Every country possesses of different types (classes) of meteorological stations, ranging from synoptic and fully automated weather stations (AWS), registering all 6 weather variables (air temperatures, humidity, pressure, wind speed, solar radiation and precipitation), to manually operated and lower WMO Class 1,2,3 and 4 stations with e.g. only precipitation a/o temperature gauges.
Figure 7 clearly reveals that although synoptic stations reveal very important weather and climate information, most countries dispose over an operational national network of meteorological stations to meet regional and local demands for weather information.

For current official (i.e. national services) meteorological station observations, we can summarize the brief analysis as follows:

**Key Strengths:**
- Climate-quality and scientifically controlled surface observation station data provide critical information on weather, the hydrologic cycle and water resources on specific sites.
- Surface meteorological observations (and the long-term time series derived from them) are the scientific evidence backbone and prime information source for any climate change related research and policy making.

**Key constraints and limitations:**
- Infrastructure: Synoptic and other surface observation station network density will always remain relatively low.
- Operational: Station (6-hourly) reporting is highly variable due to the human and technical capacities of NMHS and related organizations, responsible for the infrastructure and relay of the data.
- Technology: The gradual conversion from manually operated stations to AWS (Automatic Weather Stations) was generally welcomed, but has migrated the issues with station observations to more high-tech (read: digital soft/hardware, power supply using solar panels, GPRS transmission, etc.) problems in many countries.
- Economics: important financial resources are required for WMO standard AWS stations, including operational maintenance, instrument (re-)calibration;
- Education and training: skilled observer and quality control personnel with capacity dealing with AWS is needed;
- Issues with secondary and lower order (e.g. Class 1 to 4) station maintenance and data quality exist.
3.2.2 Meteorological Surface observations by other services (and sources)

National NMHS maintain (next to their synoptic network) also several meteorological stations of different classes, ranging from secondary full automated AWS to MWS (manually operated) stations to simple rain gauges (Class 4). Next to the official African countries National Meteorological and Hydrological Services networks, a multitude of other secondary meteorological observations are made by Sector experts from government ministries (e.g. agriculture, water and energy resources, health, etc.). Also a multitude of “project-based” expert observations exist (e.g. int’l or national research projects) and may be useful for M&F of W&C challenges. Individuals and private companies (e.g. large farmers) invest and rely typically (or at least partly) on their own private observation systems (e.g. AWS) for monitoring weather, climate and water and other ECVs in their surroundings.

An inventory of all actors involved in M&F of all African countries would be too exhaustive and is beyond the scope of this current report. AfriAlliance is working towards setting-up a Geocatalog on M&F efforts as defined in D4.1 and more information will be gradually collected and made available through the AfriAlliance web portal the next years.

Also highlighting the importance of other surface observations (next to NMHS) is relevant. We use here the South Africa country example as a use case on different data providers (actors) and station numbers.

The official South African Weather Service or SAWS disposes of a synoptic (WMO-GTS) network of stations. Next to these, it maintains an important additional secondary station infrastructure as shown on the website, to be found at http://www.weathersa.co.za/about-us/overview. When adding a sectorial expert and co-producer, e.g. the SA-ARC (South African Agricultural Research Council) meteorological infrastructure, the observation density increases (see http://www.ee.co.za/wp-content/uploads/legacy/PosIT_Apr-May_p_66-68.pdf).

Also near real-time information can be gathered today from boundary organizations such as non-governmental organizations and initiatives. An example of a popular open access (global) meteorological data portal is the “Reliable Prognosis” web portal, which holds information for 680 stations across South Africa (and also other countries; visit http://rp5.co.za/Weather_in_South_Africa).

Furthermore in SA, numerous large farmers and other organizations maintain own observation systems to monitor their agriculture or environment. We can categorize these under National and Community-level users and co-producers (ref. Figure 2). So, finally in SA, we can estimate that between 1000 to 2000 gauges operate on a (sub) daily basis. However, usually the public and many potential end-users are not aware of most observation infrastructure.

Challenges can be summarized as:

- Knowledge of existing data and information sources is limited to the public and non-professionals;
- Access to information is in some cases limited or not possible and only available through informal networks;
- Little focus on business models generating added-value products and services
- Data Quality control of co-producers can be an issue (when no quality label is provided)
3.2.3 Recent developments and opportunities in meteorological surface observations

It is worth highlighting a few current initiatives which might be game changers in the countries were the systems are deployed. They all use new Science & Technology innovations and exchanges with African partner networks, and in fact strive to a “fast-forward” gear in several African countries and regions in the weather, climate and water monitoring field. Please note that this is a limited survey, illustrating only three recent efforts deployed in Africa. It is used for illustrating the high potential impact of Boundary organizations (actors) in the water, weather and climate Monitoring and Forecasting (M&F) sector, and directly working towards better adaptation and building more resilience in vulnerable countries and regions.

TAHMO network

The Trans-African Hydro Meteorological Observatory (TAHMO) aims to develop a vast network of weather stations across Africa.

The idea behind this project is to develop a dense network of hydro-meteorological monitoring stations in sub-Saharan Africa – one every 30 kilometres. This entails the installation of 20,000 stations across the continent. By applying innovative sensor technology and ICT, TAHMO stations are both inexpensive and robust. Stations are placed at schools and integrated in educational programs, adding richness to the curriculum and helping foster a new generation of scientists. Local weather data will be combined with models and satellite observations to obtain insight into the distribution of water and energy stocks and fluxes.

Figure 8   TAHMO network

Source: http://tahmo.org/about-tahmo-2/

SASSCAL and WASCAL programmes

The SASSCAL or Southern Africa Science Service Centre for Climate Change and Adaptive Land Management program, covering a number of countries in the SADC or Southern Africa region, maintains a number of AWS, directly coupled (by GPRS) to the EUMETSAT Data Uplink and Retransmission service or to local GSM providers. This data communication technique permits rapid near real time (NRT) data and weather information acquisition by end-users and the public (see Figure 9).

These are fine examples of (research) boundary organizations co-producing secondary surface observations and they complement the synoptic WMO-GTS station network for real time data applications. For example, Angola was some 15-20 years ago (after the civil war) almost defunct of surface observations (incl. synoptic data; pls. explore the WMO-GTS archive for Angola stations in the ‘90s using the ILWIS-ISOD toolbox). Nowadays, real time AWS station information is openly available (e.g. also through the SASSCAL data portal website).
Figure 9  Example of the Southern Africa SASSCAL near real-time weather data (web-based) access

The WASCAL or West African Science Centre on Climate Change and Adaptive Land Management research program (and AA project partner) also have similar observation efforts in the West African region. Information can be found at https://wascal-dataportal.org/wascal_searchportal2/.

UNDP CIRDA initiative

An important and interesting UNDP-led initiative on weather, climate and water observations for a number of LDCs (least-developed countries) in Africa is the CIRDA or Climate Information for Resilience Development and Adaptation program. This program focuses on getting to the “last mile” in weather early-warning for Disaster Risk Reduction (DRR) in the LDC countries of Africa. For more information of this program, closely related to Afrialliance, we refer to the UNDP(2016) report (see Literature references) or website http://www.undp.org/content/undp/en/home/presscenter/pressreleases/2016/03/24/undp-climate-action-hackathon-accelerates-innovative-approaches-to-provide-weather-information-to-vulnerable-communities-in-africa-.html.

Figure 10  An automatic weather station installed on a cell-phone mast in Uganda, in the CIRDA Strengthening the Climate Information and Early Warning Systems Project.

Source: UNDP (2016)
We can conclude this brief analysis on secondary station networks and boundary organizations and other actors as follows:

**Key strengths**
Secondary station data are rapidly becoming essential supplemental data and information for national, local authorities and the public. New initiatives to increase network density and operations are emerging and are valuable contributions in several countries that lack adequate monitoring infrastructure to cope with early warning for disaster risks and climate adaptation measures.

**Key constraints and challenges (with these efforts)**
Secondary station data from official providers such as the National NMHS and other services are in many countries not directly or openly accessible. Traditional NMHS services typically still reside in a “pay per number” modus in order to increase their financial resources. Studies have however shown that income generation from meteorological data sales are minimal when compared to the overall budget of most NMHS.

**Key opportunities**
Several int’l and boundary organizations, national and community-level co-producers have initiated new M&F or monitoring and forecasting programs and initiatives (e.g. SASSCAL, TAHMO, CIRDA). These programs typically pursue near real-time and open dissemination of information to the public and generate more use and interest and application of data, and in the end probably also viability of the observation systems. Also voluntary networks and project-based efforts are receiving more importance and can contribute to regional information provision on weather, water and climate. Many of these programs are built on public-private partnerships, where knowledge exchange and implementation of newest (e.g. ICT and materials) observation and data technologies drive the changes and developments.

### 3.3 Surface observations on river runoff and water storage in Africa

Surface runoff and streamflow is typically measured at river gauging stations where water levels are monitored continuously or at regular observation intervals. Stream gauging stations need however regular maintenance and (re-)calibration of the water level - discharge relationship or rating curve. Important efforts have been undertaken in Africa in the past to increase knowledge on the hydrology of major river basins (Roche, 1963). Historical events, natural environmental conditions, socio-political and economic issues have generally led to a decline in streamflow monitoring in certain regions of Africa. In other regions, important efforts are currently underway. We highlight here (without being exhaustive) some facts and figures to evaluate the challenges and constraints related to observing runoff and streamflow in Africa.

**BAFG - GRDC Global Runoff Data Centre**
An important information center, working towards collecting and safeguarding information on runoff and streamflow from all river basins across the globe is the Global Runoff Data Center in Koblenz (FRD). This center is operating under the German Federal Government (pls. See webpage http://www.bafg.de/GRDC/EN/01_GRDC/13_dtbse). Figure 11 illustrates the river runoff observation global station distribution. One immediately notes the large spatial variations in this mapping.
It is interesting to view the time history of global runoff station observations and the current support of data to the GRDC in Figure 12. Here we clearly see that numerous stakeholder issues are currently playing a role in disseminating information on streamflow to the public. The issue of generating and disseminating runoff data is clearly not of mere technical nature, but is governed by socio-politics (e.g. transboundary waters) and economics, including environmental issues.

Figure 11  Global Runoff Stations in the GRDC database (status Jan, 24 2017)

Figure 12  Historical distribution of GRDC data and current dissemination

Source: GRDC (2017)

UNH-GRDC
The University of New Hampshire’s (UNH) Composite Runoff Data Fields or UNH-GRDC are an interesting historical Catalogue of available global Runoff data and their use in a simple global water balance. An exploration of some African basins at the website (http://www.grdc.sr.unh.edu/html/Stn.html) reveals the picture below (Fig.13). Several other global runoff data sources exist and are currently being inventoried in AfriAlliance. For example, the SAGE database from Wisconsin (https://nelson.wisc.edu/sage/data-and-models/riverdata/) can be mentioned here.
WMO – WHYCOS

The World Hydrological Cycle Observing System (WHYCOS) is a framework program of the World Meteorological Organization dedicated to improving basic observation activities, strengthening international cooperation and promoting the free exchange of data in the field of hydrology. The WHYCOS program is implemented through various components (HYCOSs) at the regional and/or basin scale. Each component is implemented independently under the overall guidance provided by the WHYCOS International Advisory Group (WIAG). Most larger river basins in Africa are a WHYCOS component as a HYCOS scheme.

Strengthening regional cooperation on water related issues is one of the main objectives of each HYCOS component. As a preliminary step toward this goal, the data from the HYCOS stations of each component is shared among participating countries to meet regional and international requirements and pursue common development objectives.
Figure 14  WHYCOS developments illustrating consolidation of river basin organizations across Africa and merging into WMO larger international global hydrological data networks

Source: WMO

Such exchange is done in accordance with the internationally agreed policy framework contained in WMO Resolution 40 (Cg-XII) - WMO Policy and Practice for the Exchange of Meteorological and Related Data and Products, and WMO Resolution 25 (Cg-XIII) - Exchange of Hydrological Data and Products. The general principles on data exchange enshrined in Resolution 40 and 25 require an agreed tool, indicating the type of data, the stations and the frequency of observation and transmission for the exchange policy.

Another WHYCOS objective is to promote global data exchange and scientific cooperation. Therefore, project-generated data and information are used by global data centers operating under the aegis of or in cooperation with WMO, such as the Global Runoff Data Centre (GRDC), the Global Precipitation Climatology Centre (GPCC) and the Global Environmental Monitoring System - Water (GEMS-WATER).

A key element for facilitating this exchange of data and information is the establishment of hydrological information systems, especially in regions where modern data management software is not widely available. Such systems provide a medium for easy, fast dissemination and exchange of water-related data and information. Participating National Hydrological Services establish sites on the World Wide Web to enable easy access to selected information. Raw data are usually available in near real-time, although the service responsible for each monitoring station will subsequently carry out data quality assurance, according to WHYCOS criteria of data standards and timeliness. Derived products, such as maps of specific runoff, may be subject to cost recovery for the hydrological services.
In total, 1500 large (2nd Strahler order) sub-basins exist in the continent, with 25 major river basin regions. Figure 15 illustrates the first and second order river basins in Africa, as derived from the SRTM (Shuttle Radar Topographic Mission) space-based “HydroSheds” dataset.

Major African transboundary river basins include: the large Nile, Niger, Chad Lake, Congo, Zambesi and Orange River basins; then the Senegal, Volta, Limpopo, Shebelle-Juba, Cunene and smaller river basins. In their report of experiences of Transboundary Basin Organizations in Africa, INBO reports on essential issues concerning data needs and sharing for Monitoring and Forecasting purposes and analysis of Climate and Water challenges. We refer further to the INBO (an AfriAlliance partner) report, where good practices and recommendations are formulated (see INBO (2014) and webpages at http://www.inbo-news.org/). As an example of the importance of surface runoff data and river basin organizations (RBO), we show here one use case example of the Niger Basin Authority. The Niger Basin Authority (in French “Autorité du Bassin du Niger”) is an intergovernmental organisation in West Africa aiming to foster cooperation in managing and developing the resources of the basin of the River Niger. The group is referred to by both French and English acronyms, NBA or ABN.

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1 Hydrosheds: Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales
The NBA has an observatory and a webportal that disseminate information on water levels and flows to the public. The hydrological bulletins published reports at the most important locations (e.g. upper Niger at Koulikoro, Bamako, Niamey, lower Niger at Likojo (Nigeria), etc.). The hydrological bulletins are issued regularly and very informative.

The NBA Observatory branch uses various tools (Computerized Flow forecasting model, Hydrologic and Environmental Information Systems, data management system GiRE-2, etc.), and is linked to the WMO - WHYCOS network (see http://nigerhycos.abn.ne/). Access to other sub-basins and national station information is done through the dashboard on the EIS (Environmental Information System or SIE).

The number of stream flow stations listed in the database per country is as follows: Niger: 31; Mali: 27; Burkina Faso: 22; Benin: 6; Cameroun: 15; Nigeria: 24; Tchad: 9; Guinee: 20; RCI: 6. This leads to a total of 160 station locations in the whole basin.

A test was done for station data download, and multiple stations (in each country) pop-up in the database. The recording density (and time series) of the stations however, are not always full. Although several (important) stations have long and actualized reporting, several other stations contain only historical campaign data e.g. hydrological year and wet season of 2011, etc. (http://nigerhycos.abn.ne/user-anon/htm/). Data download requires also permission by the NBA portal administrator.

**Water storages and large dams, lakes and impoundments**

An important element in water resources management is water storage in natural impoundments and man-made reservoirs. Operation of these is essential for water supply, flood control and also in many cases for (hydropower) energy generation. In comparison to the other continents (Europe, America’s, Asia), Africa is rather defunct of large water storage capacity and only a few large structures were built in the past (< ’70s). In view of growing population pressure, water and energy supply from increased storage of surface runoff and streamflow (where feasible) may be necessary or even urgent in some African regions.

For detailed information on large dams and reservoirs, the ICOLD (International Commission on Large Dams) holds a large information database, although paid (membership) access is required in order to obtain information on dam sites and water data. Basic inventories of current dams and reservoir sites indicates that across Africa approx. 1,300 dam sites are reported e.g. in the FAO GEO Portal database.
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(Fig.17). This Figure 17 shows that certain countries invested strongly in small (and/or medium) storage reservoirs (e.g. Burkina Faso, Nigeria, Morocco, Algeria, Tunisia, Zimbabwe, South Africa), but in many countries in Africa, large water storage is limited. Only a few large storage and hydropower reservoirs are present in Africa (e.g. Lake Nasser / Nile, the Kariba and Cabora Bassa dams / Zambesi, the Akosombo on the lower Volta). 

![Distribution of water storage dams and reservoirs across Africa](image)

Figure 17  Distribution of water storage dams and reservoirs across Africa 

Source: FAO Geoportal database; survey data from 2011

The European JRC (Joint Research Centre) developed a new global satellite-based surface water data set in the framework of the Copernicus program. It maps the global distribution of water and provides temporal statistics over the last 32 year (see satellite data Section 4.4.1).

Not only in relation to hydropower and energy, but also in direct relation to (irrigated) agriculture, the inventory of water storage is very important. IWMI recently made an interesting (data and model-based) inventory and study for the need of water storage for agricultural purposes across Sub-Saharan Africa (IWMI, 2013). Figure 18 gives a simulated projection of agricultural water storage needs and combines, natural water supply, available storage and population (demographic) growth and developments in the different SSA countries and regions.
Figure 18  Projection of water storage requirement for agriculture from 2000 up to 2100

Source: IWMI

Conclusions on streamflow, runoff and storage data and information for M&F are the following:

Key strengths:
Streamflow data are essential water resources variables for any nation, needed for the assessment of renewable water resources, potential uses of water and therefore remain a core data set of economic importance to any government, region and local community.
Runoff is also an essential (climate-related) hydrological variable to design any climate-adaptation policy and/or implement measures. Runoff data are essential information in the process of disaster risk reduction and mitigation of extreme water events, such as flash flood or riverine flooding early warnings.

Key constraints and challenges
The number of permanently operating and reporting streamflow stations in Africa is low compared to several other continents (Latin America, US, Europe, etc.). This is mainly due to the fact that streamflow data collection is tedious and requires technical skilled operators, regular maintenance (and re-calibration) of gauging infrastructure and weirs, etc. Data access and public availability is generally poor (except for some large streamflow sections) at important locations (e.g. Bamako on the Niger, etc.). Data exchanges in transboundary basins remain politically sensitive. In countries with poor to no operational runoff gauging stations, implementation of water management policy is - de facto – not feasible, and IWRM offices are usually in a kind of continuous disarray status. This is to a large part due to the fact that the lack of basic data invariably leads to a lack of quantitative information for adequate decision making at all levels.

Opportunities
As an example of an opportunity, we can mention the reservoir water storage data issue. For water storage in reservoirs, ICOLD (Int’l Commission of Large Dams) holds important information for network members (paid membership). However, current satellite observations permit to measure rather accurately (< 1 cm) water levels on earth (incl. water bodies) using radar technologies. As data access to most medium (1Km - 100m) to high (100-10m) resolution satellites is currently getting open, satellite
hydrologists can easily gather information from reservoirs and monitor storage from space. Currently, the medium high resolution satellite radar constellation of ESA, Sentinel-1A (consisting of 2 space platforms) permit a 6-day global revisit time of observations. For reservoir and larger lake levels, this interval permits sound monitoring of water level changes in medium to large water storage systems.

### 3.4 Groundwater resources (in-situ) observations

The importance of groundwater as water resource for society, ensuring more climate resilience and adaptation cannot be underestimated. We here cite the British Geological Survey (http://www.bgs.ac.uk/africagroundwateratlas/index.cfm) with regard to a recent production update of regional African groundwater information, and to highlight the importance of groundwater for Africa.

![Groundwater resources mapping](Figure 19) Groundwater resources mapping (left picture © UNDP, 2010) and (right) Aquifer Productivity

**Source:** British Geological Survey / UK (2012)

“Aquifers and groundwater are highly important in Africa, especially for dry countries in the northern and southern sub-regions. Widespread but limited groundwater represent only 15 per cent of the continent’s renewable water resources, but the source of drinking water for three quarters of the continent’s population” (UNECA, 2000). The cities of Lusaka, Windhoek, Kampala, Addis Ababa and Cairo are highly dependent on groundwater for municipal water, and groundwater contributes to the supply of other cities such as Lagos, Abidjan, Cape Town and Pretoria. Groundwater plays an important role in providing water for people and animals in rural areas of Africa and may be the only practical means of meeting rural community needs in its arid and semiarid regions. Groundwater is generally cheaper to develop compared to alternatives. Aquifers are usually protected from contamination; however pollution from human activities on the surface is a growing concern. In addition, naturally occurring fluoride [F] and arsenic [As] can cause significant problems. Groundwater is less prone to evaporation than are surface water bodies, so it is a more reliable water source, especially during droughts. Finally, groundwater is a source of seepage into water bodies such as rivers and lakes, and this interaction in the water cycle is important for maintaining the integrity of ecosystems. Most countries in the desert areas of Africa such as Libya, Egypt, Algeria, Tunisia, Namibia and Botswana receive very little precipitation and therefore rely heavily on groundwater resources. For example, groundwater provides 80 per cent of domestic and livestock demands in Botswana (SADEC and others 2008), and is the source of livelihood for 80 per cent of Namibia’s rural population. In general, groundwater represents the only source of water in North Africa. Some of Africa’s important aquifers are losing water faster than the rate of recharge, such as those found in large sedimentary basins of Lake Chad, and under the Sahara desert”.

Here a multitude of information on groundwater (GW) can be found. We fully recognize the high importance of groundwater as a major water supply resource for drinking water, irrigation and industry in Africa. Through the IGRAC website, one has access to recently updated information (McDonald et al, 2012) and a geoportal on regional groundwater resources availability, transboundary aquifers and other information. (https://www.un-igrac.org/global-groundwater-information-system-ggis). Igrac is a global and regional (external or int’l) data provider and actor, fostering open access in regional GW information provision. Within several national geological services in Africa, more information can be accessed.

**Key constraints and challenges:** In relation to groundwater, large scale regional information on aquifers and groundwater storage is publicly available (as shown above). However, access to in-situ groundwater borehole data, dug wells, and other GW points is usually restricted to National Services (e.g. National Geological Surveys, Ministries of Water & Energy, Agriculture, etc.) and public access databases are very rare (non-existing) in most countries. Information is usually only shared on project basis a/o for research purposes. Another key constraint for groundwater management and use is the lack of reliable quantitative information on aquifers, their geospatial boundaries and physical water-related properties. In general, there is a shortage of qualified hydrogeologists in Africa to pursue these groundwater resources studies. This is in part due to an important pull for geological expertise from the minerals and mining sector in many African countries.

**Opportunities:** large regional-scale groundwater information derived from in-situ hydrogeological surveys and data analysis is available. Also satellite-based monitoring of groundwater storage exists using space platforms which are able to precisely measure changes in the earth gravimetric field (e.g. the GRACE or Gravity & Climate Experiment mission; see also https://grace.jpl.nasa.gov/applications/groundwater/). Very coarse resolution (i.e. 100-250-km) satellite data on large-scale groundwater storage changes are openly available, but data interpretation is complex and only for specialists and experts.
4 Challenges and opportunities of Satellite data

4.1 Introduction

Water resources in Africa have become of strategic importance, with supply limited in terms of quantity and quality, and demand increasing due to population growth and economic development. This situation is even more adversely affected by climate variability and weather extremes. A World Bank (1996) study identified a number of main problems and trends with respect to water resources such as: water stress and access, poverty, health and food (in)security, water variability and demands, degradation of environment and aquatic systems, limited future possibilities for easy/low cost access to surface and ground water resources and last but not least the dependency on external financing and subsidies. The underlying cause is the belief that water is regarded a public good, which resulted in misuse and waste. The state of water resources is not known, therefore attention has to be given to awareness raising, capacity development and better resource management, underpinned by policies and regulations, supported by reliable data and information.

In this respect the applications of satellite based observations for water, weather and climate monitoring have become very important over the last couple of decades and are regarded internationally as indispensable next to in-situ observations. In Africa, satellite-based observations and their use to create merged in situ - satellite derived products is even more important considering the sparse and declining trend in the current observation network, especially over areas without adequate measurements.

Surveys under WMO members in Africa show that data access, product development and capacity in satellite data handling are still limiting factors to an efficient exploitation of satellite observation data and products.

4.2 Access to near real-time satellite observations

Through continued international collaboration, African countries have been assisted to obtain better access to earth observation data. Initially weather services used the HRTP/AHRTP Direct Dissemination capability, the delivery of data, products and services to a user reception station on the continent, transmitted directly from geostationary or polar orbiting satellites. Maintain these systems proved to be cumbersome. Satellite operators from African countries such as Algeria, Egypt, Nigeria and South Africa are operating their dedicated reception stations. Some other ground reception station capability is scattered across the continent, like at SANSA (South African Space Agency), in Gabon, at RCRMD (Kenya) and Sunyani (Ghana). These operators download data from (their) satellites once these are in field of view of their ground station. Access to the data is provided through online portal, as is the case for SANSA (http://www.sansa.org.za/earthobservation/services) or has limited/restricted access.

Some other satellite operators also use the onboard recording capability, like for CBERS (China-Brazil Earth Resources Satellites), and the data can be obtained through an online portal hosted by INPE. As the onboard recording capability has limited storage capacity only snapshot coverage is provided.

4.2.1 EUMETCast and GEONETCast DVBs

To improve access to satellite data and their utilization for weather forecasting, the required near real time data, NWP model output and relevant products are currently provided using the EUMETCast system, a telecommunication based data dissemination system. Many satellite operators, intergovernmental and other data and product providers also use this system for the provision of data for climate
and environmental monitoring. Data from GTS network, TAF, Metar and NWP model outputs are provided to the NHMSs, like:

- **UK MET Office - Grid 0.3 on Africa domain** (UK Met Office: Met Office Unified Model data – Africa, Met Office NWP model data for use by African National Meteorological & Hydrological Services to carry out their Public Task)
- **Meteo-France Arpege -Grid 0.5 on Africa domain** (Meteo-France: The products are composed of 10 fields on 15 isobaric levels. Plus at 10 m Wind U.V. Plus at 2 m T, HU. Plus at ISO-PV 1500 and 2000 Z U V. Plus surface pressure, CAPE, surface altitude, total cloudiness, liquid and solid precipitation. The model starts the products generation at 00:00 UTC up to 102 h, at 06:00 UTC up to 72 h, at 12:00 UTC up to 84 h, and at 18:00 UTC up to 60 h. Forecast step is 3 h up to 48 h, and 6 h after 48h. The ARPEGE model is used to generate these products)
- **ECMWF - Grib2 essential products - Grid 0.5 and ECMWF - Grib2 additional products - Grid 0.5** (ECMWF: ECMWF NWP data for the GTS (essential and additional) - NWP Model. Global surface and pressure level parameters from ECMWF IFS, produced twice a day for 00 and 12 UTC; analysis and forecast steps out to 6-10 days)
- **ECMWF - Grib2 ACMAD extra - Grid 0.5** (ECMWF: ECMWF NWP data for ACMAD members - NWP Model. Surface and pressure level parameters from ECMWF IFS for African domain, produced twice a day for 00 and 12 UTC; analysis and forecast steps out to 5-6 days)
- **ECMWF - Grib2 Wave Model - Grid 0.5** (ECMWF Wave Model: Glob Wave data of satellite-derived wind-wave and swell data, analysis and forecast up to 7 days, daily interval)

It should be noted that real time forecast data from NWPs is often restricted to NMHS only and not readily available outside this domain.

Figure 20  EUMETCAST data transmission and reception by European and African users

The data disseminated through EUMETCast can be received using cheap, simple and off-the-shelf equipment. As of September 2016 a total of 344 stations has been established in Africa: 238 stations at National Institutes, 88 stations at academic and research Institutes, the remaining ones are established by private and commercial users.

The EUMETCast system also provides access for authorized users to satellite observations and derived products in case the Charter on Disasters is activated and all satellite operators try to make maximum
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effort to record the area affected. Next to this the system is used to provide training materials, using a dedicated training channel.

The RA I Dissemination Expert Group (RAIDEG) was established as part of the strategy to improve satellite data accessibility and user awareness in developing countries (http://www.wmo.int/pages/prog/sat/ra1-expertgroup-intro.php). The Terms of Reference of the RA I Dissemination Expert Group are to:

- Collect, review and maintain requirements for access to meteorological and environmental data and products by NMHSs and partner organizations in Africa;
- Analyze the requirements for satellite-based products expressed by African NMHSs, Centers of Excellence, Training Institutes and other environmental monitoring organizations in Africa making use of EUMETCast and GTS dissemination services; and
- Make recommendations on the requirements for products and on the assignment of priorities, aiming at optimizing product dissemination through EUMETCast or the GTS.

As a result, all national hydrological and meteorological services in Sub-Saharan Africa make use of tools facilitating the efficient near real-time use of the increased volume of available meteorological data sets like more accurate NWP model outputs, more ensemble (seasonal) forecast systems, more satellite imagery channels and derived products for weather forecasting. This information is provided to politicians for better informed decision-making.

Based on the significant contribution, satellite data is already important in the generation of severe weather forecasts. An intra-ACP Programme “Building Disaster Resilience to Natural Hazards in Sub-Saharan African Regions, Countries and Communities” is implemented through the ClimDev Africa Special Fund (CDSF), and includes the following activities:

- The implementation of Regional Advanced Retransmission Service (RARS) in Africa to get real time access to various instruments onboard of polar orbiting meteorological satellites;
- The enhancement of the regional Numerical Weather Prediction (NWP) capacities in Africa;
- The strengthening of national capacities on NWP for Disaster Reduction Management (DRM).

Within this effort, ACMAD is the continental Weather and Climate Centre and is coordinating the centralized activities with special focus on the establishment and operation of the RARS network, NWP and data assimilation. Within Sub-Saharan Africa a number of other regional climate centers are identified, like AGRHYMET (for West Africa), ICPAC (for East Africa) and SADC CSC (for South Africa). Efforts are also put in place to establish a regional center “Climate Application and Prediction Centre of Central Africa” (CAPC-AC) within the Economic Community of Central African States (ECCAS).

In line with the integrated African Strategy on Meteorology to invest in ground systems, training and analytical tools to make best use of existing satellite and model information available from international partners, RARS will complement the existing EARS reception network utilizing ground stations in Gabon, Kenya, Niger and South Africa. At these stations all the sounding instruments onboard of the polar orbiting satellites operated by CMA, EUMETSAT and NOAA will be received.

At global level, WMO designated ACMAD as a Regional Climate Centre for Africa. The RCCs are regarded pivotal structures to provide science-based, need-based climate information for adaptation and risk reduction in Africa.
4.3 Access to archived EO data / products

4.3.1 EU Copernicus Program (data portal)

The Copernicus program currently delivers operational data and information services openly and freely in a wide range of application areas, including thematic product/data streams of Copernicus services on Land, Ocean, Atmosphere and Climate as well as near real-time and archive images acquired by the various dedicated Sentinel satellites. The observations from Copernicus Contribution Missions should also be mentioned in this respect (http://www.copernicus.eu/main/contributing-missions). All these contribute to operational services in the domain of Land, Marine, Atmosphere, monitoring, as well as security, emergency management and climate change services. Access to products is through online portals, for the global land service see http://land.copernicus.eu/global/products.

Free access to near real time and archived data from Sentinel is provided through the European Space Agency “Science Hub” (https://scihub.copernicus.eu/), the “Copernicus Online Data Access” Portal at EUMETSAT (https://coda.eumetsat.int) and for Sentinel 2 also via the CNES portal (http://peps.cnes.fr) or the USGS portal (https://landsatlook.usgs.gov/sentinel2/viewer.html).

The Group on Earth Observations (GEO), through its global earth observation system of systems (GEO- OSS) portal (http://www.geoportal.org/) is offering information and links to many EO resources.

4.3.2 Other large (international) archives

Examples of other open access archives for other medium resolution satellites are:

- Google Earth Engine: https://earthengine.google.com/
- LANDSAT: https://landsatlook.usgs.gov/viewer.html
- ASTER: https://lpdaac.usgs.gov/dataset_discovery/aster
- CBERS: http://www.dgi.inpe.br/siteDgi/english/index_eng.php

Examples of open archives for meteorological / climatological data are:

Ground based observations:
• Actual observations from TAF and METAR:
  ○ http://en.allmetsat.com/metar-taf/
  ○ https://www.aviationweather.gov/metar/gis
• NOAA-GSOD data:
• DWD – Historical and recent monthly station data from CLIMAT-messages:
  ○ ftp://ftp-cdc.dwd.de/pub/CDC/observations_global/

(NWP) Model data:
• ECMWF: re-analysis, basically up to 3 months before present
  ○ http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/
  ○ http://apps.ecmwf.int/datasets/data/macc-reanalysis/levtype=sfc/
• NOAA: reforecast, up to one day before present
  ○ ftp://ftp.cdc.noaa.gov/Projects/Reforecast2
• NASA-GLDAS Noah Land Surface Model:
  ○ https://hydro1.gesdisc.eosdis.nasa.gov/data/GLDAS/GLDAS_NOAH025_3H.2.1/

Geostationary and polar orbiting satellite data and products from the Meteorological Product Extraction Facility:
• EUMETSAT data center:
  ○ http://archive.eumetsat.int
• Satellite Applications Facilities on:
  ○ Climate monitoring http://www.cmsaf.eu
  ○ Now casting http://www.nwcsaf.org/
  ○ Land surface analysis https://landsaf.ipma.pt/

Forecasts:
• NCEP-NOAA: forecast from GFS and GDAS
  ○ http://www.nco.ncep.noaa.gov/pmb/products/gfs/
• UK-Met: http://www.nco.ncep.noaa.gov/pmb/products/ukmet/

Time series archives for climatological analysis:
• CAMS monthly data on air temperature and rainfall from US NOAA:
• CMAP monthly rainfall:
• Weekly and monthly sea surface temperatures /anomalies:
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● Niño indices and teleconnections:
  ○ https://www.ncdc.noaa.gov/teleconnections/
● Lake levels for number of reservoirs in Africa:
  ○ https://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/
● Hurricane and cyclone tracks:
  ○ http://weather.unisys.com/hurricane/index.php

The data sources indicated above are all open accessible by the public (from certified IP addresses).

Opportunities:
Supportive continental policy framework and actions have been put in place. Coordination efforts at AUC level exist on various initiatives, such as AMCOW, AMCOMET, Space Strategy, GMES and Africa and AfriGEOSS. For example the African Union Heads of State and Government during their Twenty-Sixth Ordinary Session on 31 January 2016 in Addis Ababa adopted the African Space Policy and Strategy to realize an African Outer Space Program, as one of the flagship programs of the AU Agenda 2063. Continental projects like GMES and Africa, ministerial conferences of AMCOMET and AMCOW result in improvement of data acquisition, dissemination and data sharing, as well as strengthening indigenous capacity to generate “African-made” added value products.

In the vision of the AUC, space-derived services such as earth observation, satellite communication, navigation and positioning, space science and astronomy are crucial for future economic development of the continent. AUC has also put in place continental Capacity Development efforts, like:
  ● Pan African University Institute of Water and Energy Sciences (including Climate Change)
  ● Pan African University Institute of Space Sciences

The AfriGEOSS initiative is developed within the Group on Earth Observation (GEO) framework and seeks to strengthen the link between the current GEO activities with existing capabilities and initiatives in Africa and will provide the necessary framework for countries and organizations to access and leverage on-going bilateral and multilateral EO-based initiatives across Africa, thereby creating synergies and minimizing duplication for the benefit of the entire continent. Other relevant networks in the domain of earth observation active in Africa are AARSE and AfricaGIS.

Some examples of other opportunities are:
  ● The Global Framework for Climate Services (GFCS) provides a worldwide mechanism for coordinated actions to enhance the quality, quantity and application of climate services, with priority areas defined in the domains of agriculture and food security, disaster risk reduction, energy, health and water.
  ● The Severe Weather Forecasting Demonstration Project (SWFDP) since its inception in South Africa in 2006 has been successful in strengthening capacity of National Meteorological and Hydrological Services (NMHSs) to deliver improved forecasts and warnings of severe weather. The project has proven to improve the lead-time and reliability for alerts and warnings about
high-impact events such as heavy precipitation, strong winds and high waves for southern Africa. It has been strengthening engagement of NMHSs with users including media, disaster management and civil protection agencies and local communities for improved disaster risk reduction (DRR) and decision-making process by users (http://www.wmo.int/pages/prog/www/swfdp/). Regional Centers involved are: RSMC-Pretoria (lead regional center) and RSMC-La Reunion (for tropical cyclone forecast support) for southern Africa and RSMC-Nairobi (for whole domain) RFSC-Dar Es Salaam (for Lake Victoria basin) for eastern Africa.

- The WISER program’s mission is to deliver transformational change in the quality, accessibility and use of weather and climate information services at all levels of decision making for sustainable development in Africa (http://www.metoffice.gov.uk/about-us/what/international/projects/wiser).

**Challenges at continental, regional and national levels**

The Climate Services Information System (CSIS) component of the GFCS is the principal mechanism through which information about climate – past, present and future – is routinely archived, analyzed, modelled, exchanged and processed. A challenge is the provision of support tools (data, web servers and geoportal) to retrieve, collect, and archive and share real time, historical and forecasts data and products from global centers for climate services generation.

For climate data and assessment service the following functionalities are required:

- Collection, QC, processing, and storage of time series of observations
- Collection and storage of meta data
- Climate monitoring products, Indices of extremes, return periods, trends
- Import/Export, thresholds analysis functions
- Visualization of time series and maps
- Gridded temperature, precipitation and surface pressure, incl. uncertainty estimations, possibly merged with satellite data in data sparse regions
- Gridded Climate Indices of extremes, related to droughts, floods, health
- Documentation, user guidance, and handling of user feedback

The Regional Framework Program to Improve Hydromet Services in Sub-Saharan Africa is a joint effort between the African Development Bank, the World Meteorological Organization (WMO), the World Bank Group and the Global Facility for Disaster Reduction and Recovery (GFDRR). In Sub-Saharan Africa it aims to improve Hydromet services on the national, sub-regional, and continental levels in order to increase the accuracy of weather forecasts that can save lives and livelihoods (https://www.gfdrr.org/program-profile-africa-hydromet).

At the national level, the program seeks to modernize or build infrastructure such as radar, automated weather stations, and others, as well as strengthen institutions and service delivery. Sub-regional efforts will include standardizing procedures to promote trans-boundary collaboration, while Africa-wide efforts will ensure Hydromet services across the continent will be linked to regional and global centers, improving data and promoting partnerships.
Key strengths:
The NMHS sector in Africa is well-established. With international agendas set and funding and collaboration mechanisms in place, NMHSs are provided with a large volume of in situ and satellite-based observations, products, and (NWP) model output. The basic requirements are in place to play a major role in the process of M&F of Water and Climate-related challenges in Africa. Large volumes of relevant (time series of) images and products are available in open access archives.

Key challenges and constraints:
Overall challenges are:
- Provide better satellite data accessibility, even though EUMETCast does not require internet connectivity, access to online (satellite) data does require sufficient bandwidth. Time series data for climatological analysis still needs to be collected from online archives.
- Development of regionally tailored products and services, including regional NWP models
- Develop technical and human capacity to process the satellite data for newly evolving application areas, especially in the thematic interest areas like soil moisture and inland water quality
- Convergence of complementary activities to have greater impact (for capacity development, creating strategic partnerships and enhance collaboration
- Maintenance and expansion of in situ observation network remains a challenge, some areas still have a limited network density
- Due to high staff turnover and keeping abreast of rapidly evolving technological capabilities continuous capacity development is required
- At NMHS institutional level additional support is required to form sound policies, organizational structures, and effective methods of management
- Linkages with African universities, e.g. ACMAD within the MESA program is actively linking with the University of Nairobi, Kenya and University Cheikh Anta Diop Dakar / University of Dakar (UoD), Senegal within their capacity development activities
- Use of free (eventual open source) software tools for (dedicated) data processing and analysis
- Reaching out to the local stakeholders like farmers i.e. “the last mile”.

ESA-TIGER

From 2004 to 2017, the European Space Agency (ESA) has funded and supported the TIGER initiative as a concrete step to implement the recommendations of the Johannesburg (2002) World Summit on Sustainable Development (WSSD). TIGER aimed at developing sustainable Earth Observation (EO) information services for Integrated Water Resources Management (IWRM) in developing countries, with a particular focus on Africa. One of the main activities carried out within the TIGER initiative was the support to water research in Africa. This was carried out through dedicated capacity building and training activities. In this context and in order to improve and enhance water research results and capacity in Africa, 50 research projects and studies were selected in 2005, among more than 95 proposals sub-
mitted by African and north-south research teams, to be the initial core of the TIGER research component. The objectives of the selected projects were twofold: 1) improving knowledge on local, regional and water resources in Africa; 2) enhancing human, technical and institutional capacity to derive, disseminate and use water-relevant information by exploiting the advantages of EO technology. The ESA-TIGER project cycle (2002-2017) had several phases up to the current TIGER-Bridge initiative lasting until 2017. The main objectives of the projects were to contribute to improve water research results in Africa by exploiting the advantages of EO technology. The Tiger Capacity Building Facility has been led (2005-2017) by ITC/UT – WRS (and AA partner). For more information, we refer to the reference Koetz et al. (2014) and ESA-Tiger webpages.

4.4 Recent Opportunities for Satellite data use and W&C applications

4.4.1 Current satellite datasets for African water management

Currently, numerous satellite-derived climate and water indicators and variables are openly available to the public and research communities. Many of them represent ECVs (Essential Climate Variables) and are core data for Monitoring & Forecasting of Climate and Water challenges. Table 2 below shows an example of key variables which can be observed by satellites and data sets with public access. Many more datasets are at the disposal of researchers and public nowadays. For the case of rainfall, an additional inventory was made and is shown in Table 4 in Appendix 2.
### Table 2  Examples of satellite data products for water resources Monitoring and Forecasting

<table>
<thead>
<tr>
<th>Indicator variable</th>
<th>Data sets</th>
<th>Data source (one example only)</th>
<th>Example thumbnail</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCP</td>
<td>Satellite derived Precipitation</td>
<td><a href="http://navigator.eumetsat.int">http://navigator.eumetsat.int</a> (see also Appendix 1 for more examples)</td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>RFC</td>
<td>Rainfall Forecasts</td>
<td><a href="http://wxmaps.org/pix/af.vv.html">http://wxmaps.org/pix/af.vv.html</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>ETA, ETR</td>
<td>Actual and Reference Evapotranspiration</td>
<td><a href="https://landsaf.ipma.pt/">https://landsaf.ipma.pt/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>SSM</td>
<td>Surface Soil Moisture</td>
<td><a href="http://rs.geo.tuwien.ac.at/dv/ascat/">http://rs.geo.tuwien.ac.at/dv/ascat/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>LST</td>
<td>Land Surface Temperature</td>
<td><a href="https://landsaf.ipma.pt/">https://landsaf.ipma.pt/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>LCC</td>
<td>Various land cover classifications, vegetation data</td>
<td><a href="https://landsaf.ipma.pt/">https://landsaf.ipma.pt/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>FIR</td>
<td>Fire risk &amp; radiative power</td>
<td><a href="https://landsaf.ipma.pt/">https://landsaf.ipma.pt/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>LWL</td>
<td>Lake water levels</td>
<td><a href="https://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/">https://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>SWB</td>
<td>Surface water occurrence (bodies)</td>
<td><a href="https://global-surface-water.appspot.com/">https://global-surface-water.appspot.com/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>GWS</td>
<td>Ground Water Storage</td>
<td><a href="https://grace.jpl.nasa.gov/">https://grace.jpl.nasa.gov/</a></td>
<td>![Example thumbnail]</td>
</tr>
<tr>
<td>WQI</td>
<td>Water quality indicators</td>
<td><a href="http://navigator.eumetsat.int">http://navigator.eumetsat.int</a> or <a href="https://coda.eumetsat.int">https://coda.eumetsat.int</a></td>
<td>![Example thumbnail]</td>
</tr>
</tbody>
</table>
4.4.2 Web portals (climate & water): Drought, Floods, WQ monitoring

In relation to the three major (global) water issues (‘too little’ or water scarcity; ‘too much’ or flooding and ‘too dirty’ or water quality/health) several data portals are on-line and can be browsed for information on droughts, floods and water quality across Africa. We only mention here a few larger websites.

Drought (portal example)
The FAO-ASIS or Agricultural Stress Index portal from the GIEWS group at FAO provides near real time decadal global agricultural monitoring using robust vegetation indexing and mapping.

Figure 22 View of the FAO ASIS “Agricultural Stress Index” open-access geoportal

Floods (portal example)
An important example of global near real-time flood monitoring is the US-Dartmouth Flood Observatory, which performs Satellite-based flood analysis with direct (web-based) dissemination to the public. (© http://floodobservatory.colorado.edu/)

Figure 23: Example of the Dartmouth global satellite-based Flood Observatory

Source: CSU, USA
Google Earth Engine and cloud-based geospatial analysis

We mention here also the rapidly (2016) emerging Google Earth Engine (GEE) as a ‘cloud’ based geospatial analysis solution. Due to its very large data catalog(s) and rapid search engine, this ‘web-tool’ is rapidly gaining importance in the geospatial data analysis communities. A use case example of the Google-EE is the search and browsing of the new FAO Agricultural Water Productivity data for Africa and the Middle East (accessed on http://www.fao.org/in-action/remote-sensing-for-water-productivity/wapor/en/#/home).

![FAO Water Productivity Open-access portal (WaPOR)](image)

**Figure 24** Access to the FAO new WaPOR portal (2017 β-version) with Agricultural Water Productivity estimates of Africa (driven by Google Earth Engine)
Another “water resource” use case of the Google Earth Engine is the Global Surface Water Explorer. The European Commission JRC recently (2016) developed a new water dataset in the framework of the Copernicus Programme. This maps the location and temporal distribution of water surfaces at the global scale over the past 32 years, and provides also statistics on the extend and change of those water surfaces. The dataset, produced from Landsat imagery (courtesy USGS and NASA), will support applications including water resource management, climate modelling, biodiversity conservation and water and food security. (ref. Pekel et al, 2016). The access of the data is powered by Google Earth Engine at https://global-surface-water.appspot.com/.

Figure 25  Quick look of the Google Earth Engine Global Surface Water Explorer

5 Constraints and opportunities for citizen science

5.1 Human sensors and citizen science

The focus of this report is on the triple sensor approach in which two traditional existing data sources (remote sensing and in-situ monitoring networks) are complemented by a new, third data stream, namely data provided by ‘human sensors’. These human sensors are ‘ordinary’ citizens and the basic idea of involving the public in data gathering has been coined differently by different disciplines, e.g. ‘citizen science’ by natural scientists, ‘volunteered geographic information’ and ‘crowdsourcing geospatial data’ by geographers and ‘people-centric sensing’ and ‘participatory sensing’ by computer scientists (Wehn and Evers, 2015a). For practical purposes, we refer to this phenomenon here as Citizen Science. Citizen Science can range from citizen-based data collection, analysis and dissemination for a scientific project to public engagement in scientific discourse (Silvertown, 2009). Advanced forms of Citizen Science are often called citizen observatories which aim to engage citizens actively not only for a longer term, with regular citizen science activities, but also to create a nexus between citizens and decision makers and new forms of participation in decision making, environmental management and governance (Liu et al. 2014; Lanfranchi et al., Wehn et al. 2015 a, b).

Various forms of citizen science have existed for a long time around the globe and have been implemented, focusing on a range of topics such as bird observation (Sullivan et al., 2009), invasive species (Carballo-Cárdenas and Tobi, 2016), forest monitoring (Pratihast et al., 2013, 2014) and water quality monitoring (Scott and Frost, 2017; Minkman, 2015). Citizen science has been heralded to address challenges of data scarcity (e.g. in climate science (Muller et al., 2015)), science education (Harjanne et al., 2015) and monitoring and forecasting (e.g. in flood risk management (Lanfranchi, et al., 2014)). It has been practiced for a long time, but has really taken off in recent decades due to a number of reasons, most of which are related to technology (Clarke, 2013):

- Internet – allowing easy connections between people and devices
- The widespread use of smartphones
- Big data – requiring large groups to analyse certain types of data, particularly images
- Budget cuts in professional science
- Time availability – people (mainly in the developed world) have time available to spend on science
- Big problems – which are relevant for many citizens.

Apart from affordable, innovative sensor technologies, smartphones and social media that provide the means for more rapid and frequent data collection, communication and knowledge exchanges, another influence for the increasing uptake of Citizen Science is the post-positivist view of science that now pertains. This has given rise to the realisation that there is a broader range of valid and relevant information than that observed, selected and generated by scientists and professionals alone, raising attention to, and the value of, citizen-based observations (Wehn et al., 2015a).

OpenStreetMap (OSM), the prime example and success of Volunteered Geo-Information (VGI), is the largest global effort in creating a free map of the world. It is built by tens of thousands of volunteers and used by millions of users around the globe. Commonly, OSM is used as a base map for planning studies, emergency operations, mobile phone applications, etc. OSM content is produced in different ways, i.e., (1) by remote mapping (individually and in groups) for adding geometries and basic attributes to the map through visual interpretation of satellite and aerial images and (2) by field mapping for adding attributes that are often only visible in the terrain, such as streetnames, landuse, etc. Some
input is generated in mapping events in which groups are given one or more mapping tasks in a specific area, e.g., for the purpose of an emergency relief operation. See also https://vimeo.com/188841387.

OSM is subject to research in geo-information science as its process contains many of the abovementioned challenges such as motivation, data quality, data heterogeneity, user interface design (Arsanjani et al, 2015).

Another open access web initiative that provides access to citizen-based monitoring data is the Water Point Database Global platform. Here, field surveys gathered by a multitude of actors, active in the field may be available for further use and insight gathering. In Figure 26, some snapshots of the datasets across Africa (sample date Dec, 2016) are shown. This shows that in certain regions and/or countries, dense surveys are or were conducted in relation to water points.

![Mapping of the Water Points Database for Africa (continental sample data and close-up of Swaziland of December, 2016) using ILWIS Open Source geospatial RS/GIS software](https://www.waterpointdata.org)

**Figure 26**  Mapping of the Water Points Database for Africa (continental sample data and close-up of Swaziland of December, 2016) using ILWIS Open Source geospatial RS/GIS software

**Source:** [https://www.waterpointdata.org](https://www.waterpointdata.org)

Nevertheless, in many countries, new “open” and voluntary approaches are still regarded with scepticism. Ownership of knowledge and data lends power to the institutions who control them, and open data may diminish the authority of some institutions. Purchasing and selling software, data and services are economic transactions that are financially beneficial for both sides, and some may not want to miss the benefits. “Open data” increases transparency which in turn enhances accountability – but not all actors may like to be accountable.
In the SEMA project\(^2\) in Tanzania, the functioning of public water points was mapped using modern tools producing open data. The reaction of the local government to this information varied among districts. Contrasting opinions included “This is not official information, I do not accept this.” as well as “Great, finally I know how many water points are out of order in my district.” This highlights that there may be a complete disconnect between the motivation to collect data and the perception of the people who are supposed to use this data.

Another project, the “Inform and Empower Initiative” by Google (2008), was based on the assumption that transparent data on the performance of utilities would improve performance levels by holding authorities accountable and by letting politicians exert pressure to improve service levels: “The Google.org Inform and Empower initiative encourages the vision of a mutually reinforcing system of empowered citizens and communities, responsive providers, and informed decision-makers in pursuit of delivering public services”. These assumptions were tested in Zanzibar in the Human Sensor Web (HSW) project. The objective of this project is to provide continuous data on the quality of the service provision, thus water availability and water quality for selected water points publicly available via a website\(^3\). Unfortunately, even with continuous attempts to sensitize and educate relevant stakeholders, water users were not interested to voluntarily report failures. A large disconnect between Western logic and African reality was observed.

The anecdotal evidence presented above highlights what has been argued before: in order for Citizen Science initiatives to deliver on their promises, motivational factors play a crucial role in the success of citizen-based monitoring schemes (Ganzevoort, 2016; Rotman et al., 2012; Roy et al., 2012; Verbrugge et al., 2016; Weston et al., 2003; Whitelaw et al., 2003; Wright et al., 2015). Moreover, various actors need to be willing and motivated to engage in Citizen Science initiatives to collect data as well as to use the resulting data (Gharesifard and Wehn, 2016 a,b).

The triple sensor approach being developed by AfriAlliance relies on the success of Citizen Science initiatives to generate the third data stream. However, no structured efforts exist that have gathered experiences with implementing CS initiatives in African contexts. AfriAlliance therefore performed a survey among CS practitioners in Africa, to capture lessons learned from existing projects in order to obtain a better understanding of the opportunities and constraints for Citizen Science in Africa and the conditions under which Citizen Science may improve monitoring and forecasting in Africa.

In this chapter, we present the framework on which the survey was based and the methodology for implementing it (section 5.2) as well as the resulting insights into the opportunities (section 5.3) and constraints (section 5.4) for Citizen Science in Africa. This is followed by a brief review recent technological advances in Citizen Science (section 5.5) and conclusions (section 5.6).

### 5.2 Framework and methodology for the survey of Citizen Science in Africa

The Theory of Planned Behaviour (TPB) (Ajzen, 1991), a relevant and proven decision making theory from Social Psychology, has been successfully applied to systematically investigate behaviours that Citizen Science initiatives rely on for success, such as the motivation of citizens to share weather data (Gharesifard & Wehn, 2016a, 2016b). While usually applied to the behaviour of individuals or even the data sharing behaviour of organisations (Plengsaeng et al., 2014; Ngo Thu & Wehn, 2016; Wehn de

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\(^2\) [http://www.itc.nl/Pub/services/Major-projects/SEMA-sensors-empowerment-accountability.html](http://www.itc.nl/Pub/services/Major-projects/SEMA-sensors-empowerment-accountability.html)

\(^3\) [https://www.itc.nl/Pub/News/in2010/Sep2010/Human_Sensor/Web.html](https://www.itc.nl/Pub/News/in2010/Sep2010/Human_Sensor/Web.html)
Montalvo, 2003), we use this framework here to structure our investigation at project level, i.e. focusing Citizen Science projects or initiatives in African contexts. In order to identify the advantages and opportunities as well as the disadvantages and barriers for Citizen Science in African contexts, we draw on the three core influential factors stipulated by the TPB: outcomes (advantages and drawbacks), social pressures (advocates and opponents) and control factors. Accordingly, Citizen Science projects are conceived to result in specific outcomes (advantages as well as drawbacks), may be encouraged by some institutions and favorably looked upon by peers (advocates) but may be rejected by others (opponents), and rely on a set of practical skills, technology availability and circumstances to be actually carried out (enablers, hinderances).

These concepts were operationalized for use in an interview protocol and a questionnaire instrument (see Appendix 3). Both were implemented in late September – early October 2017, resulting in three face-to-face interviews and 11 completed questionnaires. The survey had been widely promoted via AfriAlliance online platform as well as the networks of the AfriAlliance partners, using their social media channels. In our analysis below, we cluster the results for these factors to arrive at the opportunities (positive outcomes of CS, encouraging social pressures and enabling factors) and constraints (negative outcomes of CS, hindering social pressures and hindering factors and circumstances) for Citizen Science in Africa, based on the empirical data gathered here.

Summarised below in Table 3 are the details of the surveyed projects, including the project name and website (link), the geographic coverage of the project, its goals, the role of Citizen Science in the project and the life time of the project. As is evident, all projects are recent and ongoing for a number of years, with the exception of two (Living Atlas of East African Flora and AMGRAF) that have already finished. Together, they cover experience with CS projects in 18 countries in Africa and across all five regions that AfriAlliance has clustered African countries into (Norther, Eastern, Western, Central and Southern Africa).
### Table 3  Examples of the role of citizen science in projects

<table>
<thead>
<tr>
<th>Project title</th>
<th>Geographic region</th>
<th>Project goals</th>
<th>Role of Citizen Science in the project</th>
<th>Life time of the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIRDA</td>
<td>Sierra Leone; Liberia; Gambia; Sao Tome and Principe; Ethiopia; Tanzania; Uganda; Malawi; Zambia; Benin; Burkina Faso</td>
<td>Enable vulnerable countries in Africa to strengthen national climate information systems and early warning systems (floods, droughts) as well as to benefit from regional coordination and draw upon a platform of knowledge management.</td>
<td>Data provided by private sector (Safaricom) is used to calculate rainfall intensity; data used from microwave antennas linked to cell phone towers; when there’s rainfall this is noticed by loss of signal. This data is not used by Safaricom itself, but shared with for example Flash Call free of charge. In turn Flash Call provides early warning information on flash floods to Safaricom, so that they can disseminate the warnings to the public at risk.</td>
<td>2014-2019</td>
</tr>
<tr>
<td>Flash Call</td>
<td>Kenya and Ghana</td>
<td>Development of a flash flood early warning system and development of rainfall intensity monitoring system for Kenya using data provided by among others Safaricom</td>
<td>Trying to motivate government agencies such as Uganda National Meteorological Authority (UNMA) to use citizen observations, for example about appearance of frogs, that can be an indicator of landslides (more frogs appear when a landslide is about to happen).</td>
<td>2012-2020</td>
</tr>
<tr>
<td>Development and Innovative Use of Community-Based Water Resource Monitoring Tools to Research and Mainstream Citizen Science and Improve Trans-</td>
<td>South Africa (mainly), Zimbabwe, Tanzania, Kenya</td>
<td>To identify and develop existing and new rapid tools for citizen and school learner monitoring of water resource and catchment health indicators, in collaboration with partners in South Africa and involving neighboring trans-boundary countries.</td>
<td>Allow potential engagement of communities in WRM. Tools and approaches include: monitoring tools and approaches to WRM that allow people to understand more about what they are doing and relate to curriculum based activities (e.g. teachers including items on geography and WRM in junior/high/post school curriculum).</td>
<td>April 2014 - February 2018</td>
</tr>
<tr>
<td>Project title</td>
<td>Geographic region</td>
<td>Project goals</td>
<td>Role of Citizen Science in the project</td>
<td>Life time of the project</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Boundary Catchment Management</td>
<td></td>
<td></td>
<td>The bulk of the data will actually be collected by citizens, such as the location of fences and general basemap data collection, biodiversity sightings, reports of irregularities such as poaching and wildlife conflict. It also includes reports about flooding.</td>
<td>September 2016 – August 2019</td>
</tr>
<tr>
<td>Ground Truth 2.0</td>
<td>Zambia and Kenya</td>
<td>Demonstrating the feasibility of building a sustainable citizen observatory supporting CBNRM through a co-design process involving all relevant stakeholders (citizens living in the area, decision makers, researchers, governments, private sector and civil society).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extreme Citizen Science: Analysis and Visualisation (ECSAnVis)</td>
<td>Central African Republic</td>
<td>The development of geographical analysis and visualisation tools that can be used, successfully, by non-literate people and any other community in a culturally appropriate ways, that further fit their needs and social practices</td>
<td>The whole project is about facilitating bottom-up citizen science through participatory approaches and co-design from the start. The citizens are involved in deciding what will be collected and by whom and we want to reach the stage where they decide also which issues to explore.</td>
<td>November 2016 – November 2021</td>
</tr>
<tr>
<td>Together4Water</td>
<td>Tunisia</td>
<td>Empower citizens to take action themselves and participate in environmental monitoring using cost-effective tools, decision making and policy formulation.</td>
<td>Participatory approach to monitor the implementation of SDG-6 in Tunisia at the scale of the Medjdera Catchment which is the most important river basin in the country.</td>
<td>September 2016 – September 2020</td>
</tr>
<tr>
<td>iSpot</td>
<td>South Africa</td>
<td>To document biodiversity on the subcontinent by allowing citizen scientists to obtain identifications and feedback from taxonomists and scientists running projects</td>
<td>Multifaceted: from anyone wanting an ID, to anyone wanting to engage with experts for identification, to anyone wanting to participate in any project, to more formalized programmes such as CREW (Custodians of Rare and Endangered Wildflowers) collecting data to assist in updating Red List Assessments and providing background data for EIAs, to fishermen and divers providing data for fishery management.</td>
<td>June 2011 – December 2040</td>
</tr>
<tr>
<td>Project title</td>
<td>Geographic region</td>
<td>Project goals</td>
<td>Role of Citizen Science in the project</td>
<td>Life time of the project</td>
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<tr>
<td>SeaKeys (the southern African national marine atlas) or laymen helping with alien plant surveys, to scientists running their own projects (such as protea colour surveys, mapping invasive ladybeetles, an atlas of ants (and a fieldguide to ants that was the product of this interaction), and many more.</td>
<td></td>
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<tr>
<td>Towards improved climate-smart agriculture, wildlife conflict mitigation, and resilient livelihoods in the Kasigau Corridor landscape (SE Kenya)</td>
<td>Kenya</td>
<td>The primary goal of this project is to work out how the Kasigau Corridor landscape can retain critical ecological functions and services, including being a vital wildlife corridor, and simultaneously support resilient human livelihoods.</td>
<td>Earthwatch recruits members of the public (primarily in the US and Europe, but open to anyone) to assist the principal investigator (and co-PIs and other research staff) in constructing and installing the elephant deterrents (in accordance with the research design), assisting researchers in reviewing camera trap images for wildlife intrusions, and conducting game transects to assess which species might serve as indicators (predictors) of elephants moving through the corridor. Volunteer citizen scientists receive high-level training for each task.</td>
<td>July 2016 – December 2020</td>
</tr>
<tr>
<td>Climate Protection in Kenya: Risk Assessment, Ecosystems Management and Climate Change in Kenyan ASALs</td>
<td>Kenya</td>
<td>To assess climate variability, challenges as well as the opportunities it presents for enhancing climate resilience among the ASAL communities in Arid Kenya and evaluating the limitations of Climate early warning systems.</td>
<td>The public, in this case the local communities, play a role in data collection and observation of changes. They are involved in providing information on environmental changes, livelihood changes and their perceptions of DEWS (drought early warning systems).</td>
<td>March – December 2016</td>
</tr>
<tr>
<td>Living atlas of East African flora</td>
<td>Ethiopia</td>
<td>To document plant biodiversity in East Africa and Ethiopia. Integrates new plant information (e.g.,</td>
<td>We tried to engage ecotourist companies to have those doing safaris help document plant biodiversity.</td>
<td>October 2012 – October 2015</td>
</tr>
<tr>
<td>Project title</td>
<td>Geographic region</td>
<td>Project goals</td>
<td>Role of Citizen Science in the project</td>
<td>Life time of the project</td>
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<tr>
<td>Severe Weather Warning for Musanze City (warning system and app for lightning and floods)</td>
<td>Rwanda</td>
<td>To address the pressing need as defined by VIA Water regarding risk management in coping with floods, droughts, and other severe weather events.</td>
<td>Participatory role in defining climate/weather services and warning systems on floods and lightning.</td>
<td>January 2017 – December 2018</td>
</tr>
<tr>
<td>National Water Resources Master Plan</td>
<td>Zimbabwe</td>
<td>To develop a Master Plan for Zimbabwe that guides planning, development and management of water resources in a way that is integrated and collaborative and in support of sustainable management and development, ensuring responsible and sustainable stakeholder participation.</td>
<td>The participation of non-scientists in the process of gathering data according to specific scientific protocols and in the process of using and interpreting that data.</td>
<td>April 2017 – June 2019</td>
</tr>
<tr>
<td>AMGRAF</td>
<td>Ethiopia</td>
<td>To improve understanding of shallow ground-water resources using community-monitored data; To investigate opportunities and constraints for poor people to benefit from their use in small-scale irrigation; - explore policies, regulations and institutions required for management of shallow groundwater; - develop tools for adaptive management of shallow groundwater by local communities.</td>
<td>Residents were involved in the siting new rain and river gauges, and identifying wells that were suitable to be monitored. Daily measurements were then taken regularly. Every month, the volunteers would then give their hard copy records to the government office, who then typed them into an Excel spreadsheet and emailed to the research team.</td>
<td>April 2013 – March 2015</td>
</tr>
<tr>
<td>EVOCA</td>
<td>Ghana</td>
<td>Use of environmental virtual observatories to solve complex health and Agriculture</td>
<td>Involvement of non-scientists in research design, data collection, analysis and presentation</td>
<td>January 2016 – January 2020</td>
</tr>
<tr>
<td>Project title</td>
<td>Geographic region</td>
<td>Project goals</td>
<td>Role of Citizen Science in the project</td>
<td>Life time of the project</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>SEMA - Sensors, Empowerment and Accountability</td>
<td>Tanzania</td>
<td>The SEMA project focused on how citizens in Tanzania can directly exact accountability from water and health service providers with the human sensor web (HSW). In the project a mobile phone application was developed and tested for Community Owned Water Supply Organisations (COWSOs) for reporting the status of water points (see also <a href="http://www.itc.nl/Pub/services/Major-projects/SEMA-sensors-empowerment-accountability.html">http://www.itc.nl/Pub/services/Major-projects/SEMA-sensors-empowerment-accountability.html</a> and <a href="http://www.sema-research.net/">http://www.sema-research.net/</a>).</td>
<td>The development of the SEMA App has shed light on socio-technical lessons related to software development, system deployment strategies and organisational change behaviour. Software do evolve to address the intended problems and appropriate technology used to develop the software solution matters. In this project, the software technologies adopted to develop the initial solutions of the SEMA App were not appropriate. This calls for a through requirements and systems analysis before engaging into the software development process. Specifically, the use of USSD technologies over Android technologies in the rural areas was more appropriate.</td>
<td>2011-2016</td>
</tr>
</tbody>
</table>
Although one might suspect only one category of human sensor, namely ‘citizen scientist’, actually, a number of different human sensors can be distinguished:

1) **Professionals.** These people undertake scientific tasks, monitoring and data collection as part of their job as staff of local authorities, government agencies or NGOs.

2) **Paid Observers.** Paid observers have long existed, for example in Kenya. Water Levels at river gauging stations and meteorological data has been collected by observers paid by the responsible government organisation. Observations are entered on a data sheet and collected by the organisation, when the observer also receives his salary.

3) **Citizen Scientists.** These are people with a passion for a certain field who are engaged in collecting data related to their interest, such as weather amateurs, bird-watchers, with increasing levels of expertise based on their CS experience.

4) **Volunteers.** Citizen approached by a project to collect data for free. Also this approach is not new to the era of the internet/mobile phones. Citizens are approached by a researcher whether they would be willing to collect a certain type of data. In the past, they wrote it on a sheet of paper; nowadays, they may install an app on their telephone or get access to a website to submit their observation.

5) **The Crowd.** These are citizens not specifically targeted, but one expects/hopes that the masses will collect enough useful information that can be used and analysed. ‘Netizens’ represents the situation in which observations made by the general public are mined and collected (e.g. via social media) but the data sharer is not necessarily aware of the fact that this information is collected by the networks (Gharesifard et al., 2017).

Professional observers are one of the human sensors, but they are not considered Citizen Scientists, since they undertake monitoring and observation activities as part of their form job and typically based on adequate training. The 'Volunteers' category captures individuals and groups who are systematically targeted and recruited to freely undertake a Citizen Science task. So both, 'Citizens Scientists' and 'Volunteers' carry out voluntary activities; however, the difference lies in the way they become engaged in the activity (Gharesifard et al., 2017). In this report, we focus on categories 2-5: paid observers, ‘true’ citizen scientists, volunteers and the crowd.

### 5.3 Opportunities for Citizen Science in African contexts

“Citizen Science is the only way to attain all the SDGs” (survey respondent)

This section outlines the perceived advantages of CS, who the advocates of CS are, and what enablers of Citizen Science play a role in African contexts, as experienced by the surveyed projects.

**Advantages (positive outcomes) of Citizen Science in African contexts**

The advantages and gains perceived to arise from the surveyed CS projects in African contexts can be clustered into tangible as well intangible outcomes. The tangible outcomes refer to a range of ways in which CS projects are experienced to present cost-effective means for identifying and filling data gaps, particularly in view of biodiversity and scales involved in African contexts. Intangible outcomes of CS initiatives entail the opportunity for awareness raising and capacity development that they can present, means of empowerment of citizens and communities, (new) two-way communication and knowledge sharing between various stakeholders (incl. scientists learning from citizens), and resulting environmental protection.
### Table 4  Advantages of citizen science in Africa

<table>
<thead>
<tr>
<th>Perceived advantages (positive outcomes) of Citizen Science in African contexts</th>
<th>Tangible outcomes</th>
<th>Intangible outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tangible outcomes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost-effective means for identifying &amp; filling data gaps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasing understanding of what is going on ‘on the ground’</td>
<td>Reliable and sustainable source of environmental information</td>
<td></td>
</tr>
<tr>
<td>Filling data gaps where data that does exist is scanty, not covering the whole area, outdated, and often not easily accessible;</td>
<td>On some topics, citizen-based is the only feasible option for monitoring (wildlife, environmental phenomena); results in the identification of many new species</td>
<td></td>
</tr>
<tr>
<td>Many hands and eyes can increase the amount of data that can be collected in a short amount of time; pull data from a much larger pool of collectors which helps to get more accurate and reliable results</td>
<td>Size and remoteness of areas make monitoring systems uneconomic in large parts of the continent. Citizens-based data collection in combination with fast-spreading mobile technologies can remedy this.</td>
<td></td>
</tr>
<tr>
<td>Lots of people on the ground noticing things and reporting on them</td>
<td>Identification of major gaps</td>
<td></td>
</tr>
<tr>
<td><strong>Intangible outcomes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Awareness raising and capacity development</td>
<td>Citizens are more likely to have faith in and use data if they contributed to it themselves (especially farmers on meteorological information)</td>
<td></td>
</tr>
<tr>
<td>Exposure, training, education of those people who do not know anything about it but do have an interest (land owners, NGO’s). Citizen science provide chances to the local communities to be educated on global issues like climate change that affect them.</td>
<td>Increases awareness of issues such as biodiversity</td>
<td></td>
</tr>
<tr>
<td>Scientists aware of and planning to involve a wider community in their research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empowerment of citizens and communities</td>
<td>Sense of belonging, being heard and consulted.</td>
<td></td>
</tr>
<tr>
<td>Brings money into local communities</td>
<td>Empowerment of individuals since they are able to meaningfully engage with duty bearers and decision makers.</td>
<td></td>
</tr>
<tr>
<td>Helps project acceptance by communities; increasing community buy-in of research objectives</td>
<td>Strong support in policy formulation and a powerful tool for decision making</td>
<td></td>
</tr>
<tr>
<td>Citizen science will change the way scientific research used to be done. With citizen science, we now involve citizens and consider community participation and value their inputs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two-way communication and knowledge sharing</td>
<td>Opportunity to bring people from different backgrounds and cultures to work together to resolve problems</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sharing information between indigenous groups and scientists</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strong opportunities for cultural interaction and awareness-building</td>
<td></td>
</tr>
<tr>
<td>Environmental outcomes</td>
<td>Protecting and conserving ecosystems</td>
<td></td>
</tr>
</tbody>
</table>

These results differ for CS initiatives in other parts of the world where CS activities tend to have a stronger ‘fun’ component and belonging to a community appears to be a more strongly desired outcome.

**Advocates of Citizen Science in African contexts**

“Civil society has both the voice and the technical tools to back up that voice and tell a more compelling story around some of issues taking place, backed by more substantive data.” (survey respondent)

The surveyed projects reported that advocates for their Citizen Science initiatives in African contexts were found among a wide range of individuals or institutions, namely:

- Civil society organisations (CSO) (conservation societies; environmental organisations; those focused on water resources and management or addressing indigenous communities)
- Farmers’ associations
- Citizens
- Schools
- Scientists and research institutes, public and private academic institutions,
- International organisations, donors and funders
- Ministries and county government
- Private companies, incl. safari organisers

Notable in this list is the strong presence of CSOs as advocates of CS initiatives and the apparently increasing number of international organisations, funders and donors that are perceived to be in favour of CS. At the same time, compared to other settings, there is a noteworthy absence of institutions and moral norms such public participation or increased transparency as sources of social pressure for CS projects.

**Enabling factors for Citizen Science in African Contexts**

The lessons learned from the survey projects suggest that a diverse set of factors play a strong enabling role for CS activities in African contexts. For one, the availability of mobile phones, reliable and (fast) Internet as well as apps from other projects are deemed important. Infrastructure allowing access to remote communities as well as international funding and the means to identify the information needs of end users are all key. People are equally important: supportive stakeholders across the board (citizens, scientists, decision makers), with particular emphasis on local champions, are perceived as key for success. Data scarcity, as noted in the literature, is perceived as a driver, opening doors for CS due the absence of alternative sources of data.
### Enabling factors for Citizen Science in African Contexts

<table>
<thead>
<tr>
<th>Resources, tools &amp; infrastructure</th>
<th>Technology: access to cellphones; internet availability and speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Other CS initiatives: more apps and websites getting citizens involved</td>
</tr>
<tr>
<td></td>
<td>Means to identify the information needs of end users</td>
</tr>
<tr>
<td></td>
<td>Improved infrastructure to access communities</td>
</tr>
<tr>
<td></td>
<td>Means to capture contributions of people who are illiterate or not tech savvy enough</td>
</tr>
<tr>
<td></td>
<td>International funding</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supportive stakeholders</th>
<th>Citizens with the determination and will to improve management and monitoring of their natural resources to improve their own livelihoods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Availability of lots of interested amateurs looking to help</td>
</tr>
<tr>
<td></td>
<td>Local champions and leaders: local coordinators and partners with local language skills and enthusiasm</td>
</tr>
<tr>
<td></td>
<td>Experts and taxonomists willing to participate</td>
</tr>
<tr>
<td></td>
<td>Supportive national or local government agencies and universities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exposure, training &amp; education</th>
<th>Bring interested volunteers on board CS initiatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increase understanding and appreciation of citizen-based data collection by other stakeholders; build awareness among potential end users such as meteorological departments, wild life and museums, that citizen data can complement their own data.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incentives</th>
<th>Clear incentive to get and keep citizens actively involved in the short and in the long term, incl. feedback loops</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Data scarcity</th>
<th>Distance and remoteness require new ways of monitoring and data collection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High biodiversity and lack of other sources of information</td>
</tr>
</tbody>
</table>

### 5.4 Constraints for Citizen Observatories in African contexts

“How will data be collected, packaged and used and given back to the people that collected it, especially for people that are not online?” (survey respondent)

Despite the many opportunities reported in the previous section, a number of constraints are reported to affect the implementation Citizen Science initiatives in African countries. This section reports the perceived disadvantages, opponents of, and hindering factors for Citizen Science in African contexts, as experienced by the surveyed projects.
Perceived disadvantages (negative outcomes) of Citizen Science in African contexts

The negative outcomes perceived to results from CS can be clustered into three main categories: resource outcomes, strategic position and environmental outcomes. Several of the surveyed projects reported to suffer from considerable up-front as well as maintenance costs, e.g. for equipment, training as well as relations management and quality control. CS initiative also suffer both, from actual as well as perceived low data quality, both of which affect its usefulness and impact. Finally, CS projects are seen to be prone to a considerable number of risks, ranging from uncertainty about the availability of the ‘human sensors’ for data collection campaigns, to the abuse and misinterpretation of collected data by different parties, to power struggles for existing institutional settings. These results are largely overlapping with those observed from CS initiatives in other parts of the world where concerns about data quality are also very prevalent.

One exception here relates to the environmental outcome of poaching and trading endangered species which is a risk that is more prevalent in African contexts.

Table 6 Possible disadvantages of citizen science

<table>
<thead>
<tr>
<th>Resource outcomes</th>
<th>Strategic outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>High up-front costs: incentivize citizens, provide training; getting experts involved; developing good mobile apps; connecting with people on the ground who coordinate the CS activities</td>
<td>Perceived low quality of collected data: limited value ascribed to it by authorities; stigma of data not being scientific</td>
</tr>
<tr>
<td>Uncertainty re. availability of citizens for CS activities</td>
<td>Data misinterpretation: data may be politicised, fuel an already intense blame-culture, or otherwise misused, as citizens are not sufficiently trained to interpret data or question interpretations presented to them.</td>
</tr>
<tr>
<td>Maintenance costs: citizens need to be continuously engaged; field missions arrangements and logistics (flyers, staff, traveling, scientific equipment for validation); quality control (effort to clean and use the large amount of data generated); curation of data; keeping databases secure from hacking; management and long-term utilisation (large data sets require another level of synthesis to integrate into decision making)</td>
<td>Extractive data mining that does not benefit citizens; exploiting citizens with no actual return for them</td>
</tr>
<tr>
<td>Expensive and time consuming to train a large number of people in data collection and/or analysis and the use of technology; low level of education can be barrier.</td>
<td>Power shifts/struggles: loss of control of existing institutions; empowered citizens with access to data could become a threat or cause conflict; elites could form</td>
</tr>
<tr>
<td>High costs of setting up and managing relationships between participants and intermediaries</td>
<td>Actual low quality data</td>
</tr>
</tbody>
</table>
Perceived disadvantages (negative outcomes) of Citizen Science in African contexts

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Excuse for authorities to abstain from investing in still-needed complementary central monitoring capacity</td>
<td></td>
</tr>
<tr>
<td>Environmental outcomes</td>
<td>Leakage of information to unauthorised parties, e.g. resulting in poaching and theft of tradable species</td>
</tr>
</tbody>
</table>

Opponents of Citizen Science in African Contexts

“They get away with poor forecasts and don’t see need to change.” (survey respondent)

Opposing forces for CS in African contexts can be found both, originating from specific individuals and organisations as well as institutions, norms, and policies or even their absence. The surveyed CS projects indicated the following:

- Particular members of local communities
- Poachers
- Nature conservationists
- Hydrology and Meteorology departments
- Scientific community
- Local authorities and government agencies
- Intermediaries (e.g. for market prices)
- Lacking mandates, causing data not to be (allowed to be) shared

Although of course not applicable to all representatives of the above-mentioned categories, nevertheless, selected individuals in these groups can present strong opposition for CS initiatives in African contexts. For example, those who benefit from a lack of control and sharing of information (local authorities to maintain power, poachers to avoid competition), and/or have something to hide (e.g. fake titles, illegal fencing). Meteorological offices in particular were mentioned to be well-funded with very limited need for accountability, receiving much of their equipment sponsored by donor projects or governments. Relying mainly on high-tech instruments, they are claimed to not to consider pragmatic and potentially cheaper alternatives:

“The 'hide all the data' fraternity: people who are scared that species or other natural resources will be harvested, poaches, picked ... feel that public data prevents them from controlling information and will make conservation more fragile.”

On the other hand, opponents of CS can also be found among individuals or organisations who are concerned that sensitive data will fall into the wrong hands or that generated CS data is not of the right quality, yet they will be held accountable.

Hindering factors & circumstances for Citizen Science in African contexts

“Lack of incentives: People want to know how it helps them to bring bread on the table and how it affects their daily life.” (survey respondent)

The factors and circumstances found to be hindering the surveyed CS initiatives in Africa are to some extent the other side of the coin of the enabling factors elaborated in section 4.3. For example, the lack of capacity across stakeholders (data collectors and those needing to interpret it appropriately), unclear or conflicting incentives for citizens and other stakeholders to become and remain involved in CS and governance dynamics all frame and limit the uptake and implementation of CS. The incentives in African contexts differ
notably from those reported for other parts of the world (namely, developed countries) in that here the link to people’s livelihoods are strongly pronounced. Control over resources such as budgets and circumstantial factors such as political unrest and disease outbreaks present pragmatic limitations for the surveyed CS initiatives in Africa.

Table 7  Constraints and challenges of citizen science in Africa

<table>
<thead>
<tr>
<th>Hindering factors &amp; circumstances for Citizen Science in African contexts</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lack of infrastructure &amp; capacity</strong></td>
<td>Lacking infrastructure; limited mobile coverage and/or (mobile) internet connectivity; limited access to (mobile) tools; accessible platform where data can be shared with relevant stakeholders and published</td>
</tr>
<tr>
<td></td>
<td>Capacity gap, e.g. of government agencies, to properly interpret citizen data, which limits usefulness and credibility of the data</td>
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<tr>
<td></td>
<td>Lack of trust by (science-based) government organizations in non-scientific methods of gathering data and information</td>
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<tr>
<td></td>
<td>Low capacity in terms of education-levels and literacy</td>
</tr>
<tr>
<td></td>
<td>Lack of understanding of threats to biodiversity</td>
</tr>
<tr>
<td><strong>Unclear/conflicting incentives</strong></td>
<td>Conflicting incentives of actors such as logging and mining companies to make CS happen; limited incentive for organisations with government funding to implement CS</td>
</tr>
<tr>
<td></td>
<td>Unclear incentives for citizens: what’s in it for them; results of data collected are not shared with citizens, lack of feedback loops</td>
</tr>
<tr>
<td><strong>Governance dynamics</strong></td>
<td>Lack of trust between the different stakeholders</td>
</tr>
<tr>
<td></td>
<td>Citizens asked to collect data as structured by government departments, without addressing problems created by the division of decisions themselves</td>
</tr>
<tr>
<td></td>
<td>Staff turnover of people who are committed to participatory approaches</td>
</tr>
<tr>
<td><strong>Resource control</strong></td>
<td>Lack of budgets: project funding cycles only fund citizen science for a limited period</td>
</tr>
<tr>
<td></td>
<td>Sensitivity of the data to be gathered</td>
</tr>
<tr>
<td><strong>Circumstantial factors</strong></td>
<td>Political unrest or disease outbreaks can reduce the capability to recruit sufficient volunteers</td>
</tr>
<tr>
<td></td>
<td>Security issues within CS study area</td>
</tr>
</tbody>
</table>

5.5  Recent technological advances for Citizen Science in Africa

Citizen science doesn’t necessarily involve technological tools. Especially in areas where the education level of the population is low, using technological tools might even hinder citizen science projects. Both because the citizens are not trained to use data collection tools and/or because they do not have the access to technological (online) environments where the data is shared back to them. It is therefore crucial that citizen science projects are tailor-made to the capacities of the local population involved.
However, recent technological advances do offer ever increasing opportunities for citizen science. These advances can be grouped in three groups:

- Advances in the (mobile) tools for data collection;
- Advances in the tools available to combine data streams, analyse and visualize data and
- Advances in the internet infrastructure required to use these tools.

Even though not all parts of and populations in Africa already benefit from these advances, they become available to fast growing parts of the continent. This chapter provides an overview of the recent advances.

**Data collection tools**

The technological advancement in (mobile) data collection tools is firstly strongly related to advancements in smartphones, which have hugely increased the opportunities for data collection by citizens. Not only can a smartphone be used to input data observed by a citizen, the smartphone itself offers an increasing range of data collection options as well, from using GPS to save the location where data was collected, to using the microphone and the camera to collect data.

Smartphones on the top-end are still expensive and actually increase in price, but the technological capacities of low-end smartphones are increasing rapidly as well. These low-end smartphones are now available for prices affordable for large populations in Africa and smartphone penetration in most countries in Africa – while still limited - is increasing rapidly. The lower prices of smartphones also make them an affordable option in Citizen Science projects by handing them out to the population for use in the projects, if the population doesn’t own smartphones itself.

To illustrate the growing penetration of smartphones in Africa, below figures on a number of sub-Saharan African countries are given from a research of the PEW Research Center (PEW 2016).

<table>
<thead>
<tr>
<th>Country</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>Increase (percentage point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghana</td>
<td>15%</td>
<td>14%</td>
<td>21%</td>
<td>+6%</td>
</tr>
<tr>
<td>Kenya</td>
<td>19%</td>
<td>15%</td>
<td>26%</td>
<td>+7%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>19%</td>
<td>27%</td>
<td>28%</td>
<td>+9%</td>
</tr>
<tr>
<td>Senegal</td>
<td>13%</td>
<td>15%</td>
<td>19%</td>
<td>+6%</td>
</tr>
</tbody>
</table>

In the same research, for the entire African continent, PEW estimated that in 2015 19% of all adults owned a smartphone.

Many apps have been developed to make use of smartphone capabilities to collect data in citizen science projects, some generic and others specifically developed for use in one citizen science project. While it is not possible to give an exhaustive overview of all these apps here, the potential of these tools is presented in the box below, namely one generic data collection tool (Akvo Flow) developed by one of the AfriAlliance partners (Akvo). Further examples and projects are provided in Appendix 43.
**Akvo Flow – smartphone-based field surveys.**

"Akvo Flow is a multi-language tool for collecting, evaluating and displaying any quantity of geographically referenced data - using a simple Android smartphone app and an online dashboard. It lets you map situations on the ground and monitor changes over time.

Manual data collection is cumbersome. Staff have to carry GPS, cameras and papers into the field. Forms are re-entered into computers manually, leading to a high margin of error. Data remains locked away in spreadsheets. Results are not measurable, visible or accessible. Flow dramatically improves the accuracy of data and makes it easier, simpler and faster to gather and share by using the best available tool for this purpose – the smartphone. Akvo Flow is specially designed to work in diverse locations that are often remote or lacking reliable basic infrastructure.”

https://akvo.org/products/akvoflow/#overview

Apart from mobile phones and apps, external mobile sensors offer increasing possibilities for Citizen science data collection. Sensors recently increased dramatically in price and are available for a wide range of topics, including water quality, air quality, soil quality, noise levels, etc. Sensors can either be connected to smartphones so readings can be uploaded automatically to an online platform or readings can be reported manually in an app or website. Again, to give a full overview of these sensors is impossible and instead one example is given below.

**Akvo Caddisfly – Water quality testing on a smartphone**

"Akvo Caddisfly is a simple, low cost, open source, smartphone-based drinking water testing system connected to an online data platform. Existing features of the phone combine with software apps and pocket-sized hardware attachments, to conduct reliable tests on water samples and then share this data with the people who need to see it.” (for more info, pls. Visit https://akvo.org/akvo-caddisfly/)

AfriAlliance will develop a Blueprint on how to develop a plan to monitor water sources (T4.3). In this Blueprint, we aim to provide an overview of apps and sensors which are useable specifically to monitor water points.

Thirdly, and not related to smartphones specifically, the last years saw a large increase in the technical possibilities to mine data shared by citizens which might not be specifically related to a Citizen Science project, but could contribute to the data in such project. Data shared by citizens on social media, but also data shared in the form of news-items in online newspapers can provide very meaningful additions to data
gathered actively by citizens in Citizen Science projects. The box below gives an example of this approach from the Ground Truth 2.0 project.

**Gavagai monitor - keep track of everything that is happening online**

„What topics are receiving online attention? How is this evolving in time and what sentiments are associated with these topics? Gavagai Monitor collects all open online data and not only reads all the information, it creates visual overviews for you giving you instant insights to what is going on.

Online data can be an extensive source of information to enrich data collected by citizens in a Citizen Science project. For example, in the GroundTruth 2.0 Citizen Science project in Mechelen, Belgium, Gavagai’s tools are used to monitor Citizen’s online expressions on air-quality and noise-pollution to add to the specific measurements on noise and air-quality collected by the citizens. The project in Mechelen only recently started and below an example graph coming out of the Gavagai system is added.

A scan of online attention for topics related to the GT2.0 case in Belgium. “Luchtkwaliteit” means air-quality; “geluid” means noise. [http://monitor.gavagai.se/](http://monitor.gavagai.se/)

**Data merging, analysis and visualization tools**

The second element of the recent technological advances which increase the opportunities for Citizen Science project are the improvements in tools to merge, analyse and visualize data.

As more data becomes available and is accessible online (although openness of data is still a large challenge!), opportunities increase to enrich data gathered in Citizen Science with other data from other sources. For instance, data on population, meteorological data, satellite data, etc. However, merging these datasets can be a challenge.

Secondly, analyzing (large) data-sets and getting the most out of the gathered data is a difficult task. Mostly, this work is still done using excel which requires advanced skills and is prone to causing mistakes which easily render a dataset invalid.

Lastly, ‘data’ will only become useful ‘information’ when the data is visualized effectively to answer specific questions. Recently, tools have been developed to address each of these three aspects separately or combined. Similar to the tools on data-collection, AfriAlliance aims to provide an overview of such tools in the

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4 [www.gt20.eu](http://www.gt20.eu)
AfriAlliance Blueprint (T.4.3.). In the box below an example is given of a tool that addresses all three aspects: Akvo Lumen.

**Akvo Lumen – make sense of your data**

"Akvo Lumen is a new data analysis, transformation, visualisation and publishing tool designed for and by international development professionals. It makes it easier to combine previously incompatible data sets, including your own data and data from any other source, and make them accessible to anyone. The hard work of cleaning and transforming raw data to make it usable is substantially reduced, opening up new avenues to explore and innovate."

Lumen can help you turn diverse data into high quality information you can understand, trust, share and act on. (see also https://akvo.org/products/akvo-lumen/#overview)

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**Infrastructure**

Citizen science can be implemented without the use of internet – as is shown by many citizen science projects dating back to the early 20th century. However, most if not all of the technological advances listed above rely on (mobile) internet. To make use of these advancements, the availability and accessibility of internet is therefore crucial.

Even though internet coverage is still lacking in large parts of Africa, it is spreading rapidly. InternetWorldStats calculated the total amount of internet users in Africa in mid-2012 at 167 million users on a population of 1.037 billion. In mid-2012 therefore approximately 16% of the African population used internet. In mid-2017, these numbers increased to 388 million internet users on a population of 1.246 billion, or 31%.

Furthermore, with the 2012 report, InternetWorldStats noted that “the data on internet subscribers only partially reflect the actual number of internet users in Africa and the impact of the network on African daily life and culture”. Furthermore, they note that a large percentage of the internet users access the web using mobile devices, which are the most relevant for Citizen Science projects.

**5.6 Conclusions**

In this chapter, we have reported the results of a survey among CS practitioners in Africa, to capture lessons learned from existing projects. These insights provide us with a better understanding of the opportunities and constraints for Citizen Science in Africa and the conditions under which Citizen Science may help improve monitoring and forecasting in Africa. The key opportunities and constraints for Citizen Science in Africa are summarised in Table 9.
Table 9  Opportunities and constraints of citizen science

<table>
<thead>
<tr>
<th>Citizen Science in African Contexts</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opportunities</strong></td>
<td><strong>Constraints</strong></td>
</tr>
<tr>
<td><strong>Advantages (positive outcomes of CS)</strong></td>
<td><strong>Disadvantages (negative outcomes of CS)</strong></td>
</tr>
<tr>
<td>• Cost-effective way of identifying and filling data gaps</td>
<td>• Costs: up-front and maintenance</td>
</tr>
<tr>
<td>• Means for awareness raising and capacity development</td>
<td>• Need to strengthen capacity &amp; invest in relationships</td>
</tr>
<tr>
<td>• Empowerment of citizens and communities</td>
<td>• CS needs to remain continuously relevant</td>
</tr>
<tr>
<td>• New dialogue: inter-cultural and between scientists &amp; local communities</td>
<td>• Implications of data quality issues (perceived &amp; actual): misinterpretation, blame, stigma</td>
</tr>
<tr>
<td>• Environmental conservation &amp; stewardship</td>
<td>• Power struggles: loss of control by institutions; excuse not to invest in monitoring capacity</td>
</tr>
<tr>
<td>• Environmental degradation (species poaching)</td>
<td></td>
</tr>
<tr>
<td><strong>Advocates/supporting institutions</strong></td>
<td><strong>Opponents/hindering institutions</strong></td>
</tr>
<tr>
<td>• Civil society organisations (CSO) (conservation societies; environmental organisations; those focused on water resources and management or addressing indigenous communities)</td>
<td>• Particular members of local communities</td>
</tr>
<tr>
<td>• Farmers’ associations</td>
<td>• Poachers</td>
</tr>
<tr>
<td>• Citizens</td>
<td>• Nature conservationists</td>
</tr>
<tr>
<td>• Schools</td>
<td>• Hydrology and Meteorology departments</td>
</tr>
<tr>
<td>• Scientists and research institutes, public and private academic institutions,</td>
<td>• Scientific community</td>
</tr>
<tr>
<td>• International organisations, donors and funders</td>
<td>• Local authorities and government agencies</td>
</tr>
<tr>
<td>• Ministries and county government</td>
<td>• Intermediaries (e.g. for market prices)</td>
</tr>
<tr>
<td>• Private companies, incl. safari organisations</td>
<td>• Lacking mandates, causing data not to be (allowed to be) shared</td>
</tr>
<tr>
<td><strong>Enabling factors</strong></td>
<td><strong>Hindering factors/circumstances</strong></td>
</tr>
<tr>
<td>• Wider availability of (mobile) tools and infrastructure</td>
<td>• Lacking infrastructure &amp; capacity</td>
</tr>
<tr>
<td>• Data scarcity as a chance: filling urgent gaps – on some topics, CS is the only feasible way to collect data</td>
<td>• Technical challenges</td>
</tr>
<tr>
<td>• Availability of large numbers of interested amateurs (in some locations)</td>
<td>• Lack of available budgets for CS</td>
</tr>
<tr>
<td>• Supportive stakeholders (citizens, experts, champions)</td>
<td>• Lacking trust &amp; problematic governance dynamics</td>
</tr>
<tr>
<td>• Exposure, training &amp; education of various stakeholders (not just citizens)</td>
<td>• Security issues within the study area</td>
</tr>
<tr>
<td>• Clear short &amp; long term incentives</td>
<td>• Lacking mandates</td>
</tr>
<tr>
<td>• Unclear/conflicting incentives, incl. for organisations with government funding to invest in CS.</td>
<td></td>
</tr>
</tbody>
</table>
While CS is typically perceived as a cost-effective way for gather data, our analysis has highlighted the considerable costs that are incurred in setting up and maintaining not only relevant technical infrastructure but also engagement activities and relationships. Where relevant infrastructure is not in place, including roads to remote areas, this poses a significant obstacles for CS. Similarly, capacity development is needed to ensure sound data collection as well as data interpretation and this is perceived as a burden. At the same time, CS itself can also serve as a means for capacity development for improved governance, strengthening and empowering the role of citizens in decision making. In fact, literally all of the surveyed projects included or sought links to decision making processes.

Our analysis shows that careful attention needs to be paid to these opportunities and constraints in order to get the balance right. The conditions for successful CS initiatives are often case-specific but careful preparation and attention to the factors identified here can ensure that CS initiatives deliver on their promises, particularly since such initiatives constitute the third data stream for the AfriAlliance triple sensor approach to improve monitoring and forecasting of water resources and climate in Africa.
6 Constraints and opportunities for the Triple sensor approach

6.1 Triple collocation of sensor observations

In the previous chapters, the constraints and opportunities of three different data and information gathering approaches for monitoring and forecasting of weather, climate and water resources have been reviewed.

In this chapter, the challenges and opportunities for joint analysis of the three datasets, i.e. by applying temporal and spatial triple collocation techniques to the data sources are analyzed. The origins of the triple collocation of data sources originate from meteorology (e.g. Stoffelen, 1998; Roebeling et al, 2012). The technique has arisen from the need to jointly analyze e.g. ground station measurements of meteorological variables (e.g. wind speed) with weather model- or satellite-based predictions of meteorological variables. The main idea behind triple collocation (in meteorology) is to verify and/or to increase the accuracies of global weather forecast modelling output, needed and used in our daily weather bulletins, as well as for global aviation, maritime transportation, and early warning of weather hazards. The method is closely linked to other mathematical data merging approaches such as data assimilation, where typically meteorological station observations are ingested in weather forecast models to improve predictions ad forecasts (Bengtsson et al, 1981).

Currently, and due to the enormous increase in data sources and information provision in all societal domains, data validation and quality control of information is becoming a necessary "must do" step in any information gathering, analysis, interpretation and use process. Triple collocation and other control techniques are therefore receiving more attention today as a methods for data validation, and applications to other data types and sources (beyond meteorology) are getting developed (Zwiebach, 2012; McColl et al, 2016). In Afrialliance, a similar methodology for mapping the three independent information sources (sensors) for water resource monitoring has been proposed. It can be typically applied to:

- Mapping which of the information sources are available in a certain region or physical area of interest;
- Verify the agreement (in a statistical sense) among the three sensor data sources.

In the statistical sense, triple collocation is a technique for estimating the variance of the error (noise error) and correlation coefficients of the measurement systems (e.g. satellite, in-situ and citizen-based products), with respect to the unknown true value of the variable being observed (e.g. soil moisture, wind speed, rainfall, surface water occurrence, groundwater levels, etc.).

The three independent data sources in AA are: a) in-situ hydro meteorological or water resource ground station observations e.g. soil moisture, surface and shallow ground water levels, etc. b) satellite-based estimates of hydrological variables and c) citizen-based observations on water resources.

Where the basic idea behind this triple sensor collocation is seemingly simple and has certainly opportunities, the method is also subject to several constraints and challenges. In order to derive the constraints with the triple sensor (collocation approach), we first summarize some more important constraints and opportunities of the 3 (independent) monitoring & forecasting techniques in Table 10. This permits to better formulate the constraints of the triple sensor approach. Table 10 summarizes a number of Constraints and Opportunities of the three monitoring approaches and data sources.
### AfriAlliance Deliverable D4.4

**Constraints and opportunities for Water Resources M&F using the Triple Sensor approach**

#### Table 10  Summary of constraints and opportunities of the three sensor types for improved water resources M&F

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Data provider/actor (see also Figure 2)</th>
<th>Examples of data, information sources</th>
<th>Opportunities, advantages (+)</th>
<th>Constraints, issues (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In-situ station-based</strong></td>
<td>1 Int’l external providers</td>
<td>WMO-GTS Synoptic</td>
<td>Data quality; open access; long term series... Data quality; professional station networks</td>
<td>Low network density; GTS functioning in countries Medium network density; access usually restricted (e.g. paying)</td>
</tr>
<tr>
<td></td>
<td>2 In-country data providers (Nat. Hydro Meteorological Services)</td>
<td>NHMS Class 1,2,3,4 nat. station networks</td>
<td>Supplemental to NHMS; (gap filler to NHMS)</td>
<td>Variable density (local, regional); access variable Project-based risk, long term continuity..</td>
</tr>
<tr>
<td></td>
<td>3 Sector experts/co-producers</td>
<td>Ministry of Agric, public works, other agencies...</td>
<td>New technologies, open access, near real time,... Early warning</td>
<td>Local area networks, regional; Link-up to networks, data quality control..</td>
</tr>
<tr>
<td></td>
<td>4 Boundary organizations (media, ICT, NGO, telcom, co-prod., ..)</td>
<td>TAHMO(^5), SASSCAL,...</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 National-level users &amp; co-producers</td>
<td>Disaster risk orgs,...</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 Community-level users &amp; co-producers</td>
<td>Farmers, private, local communities</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Satellites and aerospace</strong></td>
<td>1 Int’l satellite data providers (ref. CEOS)</td>
<td>Geostationary weather satellite constellation Polar Orbiting Systems e.g. South Africa, Nigeria Egypt, Algeria; Disaster monitoring constellation (int’l) e.g. CubeSat constellations,.. Airborne surveys,</td>
<td>Full area coverage – high freq.; open access; near real time Near full Coverage – time freq. 1-5 days; high resolution African satellite systems and knowledge development DMC Rapid response to disaster emergencies Low cost space systems; Public-private-partnerships Dedicated surveying; high quality and resolutions Low cost; operational systems,..</td>
<td>Medium resolutions (e.g. 3-5Km); Bias control (in-situ) needed Know-how of data use and interpretation, application Access restricted (except SANSA-SA) Data access only per DRM int’l charter (emergencies) (Under evaluation) Flight campaign cost, and availability</td>
</tr>
<tr>
<td></td>
<td>2 In-country sat-data providers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 Sector experts, co-producers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 Boundary organizations (using new, emerging technologies)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 National-level users; co-producers and private sector</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^5\) The TAHMO or Trans-African Hydro Meteorological Observatory initiative and project (see also 3.2.3) is currently used by sector data providers as well as by citizen science-based initiatives
<table>
<thead>
<tr>
<th>Citizen science (human sensor)</th>
<th>6 Community-level users &amp; co-producers</th>
<th>UAV (drones) for both 5 and 6 (actors)</th>
<th>Know-how requirement; cost processing software</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Community-level users; co-producers, private sector</td>
<td>Mobile water point mapping platforms (e.g. AKVO, mWater); Water Point Data exchange (waterpointdata.org); On-line networks (e.g. wunderground.org); Flash Call miniSASS (<a href="http://www.minsass.org">www.minsass.org</a>) TAHMO (<a href="http://www.tahmo.org">www.tahmo.org</a>)</td>
<td>Rapid gathering of large # of observations; Higher spatial density achievable; Low cost data acquisition (compared to traditional in-situ networks); Local information and enhanced services; Local community involvement &amp; potential environmental stewardship; Last mile coverage</td>
<td>Temporal continuity (“monitoring”) not assured; Quality control &amp; standards; Cost of starting-up and maintaining citizen-based data collection; Lacking infrastructure and capacity; Opponents of CS data initiatives &amp; conflicting incentives; Need to manage stakeholder expectations</td>
</tr>
</tbody>
</table>
6.2 Analysis of constraints for the triple sensor approach

A preliminary analysis of the constraints and opportunities of the Triple sensor approach led to the following:

6.2.1 Challenge #1: spatial collocation

A first challenge with the triple sensor method is the spatial matching or triple collocation in space of the ground observations (both in-situ station and citizen observations) to the (area-wide) satellite observations.

We have seen in the previous chapters that quite much essential data and information are actually gathered across Africa, and monitoring and forecasting on water resources is done using the three sensor approaches.

In-situ station data for monitoring weather and water resources are available, but we have seen (also from Table 3) that the observation network density is rather low in several regions and countries in Africa. Also open data access is an issue for secondary in-situ station and hydrological data. Open data from new boundary organizations and co-producers, are filling in-situ data gaps in certain regions/countries, but certainly this will not be realized across the whole continent.

Citizen-based data collection is the most recent data and information collection approach (< 10-years old). The number of observations on water using this technique is rising very fast, when compared e.g. to in-situ station monitoring techniques.

Most satellite datasets have full areal coverage over Africa, but many different spatial and temporal data resolutions exist and have to be dealt with. The challenge will be to match and verify how close (e.g. in which search radius), in-situ station and citizen water data points are available in the area of interest and analysis, and can be collocated to the satellite data.

6.2.2 Challenge #2: temporal collocation

A second challenge with the triple sensor approach will be the temporal matching or collocation of the ground observations (both in-situ station and citizen point observations) to the satellite data.

Next to the spatial collocation match, for example rainfall observations (or cumulative totals) need to be of the same time or time period. Only then, one can compare and validate among the three data sources.

Most in-situ hydro meteorological stations do regular (e.g. daily, sub-daily,...) reporting and can be considered to be „monitoring“ water, weather and climate.

Satellite data are also recurrent in time, with e.g. some weather satellite data even at very high time frequency. METEOSAT Second generation or MSG data cover whole Africa, Middle east and Europe and relay 3-km spatial resolution data at 15-minutes time interval to earth. Other Polar orbiting satellites will have a 1 to 5-day overpass/repeat cycle over a specific geo-location, pending on the spatial resolution of the sensor platform and the number of satellites teaming-up in orbit (e.g. 2 Sentinel S1A systems, etc.)

Citizen-based water point observations, may or not be done at regular intervals. Currently, however, several water point data sets (e.g. WPDx database in Figure 26) show rather unique or single time-points and observations. Although this is entirely valid, this will to a certain extend, limit the temporal collocation (success rate) with the in-situ and satellite data. Satellite and in-situ observations coinciding with the citizen observation time will have to be explored.
Next to the technical spatial and temporal collocation challenges, the non-technical but more socio-political and economic issue of data sharing certainly surfaces in the triple collocation process and will need proper attention for the method to become operational in order to analyse actual (i.e. near real time) situations on water resources availability and water use.

### 6.2.3 Challenge #3: Data coherence of measurements (observations)

The third important challenge in applying the triple sensor approach will be the coherence between the three observations; what climate or water variable is observed by the three sensors and how it is represented?

It is obvious that one has to collocate and compare the same observation data variable (or related) in order to agree on collocation. This can be a surface water level, rainfall amount, a meteorological variable, soil moisture, certain water quality variables, vegetation condition, etc. Here issues on which type of variable and how the data or information is represented (e.g. as a numerical, categorical or binary e.g. boolean variable, etc.) will be crucial for successful application.

### 6.2.4 Challenge #4: Ensuring continuity & quality of the new data stream (citizen-based observations)

While citizen-based observations and Citizen Science initiatives are typically perceived as a cost-effective way for gathering data, our analysis highlighted the considerable costs that can be incurred in setting up and maintaining not only relevant technical infrastructure but also capacity development, engagement activities and relationships. Careful preparation as well as attention to the incentives of involved stakeholders (citizens AND data users) can ensure that CS initiatives deliver on their promises and provide a reliable third data stream for monitoring and forecasting in Africa.

### 6.3 Opportunities for triple sensing

As can be seen from the previous succinct constraint analysis, successful application of the triple sensor approach for improved water resources M&D has technical (scientific) and data challenges. The methods and techniques are however known and currently being investigated for the purpose of AfriAlliance (e.g. D4.5). Notwithstanding these challenging constraints for applying a triple sensor collocation to improve on information reliability, we can also mention the opportunities of this method:

#### 6.3.1 Opportunity #1: information mapping

The first opportunity of using a triple sensor collocation is the mapping potential of the technique. This is of a mere informative nature, but can be interesting for stakeholders in the waters sector to verify data availability of the three sensor types in a region or area of interest.

#### 6.3.2 Opportunity #2: improved data quality reliability

The next opportunity, if a collocation of the 3 sensor data is achieved, and the correlation and error structure among the data can be derived. The triple collocation then offers the ability to review and analyse the potential error sources in each of the data sets (i.e. information quality control and intercomparison).
6.3.3 Opportunity #3: awareness raising among data users

The collocation of the triple sensor data serves to raise awareness among various data users (public sector, private sector) of the existence and legitimacy of citizen-based observations and of the relevance and importance of the involvement of this stakeholder group in monitoring in forecasting efforts and, hence, in water management.
7 Conclusions

In this report, an inventory of constraints, barriers and opportunities for using different data sources and sensors for monitoring and forecasting water resources in relation to climate challenges is explored. As the number of datasets in the climate and water domain are enormous, only key examples of relevant data sources and techniques were sampled and analysed in order to address the key strengths, constraints and barriers for use and application, as well as opportunities for improving M&F services in Africa. We can further summarize our analysis and findings in this report as follows:

In all three “sensor” domains or sectors, i.e. surface (station) observations on hydrometeorology and water resources, satellite and airborne (e.g. UAV, airplane) observations and citizen-based data gathering approaches (using small ICT tools, e.g. smartphones), rapid developments take place today globally and also in Africa. This “global” interest and fast development pace is in large part due to the current global trust and actions geared towards climate adaptation, disaster risk reduction and other climate related issues. Also, in Africa and at high political level (e.g. African Union) actions are endorsed and undertaken (ref. AMCOMET Hydromet Forum, 2017; see also Section 2.1.1).

Production and also public access to data and geo-information on water and climate has improved very significantly, due to important knowledge gains and ICT solutions. The continent has made many countries significant achievements over the past few decades, but the combination of demographic developments with weather, climate and disaster risks may lay a claim on the current and future development gains.

Therefore, the current gains in M&F processes and dissemination of information need to be consolidated and new win-win solutions of actions among regions and actors need to be sought with urgency.

On the constraints, barriers and opportunities (CBO):

A comparison of the constraints and barriers among the three different sensor approaches reveals different sources and roots of the constraints and barriers.

- For synoptic surface observations, station network density and operational technical maintenance (transmission of data flows) will always remain a crucial element and vulnerable link on the whole observation and data communication process. This issue has been re-iterated (ref. AMCOMET Hydromet Forum, 2017) as the weak link in the Africa connection to the global WMO-GTS and GCOS.
- For the many secondary equally valuable station observations, the vast array of measurements done by a multitude of parties is difficult to fully and completely map. It remains a enormous large challenge for a user (stakeholder) to know about the existence and find water or climate observation data and information (although current smart web browsing engines increases the success rate for the trained eye).
- Satellite observations typically permit wide (to full) area coverage and gathering of spatial information might be more easy. However the scientific knowledge and technical skills on “how to” interpret and use satellite information of different spatial and temporal resolutions remains a challenge and critical factor in the successful application of EO technology and data for M&F purposes. Although important efforts are done (e.g. MESA, TIGER projects), more capacity development efforts are needed to fully use and exploit the current satellite monitoring capacity available over Africa.
- Citizen-based monitoring and Citizen Science have gained much attention over the last decade and more and more applications pop-up every day. For water resources monitoring and climate, the “volunteering” nature of many crowd-sourcing processes, is a critical factor for successful application of Citizen Science. Rapid ground data gathering using citizen science approaches seem to work well if
infrastructure and capacity development issues are addressed timely and the incentive systems of citizens as human sensors and owners of such initiatives are aligned.

During the CBO analysis, differences in constraints between meteorological and hydrological data types were also clearly observed.

Meteorological station and forecast data will always be used - a priori - by NMHS and global weather forecasting centres in order to get reliable and quality controlled information for aviation, marine transportation, public weather bulletins and disaster reduction early warning purposes. Once near real-time meteorological observations have been used for forecasting, many data sources become public and access to them for e.g. agricultural and environmental monitoring is possible by knowledgeable persons. Today (2017), it is not difficult anymore (compared to 10, 20 years ago) to find meteorological data, even from more remote areas in Africa for analysis (if stations are present of course). However the network density of in-situ stations remains low in many regions of Africa.

This is not entirely the case for hydrological data such as river discharge, groundwater levels and other essential water information. Although several global (regional) water databases can be consulted in free mode, much information and data sources are not at the immediate disposal of the public or users. Direct involvement with regional or local stakeholders is required (e.g. through cooperation projects) in order to get access to the hydrological data and information. Although this seems quite logical in many cases, we observe that (except for some countries, e.g. South Africa), hydrological data and information access at regional (or 2nd order river basin level; see Figure 16) is still rather constrained in most countries in Africa.

**On Citizens and peer production:**
Collecting data using mobile telephones, smartphones or tablets has technically become a functionality that is easily implemented. As discussed in Chapter 5, increasing numbers of services exist that allow human sensors to join without detailed technical knowledge of ICTs. The real challenge is to motivate citizens to collect (and keep collecting) relevant data for water management. A community of observers with critical mass is a key factor for success but worldwide as well as initiatives in Africa struggle with attaining this necessary critical mass. „Organized“ (read paid) crowd-sourcing or collection of ground information using ICTs may provide one means for ensuring the continuity of this new data stream.

**On Opportunities:**
In Section 3.2.3, some new initiatives in gathering of adequate meteorological surface observations were shown. These present new opportunities which may become game changers in Africa on collection water and climate information in areas and regions so far defunct from any basic ground truth or information. Although currently all success stories, one needs to make sure of medium or long term continuity of these activities and newly established observation networks (beyond their project life).

In Chapter 4, next to bottlenecks and constraints analysis, several existing and new opportunities for satellite observations for water & climate were highlighted. Together with African stakeholders, important large scale and politically endorsed (EU and AU, AMCOMET, AMCOW) cooperation actions in Africa were and are being set out for continuing and improving monitoring and forecasting of water and climate related indicators and variables. Currently GMES Africa is the comprehensive follow-up of the larger joint Europe - Africa PUMA, AMESD, MESA, TIGER and other program efforts, focusing on the meteorological and water resources agencies across the continent.
In principle, all water cycle and water balance components can today be observed from space by satellites (see section 4.4.1). Several satellite platforms are operational and users can use, compare and select sensors which best fit their region and application. Optimal use of satellite sensors is usually obtained in merged mode, by which ground truth (surface data) are ingested or assimilated in order to obtain bias-corrected information on e.g. water variables such as rainfall, soil moisture, evapotranspiration and water levels.

A challenge to mention here remains the knowledge in remote sensing techniques and data required in order to properly exploit the available data sources. Several successful capacity development actions (were) and are undertaken but more critical (human resources) mass is needed in order to fully benefit from the EO potential in Africa.

We find today also several web-based portals with important information on water resources, such as drought early warning portals, surface water and flood watch systems. These are very helpful for the public to find out about the water indicator status.

On forecasting, Afrialliance is proposing to adopt the „climate-based“ WMO regionalization of AA interactions with stakeholders and actors. For the sake of simplicity, the 2 West African WMO – RCOF (see Figure 27) were merged (although we acknowledge the difference between the 2 forums). In Afrialliance, 5 regions (Northern, East, South, Central and Western) are proposed. It is known that certain countries usually belong to more than one „region“ when it comes to demography, socio-political and economic contexts.

![Afrialliance regions (color map inset) and WMO Regional Climate Outlook Forums](source:wmo-rcof(2016))

**7.1 The Way Forward:**

In Afrialliance work package 4, the collocated use of the observations of three sensors (stations, satellites, human sensors) is being investigated as an improved and „least bias“ monitoring and forecasting information gathering technique for analysing water resources and climate challenges.

Surface information and ground truth is very important in the analysis of climate adaptation or disaster reduction and also for social acceptance of data and information on water and climate. Surface station
observations and/or rapid ground truthing using citizen-science approaches first proposed solutions for this. However, one cannot „point-observe“ on all desired locations and also do this continuously at the same time, and here wide area covering and repetitive satellite observations come into play. These, as with weather bulletins, allow end-users to view and analyse e.g. upcoming changes of weather and water conditions, etc., even on locations where one is not actually present. We believe the combination of the three observation worlds might lead to better and increase the quality and remove bias from information sources.

In AfriAlliance (WP4 D4.5), a demonstration package is currently under development (first release foreseen in M24), in which the triple sensor data analysis approach will be shown and become available for more exploration by interested users.
8 References


Arsanjani, J.(Jokar), Zipf, A., Mooney, P. and Helbich, M. (Eds.) – Lecture Notes in Geoinformation and Geography. Springer Verlag Eds.


Snow, J., Biagini, B. et al. (2016) - A New Vision for Weather and Climate Services in Africa. CIRDA Network, UNDP, New York, USA.


Appendixes
## Appendix 1: Inventory of global and continental (open access) rainfall data sets

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Name, data source &amp; producer, data access, host</th>
<th>Spatial resolution</th>
<th>Temporal frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHCN-D/M</td>
<td>Global Historical Climatology Network – Daily /Monthly <a href="https://www.ncdc.noaa.gov/ghcnm/v2.php">https://www.ncdc.noaa.gov/ghcnm/v2.php</a></td>
<td>Global / station data</td>
<td>Historical time series</td>
</tr>
</tbody>
</table>

(Near) Global Satellite - gauge combined rainfall data

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Name, data source &amp; producer, data access, host</th>
<th>Spatial resolution</th>
<th>Temporal frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIRPS</td>
<td>Climate Hazard Group Infrared Precipitation with Stations data ftp://chgftpout.geog.ucsb.edu/pub/org/chg/products/CHIRPS-latest/</td>
<td>50N-50S 180E-180W 0.05 Degree</td>
<td>Daily, 5-day, decades 1981- near present</td>
</tr>
<tr>
<td>CMORPH</td>
<td>CPC Morphing Technique global precipitation <a href="http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html">http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html</a></td>
<td>60N-60S 180E-180W ; 0.083 &amp; 0.25D</td>
<td>3-hourly, day; 1998 – NRT</td>
</tr>
<tr>
<td>G-WADI PERSIANN</td>
<td>Global Water &amp; Development Info for Arid Lands &amp; Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks from ftp://hydis8.eng.uci.edu/pub/PERSIANN</td>
<td>60N-60S 0.25 Degree and 2.5 Deg Month</td>
<td>3,6-hourly, day, month 2000 – present</td>
</tr>
<tr>
<td>TRMM (3B42)</td>
<td>Tropical Rainfall Monitoring Mission 3B42 Merged (HQ) IR precipitation <a href="http://trmm.gsfc.nasa.gov/3b42.html">http://trmm.gsfc.nasa.gov/3b42.html</a> * See also GPM</td>
<td>50N-50S 0.25 degree</td>
<td>3-hourly, day, month 1998 – 2015*</td>
</tr>
</tbody>
</table>

Global multisource* rainfall data (* satellites, gauges, weather forecast model output, re-analysis)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Name, data source &amp; producer, data access, host</th>
<th>Spatial resolution</th>
<th>Temporal frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSWEP</td>
<td>Multisource Weighted Ensemble Precipitation (using satellite, gauge observations and IFS model data) <a href="http://www.gloh2o.org/https://youtu.be/kcI0jITLqI">http://www.gloh2o.org/https://youtu.be/kcI0jITLqI</a></td>
<td>90N-90S 180W-180E 0.25 Degree</td>
<td>3-hourly, day 1979-2015 updated</td>
</tr>
</tbody>
</table>

Continental Africa precipitation data (single and/or multisource)
<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
<th>Spatial Resolution</th>
<th>Temporal Resolution</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFE-ARC (v2)</td>
<td>Rainfall Estimates – Africa Climatology v2</td>
<td>20W-55E 20N-40S</td>
<td>Day, dekad, monthly v1 and v2</td>
<td></td>
</tr>
<tr>
<td></td>
<td><a href="http://www.cpc.ncep.noaa.gov/products/fews/AFR_CLIM/afr_clim.html">http://www.cpc.ncep.noaa.gov/products/fews/AFR_CLIM/afr_clim.html</a></td>
<td>0.1 Degree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAMSAT</td>
<td>Tropical Applications of Meteorological Satellites</td>
<td>20W-55E 20N-40S</td>
<td>Dekad (10-day) 1981 – near present</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfall estimates (for Africa)</td>
<td>0.1 Degree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSGMPE</td>
<td>MSG (Meteosat 2nd Generation) Multisensor Precipitation Estimate (near real time NRT satellite obs. only)</td>
<td>Meteosat disk 0.0375 Degrees EUR, Africa, Middle East</td>
<td>15 – min, Day sums; 2004 – to NRT</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2: List of concepts in IT-based collaborations

- Open: “Open means anyone can freely access, use, modify, and share for any purpose (subject, at most, to requirements that preserve provenance and openness).” ([http://opendefinition.org/](http://opendefinition.org/))
  - Open Source (software code), Open data, Open knowledge
- Common: general term for shared resources in which each stakeholder has an equal interest
- Licensing: the new way to produce something also has created a new legal framework of non-commercial licensing and copyright models ([http://opendefinition.org/licenses/](http://opendefinition.org/licenses/))
- Free: reinforces the concept of Open (Free and Open Software (FOSS))
- Crowdsourcing: Process of obtaining needed services, ideas, or content by soliciting contributions from a large group of people, and especially from an online community. Crowdsourcing came out of “outsourcing,” or seeking cheap labor from the general public to complete tasks.
- Participatory: is a broad concept that indicates that outputs are inclusive and stakeholder based
- Gamification: concept of applying game mechanics and game design techniques to engage and motivate people to achieve their goals, and get involved.
- Commons-based Peer Production: new model of socioeconomic production in which large numbers of people work cooperatively (usually over the Internet) ([https://en.wikipedia.org/wiki/Commons-based_peer_production](https://en.wikipedia.org/wiki/Commons-based_peer_production))
- User Generated Content: is voluntarily developed by an individual or a consortium and distributed through an online platform.
- Social Entrepreneurs: Social entrepreneurship in modern society offers an altruistic form of entrepreneurship that focuses on the benefits that society may reap ([www.ashoka.org](http://www.ashoka.org)).
- Citizen Science: projects are activities sponsored by a wide variety of organizations so non-scientists can meaningfully contribute to scientific research. Some are more than 100 years old (weather observers), but it was boosted since 2000 with the advent of the internet. ([https://en.wikipedia.org/wiki/List_of_citizen_science_projects](https://en.wikipedia.org/wiki/List_of_citizen_science_projects)) Related concepts are: citizen observatories, community based monitoring, participatory monitoring, participatory sensing, human sensing, crowdsensing, citizen observatory web, human sensor web, mobile data collection, VGI, citizens as sensors
- Cloud: Storage Cloud, Network Cloud, Cloud Computing.... Etc...: The word “cloud” often refers to the Internet, and more precisely to some datacenter full of servers that is connected to the Internet.
- Volunteered Geographic Information (VGI). The term Volunteered Geographic Information (VGI) has been coined by Goodchild and is defined as by the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals (Goodchild, 2007).
- Disruptive: is an innovation that creates a new market and value network and eventually disrupts an existing market and value network, displacing established market leaders and alliances.
Appendix 3  Questionnaire for AfriAlliance survey on Citizen Science in Africa

Note: This questionnaire was implemented with the QuestionPro online survey tool. The formatting of the questions and the response spaces therefore differs here from the online implementation.

Dear Sir/Madame,

The AfriAlliance project aims to better prepare Africa for future climate change challenges. One of its objectives is to help improve water and climate monitoring and forecasting processes and tools in Africa. The purpose of this survey is to identify constraints and opportunities for Citizen Science in Africa. Who should participate in this survey? We invite practitioners with experience in implementing Citizen Science (e.g. citizen-based monitoring, citizen-based data collection, crowdsourcing data, etc.) in Africa to share lessons learned from their project(s). Your participation in the survey will help us to obtain a better understanding of the conditions under which Citizen Science may improve monitoring and forecasting in Africa. This survey is open between Wednesday, 27 September – Wednesday, 4 October 2017.

Before you start:

The information provided by you in the survey is voluntary and will be used for research purposes only. Unless you explicitly authorise us to do so, you will not be identified by your individual responses. Most participants find the discussion interesting and thought-provoking. If, however, you feel uncomfortable in any way while completing the questionnaire, you can decline to answer any question or end the interview. Anonymized research data will be archived in the AfriAlliance data archive held by IHE Delft, in order to make them available to other researchers in line with current data sharing practices. To receive a copy of your data or to retract the data, please identify yourself and, referring to this survey, contact us at: Linda Velzeboer, Project Assistant AfriAlliance, IHE Delft or via email: l.velzeboer@un-ihe.org

- Respondent name
- Organization

The following questions serve to document your experience in one specific project and context. If you have several projects, please select the most salient one.

Project name
Project website

Please indicate the main country in Africa in which your project is/was located (only one selection possible):
<clickable map of Africa>

Please indicate the geographical scope of your project

1. City
2. Basin
3. Sub-national region
4. Country
5. Other __________
Project start date:
  •

Project end date
  •

What is or was the main goal of your project?

How would you define Citizen Science?

What role did or does Citizen Science play in your project? How are/were citizens involved?

How many citizens did/are you planning to involve in your project?
  1. <100
  2. hundreds
  3. thousands
  4. don't know

In your project, what do you see as the advantages/gains/benefits resulting from Citizen Science?

In your project, what do you see as the disadvantages/costs/losses resulting from Citizen Science?

In a wider African context, what do you see as the advantages/gains/benefits resulting from Citizen Science?

In a wider African context, what do you see as the disadvantages/costs/losses resulting from Citizen Science?

Which individuals or institutions do you think are in favour of Citizen Science in the geographical area of your project?

Which individuals or institutions do you think are against Citizen Science in the geographical area of your project?

What do you see as the main factors or circumstances that HELP or ENABLE Citizen Science in the geographical area of your project?

What do you see as the main factors or circumstances that HINDER or PREVENT Citizen Science in the geographical area of your project?

What else would you like to share with us on the topic of Citizen Science in Africa, please include it here?

Please indicate the way in which you would like us to refer to your responses (multiple answers possible):
  1. Anonymously
  2. Refer to the project title only
  3. Refer to your name & project title __________

If you would like to receive the resulting report by AfriAlliance, please enter your email address here:

Thank you for taking the time to take part in this survey!

This is helping us to obtain a better understanding of the opportunities and constraints of Citizen Science in Africa and the conditions under which Citizen Science may improve monitoring and forecasting in Africa.

If you would like to find out more about AfriAlliance, the Africa-EU Innovation Alliance for Water and Climate, please visit us here and join the AfriAlliance Community of Stakeholders:

www.afrialliance.org
#AfriAlliance1
Appendix 4  Brief overview of apps & projects for citizen-based data collection for Water Management

AKVO Flow
Map, monitor and evaluate infrastructure, social issues, interventions and services — or anything else. Akvo FLOW is affordable, reliable and highly scalable. It uses smartphones to dramatically improve the ease, speed and accuracy of data collection. AKVO Flow captures field data along pre-specified survey forms with image, video, audio attached. The software is free and open source. AKVO is specialized in setting up training and carrying out very large surveys. Against payment AKVO will provide cloud-services and data can be accessed thru a dashboard.
Website: www.akvo.org

Functionality:

COBWEB, the Citizen OBservatory WEB, was a project to empower everyday people with the ability to collect environmental information using mobile devices. The collected information would be suitable for use in research, decision making and policy formation.
Website: cobwebproject.eu

Citclops: Citizens' Observatory for Coast and Ocean Optical Monitoring
The EU-funded Citclops project aims to develop systems to retrieve and use data on seawater colour, transparency and fluorescence, using low-cost sensors combined with people acting as data carriers, contextual information (e.g. georeferencing) and a community-based Internet platform, taking into account existing experiences Website: http://www.citclops.eu/

FreshwaterWatch
FreshWater Watch is a global citizen scientist project investigating the health of the world’s fresh water set up by Earthwatch, Earthwatch is an international environmental organisation. FreshWater Watch has two levels which work together to investigate the health of the world’s freshwater ecosystems (global and local). Citizen Scientists receive training, use the FreshWaterKit to test water quality and upload their observations on the online FreshWaterPlatform.
Website: freshwaterwatch.thewaterhub.org

GeoChat and Ushaidi are two open source platforms that enable the easy deployment of crowdsourced interactive mapping applications with Web forms/e-mail, SMS (Short Message Service) and Twitter support.
Websites: www.ushahidi.com/about
instead.org/technologies/geochat/

Mobile Water Management (MWM) is a monitoring method registering water levels, groundwater levels, gate openings and water quality tests by simply taking a picture with a mobile device. Compared with manual readings this patented innovation reduces monitoring costs by 50%. An app is using a combination of image analysis and Optical Character recognition (OCR) to read staff gauges, groundwater dippers, water quality test
Website: mobilewatermanagement.com/contact/

The Open Data Kit (ODK)
Open Data Kit (ODK) is a free and open-source set of tools which help organizations author, field, and manage mobile data collection solutions. ODK allows to setup survey forms of basically anything one can think that are automatically georeferenced. Forms can be linked to images, video or text. Will work without internet connection, and data can be synchronized once connection is reestablished.
Website: www.opendatakit.org and https://nafundi.com (Nafundi is a commercial spin-off of the creators of ODK).

WeSenselt-Citizen Observatories of Water, another EU funded project (2012-16), targeting water related issues. WeSenselt was an EU FP7 project developing citizen observatories of water and flooding to facilitate closer engagement and interaction between citizens, authorities and other stakeholders in the governance of water resources.
Website: www.wesensit.eu
More Water Quality Apps

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4586647/

http://scistarter.com/blog/2013/09/picture-saves-thousand-streams-water-quality-monitoring-smartphone/#sthash.tRl0vu8n.dpbc

http://www.fulcrumapp.com/apps/water-sampling-survey/