WATER RESOURCES MANAGEMENT

EXPERTS
Dominic Mazvimavi[1], Ben Maathuis[2]. Based on first version by David Kirugara[3] and Diego Fernandez[4]

INSTITUTIONS
[1] Department of Earth Sciences and Director for the Institute for Water Studies (Faculty of Science), University of the Western Cape, Cape Town, South Africa. dmazvimazi@uwc.ac.za
[2] Department of Water Resources, Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, The Netherlands. b.h.p.maathuis@utwente.nl
[3] Consultant, P.O. Box 6166—00200, Nairobi, Kenya. Tel: +254 721 360 222
[4] European Space Agency (ESA), ESA-ESRIN, Via Galileo Galilei, 00044 Frascati, (Rome) Italy, Tel: +39 06 94180 676 / Fax: +39 06 94180 552

1. INTRODUCTION

1.1. THEMATIC CONTEXT

Africa, after Australia, is the world's second-driest continent. With about 15% of the global population, it has only 9% of global renewable water resources that are either abundant or scarce depending on the season or the place. Furthermore, water is a crucial element in ensuring livelihoods since more than 40% of Africa's population lives in arid, semi-arid and dry sub-humid areas and about 60% live in rural areas and depend mainly on rain-fed agriculture for their livelihoods[1]. Africa faces significant challenges to ensure effective use and efficient management of its water resources:

- The multiplicity of transboundary river basins in Africa poses a challenge for ensuring equitable sharing and development of water resources among riparian nations[2];
- There is low level of development and water utilization. For instance, only about 4% of the available water is used in the whole continent. In the case of irrigated areas, the actual use amounts to less than 10% of the potential, while only 7% of the hydropower potential has been developed, with an electrification gap that keeps on growing[3];
- Africa has a very low level of development of the water infrastructure with less than 50 m^3/person storage capacity having been developed compared to over 3000 m^3/person in Europe and 5000 m^3/person in the USA;
- Most African countries will not achieve the Millennium Development Goals (MDGs) related to the provision of clean drinking water and basic sanitation by 2015[4];
- There is a rapid increase in the demand for water due to growing populations, especially in peri-urban areas and slums, and also improvement of lifestyles. It is estimated that by 2025 about 600 million people will be exposed to water scarcity situation (<1000 m^3/capita/year). This is further aggravated by pollution of surface waters and shallow aquifers caused by industries located along the fringes of urban areas;
- Water-related disasters caused by floods and droughts frequently affect many parts of Africa;
- Climate change has the potential to exacerbate existing adverse effects of floods and droughts, and also reducing the availability of water resources in some parts of Africa;
- Conservation needs to protect the ecosystems and prevent degradation of natural (water) resources. Land degradation which affects many parts of Africa particularly the semi-arid and arid regions adversely affects both the quantity and quality of water resources;
- Most African countries have inadequate institutional, financial and human capacities for managing water resources.

Several African countries are experiencing rapid economic growth and high growth rates of the urban populations resulting in increased demand and competition for water. Population growth has increased the number of people

[1] UNEP (2010): Africa Water Atlas. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), Nairobi, Kenya.
[2] World Economic Forum (2013): Global Risk Report. The report states that "Impact and likelihood of water supply crisis has been ranked within the 'top-5' of global risks".
[3] African Water Facility (2012): Strategic Plan 2012-2016. Towards water for all by 2025.
[4] http://www.un.org/millenniumgoals/pdf/2012_Progress_E.pdf

exposed to water-related disasters. In this complex and challenging context, adequate information for sustainable management of water resources is fundamental for improving water governance and successful implementation of Integrated Water Resource Management (IWRM) strategies. For most African countries, policies and management decisions are often based on sparse and unreliable information[5], which is a major limitation for achieving the water-related MDGs and putting into practice IWRM plans.

1.2. PRESSURES (OR CONSTRAINTS)

African leaders have committed to the implementation of an Integrated Water Resources Management (IWRM) approach in order to achieve sustainable management and development of Africa's water resources. Although progress has been made, a great deal of work still needs to be carried out in order to strengthen and create an enabling environment[6] for water resources management. For most countries, appropriate policies, laws and plans for IWRM implementation are in the early stages of being put into practice except for some North African countries[7]. Virtual water use and water footprint issues are other issues that need to be included in planning and implementation of IWRM.

The provision of data required for IWRM implementation is a major challenge due to poorly developed and/or deteriorating systems for collecting relevant water resources data in most African countries. Consequently policies and management decisions are based on unreliable information resulting in ineffective and unsustainable management of water resources. Without adequate data for planning and managing water resources, competition and conflicts over these resources are not effectively and efficiently resolved. Overcoming challenges arising from inadequate and unreliable data is partly hampered by the reluctance of (inter)national funding mechanisms to provide long-term support for maintaining (*in-situ*) observation networks[8]. Without urgent action to increase the availability of water resources information on a sustainable basis, implementation of IWRM and achieving the Africa Water Vision - 2025 will remain unattainable for a large number of African countries.

GMES and Africa provides an opportunity for the participation of African countries in the rapidly evolving global 'Earth Observing System', (e.g., Global Earth Observation System of Systems, Sentinel series of the European Space Agency and the European Commission, national contributing missions, etc.). This participation will enable collection, management, analysis and dissemination of water-related information, in a cost effective and sustainable way.

2. POLICY DRIVERS AND NEED ANALYSIS

2.1. POLICY DRIVERS

The *Africa Water Vision for 2025*[9] endorsed by the African Ministerial Conference on Water (AMCOW) and by the Heads of States of the African Union during the February 2004 Extraordinary Summit on Water and Agriculture in Sirte, Libya, serves as a basis for formulating long-term national, sub-regional and regional policies and programmes for equitable and sustainable use of water for socio-economic development on the continent. The framework for achieving this shared water vision[10] calls for strengthening governance of water resources, and developing the capacity for collecting and disseminating information about water resources. Since water is intricately intertwined with agricultural production and energy generation in Africa, effective and efficient management of water resources is critical to the agriculture and energy sectors which are the main drivers of

[5] Jerven, M. (2013): Poor Numbers. How we are misled by African development statistics and what to do about it. Cornell University Press. ISBN 978-0-8014-5163-8.

[6] This involves developing and implementing the policy, planning and legal framework needed for guiding and coordinating water resources management, development and use. Transboundary agreements are an important part of the enabling environment for water management, especially in Africa where most countries share water in transboundary basins.

[7] AMCOW (2012): Status Report on the Application of Integrated Approaches to Water Resources Management in Africa. ISBN: 978-87-90634-01-8.

[8] World Water Council (2003). Camdessus, M. (ed). Report of the World Panel on Financing Water Infrastructure: Financing Water for All.

[9] http://www.uneca.org

[10] The shared Water Vision for Africa is defined as: 'An Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socio economic development, regional cooperation, and the environment (Africa Water Vision 2025).

socio-economic development.

The African Union Science and Technology plan[11] which consolidates the science and technology plans of the African Union Commission and NEPAD, places the development, supply and management of water high on the agenda owing to the fact that water scarcity and related insecurity contribute to the continent's underdevelopment. This plan explicitly identifies scientific assessment of Africa's water resources and systems, research and technologies to assess and monitor water-related disasters, and technologies for improving water quality and quantity as the key water projects to be implemented. The African Water Facility (2012-2016)[12] also includes the development of water resources projects, enhancing water governance, and promotion of water knowledge in the current (realigned) strategic plan.

Table 1 below provides additional recent policy drivers relevant to the Water thematic area besides the Sirte Declaration on Agriculture and Water in Africa, the African Water Vision 2025, and MDGs on Water Supply and Sanitation already discussed above.

Table 1: Policy drivers relevant for the Water theme

- AU Sharm El- Sheikh Declaration on Water and Sanitation - eThekwini Ministerial Declaration on Sanitation - Declaration on Climate Change in Africa - Tunis Ministerial Declaration on Water Security - Africa – EU Statement on Sanitation - AU guideline on establishing cooperative framework in transboundary basins - AU Abuja action plan - ClimDevAfrica	- AU comprehensive African Agricultural Development Plan (CAADP) - NEPAD Infrastructure Action plan - NEPAD Environmental Action plan - African programme on action on implementation of the African regional strategy on disaster risk reduction - Great Green Wall for the Sahara and the Sahel Initiative - AMCOMET – Global Framework for Climate Services

The *eThekwini* Declaration is a commitment of African Water Ministers to accelerate the attainment of sanitation MDGs. The *Tunis* Declaration adopted during the first African Water week focusses on improving water security for Africa's social-economic development. The commitments and actions identified under the various declarations have formed the foundation of activities at continental, regional, transboundary and national levels. These activities fall into the following 7 main themes; (i) water infrastructure for economic growth, (ii) managing water resources, (iii) transboundary water resources, (iv) meeting sanitation, hygiene and water MDG gaps, (v) global change and risk management related to climate variability and change, (vi) financing, and (vii) education, knowledge and capacity development. The African Ministerial COnference of METeorology (AMCOMET) is contributing to the achievement of the MDGs in Africa by encouraging the use of meteorological and climatological information and services, linking weather and climate knowledge to disaster risk reduction, developing usable weather and climate products for users at various levels.

From a global perspective as stated in the UN Water's "*4th World Water Development Report*"[13], it is recognized that the absence of systematic data collection in most countries impedes regular reporting on water resources and water-use trends. On the other hand, there is a growing interest in and demand for accurate and consistent water data and accounting. This requires structured data acquisition and subsequent derivation of information about water. This report concludes that little progress has been made in terms of improving observation networks and systems for water resources monitoring. Other international policy drivers include the United Nations Convention to Combat Desertification (UNCCD), and the recent "*Zero Net Land Degradation*" initiative proposed during the Rio+20 Conference. Information about water resources in Africa is also required to complement the international "*Essential Climate Variables*" (ECV's) research agenda.

2.2. THE NEED ANALYSIS

According to AMCOW, Africa's water challenges arise from the need to provide safe drinking water and adequate sanitation, cooperating in managing transboundary river basins, improving use of water for food security, developing hydropower, satisfying the growing water demand, preventing land degradation and water pollution,

[11] NEPAD Office of Science and Technology (2006): Africa' Science and Technology Consolidated plan of Action. Johannesburg, South Africa.

[12] African Water Facility (2012): Strategic Plan 2012-2016. Monitoring Resources for Water in Africa.

[13] United Nations (2012): World Water Development Report. Chapter 6. Muller, M. (ed): Managing Water under uncertainty and risk, Volume 1.

managing water under global climate change, and enhancing the capacity to address these water challenges. An additional challenge relates to the need to provide early warning information regarding the onset and duration of rainy seasons, intra-seasonal dry spells, and rainfall anomalies based on the impacts of El Niño and La Niña.

In December 2007, the '*Lisbon Declaration on GMES and Africa*' was adopted under the aegis of the Portuguese Presidency of the Council of the European Union. This Declaration calls for the preparation of an action plan to be submitted to EU and African constituencies. In this context, the objective of *GMES and Africa* water resources management thematic area will be:

1. To enhance African technical, human and institutional capacities to meet the need for timely, quality long term information at national, regional, transboundary and continental scales as a basis for sound decision making, improved Integrated Water Resource Management and effective climate change adaptation and mitigation plans;

2. To build upon existing initiatives and programmes, and establish long-term sustainable end-to-end information systems and services for the major national and transboundary river basins in Africa and thus enable relevant water authorities and water sector stakeholder to fully exploit the global Earth Observing System in collecting, analysing and disseminating water related information in a cost effective and sustainable manner.

Although IWRM encompasses a wide range of issues such as implementation of policies, laws and plans which differ over the African continent, this Chapter covers the generic elements needed for making appropriate information available for sound decision-making related to water resources management.

3. IDENTIFICATION OF COMMUNITIES

To achieve the *GMES and Africa* objectives, it is fundamentally important to mobilize resources, expertise and contributions from different sectors at national and international levels in order to improve the collection of relevant information for implementing integrated water management plans. In this context, *GMES and Africa* should foster partnerships between the various national stakeholders, space agencies - other data providers, expert centres in applications using Earth Observation derived data for water management such as key universities and international research organizations, the private sector (e.g. value adding companies), relevant NGOs, financial and development agencies.

National Meteorological and Hydrological Services (NMHS) play a critical role with regards to maintaining and coordinating the network of *in-situ* observations, maintenance of long term data archives based on these observations, developing and disseminating usable products from these data, and provision of early warning information. Other relevant national and regional bodies in specific transboundary river basin authorities, are those dealing with renewable energy (hydropower), agricultural production, land and soil conservation, water supply, water quality management, water-related diseases (and health), and those which are part of institutional frameworks for IWRM implementation. All these organizations collectively represent the ***GMES and Africa* Water Theme Stakeholder Group**. Table 2 below categorizes the main stakeholders groups.

Table 2: GMES and Africa Water Theme Stakeholders

Level	Category	Interests
UN agencies	UN-Water; UNESCO – International Hydrological Programme; UNEP DEWA programme and GEMS/Water; UN-Habitat Water and Sanitation Programme; World Hydrological Cycle Observing System (WHYCOS) of WMO; UN-ECA, UNCCD; WHO-UNICEF Joint Monitoring Programme for Water Supply and Sanitation; UNDP Cap-Net, etc.	Global trends on the status, quality and quantity of water resources and improving access to water. Provision of in-situ networks and improving free exchange of data to compliment EO based observation and modelling Capacity building. Early warning and assessment.
International	GEO (e.g. Africa Water Cycle Coordination Initiative and GEO Capacity Building task - EOPower); CEOS; World Water Council; World Water Partnership; Ramsar	Earth Observation data providers for water management and dissemination. Promotion of better practices on water management in Africa. Strategic framework for Water Resource Management.

	Secretariat; Global Energy and Water Experiment (GEWEX); ESA; NOAA-CPC; EUMETSAT and SAF Network (e.g. Hydrology SAF); GEONETCast; FAO-AquaSTAT Programme; etc.	Provision of in-situ networks to compliment EO based observation and modelling. Capacity Building.
Continental	AU, AMCOW; AMCOMET, Experts Centres for Water Science and Technology promoted by NEPAD; Regional Economic Communities in Africa; African Space Agencies; AMESD-MESA; TIGER; AFREF; AfricaArray; TrigNET; ARSIMEWA; AARSE; African Water Academy; Groundwater Commission of Africa and African Network for Basin Organizations, Pan African University, etc.	Providing political direction regarding water management issues across Africa. Ensuring the provision of African EO data to African stakeholders. Networking among African players involved in IWRM. Capacity building.
Regional	River Basin Authorities (e.g. NBI, LCBC, VBA and Réseau Africain des Organismes de Bassin, based in Dakar); Regional and transboundary organizations; Remote Sensing Centres in Africa (e.g. AGRHYMET, RCMRD, RECTAS); OSS; African Meteo Centres of Excellence (e.g. IMTR, SAWS), etc.	Networking, developing and implementing regional water management plans in Africa including capacity building. Potential providers of geo-information in support of envisaged water management plans. Provision of in-situ networks to compliment EO based observation and modelling. Capacity building.
National	Ministries of Water Resources, National Meteorological and Hydrological Services, Water Resource Management Authorities, Soil Conservation Agencies, Hydropower Agencies, Water supply – purification, industrial and urban water sectors, other relevant National institutions, Local Universities; Research Institutions (e.g. CERSGIS, CRTS; CSIR), Ground reception station operators (like SANSA); etc.	Developing and implementing national water management plans in Africa. Real-time EO data collection. Provision of in-situ networks to compliment EO based observation and modelling. Scientific research on water related issues in areas of jurisdiction. Capacity building.
Donors	African Water Facility; European Commission; World Bank; Global Environmental Facility; Relevant Development Agencies	Provision of resources aimed at supporting African countries to achieve MDGs water targets.
International and local NGOs	WaterNET; Water Harvesting and Soil Conservation Networks; Health Agencies; etc.	Capacity building, Water advocacy, Community based mobilization.

4. MAPPING EXERCISE

There are several projects long term programmes and initiatives completed, on-going or planned in Africa using EO technology for water resource management. The PUMA-AMESD-MESA programme and TIGER Africa Initiative typify African - European cooperation in water resource management applications using space technology and are continental in scale, operational in nature, and thus relevant to and can be used as a model for *GMES and Africa.* Other programmes are starting to take shape like the GEO 'African Water Cycle Coordination Initiative' (AfWCCI) or as follow-up from the Rio+20 process, like the objective to have drought policies and drought preparedness implemented in all drought prone regions/countries by 2020[14] for which EO data is instrumental, e.g. as a monitoring instrument. The 'Disaster Charter' is another example. Note that all these programmes are benefitting from sensor observations from new satellite missions, such as the Sentinel satellites intending to provide open and free operational observations over the next 20 years. Table 3 (not exhaustive) provides an overview of potential information services that have been developed or will be developed

[14] UNCCD (2012): Zero Land Degradation, A sustainable development goal for Rio+20.

in the near future.

Table 3: Overview of some programmes relevant for the provision of water-related information

Programmes	***Information services and scale***		***Data collection, accessibility***		***Products, Monitoring and Assessment***	
	Service	***Scale***	***Data Collection***	***Data Access***	***Products***	***Monitoring and Assessment***
PUMA- AMESD and _MESA (on-going)	National Meteorological and Hydrological Services	Sub-Sahara Africa, at country level	Field Data EO Data	Thematic data	Weather and climate information	Continuous reporting and climate outlooks
	Water Management for Cropland and Rangeland Management	Regional (ECOWAS)	Field Data EO Data	Thematic data	Vegetation state; Extent and dynamics of small water bodies;	Yield estimation and drought risks delineation
	Water Resource Management focusing on environmental aspects of watersheds	Regional (CEMAC)	Field Data EO Data	Thematic data	NRT water level for the Ubangi river	Low water alert system
	New MESA services, like the flood service for the SADC region and new Climate RIC	Regional (SADC) and Continental Climate Service (ACMAD)	Field Data EO Data	Thematic Data	To de defined	To de defined
SERVIR Africa	Environmental monitoring and management and (flash) flood modelling and forecasting	East Africa - Continental	Field Data EO Data Modelling	Thematic data	Flooding and droughts	Mitigate against natural disasters
TRMM, CMORPH, UNESCO G-WADI, etc.	Global (near) real-time satellite based precipitation estimates	Continental	Field Data EO Data Modelling	Thematic data, visualize on server	Operational precipitation estimates	Monitoring, forecast and mitigation of hydrologic disasters
Water Cycle and Drought Monitoring over Africa	Real-time monitoring of land surface hydrological conditions	Continental	Field Data EO Data Modelling	Thematic data	Precipitation, evapotranspiration, runoff, snow and soil moisture	Water Cycle and drought monitoring over Africa
TIGER	Various water related application: surface and ground water analysis, water quality, levels, soil moisture, wetland management, mapping of water and catchment characterization, etc. Regional services through locally operated open source Water Observation Information Systems	Continental, regional and local study areas	Field Data EO Data and Modelling	Thematic data	Various thematic products, like ground water potential and exploration maps, NRT soil moisture maps, river and lake levels, etc.	Derived water consumption and extraction estimates, flood mapping, land use change monitoring, etc.
ClimDevAfrica, Global Framework for Climate Services	Provision of climatological, meteorological products and services in support of economic and social development	Continental	Field Data EO Data and Modelling	Thematic data	Weather and climate information	Various meteorological products, early warnings, etc.
GLDAS-NOAH, ECMWF Era-Interim, WMO-GTS and GSOD, Meteorological Data Dissemi-nation Service	Meteorological information, (real time) *in situ* measurements and weather forecast information, numerical weather prediction model data	Global	Field Data EO Data and Modelling	Thematic data	Various thematic products, like mean sea level pressure, winds at various pressure levels, evapotranspiration, total precipitation, etc.	(real time) Weather data and short range forecast, climatological data archive, NWP model data, etc.
Satellite Application Facilities (e.g. LSA-SAF), Copernicus and Africa Platform	Land surface analysis data and vegetation products	Continental	Field Data EO Data and Modelling	Thematic data	Various thematic products, like Albedo, Down Welling Surface Fluxes, ET, LST, Fire and various other vegetation parameters	Continuous thematic product provision

FEWS-Net and NOAA- Climate Prediction Centre	Time series rainfall and vegetation index products	Continental	EO Data and Modelling	Thematic data	Various thematic products, like rainfall, PET, NDVI, etc.	Continuous thematic product provision

5. IDENTIFICATION OF GAPS AND SUITABLE PROGRAMMES

5.1. GAPS

General. Based on the experiences gained and lessons learned related to support service development in Africa, several general blocking factors and gaps have been identified that need to be addressed by the *GMES and Africa* process in order to ensure successful development and implementation of sustainable operational services utilizing Earth Observation derived data. Apart from financial barriers related for instance to high resolution (airborne) image and laser scanning data acquisition, attention has to be given to the following blockages:

- **Institutional blockages**: These include lack of awareness of (new) EO capabilities and limits; low level of penetration of Information Technology (IT) in several African institutions, lack of solid links between users (water authorities) and potential service providers in Africa; lack of solid institutionally established procedures to integrate geo-information into management practices and planning; lack of a solid consolidated group of potential service providers in Africa including technical centres, universities and private sector. Governments still have to register to become members of relevant international bodies, like GEO or the Disaster Charter;
- **Human blockages**: These include lack of skilled technicians and EO operators because of inadequate training programmes for professional operators, and the high turnover of skilled personnel, lack of skilled personnel in water authorities with a good knowledge of GIS and EO technologies, lack of appropriate higher education curriculum in African universities ensuring the consolidation of a critical mass of African professionals in the area of EO applications, collaboration between centres of expertise in general;
- **Technical blockages:** These include the limit of current EO systems that will be significantly enhanced with the advent of new satellites; inadequate *in situ* (telemetric) data infrastructures; lack of full long-term continuity and user-friendly EO data provision and access; inadequate software and hardware infrastructures in African institutions; slow progress in improving fast internet connectivity, lack of ground reception infrastructure over various regions for direct-real time EO data reception and higher order image generation and dissemination; lack of low cost large bandwidth DVB (-S2) telecommunication based ground reception stations to receive (near real-time) from communication satellites large volume of EO data and products, like those from the various Sentinel series of satellites.

GMES and Africa should build upon existing programmes and implementation models with the long-term target for developing an end-to-end African ownership of the full service chain, allowing for the long-term sustainability, institutional and user acceptance of the GMES process. The first prerequisite for sustainable uptake of EO data in Africa is to enable the full, free and open data access to satellite observations, which is currently significantly limited by the available infrastructure, e.g. low internet bandwidth. Overall, the water related service gaps to be addressed are:

- Ensure that all of the African water challenges are fully covered:
  - At local, transboundary, regional and continental scales;
  - Have and use of *in-situ*, EO data and application of models.
- Translating science into practise:
  - Capacity to develop products relevant to water resource problems at various scales;
  - Dissemination of products derived from EO data in a manner that is readily accessible to the users.
- Capacity development programmes addressing continental and regional needs in such a manner that all countries have similar opportunities to develop the capacity which will enable them to participate in utilizing EO data and sharing information at regional and continental scales.

More specific gaps related to the space based observation needs are presented below.

Table 4: Space-based observation needs

Scale	Identification of Gaps	Dimensions that GMES Africa service would provide

Continental	Lack of (continuous – reliable provision of) a core set of continental scale products covering different components of the water cycle: e.g. Precipitation; Evapotranspiration; Soil moisture; Water quality; Surface and ground water levels; (short / long range) forecasting products.	GMES should ensure the provision and accessibility of these products at continental scale; Capacity Building in EO applications, *in situ* and modelling integration to forecast and produce hydrological process early warning tools.
Regional (transboundary river basins) and national	Local operational observational capability for information services addressing the needs of riparian states and stakeholders on major transboundary river basins e.g.: • Base mapping for supporting infrastructure development (water supply and sanitation); • Irrigation areas, Crop mapping; • Ephemeral water bodies; Flooding; • EIA for hydro power, water diversions and impoundment or other water related engineering – diversion plans.	GMES should support the empowerment of key African institutions at transboundary level being able to operate and run information services allowing the observation and monitoring of water resources over major transboundary river basins and lakes in Africa, while offering a coherent service to their riparian countries (e.g. national water authorities) to better exploit and integrate potential GMES African water services into the national planning and decision making activities.
National	Lack of information to assist farmers in decision-making throughout the crop production cycle. IWRM administration and planning; Urban Sanitation	GMES should provide training and support the development, production and dissemination of relevant Earth Observed derived water-related information for assisting farmers in decision-making throughout the crop production cycle, IWRM and sanitation planning.

***In-situ* based observation needs.** Concerning *in-situ* hydrometeorological networks, reference is already made to severely dilapidated or out-dated *in-situ* networks for collection of water-related data in Africa; hence information derived from them is unreliable to (locally) calibrate/validate EO data. Some existing programmes such as WHYCOS facilitates the installation and free exchange of data obtained from several *in-situ* networks to compliment EO based observation and modelling. Additional effort should be directed to use of other observation infrastructures - techniques, e.g. use of microwave links from telecommunication networks and the potential to derive relevant hydrological parameters, like rainfall or equip existing telecom towers with other sensors to derive wind speed-direction, etc. or use of sensors (eddy correlation, scintillometer) on multiple towers to record fluxes, e.g. to derive evapotranspiration.

For *GMES and Africa* service, a strong effort should be dedicated to enhancing permanent *in-situ* network infrastructures allowing data to be regularly collected, harmonised, standardized, and structured in accessible and interoperable databases. Attention should be given to the distribution of the *in situ* network and near-real time availability of the measurements as well. This is critical in order to develop and validate effective operational (near real-time) services that integrate both EO and *in situ* data in a scientifically sound manner.

Table 5: In Situ based observation needs

Scale	Identification of Gaps	Dimensions that GMES Africa service would provide
Continental to national	Inappropriate *In-situ* networks for water management and monitoring; *In situ* data is mandatory for calibration / validation of EO based services in Africa; Other observation methods, e.g. use of telecommunication microwave links or GRACE for ground water! Selection of representative cal/val locations, to; prepare for new satellite missions: e.g. SWOT – to derive discharge, here other *in situ* data is required like cross section information; prepare / test new products / algorithms, e.g. for inland water quality estimation linking EO and *in situ* data.	Problem solving: Focus on basin–wide water budget (rainfall and evapo-transpiration), transboundary river discharges, water extraction (information on well depths, piezometric measurements, well density and pumping rate) for aquifer management, water consumption, water-related infrastructure and investments. Scientific collaboration: Involvement in existing and new satellite missions for validation and if needed the development of locally validated algorithms for (new) products.

Gaps related to climate variability - change. Water resources are inextricably linked to climate, so the prospect of climate variability - change has serious implications for water resources availability and regional development in Africa. Appropriate adaptation and mitigation strategies require hydrological data and information to enable assessment of the impacts. Earth Observation technology provides a major contribution to eliminate the gaps in the availability of water resources information in Africa. Within *GMES and Africa* Water Thematic Area, beneficial synergies need to be created with Climate for Development in Africa Programme (ClimDevAfrica) spearheaded by the African Union Commission and the new Climate Regional Implementation Centre under MESA, proposed for implementation by ACMAD. Together with the NMHS's, these authorities should take the lead to assemble long term climatological data sets and derived climatologies, preferably on the water theme related Essential Climate Variables, in line with the Global Framework for Climate Services. Re-analysis might be a point of consideration.

5.2. EXISTING OR PLANNED THEMATIC FUNDING PROGRAMMES

A number of relevant funding programmes, although not exhaustive, are indicated below:

- **European Water Facility:** In 2004, the EU Council decided to consider allocating a total amount of € 500 million for an ACP-EU Water Facility. An allocation of €200 Million from the 10th European Development Fund (EDF) has been allocated to the Water Facility. Three calls for proposals and the Pooling Mechanism were launched between February 2010 and December 2011. The specific objectives of the 10th Water Facility are:
  - To help achieve the water and sanitation Millennium Development Goals (MDGs), which are to halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation, key prerequisites for reducing child and maternal mortality and combating diseases;
  - To contribute to improving water governance and management of water resources and to the sustainable development and maintenance of water infrastructure.

- **European Development Funds:** The European Development Fund (EDF), funded by the Member States, is the main instrument for providing Community Aid for development cooperation with the ACP States and the OCT. The tenth EDF covers the period from 2008 to 2013 and provides funds allocated to national and regional indicative programmes of the ACP countries, including intra-regional cooperation, and to Investment Facilities. An innovation in the tenth EDF is the creation of "incentive amounts" for each country.

- **7th Framework Programme and Horizon 2020:** Research and development programme of the European Union also supports activates related to GMES and service development, the support for GEO and on other research issues like climate change and water (and waste) management related research and technology development.

- **African Water Facility:** The African Water Facility (AWF) is an initiative led by the African Ministers' Council on Water (AMCOW) to mobilize resources to finance water resources development activities in Africa through the establishment of the African Water Facility Special Fund. The African Development Bank (AfDB) hosts the Facility at the request of AMCOW. AWF applies fast-approval and flexible procedures and can provide support to communities as well as to national and multinational institutions. It is furthermore committed to enhancing water governance and promotion of water knowledge in the current (realigned) strategic plan (2012-2016).

- **Bilateral and multi-lateral funding programmes**, some examples are:
  - UN multi-lateral funds such as through UNICEF related to water and sanitation (in e.g. Ethiopia, Kenya, etc.);
  - Bilateral water sector donor programmes;
  - Programmes by other international donor (e.g. World Bank) and national developing agencies and follow-up funds related to international initiatives, like Rio+20;
  - Collaboration programmes for capacity development such as the funding programmes for WaterNet and Cap-Net (through UNDP).

- **Dedicated programmes** from NGO's, for example WWF is currently funding IWRM programmes in the Southern African region.

6. BUILDING GMES - AFRICA SERVICE

6.1. SERVICE DEFINITION AND PROVISION

On the basis of technical considerations the setting up of an operational observation and information programme for water in Africa requires dedication of significant resources to further consolidate, develop and validate a solid portfolio of scientifically sound information services based on the results of existing initiatives, projects and programmes in African and Europe. This should give special attention to the full data access to and the synergistic use of EO data, *in situ* networks and appropriate model outputs.

Table 6 below provides a summary of some of the potential operational services that could be the basis for the *GMES and Africa* water component. Some of the services listed below have already been demonstrated and validated in several programmes. The *GMES and Africa* water service should be: (i) Pan-African, (ii) utilizing EO data from space agencies, (iii) comprehensive such that end-to-end services are provided with value-added products, (iv) build on existing (research) programmes (e.g. to ensure incorporation of the achievements within AMESD and those foreseen in MESA), (v) maintained and operated by Africans (through further strengthening of African capacity in various African centres of excellence), (vi) linkage with national, regional and continental governance schemes and ensure effective consultation with all stakeholders involved, (vii) equipped with sufficient and continuous funding to achieve sustainable operation of the service. It is furthermore important to aim in the first instance for attainable results, a clear and sound work plan for generation of usable products with appropriate product documentation, including calibration/validation information.

Table 6: Potential GMES and Africa Services

Scale	Service Description	Users
Continental	A core set of continental scale products covering different components of the water cycle at low spatial (approx. 1 Km) but higher temporal resolution (once per day) e.g.: • Soil moisture; • Rivers and lake water levels; • Precipitation; • Potential and actual Evapotranspiration; • Basic meteorological products and short range outlooks, etc. • Water quality monitoring in large lakes (temperature, suspended sediments, chlorophyll, etc.); • Water related disease indicators (rainfall, humidity, etc.); • Integration of some components to derive water balance, etc.; •	National authorities, basin authorities, hydrological services, local communities, farming communities, fisheries industry and other stakeholders. Many of the proposed services also address transversal needs. In particular many of them may cover the needs of: • Agricultural agencies; • Environmental agencies; • Developing agencies (for monitoring and assessment purposes); • Forestry departments; • Weather services; • Civil protection services; Research community
Regional (trans-boundary river basins) and national	Base mapping, linked with socio-economic information, for enhancing infrastructure development with focus on water supply and sanitation at high resolution (approx. 10m or higher if required); Catchments characterization including a core set of products at basin scale at high resolution (10-100 meters): e.g., • Land cover and land use; • Crop and vegetation mapping; • Irrigation areas; • DEM's; • Hydrological Network; Ephemeral water bodies identification and monitoring in arid and semi-arid regions at high resolution (10-20 meters);	

	Support ground water management including (from 10 to 250 meters): • Estimation of water extraction; • Ground water exploration (e.g., identification of infiltration areas); Rapid mapping of flood affected areas at high resolution (10-20 m); Early warning and outlook for droughts; Wetland and protected area monitoring and mapping at high resolution (10-20m): • Water extension dynamics monitoring; • Inundated vegetation dynamics; • Change analysis;	

Advanced information services which are currently still in the research domain should be considered part of a long-term development process aimed at exploiting in a synergistic manner the assimilation of new EO data (e.g. Sentinels, CBERS, PROBA-V, Landsat DCM, etc.), in conjunction with *in situ* data and suitable models (e.g. for runoff modelling, flood mapping, water budget calculations, etc.), but also related to the use of e.g. GRACE for groundwater applications, inland water quality monitoring using higher resolution sensors and applying algorithms initially developed for ocean water to derive inland water quality parameters, river and lake level determination and calculation of river discharge, etc.

6.2. CAPACITY BUILDING

6.2a. NECESSARY ELEMENTS

Considerable differences in EO data application capacity for the proposed Water service exist in Africa with some countries already utilising EO-based systems, while others have little rudimentary capacities. A major component of *GMES and Africa* shall therefore be devoted to ensuring the development of the required human, technical and institutional capacities to empower African nations to participate effectively in implementing and running the *GMES and Africa* water service in a sustainable manner. This will require a significant effort dedicated to:

- Enhancing the long-term development of African operators, technicians and scientist with the capabilities to exploit EO technology for IWRM;
- Enhancing the technical capacity of potential African service providers (institutions with technical competences, regional centres, remote sensing centres) with the capacity to provide GMES services to water authorities;
- Ensuring the enhancement of the *in situ* networks that contribute to GMES services;
- Developing an African private sector that provides value added GMES services to African users. This will require a significant effort in terms of subsidising the initial steps in the development process;
- Enhancing the institutional links between service providers and water stakeholders establishing long-term links and partnerships that may be the basis for long-term Service Level Agreements;
- Enhancing the capacity of water authorities to understand, integrate and use GMES services in their management and operational practices, and thus ensuring clear short-term impacts in the field;
- Enhancing the provision of water related information to the various political levels for sound decision making.

6.2b. STRATEGY

These efforts need to build on the experiences of existing initiatives and capacity building efforts carried out by different institutions (developing agencies) and programmes (e.g. TIGER Capacity Building Facility, AMESD-MESA, WHYCOS, etc.) and take into account key African players already involved in capacity building activities in the water sector (e.g. regional technical centres such as RCMRD or AGRHYMET, WaterNET, Cap-Net, on-going collaborations between universities, both south-south and south-north, etc.).

In this context, it is also worth mentioning the major role that the Expert Centres for Water Science and Technology promoted by NEPAD should play in *GMES and Africa*. In particular, *GMES and Africa* should support the development of those key centres as a basis for service development, service provision and best

practice sharing in Africa. However, the *GMES and Africa* strategy for capacity building should mobilize significant dedicated resources in order to address the needs identified above with the major focus on the following:

In the short term:

- A critical mass of African technical centres and value adding companies need to be established and supported with the capacity to develop, run and operate information services addressing the information needs of the African water sector. Reliable data access to large volume satellite observations is a prerequisite for operating relevant EO services.;
- Users (water stakeholders) need to be supported with the capacity to exploit GMES services and EO-based geo-information to enhance water governance and decision making.

In the long-term:

- High-level Pan African educational programmes need to be developed and supported in order to ensure the continuous provision of post-graduate technicians and managers with a solid knowledge of EO technology and their applications in the water sector (among others).

6.3. PRIORITIZATION OF REQUIREMENTS AND ACTIONS

Implementing operational information services involving EO technology, *in situ* observations, and models is a complex process. The European EO programme 'Copernicus'[15] represents a reference on how the water service can further be defined, developed and implemented at continental scale involving multiple partners and institutions at different political, technical and institutional levels. In this context, the *GMES and Africa* Programme Implementation may follow a similar approach as the one used in Copernicus.

The following key points for implementation are critical for the success of the *GMES and Africa* water thematic area:

- Suitable mechanisms shall be established in order to maintain a long-term dialogue with the different actors in the ***GMES and Africa* Water Theme Stakeholder Group.** This shall exploit existing mechanisms and forums such as the African Water Week, the World Water Week or the World Water Forum and relevant programmes such as MESA. Such *GMES and Africa* forums (having annual occurrence) shall be coordinated at high level by the EU and the AUC with the support of the *GMES and Africa* services coordination group.

- A key element of the consultation process shall be dedicated to improve the communication between African water stakeholders and service providers. For this specific water theme, AMCOW should play a key role, being the African interlocutor in support of AU, supported by AMCOMET.

- *GMES and Africa* shall be an African driven process aimed at establishing long-term sustainable information services in Africa addressing African priorities and needs. In this context, governance shall ensure that African institutions retain the ownership and programmatic leadership of the process.

- GMES data policy should enable free access to African institutions providing *GMES and Africa* services. This data sharing policy should be harmonized with those adopted by GEO. African Space Organizations (from e.g. Nigeria, Algeria, Egypt, South Africa) should be persuaded to contribute to these GEO data-sharing principles and allow free access of data from their missions to ensure the full and open exchange of data, metadata and products. More (GEONETCast) ground receiving stations covering Africa should be established at various African Regional Centres to enable use of EO data from (weather) satellites, to provide real time image coverage and associated derived key (meteorological) products as well as the use of these dissemination techniques for provision of products generated through the *GMES and Africa* services. Action should be taken within Copernicus/GMES to ensure appropriate large bandwidth satellite telecommunication.

[15] http://copernicus.eu/

- Observational infrastructure and network integration will be a key feature to achieving the operational sustainability of *GMES and Africa* water service initiative. This will harmonize the structures for collecting and sharing *in-situ* data since some countries have more advanced structures than others and therefore an independent coordination and harmonization exercise of networks at the African and European level is necessary.

6.4. ORGANIZATIONAL SCHEME

The African ownership of the service definition and development of decision-support tools for (African) stakeholders is the key element that should be taken into account for *GMES and Africa* service model. In this context, the organizational scheme for *GMES and Africa* shall ensure an African driven process involving the following points:

- AMCOW should be the main political driver for the initiative that has to endorse the implementation plan;
- *GMES and Africa* should consider the basin authorities from sub-national to transboundary scales and national water stakeholders as the main users of the services and end-beneficiaries of the process;
- Services should be operated by a number of local and regional technical centres in Africa. It is worth noting that the transboundary water authorities will need to incorporate technical units with the capacity to operate and provide relevant information services. Transboundary basin commissions will play a key role as regional service providers for the different national authorities (e.g. LCBC).

6.5. TIMETABLE

The following three phase implementation strategy is recommended:

- **Phase 1 (3 years). Consolidation period:** aimed at fully developing, validating and consolidating an initial set of services on the basis of existing initiatives, projects and programmes in Africa and Europe. In this context, to successfully define sustainable and fully accepted GMES services for the African water sector, a number of key issues should be taken into consideration:
  - Identification of needs will involve close consultation process with water stakeholders at national and transboundary levels under the leadership of AMCOW;
  - Ownership of the service definition and implementation at all levels should be African (defined by African stakeholders and implemented by African Institutions);
  - The identification of needs and service definition should ensure that different characteristics, conditions and requirements of different institutions and regions are taken into consideration. A one-size-fits-all approach will not work: e.g. water scarcity is a problem in certain areas of Africa and not in others;
  - Suitable service models should be developed depending on regional and national existing institutional set- up and partnerships.
- **Phase 2 (3 years). Scaling up period:** On the basis of the results achieved in Phase 1, selected services should be developed and scaled up (extending the user base together with further development of African capacity to operate and run the selected services). This will involve additional capacity building and institutional development efforts in order to build a solid basis to establish operational and sustainable services.
- **Phase 3 (4 years). Implementation Period:** In this phase, services will be implemented and run in an operational manner.

It is critically important that the timing of the *GMES and Africa* programme is in line with other initiatives, like MESA, to ensure that capacity already developed can be seamlessly transferred. This requires starting *GMES and Africa* by the end of 2017 or in 2018 latest.

6.6. INDICATIVE DEVELOPMENT PLAN AND BUDGET ESTIMATE

Taking into account the required effort against the existing pre-conditions in Africa and with the example of the GMES process in Europe, a proposed budget for independently implementing the water component will amount to about 60 million Euros distributed among the proposed stages as following:

- Phase 1: 10 million Euros
- Phase 2: 20 million Euros
- Phase 3: 30 million Euros

Appropriate funding programmes (European Development Fund) should therefore be mobilised in order to cover the needs to develop and implement *GMES and Africa* Water Thematic Area. Synergy with other *GMES and Africa* services could lead to costs sharing approaches.

7. RECOMMENDATIONS

A number of general priority actions were already highlighted, like:

- Development of information services addressing water resources monitoring and early warning systems, including vulnerability assessment and formulation of adaptation strategies in IWRM especially within the global climate change domain;
- A free and open EO data policy with full support to data access for the African community is a prerequisite for sustainable information services for IWRM;
- Broadcasting of EO data using inexpensive DVB (-S2) based telecommunication broadcast system amongst other means.

The following additional recommendations are proposed for the *GMES and Africa* water thematic area:

Ownership: It is recommended that African ownership of the service definition and development of decision-support tools for water resource stakeholders be the key element that will be taken into account for *GMES and Africa* service model.

Operational scale: It is recommended that the basin authorities from sub-national to transboundary scales and national water stakeholders will be the main users of the services and hence the main end-beneficiaries of the process.

Capacity building: It is recommended that a dedicated Capacity Building Programme at continental scale, building on existing capacity, is further developed to ensure a critical mass of expertise, African technical centres and value adding companies have obtained the necessary capacity to develop and operate EO-based water information services.

Partnerships: It is recommended that a mechanism be created to interface the various African stakeholders with on-going African and international programmes and that there is a clear linkage – network with other components of the *GMES and Africa* services.

8. SUMMARY

Water is intricately intertwined with agricultural productivity and energy generation in Africa which are the main drivers of socio-economic development. Equally important are the MDG's and water related health issues. Implementing Integrated Water Resource Management (IWRM) is a challenging task in Africa where water information systems are poorly developed or deteriorating, resulting in policies and management decisions being based on unreliable information.

GMES and Africa therefore represents a unique opportunity to:

- Enhance African human, technical and institutional capacities to meet the need for timely, quality long-term information at national, regional and transboundary scales as a basis for sound decision making and improved Integrated Water Resource Management and water governance.

- Improve the decision making processes and planning in water resource management in Africa by establishing long-term sustainable information services that overcome the water information gap in Africa by fully exploiting the increasing global EO capacity.

The *GMES and Africa* water resource model can be built on the solid basis of several initiatives that have demonstrated the strong potential of EO-based information to support African progress towards achieving Integrated Water Resources Management at both national and transboundary levels. Key African stakeholders including the African Ministerial Council on Water have supported strongly some of these efforts.

Today, the policy basis is clear; user needs are identified, Basin Commissions and NHMS's are already strongly engaged, methodologies have been validated and demonstrated in several countries. The critical issue for Africa is long-term sustainability. The Lisbon Declaration opens the prospect for a long-term cooperative AU-EU framework which should enable information services to be fully transferred in a sustainable manner to African partners. In order to underpin the high-level Lisbon process, it is necessary to continue building upon existing capacities in Africa, further develop existing cooperation with African partners and the stakeholder community, maintaining existing service capabilities, with special emphasis on capacity-building and building-on-capacity.

The information needs are broad including supporting the establishment of national and regional monitoring and evaluation mechanisms for assessing water quality and quantity, and activities by River Basin Organizations. There are many relevant EO-based precursor services (e.g. base mapping, hydrological network mapping; water availability estimation; catchments characterization; large lake water quality; ground water exploration; water Infrastructure monitoring) already on-going to be re-enforced and build on.

The proposed *GMES and Africa* will accelerate cooperation between African water authorities and other stakeholders, European and African service providers in the context of the AU-EU framework. The African water ministries, river basin authorities, national, regional and transboundary stakeholders are the principal users. African Regional and National Technical Centres are the main service providers, along with universities, research centres and other national institutions.

A 10-year three phase implementation strategy is proposed including a consolidation phase (3 years) followed by a scaling up period of 3 years and a final implementation period of 4 years. The budget proposed for each phase is 10 M, 20 M and 30 Million Euro respectively.

ABBREVIATIONS

AARSE	African Association of Remote Sensing of the Environment
ACP:	Africa Caribbean Pacific
AGRHYMET:	Centre Regional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationnelle, Niamey, Niger
AMCOW:	African Ministers' Council on Water
AMESD:	African Management of the Environment for Sustainable Development
AQUAKNOW:	Dynamic Virtual Space for Information sharing for water sector stakeholders
ARMC:	African Resource management Satellite Constellation
ARSIMEWA:	Applications of Remote Sensing for Integrated Management of Water Resources in Africa
AU:	African Union
AUC:	African Union Commission
CB:	Capacity Building
CEMAC:	Communaute Economique et Monetaire de l'Afrique Centrale
CEOS:	Committee of Earth Observation Satellites
CERSGIS:	Centre for Remote Sensing and Geographic Information Services
ClimDevAfrica:	Climate for Development in Africa Program
COI:	Commission de l'Ocean Indien
CPC:	Climate Prediction Cnetre
CRTS:	Royal Centre for Remote Sensing, Morocco
CSIR:	Council for Scientific and Industrial Research, South Africa
DTM:	Digital Terrain Model
EC:	European Commission
ECMWF:	European Centre for Medium Range Weather Forecast
ECOWAS:	Economic Community Of West African States
EDF:	European Development Fund
EO:	Earth Observation
ESA:	European Space Agency
EUMETCast:	EUMETSAT Broadcast system for Environmental Data
EUMETSAT:	European Organisation for the Exploitation of Meteorological Satellites
GEO:	Group on Earth Observations
GEONETCast:	Global Network of Satellite-based Data Dissemination Systems
GEOSS:	Global Earth Observation System of Systems
GEWEX:	Global Energy and Water Cycle Experiment
GIS:	Geographical Information System
GMES:	Global Monitoring for Environment and Security
GWh:	Gigawatt Hour
IGAD:	Intergovernmental Authority on Development
IT:	Information Technology
ITC-UT:	International Institute for Geo-Information Science and Earth Observation – University Twente
IWRM:	Integrated Water Resource Management
JRC:	Joint Research Commission of the EC
LC:	Land Cover
LCBC:	Lake Chad Basin Commission
LU:	Land Use
MESA:	Monitoring of Environment and Security in Africa
MDG	Millennium Development Goals
NBI :	Nile Basin Initiative
NEPAD:	New Partnership for Africa's Development
NGO	Non Governmental Organization
NHS:	National Hydrological Services
OSS:	Sahara and Sahel Observatory
PUMA:	Preparation for the use of Meteosat Second Generation in Africa
RCMRD:	Regional Centre for Mapping of Resources for Development
REC:	Regional Economic Countries
RS:	Remote Sensing
SAC:	Satellite Application Centre, CSIR, South Africa
SADC:	Southern African Development Community
SAI:	Iullemeden Aquifer System
SASS:	Système Aquifère du Sahara Septentrional or North-Western Sahara Aquifer System
SRTM:	Shuttle Radar Topography Mission
TCBF:	TIGER Capacity Building Facility
TIGER:	A European Space Agency led initiative dealing with Integrated Water Resource Management for Africa using Space Technology

UN-ECA:	United Nations Economic Commission for Africa
UNEP–DEWA:	United Nations Environmental Programme Division of Early Warning and Assessment
UNESCO-IHP:	United Nations Education, Scientific and Cultural Organization International Hydrological Programmes
WHYCOS:	World Hydrological Cycle Observing System
WMO:	World Meteorological Organization of the United Nations