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Introduction

The African Centers of Excellence on Water (ACEWATER2) project, in its second phase (2016-19), promoted by the African Ministers of Water and financed by DG DEVCO, aims at supporting the establishment of Human Capacity Development Programme of the AMCOW (African Ministers' Council on Water) in the Water Sector, strengthens institutional networking and improving research support to policy making by scaling up the approach of the pilot phase.

The main activities of the project consist in:

- Strengthening of two existing NEPAD water Centers of Excellence networks in West and Southern Africa;
- Expanding the NEPAD water Centres of Excellence network to Central and Eastern Africa;
- Strengthening institutional networking and improving research support to policy making in the water sector;
- Supporting the implementation of the African Water Ministers' declaration urging AUC and NEPAD Centers of Excellence to develop a "*Human Capacity Development Programme for junior professional and technician level capacity challenges in the water sector*";
- Developing an Atlas on Regional Water Cooperation.

The project geographical scope covers three major regions: Southern Africa (8 countries), Western Africa (4 countries) and Eastern/Central Africa. The project is implemented by DG JRC (overall project management and scientific cluster) with UNESCO (human capacity development cluster).

Within this project, a Workshop has been organized in Accra (Ghana) from October 31st to November 3rd 2016, specifically devoted to the sharing among CoEs of scientific interests, competences and methods towards the effective planning of (scientific) activities, achievement and delivery of scientific tools and products to support (science-based) decision making processes. By means of scientific as well as technical presentations, round tables and participative sessions, the participants (35 people representing more than 30 Institutions among Universities, Research Centres, River Basin Authorities, Regional Economic Communities and key stakeholders on water issues, further to European research Institutions as CIRAD and CREAF) shared valuable experiences and competences, including case studies, around key thematic pillars, such as: Climate Issues (Session 1), African Water-Energy-Food nexus (Session 2), Groundwater (Session 3) and Water Governance&Diplomacy (Session 4).

Workshop Proceedings gather all relevant contributions in the form of (extended) abstracts and short papers, providing a general overview of key relevant issues and partners scientific interests, turning to be a valuable resource for effective planning of next project steps.

Hydrologie et ressources en eau à l'échelle des petits et moyens bassins du Burkina Faso

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2iE à travers son laboratoire hydrologie et ressources en eau (LEAH) travaille depuis 14 ans sur les aspects irrigation, hydrologie, hydrogéologie et adaptation des populations aux changements globaux. Les activités du laboratoire LEAH visent à contribuer à l'amélioration des connaissances des ressources en eau de surface et souterraine dans un contexte de changements globaux et à étudier les stratégies d'adaptation des populations face à ces changements. Le LEAH se concentre prioritairement sur les petits et les moyens bassins versants. Parmi les projets pilotés par le laboratoire, on peut citer :

- le projet AMMA (Analyses Multidisciplinaires de la Mousson Africaine, 2004-2009) qui a été mené par un consortium de chercheurs de plus 57 institutions de recherche et dont le volet «Ressources en Eau» a été piloté par LEAH. Ce projet avait pour but de modéliser la Mousson Ouest Africaine pour une meilleure prévision climatique et d'évaluer la vulnérabilité des ressources en eau pour des scénarios climatiques futurs (2020 et 2050) ;
- Le projet Afromaison (2011-2014) a été mené par un consortium de 15 partenaires du Nord et du Sud. Il avait pour objectif de contribuer à la mise en place du concept de gestion intégrée des ressources naturelles (GIRN) à l'échelle méso-géographique sur des sites pilotes situés en Afrique du Sud, Éthiopie, Ouganda, Tunisie et Mali;
- le projet Challenge Program (2011-2013) s'était focalisé sur la gestion et l'optimisation des petits réservoirs (Barrage de Bourra au sud du Burkina et Binaba au Nord-Est du Ghana) ;
- Le projet irrigation de complément (2011-2015) avait pour objectif la sécurisation de l'agriculture pluviale au Sahel par l'irrigation de complément dans un contexte de variabilité et changement climatique ;
- Le projet GRIBA (2012-2015) avait pour objectif de comprendre et de prédire le comportement des eaux souterraines en zones de socle africaines ;
- Le projet UEMOA Hydrologie (2012-2015) avait pour objectif de contribuer à l'amélioration de la conception et la gestion des infrastructures hydrauliques et routières en les adaptant aux nouvelles conditions hydrologiques ;
- Le projet AMMA 2050 (2015-2019) a pour objectif d'analyser les événements climatiques extrêmes à l'horizon 2050 en Afrique de l'Ouest et leurs impacts sur l'agriculture au Sénégal et sur l'hydrologie de la ville de Ouagadougou.

Dans le cadre de ses projets de recherche, le laboratoire LEAH a mobilisé différents outils et méthodes selon les domaines de recherche :

- Climat (les sorties de modèles climatiques) : RCM AMMA-ENSEMBLES (11 RCMs) et RCM CORDEX (3 RCMs) ;
- Hydrologie : GR4J (Global, Journalier), GR2M (Semi-distribué, mensuel), IHACRES (Global, Journalier), ORCHIDEE (Distribué, Demi-heure), SWAT (Distribué, journalier) ;
- Hydrogéologie : FEFLOW (Trois dimensions: Ecoulement, Transport de masse et transfert de chaleur) ;
- Socio-économie /Agriculture : CROPWAT (modéle de culture), WEAP (Water Evaluation and Planning System) et MIKE BASIN.

À travers ses projets de recherche LEAH dispose de données détaillées sur des sites pilotes:

- Bassin versant expérimental de Tougou au Burkina Faso (Données socio-économiques, hydrologiques, climatiques et agronomiques depuis 2004) ;
- Bassin versant du Nakambé (Burkina Faso), Bassin versant de l'Ouémé au Bénin et les sous Bassins du Fleuve Sénégal (Gourbassy, Bafing Makana et Oualia) : Evaluation des ressources en eau et de leur vulnérabilité pour des scénarios climatiques futurs (2020 et 2050) ;
- Etude des débits maximaux sur les petits bassins sahéliens (7 bassins au Burkina Faso et 7 bassins au Sénégal, Mali et Guinée) ;
- Gestion et optimisation des petits réservoirs (Barrage de Bourra au sud du Burkina et Binaba au Nord-est du Ghana) (Données climatiques, Niveaux d'eau, Evaporation) ;
- Site expérimental de recherche de Sanon au Burkina Faso : données hydrogéologiques depuis 2011) ;
- Etude du Fonctionnement hydrique, de la productivité agricole, érosion des sols dans le bassin de Tougou dans un contexte de CC (recherche en cours) ;
- Prévision des événements climatiques extrêmes à l'horizon 2050 en Afrique de l'Ouest et Impacts des événements météorologiques extrêmes sur l'hydrologie urbaine au Sahel : cas de la ville de Ouagadougou, Burkina Faso (recherche en cours + suivi hydrologique en cours).

Le laboratoire travaille en collaboration avec le laboratoire HydroSciences de l'IRD de Montpellier, le laboratoire Ecohydrologie de l'EPFL de Lausanne, le Consortium de recherche sur le Climat OURANOS (Canada), ACMAD (Niger), IWMI-Accra, CIRAD, Université de Montpellier 2, Université Pierre et Marie Curie Paris 6, le CNRST du Burkina Fao, IEPF (Canada), le CEH (Royaumes unies) et l'Université de Ouagadougou.

IGAD-HYCOS project achievement and challenges

ABDOURAHMAN Houmed Gaba Maki, IGAD-ICPAC, Kenya

The IGAD-HYCOS (Hydrological Cycle Observation System) Project is one of the major activities of the IGAD Water Programme (Inland Water Resources Management Programme - INWRMP). INWRMP is to strengthen regional and national capacities in the sustainable management of water resources in the region for peace and security, stability and integration and improved water governance. The INWRMP was supported by EU and implemented by IGAD through Technical Assistance (TA) Team between 2010 and 2016 following identified four areas of implementation:

- Establishing Regional Water Dialogue Forum;
- Improve Policy and Legal Frameworks in the Region;
- Strengthen Regional and National Water Institutions in the Region;
- Develop a Regional Water Information System (IREWIS) including IGAD-HYCOS Project.

IGAD-HYCOS provides inputs to the INWRMP's result area 4; it is implemented by the World Meteorological Organization (WMO) through a Project Management Unit (PMU) based in ICPAC premises, Nairobi. At the request of East African Community (EAC) the scope of the IGAD-HYCOS project has been extended to cover additional countries. The participating countries in the IGAD HYCOS Project are the IGAD countries plus Burundi and Rwanda. The project is operational since June 2011 and will be completed on November 2016.

The project is designed to provide the participating countries with a hydrological information system, a tool for regional integrated water resources assessment, monitoring and management. It will also reinforce regional infrastructure for data collection, transmission, archiving and retrieval. The project is expected to also enhance the skills of the NHS's personnel in various technical fields related to the water resources in the participating countries. It will strengthen Regional cooperation in the field of water resources management.

The project is completing the implementation of:

- 163 Stations including 116 for weather and surface water monitoring and 47 for Groundwater monitoring stations. Most of the stations are on data transmission system using GPS/GPRS or METEOSAT network;
- Water database and web portal in every country concerned by the project;
- Seven Regional Training of Trainers on relevant fields for 125 personnel of key institutions;
- Five National training per country are under completion targeting more than 500 peoples at national level;
- Completing the Establishment of IGAD Regional Water Information system to be transferred in ICPAC.

Challenges:

- Difficulties in stations operation and maintenance at national level;
- Data Transmission system issues, GPRS and EUMETSAT;
- Lack of capacity at national level on technical skills;
- Output/products yet to be defined and agreed upon;
- Missing proper data sharing agreement.

The project was conducted in coordination with National Hydrological services of the 9 concerned countries. The technical support from WMO was considerable. The Regional Water information system created by this project need to be sustained and ultimately extended with more stations. The sustainability of the IREWIS will require strong regional support service in ICPAC and national institutional capacity building.

Climate variability and its impact on water resources in semi-arid areas - the case of Botswana

PARIDA Bhagabat Prasad and KENABATHO P.K., University of Botswana

Manifestation of the response of the earth systems to the global change such as climate, land use and land cover changes impact on the intensity and magnitude of floods, droughts and agricultural production, among others. These have far reaching implications on sustainable livelihoods and food security, particularly in semi-arid/arid areas. Botswana located in the Southern African region experiences a semi-arid climate with low rainfall and high evaporation and suffers from frequent droughts, flash floods and inadequate fresh water availability which impact on its food security and livelihood. This water related disasters are also observed in the SADC region, particularly countries around Botswana with different scale and magnitude. Since most of the water related disasters are either climate related or related to land use or both, understanding and planning towards overcoming such disasters would need a regional mapping of such problems.

In the presentation, a general overview of the water resources and climatic variability in Botswana has been discussed based on long term climate data. To understand the climatic regime changes, intervention analyses have been undertaken and then trend determined for the non-intervened data. Furthermore, delineation of rainfall regions has been undertaken using Radial Basis Function and the results are presented to highlight the possible impact of land use on the regional characteristics and vice-versa. Besides this, based on a case study, the contribution of land-use and climate change on water resources has been discussed. To understand the drought dynamics, changes in dryness conditions leading to severity of droughts have been undertaken using Standardised Precipitation and Evaporation Index (SPEI) in different time scales viz: 1-month, 6-month and 12months, and their association with Aridity Index discussed. For drought preparedness planning, the duration for which SPEI was determined has been explored and the state of future conditions determined (i.e. whether it is likely to be wet, dry or continuation of the existing conditions has been assessed through the use of Hurst's coefficient) through rescaled range analysis.

Overall, the presentation will assist the water managers in formulating science-based policies to address water related disasters through sound water resources management policies and strategies particularly in water scarce areas/ semi-arid regions.

Promoting a water secured Africa through adaptive research and innovative sensing

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ABSTRACT

Water Security requires the provision of water in good quality and quantity. This is only possible when water bodies are protected, the right facilities for water treatment and distribution are built and stakeholders are motivated and effectively engaged in the provision of water services for productive uses. Ghana, like most countries of the Sub-Saharan Africa region, faces various challenges in ensuring water security for its inhabitants. The challenges include urbanization and population growth, increasing pollution loads from untreated and unmanaged waste (solid and liquid), seemingly weak institutions and the lack of enforcement of laws and regulations. These are further exacerbated by the impacts of climate change. In order to address these challenges, there is the need to identify the root causes, appraise options for solving them, implement measures that make communities and inhabitants more resilient to these challenges, find innovative ways to monitor and evaluate the effectiveness of the measures put in place and determine their impacts with time (Annor, 2014). In all of these, research which appears not to have received enough attention in countries of the Sub-region is at the heart of the solution for addressing the challenges identified. Adaptive research entails the use of innovative tools to solve trending challenges. It calls for continuous data collection using innovate sensors (in terms of costs and robustness), project appraisals, training in technological advancement and effective engagement with stakeholders especially those at the grassroots, and analysis for informed decision making. The KNUST Regional Water and Environmental Sanitation Centre, Kumasi (RWESCK) is carrying out cutting edge postgraduate capacity development programme (Modules) targeted at supporting policies, guidelines and technologies to address challenges with water resources management in Ghana and West Africa. The Centre is involved in building hydro-meteorological database through the Trans-African Hydro-Meteorological Observatory (TAHMO). The TAHMO is an initiative building Public Private Partnerships (PPPs) with National Hydrological and Meteorological Services in Africa to make water and weather data readily available for adaptive research. This data is essential for developing early warning systems for flood and drought, and agriculture water management in general. The Centre through its staff and research partners such as the Delft University of Technology in the Netherlands, the Water Resources Commission of Ghana, the Ghana Global Water Partnership, the International Water Management Institute and the Volta Basin Authority have carried out extensive research and applications in the area of water resources management in the Volta basin. This includes Agriculture Water Management, Innovative Sensing, and Mainstreaming of Water Security and Climate Resilient Development in development planning in Ghana and other parts of Sub-Saharan Africa. Current research includes mapping open water bodies, flood mapping, run-off and evaporation estimation, as well as soil moisture monitoring in the Volta basin using current satellite images such as Landsat 8, Spot5, Sentinel-1, Sentinel-2 and Radarsat-2 acquired through the European Space Agency's (ESA) TIGER, Alcantara and Spot5-Take5 projects, as well as the Canadian Space Agency's SOAR Africa project. Staff of the Centre supported the development of a water allocation model to evaluate trade-offs between hydropower production and downstream flow requirements for the Akosombo and Kpong dams sponsored by the African Development Bank and led by the Water Resources Commission of Ghana . Research focus areas of the Centre include Integrated Flood Management, Rain Water Harvesting Technologies, Downscaling General Circulation Models (GCMs), Groundwater Exploration and Monitoring techniques, developments of Low-Cost High-Tech Irrigation systems, Water Treatment Technologies and Transboundary Water Management. This paper presents a case study of one of the on-going research by the KNUST Regional Water and Environmental Sanitation Centre, Kumasi (RWESCK) that draws lessons for promoting water security in Ghana and the rest of Sub-Saharan Africa.

INTRODUCTION

The Trans-African Hydro-Meteorological Observatory (TAHMO) is an initiative started by the Delft University of Technology (TU Delft) in the Netherlands together with the Oregon State University (OSU) in the USA. In Ghana, the initiative is led by the Kwame Nkrumah University of Science and Technology (KNUST) with the support of the two founding Universities (TU Delft and OSU), the Ghana Meteorological Agency and Farmerline Limited (a private agro-industry content provider in Ghana).

The World Meteorological Organization (WMO, 2015) reports of a total loss of US$ 2.4 Trillion caused by hydro-meteorological disasters over the past four decades. Sub-Saharan African countries bear the full brunt of these losses: changing climate and weather are challenging its capacity to collect localized information and deliver adequate tools for planning and decision making (Annor et al., 2016). TAHMO intends to help bridge the data gap in Africa, by improving the network of meteorological stations together with National Hydrological and Meteorological Services (NHMS) in Sub-Saharan Africa to a density of 1 station within every 30 km (WMO recommendation). This requires the installation of about 20,000 Automatic Weather Stations (AWS) in Africa. TAHMO has three components: i) the design of robust and cost-effective automatic weather stations suitable for the African climate, ii) climate education in schools (pre-tertiary and tertiary institutions), as well as the iii) development of business models to sustain the operation and maintenance of the weather stations to be installed. After working in Africa for almost 30 years, the initiators of TAHMO realized that maintenance of hydro-meteorological equipment and instruments was a major set-back in the collection of continuous and reliable data for sound decision making through hydrological models. This challenge motivated the TAHMO researchers to design a station that required very little maintenance, had no moving part, no cavity, extremely robust and cost effective (Figure 1). The stations were built with the support of Decagon Devices (now called Meter), a company based in the USA with over 30 years' experience in the design, building, manufacturing and marketing of scientific equipment in the world.

Figure 1: Staff of the Ghana Meteorological Agency installing a TAHMO Generation 2 Weather station at a school in Ghana (Source: Annor et al., 2016)

APPROACH

TAHMO uses the three components stated in the previous section as follows: the design concept is stimulated through "design competitions" organized for tertiary institutions in various countries. Young engineers and scientists from Universities and Polytechnics are motivated to build their own suites of sensors that they find suitable for the collection of data in Africa. Very promising ones like the lightning detection sensors developed by Gilbert Mwangi Kamau from Kenya are then enhanced and scaled-up with the support of Decagon Devices Company. The AWSs designed have telemetry to allow for hourly transmission of data to the servers of the meteorological agencies where functional database is set up to store and process the data collected. The collected data is first passed through an automated quality control system. The sensor suites on the third generation station (MEM) provides a 5-minute resolution data for temperature, humidity, rainfall, wind speed, wind direction, barometric pressure, lightning occurrence within 40 km, solar radiation and has an accelerometer to check the movement of the station. All these measurements are provided each hour by default via a web-API although the reporting time could be set to a few seconds to once daily depending on user needs, preferences and the application. The water and climate education component of TAHMO looks at the placement of the weather stations in educational institutions. This provides a safe and conducive environment for the operation and maintenance of the Stations as well as used for geography and science lessons in the schools under the auspices of the Ministries of Education in the various countries. This is currently very active in Ghana, Uganda and Kenya. At schools, environmental clubs with the support of science and geography teachers can easily dust the solar panel of the station and do minor maintenance while the Meteorological Agencies and TAHMO Engineers attend to major maintenance works when needed. Data is shared with the school using the school2school (www.school2school.net) portal developed (See Figure 2).

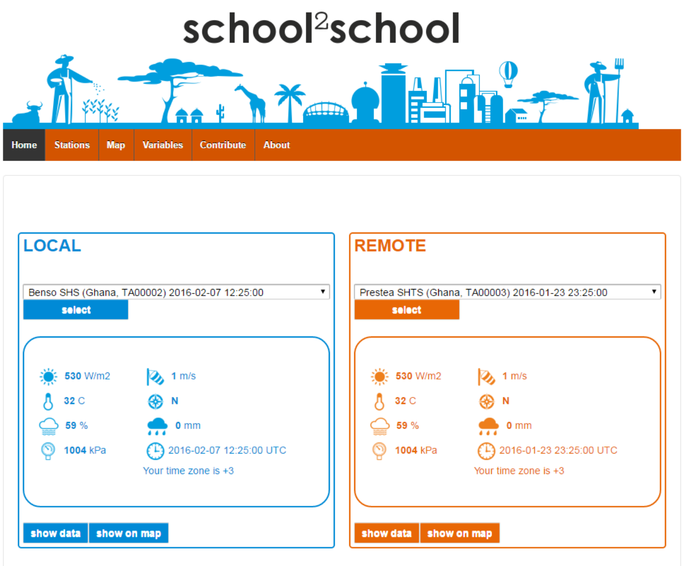

Figure 2: TAHMO School2School Portal

The last component of TAHMO looks at the financial sustainability of the operation and maintenance of the stations. This is what led TAHMO to pilot the PPP arrangement with the NHMS. Various business models have been developed and are being tested to ensure that the stations are kept on-line at all times with a downtime of less than 48 hours with over 95% reliability. To provide user-centered products and services, market surveys have been carried out to determine the specific needs of end-users especially companies that might pay for the services and farmers who need the products and services for the sustenance of their livelihoods. Data is made free of charge to government agencies, for research and for universities.

RESULTS

So far over 100 stations have been installed with a total of 400 planned by the end of 2017. The initiative is just 2 years old and hopes to achieve its aim by 2025. Over 60 schools are active on the School2School program. Two key design workshops have been organized, two Memoranda of Understanding (MoU) have been signed in West Africa (Ghana, Benin) with four more near completion (Burkina Faso, Mali, Cameroon, Nigeria). MoU with Cote d'Ivoire is under preparation. In East and Southern Africa, two MoUs (Kenya, Malawi) have been signed with four (Tanzania, Ethiopia, Uganda, Rwanda) underway.

CONCLUSION

The difficulty of collecting hydro-meteorological data is a major concern and largely due to the fact that the hydro-meteorological data is considered a public good with the full cost borne by government. However, governments support to the NHMS has dwindled over the past decade, making the installation of new stations and the maintenance of existing ones extremely difficult for the national agencies. Development partners have been filling in the gap where national governments have failed. Notably, their supports have been more of aids through projects and the maintenance aspect of the stations remains a challenge after the project completion. TAHMO's PPP arrangement intended to solve this problem while supporting farmers to increase food production for the growing population in the sub-regions. It is projected that Africa will provide 65% of the world's food in the next two decades because of its arable land and climate (AfDB, 2016). This will only be possible with sound planning based on useful and localized agronomic information including soils, water and weather. Research institutions are therefore required to make good use of the data and continuously co-develop products and services that will support adaptation to climate change and climate resilient development in the water-energy-food nexus in Africa.

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Le Système d'information sur l'eau pour une meilleure connaissance et une gestion durable des ressources en eau en Afrique centrale.

TANANIA KABOBO Charles, Economic Community of Central African States, Gabon

ABSTRACT

The analysis of water resources management in Central Africa highlight the lack of reliable water information systems at both country, basin and regional levels, with at best the existence of scattered systems handling one or more thematic, but with no access to other actors in the water sector. Although some countries in the Region have a national water information system, and for those who are implementing it, a regional gathering and synchronization system seems essential and must be implemented at the basin and regional levels to gather needed data to process the reliable and detailed water information for a sustainable management, development and valuing of water resources with appropriate water infrastructures.

L'analyse des états des lieux mettent en évidence l'absence de systèmes d'information sur l'eau fiable au niveau des pays et des bassins avec au mieux, l'existence de systèmes épars traitant d'une ou plusieurs thématiques mais restant inaccessibles aux autres acteurs du secteur de l'Eau. Quoique certains pays de l'Afrique centrale disposent déjà d'un SINEAU, et pour ceux qui le mettent en place entre temps, un dispositif de collecte et de synchronisation régional s'avère indispensable et doit être mis en place au niveau des bassins et régional pour récupérer les informations nécessaires avec le niveau de détail du Système d'Information sur l'Eau pour la gestion, le développement et la valorisation des ressources en eau à travers des infrastructures hydrauliques adaptées.

CONTEXTE GENERAL DE L'INFORMATION SUR L'EAU EN AFRIQUE CENTRALE

L'état de l'information sur l'eau dans la Région de l'Afrique Centrale est caractérisé par une complexité à décrypter en trois grands aspects. Il s'agit de :

1. La complexité liée à la diversité des échelons de production et d'utilisation des données et des informations sur l'eau. Ces échelons s'étendent : i) au niveau transfrontalier: étendue spatiale régionale et de bassin, et ii) au niveau national et local;
2. La complexité liée à la dispersion des données sur l'eau. En fait, l'étude de l'état des lieux, menée au niveau régional et dans dix pays de la région, sur la disponibilité et la gestion des données sur l'eau et de l'information sur l'eau a révélé des faiblesses et des lacunes marquées par l'existence de systèmes épars traitant d'une ou plusieurs thématiques mais restant inaccessibles aux autres acteurs du secteur de l'eau.
3. La complexité liée aux difficultés d'accès à l'information technique et scientifique sur l'eau. L'accès reste très limité lorsqu'il existe, et dans ce cas les données et les informations sont souvent peu fiables et surannées.

Devant ce tableau complexe de la gestion des données et de l'information sur l'eau, et face aux constats pessimistes quant à la capacité actuelle des pays à fournir les données statistiques exigibles pour une gestion durable et efficiente des ressources en eau avec le niveau de qualité et de régularité demandé, les Hautes Autorités de l'Afrique Centrale ont, dans le cadre de la mise en œuvre de la Politique Régionale de l'Eau adoptée en 2009 à Kinshasa par les Chefs d'État et de Gouvernement, décidé de mettre en place le Système régional d'Information sur l'Eau (SIE).

Le SIE aidera à combler les lacunes en matière de disponibilité et de gestion des données et de l'information sur l'eau en Afrique centrale et dans chacun de ses pays en prenant en compte les facteurs institutionnels, les systèmes d'information sur le secteur de l'eau et les réseaux hydrométriques, hydrologiques, hydrogéologiques, climatologiques et qualitatifs existants.
Les résultats escomptés de la mise en place du SIE devront permettre à cerner les besoins et les demandes en eau en terme de développement des infrastructures hydrauliques et de valorisation des ressources en eau de l'Afrique Centrale. Ils contribueront

aussi à renforcer les capacités thématiques, technologiques et humaines des acteurs nationaux et régionaux de l'eau en matière de gestion des SIE (Figure 1).

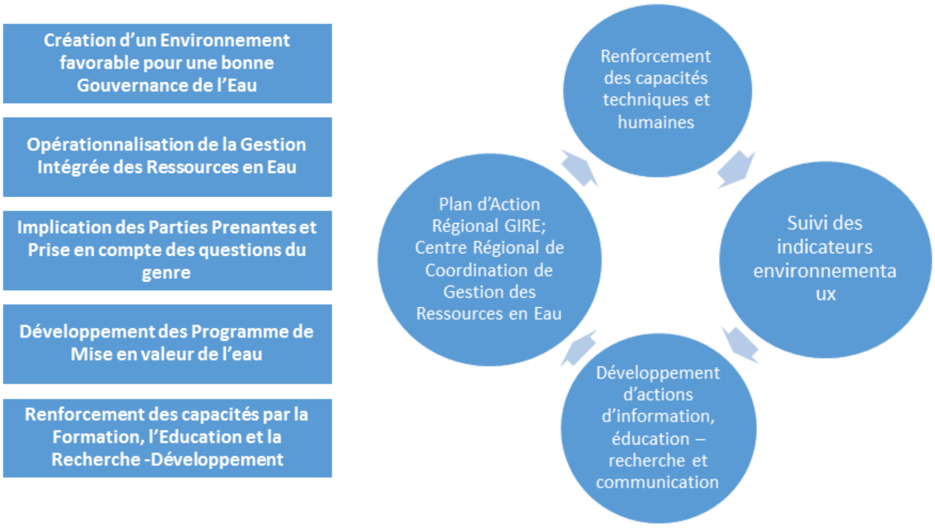


Figure 1: les 5 Axes de la Politique Régionale de l'Eau de l'Afrique Centrale (gauche) et Ensemble d'Outils inter reliés pour assurer la bonne gouvernance de l'eau (droite).

VISION DU SYSTÈME D'INFORMATION SUR L'EAU DE L'AFRIQUE CENTRALE

La Vision du système d'Information sur l'eau de l'Afrique Centrale est de mettre en place un outil organisé comprenant des éléments relatifs à l'eau (données, équipements, logiciels, procédures, personnels, institution, etc.) constitués en ensembles inter reliés qui se coordonnent (mesure, saisie, stockage, traitement) pour concourir à la restitution d'une information d'aide à la prise de décisions éclairées en gestion intégrée des ressources en eau, pour leur valorisation et leur développement durable.

Cette information restituée vise à l'avancement des connaissances des administrations, des gestionnaires, des aménageurs d'ouvrages hydrauliques, des intervenants des secteurs institutionnels et privés, ainsi que du « grand public ».

Le SIE se fonde sur un référentiel régional sur lequel s'imbriquent les référentiels nationaux communs en vue de modéliser et de structurer les données et les informations sur l'eau et de les classer sous forme de domaines thématiques pour une coordination efficiente permettant une restitution de l'information homogène et utile à l'aide à la décision (Figure 2).

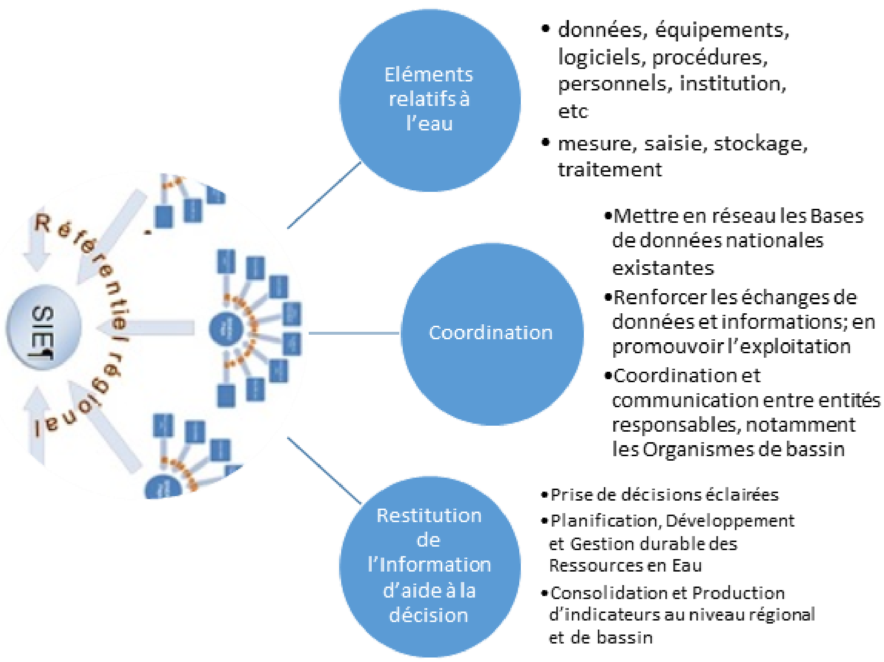


Figure 2 : cadre conceptuel du SIE.

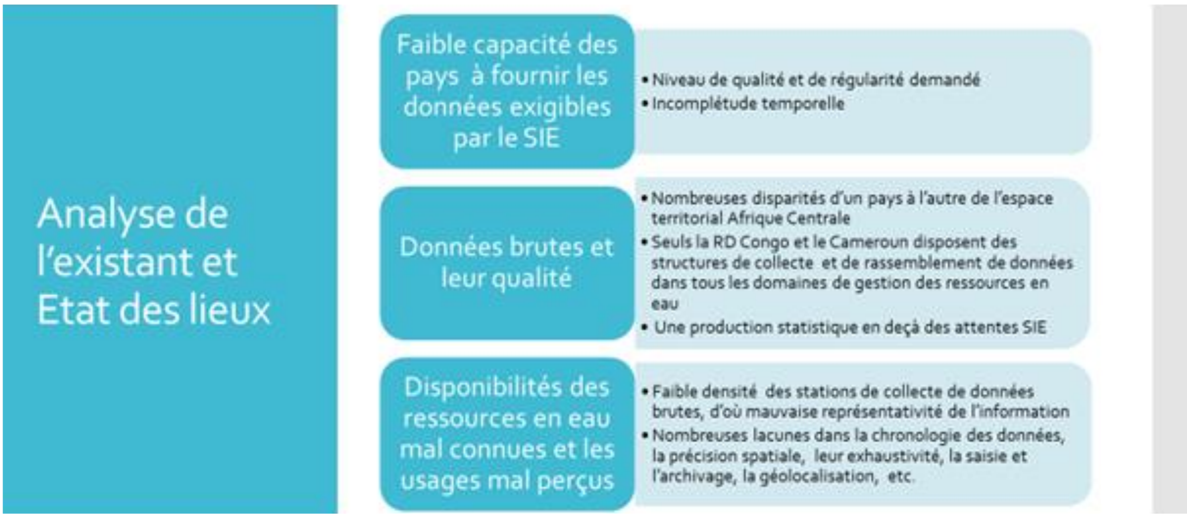
OBJECTIFS DU SYSTÈME D'INFORMATION SUR L'EAU

L'objectif du Système d'Information sur l'Eau de l'Afrique Centrale et de constituer une base de données et d'informations fiables sur les ressources en eau et leurs usages en Afrique Centrale, en vue d'en assurer un suivi dynamique et environnemental, et de permettre et de renforcer l'échange de données entre acteurs et produire des outils d'aide à la décision.

ETAT DE LA SITUATION DE LA SITUATION DE L'INFORMATION SUR L'EAU EN AFRIQUE CENTRALE

Les tableaux ci-dessous (Figure 3) donnent les résultats de l'analyse de l'état des lieux de la gestion des données et de l'information sur l'eau en Afrique Centrale. En somme, il se dégage :

- La faible capacité des pays de l'Afrique Centrale à fournir des données exigibles par le système d'information sur l'eau ;
- Les données disponibles sont brutes et éparses avec une qualité souvent pas trop satisfaisante ;
- Les disponibilités des ressources en eau sont mal connues et les usages mal perçus.



Existant et Besoins des acteurs

	Etat	Angola	Burundi	Cameroun	Congo	Gabon	Guinée Equatoriale	RCA	RDC	Sao Tomé et P	Tchad	%
Eaux de surface	DNG	7	7			9	27			9		15%
	DG	14	9	16	15	12	4	11	10	9	22	31%
	DNC	33	38	38	39	33	23	43	44	36	32	55%
Eaux souterraines	DNG		1	1		1	13			3		14%
	DG	2	1	2	8	3		3	3	2	8	23%
	DNC	52	52	51	46	50	41	51	51	49	46	64%
Total	DNG	7	8	1		10	40			12		14%
	DG	16	10	18	23	15	4	14	13	11	30	29%
	DNC	31	36	35	31	29	10	40	41	31	24	77%
%	DNC	57%	67%	65%	57%	54%	19%	74%	76%	57%	44%	57%
	DNG ou DNC	70%	81%	67%	57%	72%	93%	74%	76%	80%	44%	71%

Figure 3 (a/b) : analyse de l'état des lieux de la gestion des données et de l'information sur l'eau en Afrique Centrale; LDNG = Données non gérées au niveau pays; DG = Données gérées au niveau du pays avec indication éventuelle du système permettant sa gestion; DNC = Informations manquantes sur la gestion au niveau pays des données.

Avec l'analyse de la situation de l'information sur l'eau, les besoins ci-après ont été identifiés. Il s'agit notamment de:

1. Mettre en place des Systèmes nationaux d'Information sur l'eau arrimés au Système Régional d'Information sur l'Eau:
   - Offrir l'accès aux structures disposant des données ou bases de données sur l'eau à déposer dans le SIE selon une fréquence donnée et un format approprié;
   - Améliorer les arrangements institutionnels pour la gestion du Système d'Information sur l'Eau.

2. Articuler le SIE à trois niveaux pour répondre à la Vision SIE:
   - Référentiel commun au niveau régional afin de faciliter le partage, la codification et l'encapsulation des données au niveau pays, bassins et région;
   - Constitution des Centres de compétence à rayonnement régional avec des équipes partageant des outils de connaissance et de gestion des ressources en eau de l'Afrique Centrale.

3. Établir des protocoles d'échanges de données sur l'eau entre acteurs:
   - Besoins en données générales, thématiques et sur les ressources en eau;
   - Diffusion de l'information et partage des données;
   - Besoins en renforcement des capacités.

DOMAINES THÉMATIQUES DE CLASSIFICATION ET D'INTÉGRATION DE L'INFORMATION SUR L'EAU EN AFRIQUE CENTRALE

Les domaines thématiques de classification et d'intégration de l'information sur l'eau en Afrique Centrale peut être matérialisée dans les deux structures (Figure 4) ci-dessous qui montrent respectivement comment l'information sur l'eau s'intègre globalement dans l'information environnementale, dans les programmes et projets de valorisation des ressources en eau, le tout dans un contexte de la Politique régionale de l'eau adoptée en 2009 par les Chefs d'État et de Gouvernement de la Communauté Économique des États de l'Afrique Centrale.

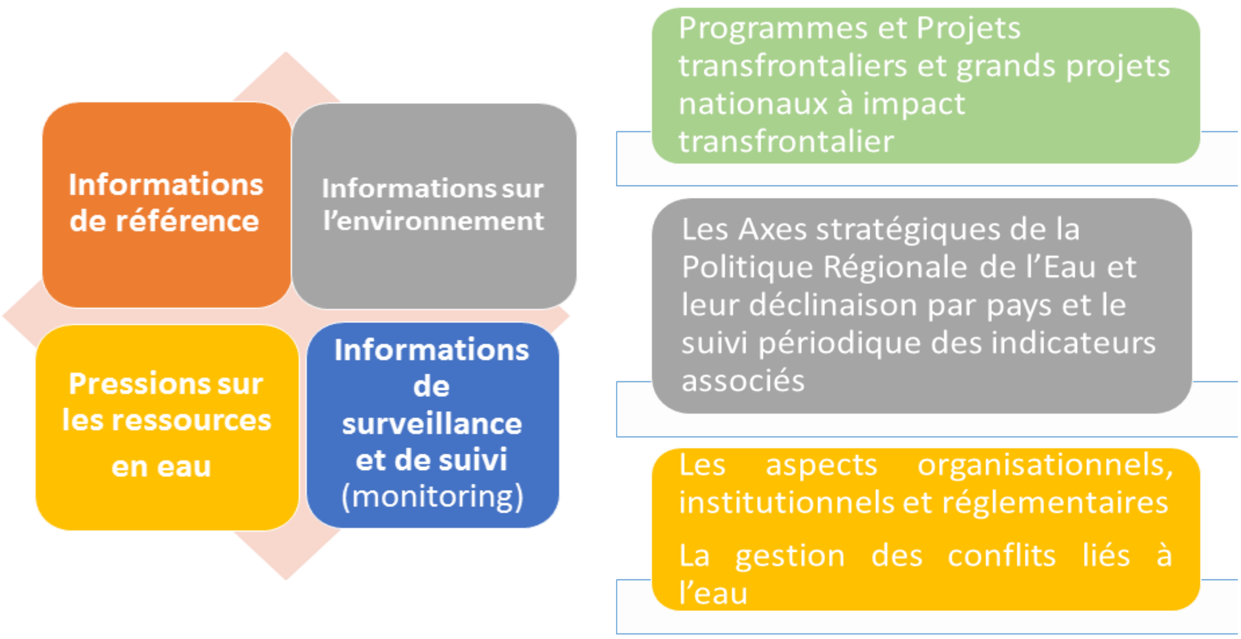


Figure 4: structures de classification et d'intégration de l'information sur l'eau en Afrique Centrale.

NWRC-Egypt contribution in the framework of ACEWATER2 project

SAAD Samy Abdel-Fattah, National Water Research Centre, Egypt

The Nile River basin is one of the most complex river systems in the world. It extends from 4° South latitude to 31° North latitude, from wet regions of fairly heavy rainfall on the Ethiopian and Equatorial lakes plateaus to arid and rainless regions in the north of the basin. The basin contains many varieties regarding climate, topography, geography, and other physiographic, geomorphologic and hydrologic characteristics. The Nile basin is shared by eleven countries: Burundi, D.R. Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, South Sudan, Tanzania and Uganda. It has a length of about 6,750 km and a catchment area of about 3,300,000 km2. It originates in two distinct geographical and climatological zones: the Blue Nile, Atbara and Sobat rivers originate from the Ethiopian Plateau and the White Nile, which originates from the Equatorial Lakes.

Only a fraction of the rain falling on the watershed is channeled through the river to its downstream part. The revenue of the Nile River from the proceeds of rain falling on Equatorial, Ethiopian plateau constitutes 5% of the total amount of rainfall which is estimated at 1660 billion cubic meters annually. In spite of that, the water shares of Egypt and Sudan are only 55.5 and 18.5 BCM, respectively, in accordance with the 1959 Agreement. The main tributaries draining the discharge of the Equatorial Lakes are Bahr El-Gebel and Bahr El-Zaraf, where they both discharge into the White Nile. Bahr El-Gazal catchment starts with several tributaries that discharge in some swamps where most of the water is lost by evapotranspiration and deep percolation in a very wide swamp region.

On other hand, Egypt faces serious risks from climate change. With 93% of its water coming from the Nile River and 97% of its population living along the Nile River Delta, a substantial reduction in flow of the Nile would pose a serious risk to Egypt. In addition, sea level rise threatens settlements and agriculture in the Nile Delta and also in the Red Sea. Egypt has no effective rainfall, except in a narrow band along the northern coastal areas where some rain-fed agriculture is practiced. Ground water underlying the Nile Valley and the delta entirely depends on both deep percolation and seepage of irrigation water diverted from the Nile. These characteristics and conditions of the Nile basin offer great opportunities for the shared countries to cooperate in order to achieve the sustainable developments for their people.

The National Water Research Center NWRC is the research arm of the Ministry of Water Resources and Irrigation of Egypt. NWRC is a center of excellence that possesses the knowledge and expertise in water resources, and dedicated to conduct applied research at the highest water policy-making level. NWRC conducts applied research vital to the management, development and protection of Egypt's water resources. In addition, NWRC leads the way in monitoring and assessing the status of water quantity and quality, and to find the proper and economic design for water structures.

NWRC's organization consists of twelve research institutes; basically tackling the following water related topics: Water Resources Planning, Development, Management and Conversation, Irrigation and Drainage, Hydraulic structures and Machinery, Navigation and River Transport, Application of Nano Technology and Nano Materials in Hydraulics and Water Quality, Surface and Groundwater Hydrology, Erosion and Sediment Transport, Water Quality Management, Coastal and Lake/Shore Environment Protection, Integrated Coastal Zone Management (ICZM), Climate Change and Geo-Measurements Analysis, Socio-Economic Aspects in Water Related Projects, Water-Food-Energy Nexus. Each of the institutes covers one or more of these research areas. NWRC offers a wide spectrum of high quality capacity building programs and hosts a number of training modules supported by national, regional and international donors. Among these modules are:

- Quality of Laboratory Analysis to Counter Environmental Risks
- Maintenance and Aquatic Weed Management in Open Channel
- Physical Modeling and its Applications in River Management
- Hydrographic Survey and GIS Applications in Rivers

- Basic and Applied Techniques for Flow Discharge and Bed Sampling Measurements in Rivers
- Flash Flood Management: From Theory to Practice
- Watershed Modeling and Application of GIS in Hydrology
- Engineering Aspects of Water Harvesting in Arid / Semi - Arid Environments
- Hydropower Development
- Pump Design, Performance, Operation, and Maintenance
- Environmental Impact Assessment of Water Related Projects in Dry Regions
- Introduction to Climate changes sciences, data, models, vulnerability and adaptation

The cooperation between the African centers of excellences in water in the scientific and capacity building activities through the ACEWATER-2 project will enables us to overcome the challenges of shortage of water availability per capita, food security, climate issues.

Scientific activities performed by the National University of Science and Technology of Zimbabwe

CHINYAMA Annatoria, National University of Science and Technology, Zimbabwe

National University of Science and Technology (NUST) is mainly focused on science and technology research although it also looks at socio-political issues surrounding the science and technology especially in water and environmental science. The main "water-crises-cooperation" thematic area of interest for NUST are as follows: Climate Change / Variability; Water Quantity and quality; WEF (Water-Energy-Food nexus); Industry; Health (Sanitation, waterborne diseases); Socio – demography; Politic –Governance.

The geographical research scope for the institution has been at regional scale as we are in a drought prone water scarce region. Collaboration on National projects with other universities and research institutions have also been undertaken. Past and ongoing case studies have been on management of water demand in collaboration with the local municipality, water pollution of rivers bordering the city from waste from the city's industry and wastewater plants; water pollution of rivers in the region from small scale mining activities; water treatment technologies for rural communities in the region; waste water reuse for irrigation and food production.

Planned projects include wastewater management technologies and climate change adaptability strategies. Methods of analysis have been statistical and experimental, models in hydrology have been limited by lack of resources. Data scale and sources are regional and local. Ground based collected data is in the form of reports of projects produced and monitoring networks, have not been established. Spatial and temporal data collection frequency is as per needs of a particular project.

EXAMPLES OF CASE STUDIES

Exploitation of alluvial aquifers for increased food production in Mzingwane Sub-Catchment, Limpopo transboundary basin.- *(A4 Labs - Arid African Alluvial Aquifer Labs securing water for development)*

Partners: UNESCO-IHE, Dabane Water Trust, ZINWA, Mzingwane Catchment Council, ADCR, Direcção Nacional, Oxfam Novib, Oxfam Mozambique, Mekelle University-Ethopia, Wukro Saint Mary College- Ethopia, Relief Society of Tigray REST-Ethopia, University of Zimbabwe, National Directorate of Water Supply and Sanitation- Mozambique, Dept. of Irrigation Development- Zimbabwe

- Developing a groundwater and surface water management framework for utilization of potable water resources within Bulawayo and its surrounding environs
  Coordinated by Geophysics Research Group- NUST

TOOLS AND METHODS

- GIS and remote sensing techniques, rainfall data analysis (MESA weather station being set up) and water table monitoring for the entire area of study;
- Use of structural geology and stratigraphy to establish the vulnerability of groundwater resources to contamination;
- 2D visual model of the vadose zone solute transport;
- numerical models;
- screening area surveys to map out levels of background radiation.

The biggest challenge in scientific activities at the institution has been lack of resources as well as effective collaboration with external institutions such as the Meteorological Department. Under the ACEWATER2 project, efforts will be made to strengthen relations with organizations that can share data as well as those that can use the data generated.

Research activities performed by the Water Research Centre (University of Khartoum) relevant to ACEWATER2 project

GAMALELDIN MORTADA Abdo, University of Khartoum, Sudan

The Water Research Centre, University of Khartoum is a multidisciplinary research and capacity-building center established by the University of Khartoum in 2009 within the Faculty of Engineering. It aims at conducting multi-disciplinary research and development studies about water and the environment, promoting capacity-building through continued training of water resources professionals, providing technical, strategic and policy advice to policy makers and stakeholders and enhance the role of the university in community development and its involvement and leadership in regional and international water activities. In 2014, the Ministry of Higher Education and Scientific Research have awarded the Centre as Centre of Excellence in Water Research. The center has seven departments specialized in various aspects of water resources and environmental management and conducting research in areas relevant to the scientific component of ACEWATER2 project. Research areas include arid zone and dry land hydrology, flash flood and drought management, water conservation, watershed modeling and management, climate change studies, irrigation management and water use efficiency, water supply sanitation, water quality management as well as transboundary water management and water-energy-food security nexus for the Nile river basin. The center has scientific collaboration with many universities, research institutions, specialized networks and programs nationally, regionally and internationally. These include UNESCO International Hydrological Program (IHP), Global G-Wadi (Water and Development Information), African G-Wadi, Arab G-Wadi, International Flood Initiative (IFI), International Sediment Initiative (ISI), World Bank-Nile Basin Initiative NBI/, Eastern Nile Technical Regional Office (ENTRO), UNESCO-IHE, Delft University in Netherlands, Cologne University of Science and Technology in Germany, Imperial College of Science and Technology in London, Oxford University as well as many African Universities including Addis Ababa and Nairobi Universities, Kenyatta University, Dar el Salaam, Cairo and Ain Shams Universities. The following are few case studies in which advanced methodologies have been applied such as hydrological and hydro-geological modeling, climate change modeling and remote sensing (RS) and geographic information system (GIS).

CASE STUDY 1: DEVELOPMENT OF REGIONAL FLOOD FREQUENCY CURVES FOR THE EASTERN NILE RIVERS (ABDO, 2014)

In this study, flood frequency analysis was carried out for the rivers of the Eastern Nile basin (the Blue Nile and its tributaries and river Atbara). The aim of the study was to establish the underlying statistical distributions for various sites in the basin, to derive hydrologically homogenous regions and establish the corresponding regional frequency curves. The analysis was statistical using at site instantaneous annual maximum flood peaks as well as regional data. For around 30 years at seven stations across the basin, different flood frequency models and parameter estimation methods have been used. The selection of the best site model was based on the results of a Chi-squared test, the root mean squared error and the standard error estimates. To cater for very high floods with larger return periods and to avoid inaccuracies resulting from extrapolation of the probability distribution, a separate analysis of the general behavior of the tail of the distribution was carried out using the extreme value theory and Q-Q plots. The results of the at- site analysis show that the three parameter log normal distribution allows a most accurate calibration for all the stations. The extreme value analysis reveals a normal tail for all the stations and the EVI or Gumbel distribution as the best fit. Regional frequency analysis shows that the Easter Nile basin can be divided into two distinct homogenous regions, namely the Blue Nile and River Atbara regions. Consequently, a flood frequency curve was developed for each region (Figure 1). Regression analysis was later applied to develop a relationship between the mean annual flood and catchment characteristics. The developed regional frequency curves and regression model can be applied for the estimation of floods with various return periods in un-gauged catchments homogenous with the regions under consideration.

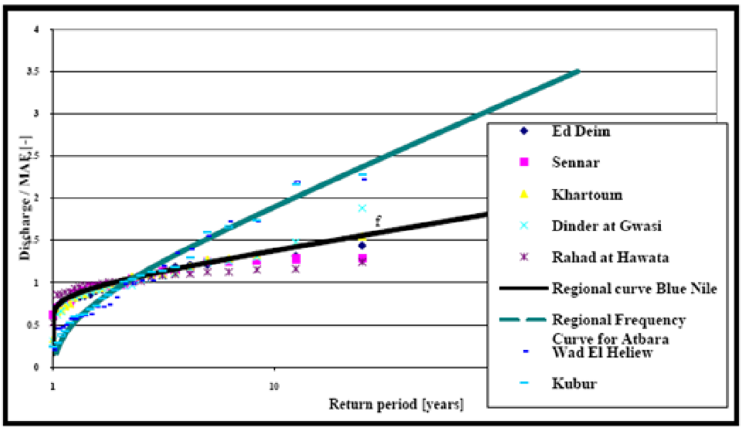


Figure 1: Flood Frequency curves for the Eastern Nile Regions

CASE STUDY 2: DROUGHTS AND FLOODS OVER THE UPPER CATCHMENT OF THE BLUE NILE AND THEIR CONNECTIONS TO THE TIMING OF EL NIÑO AND LA NIÑA EVENTS (ZAROUG ET AL, 2014)

This study was carried out as part of PhD research at the Water Research Centre. The aim of the study was to investigate the occurrences of droughts and floods over the upper catchment of the Blue Nile and their connections to the timing of El Niño and La Niña events. The Blue Nile originates from Lake Tana in the Ethiopian Highlands and contributes about 60–70% of the main Nile discharge. Previous studies investigated the relationship of sea surface temperature (SST) in the Pacific Ocean (Niño 3.4 region) to the occurrence of meteorological and hydrological droughts in the Nile Basin. In this work, focus was on the dependence of occurrence of droughts and floods in the upper catchment of the Blue Nile on the timing of El Niño and La Niña events. The comparison between the discharge measurements (1965–2012) (Figure 2) at the outlet of the upper catchment of the Blue Nile and the El Niño index shows that when an El Niño event is followed by a La Niña event, there is a 67% chance for occurrence of an extreme flood. Furthermore, it was also found that 83% of El Niño events starting in April–June resulted in droughts in the upper catchment of the Blue Nile. Although the current study is limited by the reduced number of samples, it is proposed that observations as well as global model forecasts of SST could be used in seasonal forecasting of the Blue Nile flow.

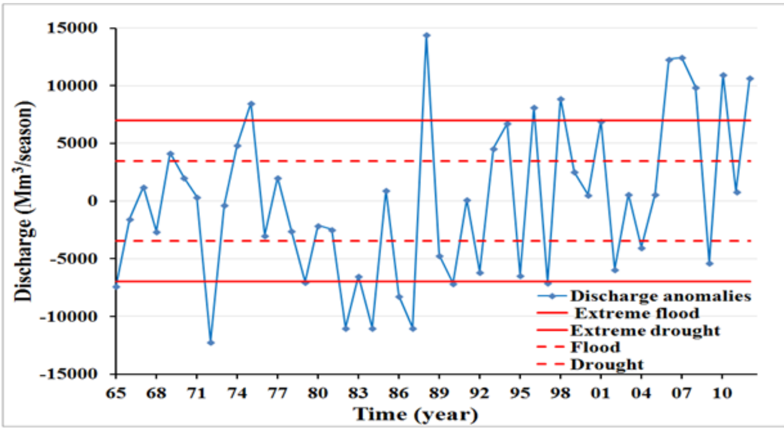


Figure 2: Discharge Anomalies of the Blue Nile at the outlet of the Blue Nile (note that over 50 years, 39 floods and drought events have occurred, 18 of them were extreme flood or drought events)

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Water-related research activities performed by the University of KwaZulu-Natal (South Africa) and potential contribution to the ACEWATER2 Project

SENZANJE Aidan, University of Kwa-Zulu Natal, South Africa

ABSTRACT

The University of KwaZulu-Natal (UKZN) is involved in a wide range of water-related research activities right across the various units, programs and centers. What follows below is a summary of the units at UKZN involved in water related research, the actual research activities under the main 'water-crises-cooperation' thematic areas of interest and the potential linkages or contribution to the programme. The research units include the Center for Water Resources Research (CWRR) involved in research and capacity building in the areas of water resources and currently has a wide range portfolio of research topics ranging from hydrological process studies through to agricultural water management, such as: climate change and variability (CC&CV), water quantification, agriculture and the Water-Energy-Food (WEF) nexus. The Pollution Research Group (PRG) of the university conducts innovative research projects on water resources, wastewater reclamation, the impact of effluents on local environments, sanitation systems, and other water related environmental issues. The Centre for Civil Society (CCS) in the School of the Built Environment and Development Studies (SoBEDS) undertakes research on global warming, energy and water, amongst the others. The Farmer Support Group (FSG) looks at governance issues in water, and other systems. All these contribute directly to the thematic area of the framework that include access to water, hydropower, governance and socio-economic issues. This extended abstract presents selected research work that fits into the planned ACEWATER2 research in Southern Africa across the Zambezi River Basin that is mainly populated by smallholder farmers whose livelihood strategies are agro-based. Therefore, relevant area of research includes rural water supplies and agricultural water management, with application on small-scale rural water infrastructure (SWI), smallholder irrigation development and performance, and soil and water conservation practices uptake by smallholder farmers.

INTRODUCTION

The bulk of the economies in southern Africa are agro-based, with an estimated 60% of the populations being based in rural areas and as such, these populations suffer from the vagaries of nature, such as droughts and floods due to climate change and climate variability. Consequently, any initiatives to uplift the lives of these communities must have an agricultural inclination. About 80% of farmers in Sub-Saharan Africa are smallholder and they contribute up to 90% of the food production in some countries. Smallholder farming produces mainly staple food for household consumption and only a very little makes it to the market. This agriculture is highly differentiated by gender, with women making up the large percentage. Agricultural water management and rural water supplies are important topics of research as well as areas of intervention by governments and others. Agricultural water management comprises both irrigated and rain fed agriculture, and rural water supplies includes piped water systems as well as stand-alone water supply like boreholes, wells and small reservoirs. In the sections that follow, a summary of three research projects is given covering the above-mentioned areas.

SMALLHOLDER IRRIGATION DEVELOPMENT AND PERFORMANCE RESEARCH

Background

Irrigation is still considered a relatively effective approach to ensure food security in many places. Regrettably, irrigation consumes a large proportion of freshwater water resources in less developed countries, in most cases estimated at over 80%. The reality is that water is facing increased demand from other uses such as domestic water, industries and the environment, which, in some instances, give higher economic and social returns. To meet the increasing demands for food with an increasingly scarce water supply, water resources management must be significantly improved.

Deriving Best Management Practices for Smallholder Irrigation Schemes from the Farmers' Perspective

Smallholder irrigation schemes are reportedly performing below expectations due to shortcomings in management of resources. To improve the performance of these schemes, management should be improved through adoption of best management practices (BMPs). Adoption of BMPs in smallholder irrigation (SHI) schemes, however presents complex challenges to irrigation scheme managers, especially where irrigation water is shared among farmers. These challenges can be addressed by involving farmers in adopting BMPs. There are several methods that can assist in making decisions in the presence of multiple criteria and alternatives, such as in the selection of BMPs for smallholder irrigation schemes. In the research reported herein, farmers were tasked with the selection and ranking of BMPs for their scheme. The BMPs were selected using the framework provided by Texas State Soil and Water Conservation Board. The overall ranking of farmer-selected BMPs was done using Analytic Hierarchy Process (AHP). Pair-wise judgment of the BMPs was derived from questionnaires administered by the farmers and then ranked using SuperDecisions® software. The results show that farmers have several BMPs they want adopted for the smooth running of their scheme. The BMPs included irrigation scheduling, volumetric water measurement, lining of field canals, tail water reuse, replacing canals with pipes, payment of irrigation water fees, and routine irrigation infrastructure inspection. It was concluded that irrigation scheduling was the most preferred BMP, while volumetric water measurement was the least. It is recommended that farmers be involved in the selection of the irrigation BMPs for their scheme to ensure acceptability and responsibility in scheme water management (Gomo, et al., 2011).

UPTAKE OF SOIL AND WATER CONSERVATION PRACTICES RESEARCH

Background

Conservation agriculture (CA) practices have been proven to effectively contribute to the restoration and preservation of the productive potential of agricultural land. CA is premised on three tenets: i) minimum soil disturbance; ii) permanent soil cover (mulching) and iii) effective crop rotations, all these aimed at rebuilding the soil. In its broadest sense, CA includes also *in-situ* Rain Water Harvesting (IRWH) – also referred to as water conservation. It involves the prevention of runoff from a cropped area, by increasing soil water storage. IRWH is achieved through soil and water conservation (SWC) farming techniques that include: tied-ridging, micro-basins, *fanya juu*, contour farming, *zai* pits, dead level contours and mulching. Studies have shown that crop yield under dryland agriculture can be doubled by using rainwater water harvesting techniques. Despite the fact that the effectiveness of soil and water conservation practices has been proven, the uptake of such practices by the intended beneficiaries (smallholder farmers) leaves a lot to be desired (it's very low!). The success of the adoption of each technique varies with location, based on the local socio-economic characteristics of farmers and the biophysical attributes of the areas concerned.

Assessing Factors that Affect the Adoptability of Soil and Water Conservation Practices by Smallholder Farmers

Over 70% of South Africa's land surface has been impacted by erosion. A large proportion of smallholder farmers in South Africa face challenges that range from poor soil conditions to low and erratic rainfall. There is a need for agricultural production methods to incorporate soil and water conservation (SWC) practices in order to increase water use efficiencies and soil fertility to facilitate crop growth for improved food security in rural South Africa. In a quest to maximize crop production, SWC techniques have been promoted to smallholder farmers. Even if the adoption of SWC practices has been consistently achieved in some few area of Sub-Saharan Africa, it has been very low among smallholder farmers in South Africa. The research summarized herein looked at the factors that determined the adoption of SWC practices by smallholder farmers. The study was undertaken in Bergville, which is under the Okhahlamba District Municipality in the province of KwaZulu-Natal, South Africa. A sample of 300 farmers was drawn randomly from 13 villages where farmers were interviewed from their plots using a structured questionnaire. The assessment was undertaken to determine the adoption of the SWC practices. To analyze the adoption of the different practices, descriptive statistics and T-tests for comparison of means were used. The results showed the number of households who adopted the practices to be at 42.8% for intercropping, 41% for minimum tillage, and 16.1% for those who practice crop rotations, mulching and for garden beds in combination. Using the Multinomial Logit Regression model, it was found that variables such as membership of a farmer support group, the access and use of credit, method of fertilizer application, and the condition of the soil, extension officers and off farm employment were variables that determined adoption of the SWC practices (Lamula, et al., 2016).

SMALL-SCALE RURAL WATER INFRASTRUCTURE (SWI) RESEARCH

Background

Small-scale water infrastructure (SWI) is central to the livelihoods of rural communities as it is used for domestic and agricultural purposes in both a single use (SUS) and multiple uses (MUS) context. Small-scale water infrastructure is defined as any technical hardware that is used by farmers in managing water resources for both domestic and agricultural use, and operated on a small-scale basis, as well as by smallholder farmers. This definition allows adequate focus on rural infrastructure that services smallholder farmers and communities and taking into account their unique circumstances. Given the enormity of the role played by SWI in rural livelihoods, it is imperative that these SWI are fully functionally at all times in order to provide the expected service. In a recent study in the Limpopo Basin, it was found that up to 45% plus of the SWI were not functional or were operating sub-optimally. The main cause of failure or sub-optimal operational status of SWI can be grouped into three main categories: i) *technical problems* – SWI failing due to poor products, poor workmanship, poor maintenance, poor planning, poor water quality from the SWI; ii) *community shortcomings* – SWI failing because communities do not take responsibility for the operation and maintenance of the SWI due to undefined roles and responsibilities, not enough resources, poor access; and iii) *social conflict* – SWI failing because of theft, vandalism, lack of community cohesion and togetherness. From the above it is imperative that SWI rehabilitation guidelines for rural communities are developed. The rehabilitation guidelines need to take into account the unique nature of rural SWI (compared to urban and provincial type infrastructure) where ownership and responsibility roles may not be clearly defined as well as limitations in resources available.

Rehabilitation Guidelines Framework for Small Scale Water Infrastructure

Presented herein is a summary of the Rehabilitation guidelines for small-scale water infrastructure (SWI) report. The rehabilitation guidelines framework is presented in a generic and flexible manner allowing it to be adapted to suit conditions that may exist at a particular location. In order to plan for the sustainable operation, maintenance and rehabilitation of rural SWI, there is need for the development of asset management plans by the various entities or authorities responsible for these SWI. The asset management plan provides a suitable entry point for the development and application of SWI rehabilitation guidelines. The rehabilitation guidelines framework is supposed to be used by rural communities, rural municipalities, NGOs, government departments and donors. The guidelines are based on the asset management plan concept presented as SWI rehabilitation project cycle.

The rehabilitation cycle has seven steps. The cycle is preceded with five (plus 1) key asset management questions that seek to answer the following: who is responsible for the SWI, the current status of the SWI, the expected or required level of service, the SWI assets minimum life cycle costs, and the best long term funding strategies. Answers to the questions initiate the process for data collection for SWI rehabilitation. The rehabilitation guidelines also presents the seven steps of the SWI rehabilitation guidelines framework: identifying the authority or entity responsible for SWI operation and maintenance, community mobilization and stakeholder buy-in, data collection (technical, financial and socio-institutional), generating the asset management plan, mobilizing resources and implementing the asset management plan, undertaking SWI maintenance, rehabilitation or replacement, and finally monitoring and evaluation of the whole programme with a view to improving it. Also presented is the purpose of each step in the cycle, the procedure to follow and in some cases the tools or methodology to follow (Senzanje, et al., 2014). The diagram below (Figure 1) summarizes the SWI rehabilitation cycle.

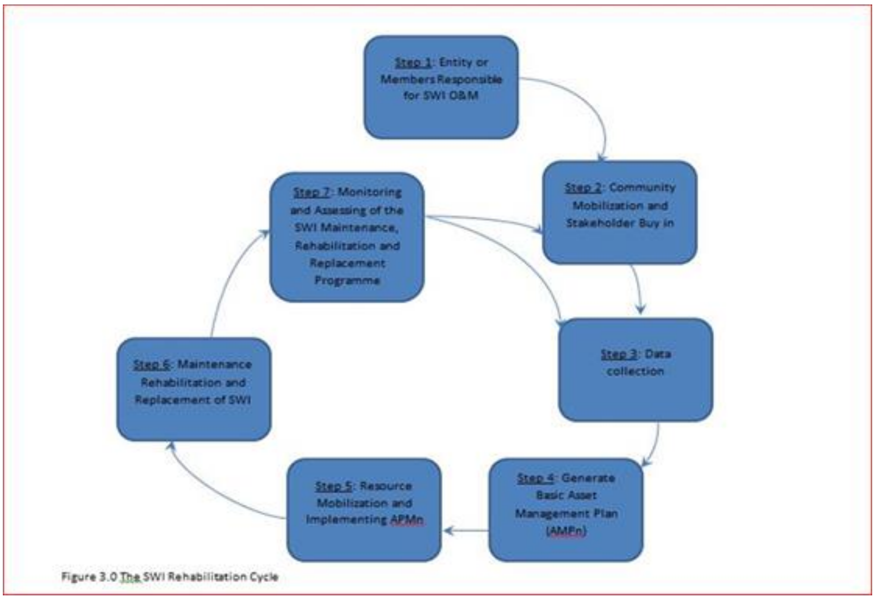

Figure 3.0 The SWI Rehabilitation Cycle

Figure 1: the SWI Rehabilitation Cycle (Source: Senzanje, et al., 2014)

CONCLUSIONS

The research projects summarized above are relevant to the ACEWATER2 research thrust in that they touch on key elements that include: rural communities, smallholder farmers, food security considerations, rural water supplies infrastructure, agricultural water management (for both rain fed and irrigated agriculture) and general water resources management. All these speak to the themes on water governance, water-energy-food nexus and groundwater resources exploitation. The research offers many pertinent lessons to the intended research in the Zambezi River Basin.

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NUST Research projects (2015 & 2016)

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The Namibia University of Science and Technology (NUST) performs research autonomously and in collaboration with other institutions. Most of the projects done by staff members also involve students participating mostly as research projects for bachelor's degrees and theses for Masters and PhD degrees. A large number of collaborations and externally funded research projects are in mining, energy, water and agricultural sectors. Namibia is an arid and relatively water scarce country receiving rainfall in the range 10 mm to 600 mm while potential evaporation is over 2500mm per annum, hence most researches in the water sector focus on sustainable water management, equitable access, water pricing, perceptions on water connection systems, water loss reduction, reclamation and reuse of wastewater. Most researchers in the agricultural sector focus on improving food security through fertility management in dry land agriculture, nutrients leaching and pollution reduction, nitrate transport modelling in irrigated agriculture, utilization of wood as renewable energy resources, environmentally friendly bush encroachment control, pastures management and pollution mitigation for environmental conservation.

Research projects include use of laboratory and industrial scale prototypes on utilization of solar and wind energy for industrial power supply and seawater desalination. Seawater greenhouses prototypes will be constructed and evaluated on effectiveness as high value gardens for commercial irrigation of high value crops and desalination plants for urban water supply in the cool and arid climate of Namibia's Atlantic coast. NUST participated in The Future Okavango Research Project that analyzed the past and existing ecosystem services and their impact on the hydrology of the trans-boundary Okavango River basin and hence predict the long term impacts on the river system, and the tools employed were GIS analysis of satellite images, hydrological modelling and measuring river water quality parameters. Major findings were that the river was attenuating the nutrient load it received, irrigated agriculture and other land use were causing insignificant increase in nutrient load into the Okavango River mainstream, although there was evidence that nitrates were leached from irrigated fields into the riparian zones of the Okavango River. With international collaborators, NUST is assessing impact of measures on water demand and pressure management and methods for reduction of unaccounted for water for the Keetmanshoop Town. NUST and NamWater Corporation have agreed to assess the need for pressure management for reducing high water losses in three towns. NUST also analysed the effectiveness of an old and new wastewater treatment plants in Windhoek City and the effluent's impact on water quality of the receiving rivers. In addition, the effectiveness of conventional water treatment chemicals like *actiflo* and alternative natural water purifying products like *moringa*, indigenous wood and bentonite clay on water and wastewater treatment were evaluated. The moringa and wood products' removal efficiencies of nitrates and fluorides were greater than 60% while conventional treatment chemicals' removal efficiencies were less than 30%.

Research assessed impact of uranium mining on the environment through measuring radon isotopic composition of water bodies in catchments with uranium mining and compared to catchments without mining activities. There was low evidence of transport of radon isotopes into water resources in the catchments with mining activities. Namibia is prone to floods and drought hazards, and hence some researches assessed vulnerability and adaptive capacity of prone communities and the conclusion was that vulnerability was high and adaptation of low-income communities was low in the Zambezi catchment. Adaptation measures to fresh water scarcity in Namibia's central regions are wastewater reclamation for urban water supply and reuse in irrigation hence NUST researchers are evaluating the potential of salinization of soil, heavy metal poisoning and pathogens infecting consumers and farmworkers in Windhoek's irrigated gardens that reuse effluent. The wastewater contained low levels of heavy metals, and coliforms were within acceptable limits for irrigation of field crops or vegetables that are eaten after cooking, as per recommended limits in FAO guidelines.

Vulnérabilité climatique et variabilité des ressources en eau en Afrique de l'Ouest : l'exemple du bassin du Sénégal

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ABSTRACT

Like many countries in West Africa and particularly those of the Sahelian area, Senegal is since several decades subject to tremendous climate vulnerability. Beyond the structural aspect of the climatic variability, we also observe the effect of socioeconomic activities and the implication of sociocultural practices. This situation reverberates dramatically on water resources and particularly on the hydrologic ones in shared catchments like those of Senegal and Gambia. Despite some periods of respite, statistics are not truly pleading for a return of better climatic conditions, rainfall precisely. The degradation of the endowment in surface water is nowadays a reality in the catchments and a daily experience for the population particularly affected with weak resilience facing an environment in continual deterioration. In Senegal, the isohyet 300mm did a migration of several kilometers southbound. The estimations realized by the UNEP on water resources at the African scale, foresee a critical situation on the horizon 2025, particularly in the Sahel where some situations are already dramatic. Despite its outstanding hydric potentialities for a sahelian country, Senegal risks to experience water stress while it disposed of more than 4000 m^3/pers/year in 1990. This variability of precipitations in a context where agriculture involves more than 80% of the population is enhancing the use of surface waters. Added to this, the current challenge represented the politic choice of Senegal through the "Plan Senegal Emergent" targeting self-Sufficiency in rice by 2017. Since many decades, under the aegis of the OMVS, several programs have been implemented in the Senegal River Basin with the major objective to fight the effects of the climatic pejoration and the mobilization of surface water resources. Despite all these efforts, there is a lot to do in term of understanding of water resources variability and defining the suitable programs of attenuation of the vulnerability of communities and strengthening their resilience.

Keywords: Senegal, Senegal River Basin, Climatic vulnerability, water resources variability, water resources management, OMVS

INTRODUCTION

Le Sénégal est soumis depuis plusieurs décennies à une très forte vulnérabilité climatique (Oyebdande et al., 2008). Dans le bassin du fleuve Sénégal, les études récemment menées sur la variabilité de la pluviométrie ne plaident pas en faveur d'une amélioration du capital en eau de surface, surtout si l'on considère la forte dépendance entre régime pluviométrique et régime hydrologique sous ces latitudes (Paturel et al., 1996). Dans le contexte sénégalais où l'agriculture occupe plus de 80% de la population active (Vidal et al., 2016), la péjoration climatique pousse de plus en plus vers l'utilisation des eaux de surface dont le renouvellement pourrait être compromis à plus ou moins long terme. Les répercussions socio-économiques se révèlent particulièrement complexes, en particulier dans les bassins versants transfrontaliers comme celui du Sénégal.

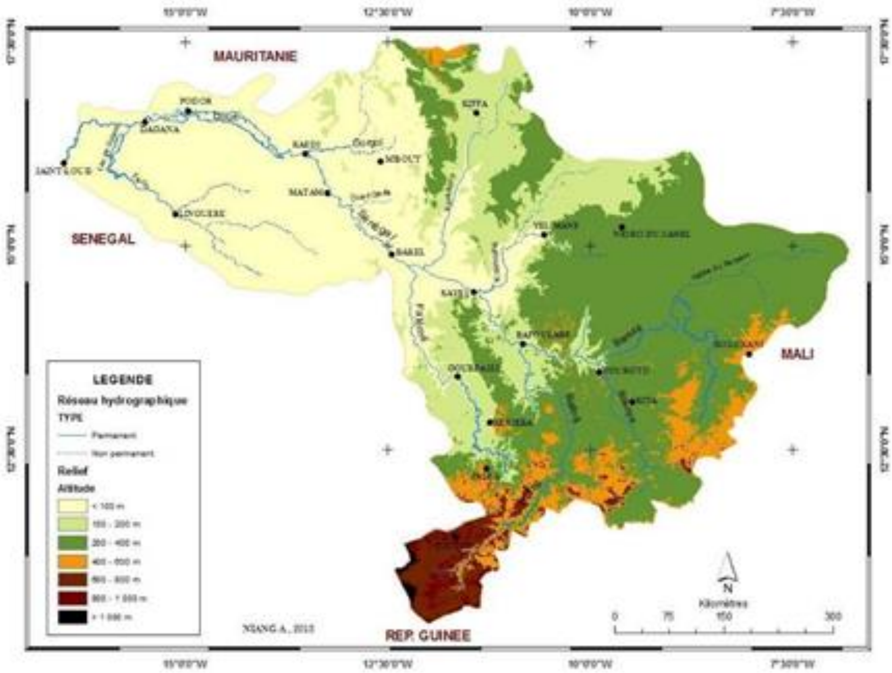

Figure 1: Bassin du fleuve Sénégal (source: Niang, 2014)

LA PLACE DU BASSIN DU FLEUVE SÉNÉGAL EN AFRIQUE DE L'OUEST

La région ouest-africaine est drainée principalement par trois grands organismes fluviaux: le Niger, le Sénégal et la Gambie, complétés par le complexe du lac Tchad et quelques bassins côtiers. La majorité des bassins ouest-africains sont transfrontaliers. Dans le secteur des ressources en eau, la dépendance entre Etats est en effet très élevée; à l'exception du Cap-Vert, tous les pays de la sous-région partagent au moins un cours d'eau. Le fleuve Sénégal (Figure 1) est le deuxième plus grand fleuve d'Afrique de l'Ouest après le Niger. Il est entièrement situé dans la zone tropicale à longue saison sèche (Michel, 1973) et réparti entre les quatre États que sont la Guinée, le Mali, la Mauritanie, et le Sénégal. Le bassin couvre une superficie d'environ 300 000 km² et est drainé par le fleuve Sénégal, long de 1800 km, qui nait dans le massif du Fouta Djalon en République de Guinée. Ses principaux affluents sont le Bafing, le Bakoye et la Falémé (cf. Figure 1).

De sa source en Guinée à l'embouchure au Sénégal, le fleuve Sénégal traverse une variété de milieux et de paysages bioclimatiques qui font toute sa richesse et sa renommée. L'aménagement du bassin est le fruit d'un long processus amorcé depuis la colonisation. Il a démarré dans la partie sénégalaise avec une série d'aménagements artisanaux (Gac et al., 1986), puis s'est poursuivie et modernisée sous la houlette de l'OMVS, dans un contexte de lutte contre la sécheresse et l'avancée de la langue salée, d'optimisation des ressources en eau et de production d'énergie hydro-électrique pour les Etats riverains. Aujourd'hui, le bassin compte trois grands barrages opérationnels: Diama, Manantali et Felou, mis en service respectivement en 1985, 1987 et 2013. La réalisation des projets de barrages de Gouina, Koukoutamba, Boureya et Gourbassi (www.omvs.org), devrait faire du Sénégal, dans un proche horizon un bassin aux écoulements maitrisés et à fort rendement économique du fait de l'irrigation et de la production d'hydro-électricité. Ces barrages comportent en effet des enjeux énormes en termes de développement économique et social pour les Etats. Ils procèdent d'une vision régionale développée par l'OMVS et qui visent à faciliter le développement et l'intégration économiques des quatre Etats riverains du bassin (Ould Merzoug, 2005).

LA VARIABILITÉ CLIMATIQUE ET SES CONSÉQUENCES SUR LES RESSOURCES EN EAU

En Afrique sub-saharienne, la variabilité climatique est une réalité constatée à partir de plusieurs études et recherches menées depuis près d'un siècle (Equesen, 1993). La compréhension de l'évolution climatique récente et surtout des tendances à moyen et long terme sont devenues, depuis quelques décennies, un enjeu important de développement.

Dans le bassin du fleuve Sénégal, du sud au nord, trois domaines climatiques correspondant à un gradient pluviométrique sud-nord très marqué ont été identifiés (Sow, 1984; Sall, 2006). On note également l'existence d'un gradient ouest-est particulièrement prononcé à proximité de l'océan où la présence de masses d'air froid peut, par moment, favoriser des précipitations pluvieuses hors saison.

L'évolution climatique récente au Sahel et dans le bassin du fleuve Sénégal a été largement étudiée au cours des trente dernières années (Leroux, 1988; Le Borgne, 1988 ; Dione, 1996 ; Sagna, 1998). La disponibilité d'une importante masse de données permet d'analyser l'évolution climatique sur plusieurs décennies et pour permettre la réalisation d'études prospectives. Un des principaux constats est la constance de la variabilité climatique, avérée à presque toutes les stations du Sahel. Une autre constatation est le déficit pluviométrique généralisée des précipitations depuis le début des années 1970 malgré une légère reprise notée au début des années 2000 (Figure) mais sans que l'on retrouve les conditions de pluviométrie qui prévalaient dans les années 1950. Ces résultats confirment plus ou moins les tendances déjà observées, à savoir, une pluviométrie annuelle réduite de 35% dans la partie sahélienne du bassin (Albergel et al., 1997) ; un déficit pluviométrique de l'ordre de 20% pour l'ensemble des stations du bassin (Servat et al., 1999 ; Bodian, 2010).

Dans le cadre de la collaboration entre le réseau ouest-africain des Centres d'Excellence du NEPAD et JRC,[1] un programme d'analyse régionale de la variabilité des précipitations basée sur l'approche L-Moment a été mise en œuvre sur l'Afrique de l'Ouest et le Sénégal (Niang, 2014). Sur la base des observations des stations au sol de différents pays de la sous-région, des ré-analyses climatiques issues de WordlClim, différents scénarios de distribution des précipitations basés sur L-Moment (Maeda et al., 2012) et élaborés à l'aide de l'outil d'analyse fréquentielle REFRAN-CV[2]. Cette approche testée et validée sous d'autres contextes climatiques a permis de réaliser une prospective sur l'évolution des précipitations au Sénégal, aux horizons 2020 et 2050. Le principal constat est que la dynamique actuelle des précipitations en Afrique de l'Ouest risque de se maintenir dans les années à venir, c'est-à-dire fortement variables et irrégulières mais avec une forte probabilité de survenue d'événements extrêmes comme les sécheresses ou les inondations.

Mais il s'agit de résultats très préliminaires qui devront être validés sur des données plus fines et plus récentes. Cependant, la migration de l'isohyète 300 mm, de plusieurs kilomètres vers le sud, environ 200 km selon certains auteurs (Niasse, 2007), reste l'un des marqueurs les plus remarquables de la dégradation climatique.

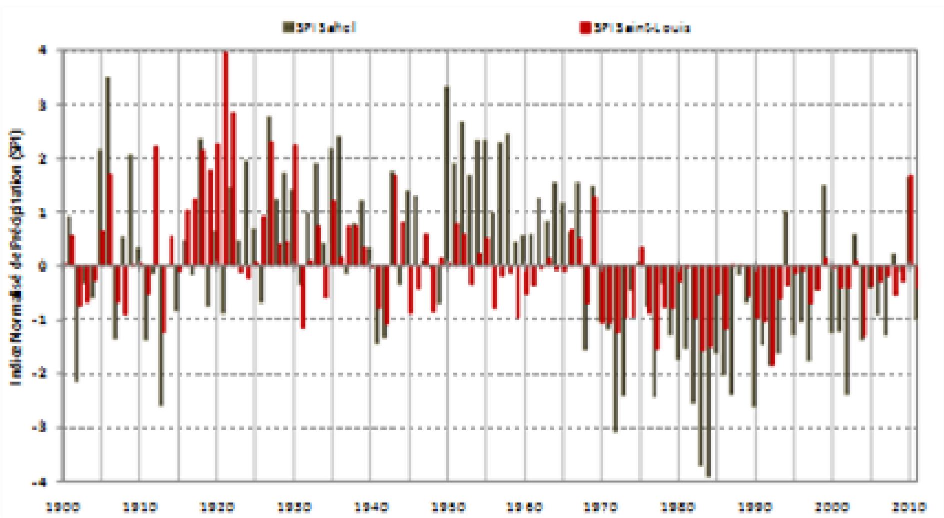

Figure 2 : Indices d'anomalies pluviométriques de la zone sahélienne et de la station de Saint-Louis pour la période 1900-2010 (source données : JISAO[3] et ANACIM[4])

La problématique du changement climatique est généralement abordée, plutôt sous l'angle de questionnements que de faits avérés. Les températures auraient augmenté en Afrique de l'Ouest de 0,68°C au cours de 50 dernières années, soit beaucoup plus que la moyenne enregistrée à l'échelle mondiale (GIEC, 2007). Il semblerait que les extrêmes de température aient significativement augmenté au cours de la décennie 2000-2010 (IPCC, 2013). Malgré les importantes avancées scientifiques, il est vrai que la réalité d'un changement climatique au Sahel, reste encore bien difficile à matérialiser. Mais le développement d'approches basées sur la compréhension du mécanisme des interactions climat - environnement à l'échelle locale, devrait apporter de biens meilleurs résultats (Leroux, 1997).

[1] Joint Research Centre (Ispra, Italy)
[2] Regional Frequency Analysis – Climate Variability
[3] Joint Institute for the Study of the Atmosphere and Ocean
[4] Agence Nationale de l'Aviation Civile et de la Météorologie

La dégradation climatique s'accompagne d'une baisse du potentiel en eau ressources en eau de surface pour de nombreux états ouest-africains dont le Sénégal. En effet, les estimations réalisées par le PNUE[5] sur les ressources en eau à l'échelle africaine laissent présager d'une situation critique à l'horizon 2025, en particulier pour les pays du Sahel (UNEP, 2006). La baisse des précipitations pluvieuses s'est accompagnée d'une réduction encore plus marquée des écoulements dans la région sahélienne. La baisse des débits est estimée entre 40 et 60% depuis le début des années 1970. Le Sénégal malgré un potentiel hydrique remarquable pour un pays sahélien risque d'être placé en état de stress hydrique alors qu'il disposait de plus de 4000 m^3/pers/an en 1990.

L'agriculture étant la principale activité génératrice de revenus, tout ceci laisse présager d'une rareté accrue de l'eau de surface avec tous les impacts que l'on peut en attendre au niveau socio-économique, justifiant d'ailleurs la mise en œuvre du programme d'aménagement de l'OMVS. L'analyse de la variabilité des écoulements dans le bassin du fleuve Sénégal, en relation avec la mise en service des barrages sur le fleuve Sénégal a été décrite par Kane (1997). Les débits du fleuve Sénégal à la station de Bakel (Figure) montrent une variabilité importante surtout entre 1970 et 1984-85 ; à partir des années 1990, soit postérieurement à la mise en service des deux premiers grands barrages, on note une tendance à la stabilisation liée à la présence des barrages. La variabilité des écoulements est exprimée à travers le débit moyen qui passe de 700 m^3/s pendant la période 1903-1970 à 400 m^3/s durant la période 1970-1990. Depuis cette période, le débit moyen du Sénégal à Bakel est resté stabilisé entre 300 et 400 m^3/s.

L'opportunité de la mise en place des barrages sur le fleuve n'est plus à discuter, eu égard à la maîtrise des écoulements et le soutien aux débits d'étiages qui joue sur la disponibilité de l'eau. La principale difficulté est aujourd'hui la capitalisation des bénéfices tirés des ouvrages. Pour le Sénégal cependant cette opportunité se traduit en un important défi dans le cadre du PSE[6], mis en place en 2012 qui vise l'amélioration de l'accès des populations à des services d'eau potables et d'assainissement de qualité, à des coûts acceptables et la promotion d'une bonne gouvernance du secteur. La production massive de riz dans la vallée et le delta du Sénégal, pour réduire voire mettre fin aux importations de riz dans un très proche horizon, va bien évidemment nécessiter la mobilisation d'importants volumes d'eau.

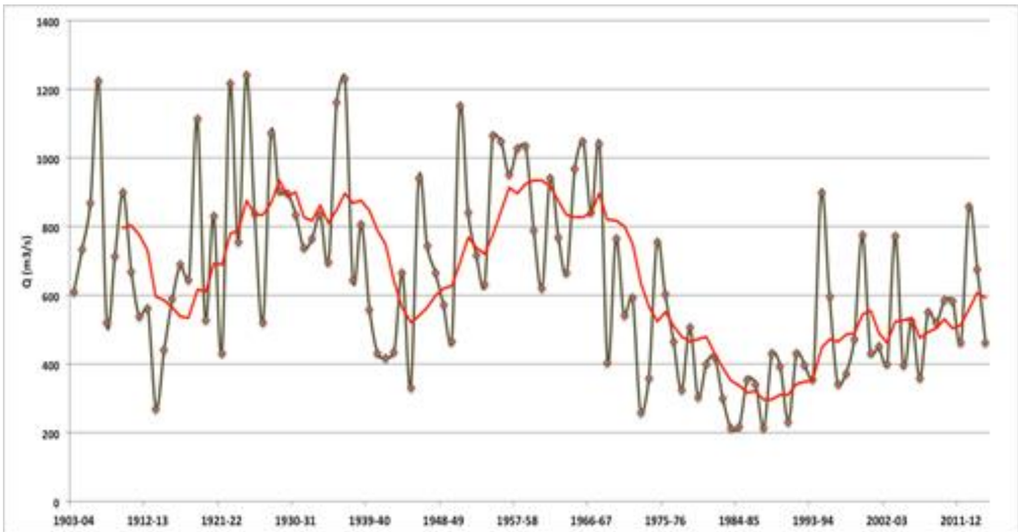

Figure 3 : Débits moyens du fleuve Sénégal à la station de Bakel de 1903 à 2015

GESTION DES RESSOURCES EN EAU DANS LE BASSIN

Le contexte sahélien et le caractère transfrontalier qui qualifient le bassin du fleuve Sénégal, expliquent la place importante qu'y occupe la gestion des ressources en eau. Les politiques et programmes à l'échelle internationale se sont traduite à l'échelle nationale puis sous régionale en une série de législations, d'institutions et de projets qui marquent le paysage des Etats riverains du bassin depuis plusieurs décennies. Deux niveaux sont à noter dans la gestion de l'eau du bassin du fleuve Sénégal : le niveau national, avec le code de l'eau et d'autres textes complémentaires et le niveau sous régional, à travers les organes de l'OMVS. Cet organisme de bassin créé en 1972 par les quatre états riverains a pour missions de :

[5] Programme des Nations Unies pour l'Environnement
[6] Plan Sénégal Emergent

- réaliser l'autosuffisance alimentaire pour les populations du bassin et de la sous-région,
- sécuriser et améliorer les revenus des populations,
- préserver l'équilibre des écosystèmes dans le bassin,
- réduire la vulnérabilité des économies des États-Membres face aux aléas climatiques et aux facteurs externes,
- accélérer le développement économique des États-membres.

Initialement, le programme d'aménagement de l'OMVS était presque exclusivement tourné vers la maitrise des écoulements et la production d'hydro-électricité. Puis le plan d'aménagement de la vallée a été réorienté pour permettre à partir de crues simulées (Lamagat et al., 1999) de favoriser le maintien des productions traditionnelles comme la pêche dans les zones inondées ou les cultures de décrue, tout en favorisant de nouvelles spéculations basées sur l'irrigation. Par exemple, le barrage de Diama mis en fonction en 1985 dans un contexte de péjoration climatique et d'insécurité alimentaire, avait comme vocation première d'empêcher la remontée de la Langue salée qui à l'étiage du fleuve remontait le cours d'eau jusqu'à près de deux cent cinquante kilomètres interdisant toute culture. La mise en service du barrage hydro-électrique de Manantali a ouvert une ère d'espoir. La mise en place de périmètres irrigués à grande échelle devait aider les Etats riverains dans leurs programmes d'atteinte de l'autosuffisance alimentaire.

La mise en place des aménagements hydro-agricoles (barrages, endiguements et périmètres irrigués) a été source de perturbations pour l'environnement du bassin, soumis alors à plusieurs dysfonctionnements. On peut souligner, entres autres, la forte diminution de la faune ichtyologique, la canalisation progressive de la vallée du fleuve avec la régularisation des débits, la perte de compétence des crues, la rétention du transport solide le transport solide, le développement des plantes aquatiques envahissantes, l'émergence ou la réémergence de maladies liées à l'eau, etc.

Tous ces changements hydrauliques et environnementaux et sociaux n'ont pas nécessairement suscité toute l'attention qu'elles auraient méritée de la part des autorités en charge de la gestion. Cependant, tout le monde s'accorde sur la réussite de l'OMVS qui a su assoir de manière durable la paix et la conciliation autour du partage et de la gestion des ressources en eau du bassin d'une manière générale. Une évaluation récente des organismes de bassins à l'échelle mondiale réalisée par Strategic Foresight Group classe le bassin du Sénégal par les meilleurs exemples de coopération transfrontalière dans le domaine de la gestion et du partage des ressources dans une optique de développement.

Cependant, un certain flou demeure toujours entre les prérogatives des Etats et les rôles et responsabilités de l'organisme de bassin. L'exemple du Sénégal avec la prise de décision d'ouvrir une brèche dans l'estuaire, en territoire sénégalais en est une parfaite illustration. En effet, cette brèche ouverte en octobre 2003 dans la flèche sableuse de la Langue de Barbarie a contribué très significativement à la mise en place d'une nouvelle dynamique dans la gestion du barrage de Diama entièrement placé sous l'autorité de l'OMVS. De cette imbrication entre les décisions nationales et internationales, de leurs conséquences, et des incertitudes résultantes sur les responsabilités réciproques ou partagées, naissent de nombreux préjudices à un développement durable du bassin du fleuve Sénégal. Cependant, la prise de conscience de ceci a poussé l'OMVS à développer depuis une dizaine d'années de nombreux programmes et projets visant à atténuer les effets des aménagements et assoir un développement économique et social au bénéfice des communautés du bassin.

CONCLUSION

La vulnérabilité climatique des Etats ouest-africains est une réalité attestée par les nombreuses études réalisées sur le sujet. La forte dépendance entre la pluviométrie et les écoulements, représente une forte contrainte dans le bassin, à l'heure où les changements climatiques se posent de plus en plus comme une donne à intégrer dans les projets de développement. Les récentes inondations notées un peu partout dans la sous-région, notamment au Togo, au Bénin, au Burkina Fao et au Sénégal (AGRHYMET, 2010) représentent un signal fort de la situation climatique qui se caractérise désormais par la survenue d'événements extrêmes, de manière très rapprochée dans le temps.

L'analyse du climat doit donc être approfondie afin d'offrir à nos communautés les infrastructures urbaines adaptées à leur climat et à leur environnement. Il s'agira également de développer ou renforcer les systèmes d'alerte existant de manière à éviter des actions aux conséquences mal évaluées comme celle menées en 2003 dans le bas estuaire du Sénégal.

Il est vrai que depuis environ trois décennies, sous l'égide de l'OMVS, plusieurs programmes et projets ont été implantés dans le bassin du Sénégal avec comme objectif majeur la lutte contre les effets de la péjoration climatique et la mobilisation des ressources en eau de surface. Malgré ces efforts conséquents, beaucoup reste aujourd'hui à faire pour comprendre la variabilité des ressources en eau et définir des programmes adéquats d'atténuation de la vulnérabilité des communautés et de renforcement de leurs capacités de résilience.

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Unlocking the potentials for multiple utilization of dams and reservoirs in Nigeria

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INTRODUCTION

Nigeria currently with a population of about 170 million people require a large volume of potable water for drinking and other purposes, energy particularly for electricity and enough food to feed such a large population. In the country, the demand for water, food and energy will continue to rise as a result of increase in population growth. The rapid drop in the prices of crude oil, the lack of coordinated National policy on agriculture and the summersault from a rebranded largest economy in Africa to a recessed economy is bringing back fears about food security. There are increasing concerns on the demand side as essential food commodities are disappearing from the market and prices of available commodities are now outside the reach of the average Nigerian. Today, much of the energy supply in the country is expected to come from hydropower as a result of the current unstable gas supply due to militancy in the Niger Delta Region. In order to derive the needed energy supply, many of the existing dams and reservoirs need to be upgraded to multipurpose use not only for water supply but hydropower generation as well as for irrigation and fishery. In this complex system, reservoirs are expected to be used for irrigation, provide potable water supply to communities and power turbines for energy generation. Water becomes scarce as a result of the multiple usages, there is growing competition between energy, agriculture and domestic water availability. Therefore, there is the need to develop effective cross-sectorial mechanism to address the problem and ensure that decisions taken on water demand and availability are coordinated in such a way as to provide an integrated multi sectorial strategy.

DAMS IN NIGERIA

A compendium of Nigerian Dams compiled by the Department of Dams and Reservoir Operation (2007) put the number of dams in Nigeria at 198. Nigeria is divided into 8 hydrological zones. Fig 1 shows the hydrological zones of Nigeria and location of the major dams. Table 1 shows the distribution of reservoirs and dams in each hydrological zone.

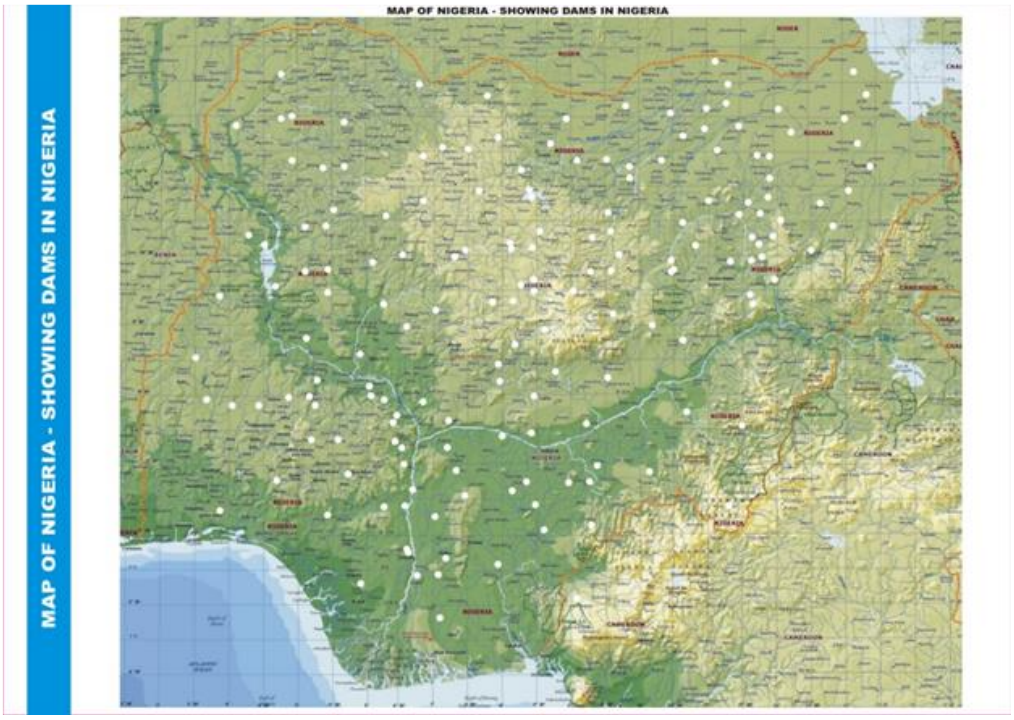

Figure 1: Map of Nigeria showing the hydrological zones.

Table 1: Distribution of Dams per hydrological zones (Source: Compendium of Dams in Nigeria, 2007)

S/NO	HYDROLOGICAL ZONE	NO OF LARGE DAMS	NO OF SMALL DAMS	TOTAL NO
1	1	8	15	23
2	2	26	14	40
3	3	3	4	7
4	4	12	21	33
5	5	1	6	7
6	6	13	35	48
7	7	2	9	11
8	8	13	16	29
	TOTAL	**78**	**120**	**198**

From the table it can be seen that zone 3 and 5 have the least number of dams while zone 2 and 6 have the highest number of dams. The limited number of dams in hydrological zones 3 and 5 is mainly due to the nearness of the area to sea level as well as the topographical and geological characteristics of the region.

PROBLEMS OF DATA AVAILABILITY FOR DESIGN AND CONVERSION OF DAMS AND RESERVOIRS FOR MULTIPURPOSE USE

River flow records are vital assets critical for the sustainable management of water resources. They serve as both indicators of past hydrological variability and fundamental contributors to hydrological models for future behavior prediction. The completeness of such record is critical for their effective utilization. Even very short gaps preclude the calculations of important summary statistics, such as monthly runoff, totals or n-day minimum flows and inhibits the analysis and interpretation of flow variability (Marsh, 2002). In this sense, the establishment of twelve River basins in Nigeria was to harness the nation's water resources and optimize its agricultural resources for food sufficiency. This development raised hope among the various stakeholders that the RBA would apart from agricultural needs provide other basic needs such as hydrological data collection and management associated with water resources. Over the years however, the River Basins and other rivers in Nigeria have been poorly gauged (World Bank Report, 2003), and discharge measurements were neglected and poorly carried out. Data were poorly managed and stored. It is therefore necessary to carryout discharge and other hydrological forecast for effective management of the River basins and the infillings of the missing discharge data in many of the rivers to enhance their effective use in the development of dams and reservoirs for multipurpose use. This requires greater research efforts.

DAMS AND THE WEF NEXUS

In a country such as Nigeria, food production depends in the main on rural communities. Rural communities need access to a range of energy supply and services in household productive use and community services to support human social and economic development. They use various resources to ensure food security and preservation every day. In our communities, these rural dwellers are in most cases not factored into the national energy plans. It should be noted that for a county such as Nigeria to become not only self-sufficient in food production for consumption but enough for export, there is the need to develop a number of micro-hydro projects which will serve different purposes for different socio economic groups. For instance, clean lighting and better access to information (via television, radio and phones) can support improved agricultural practices indirectly through better connection to markets, reduce expenditure on power for lighting and batteries, milling cassava, rice and grinding, processing oil, electrical machine to pump water for irrigation schemes, cold storage facilities to help keep farm product fresh.
It has been established that agriculture accounts for 70% of all water withdrawal globally. Global energy consumption is also increasing and will continue to increase. On global scale oil, coal and gas have remained the main energy sources. In Nigeria,

however the activities of militants in the Niger Delta region blowing up oil and gas pipelines leading to reduction in the level of energy supply for electricity has made it imperative that alternative source of energy need to be developed. Therefore, it is important and necessary to accelerate the development of alternative source of energy and water is the key factor. Hydropower is seen to be a clean source of energy and its development should therefore be encouraged. However, in doing this, other uses of available water resources need to be considered. For most part of the 20th century, infrastructural projects were used to increase water withdrawal from rivers and ground water in order to meet the need of an expanding population. In order to effectively manage the water resources in Nigeria, River Basin authorities were created and series of dams were constructed largely for water supply, irrigation and hydropower generation etc. In 2015 the Federal Government of Nigeria decided that majority of the dams in the country be converted to multipurpose Dams. Dam construction along with other infrastructures enhance societies capabilities in the Planning and management of water resources and by association the related issues of food and energy security.

ENVIROMENTAL CONSIDERATION IN THE USE OF DAMS FOR WATER RESOURCES, ENERGY AND FOOD

Dams fundamentally alter river courses. Construction of (large) dams involves tradeoff between economic, social and environmental benefits and costs. It has been suggested that while reservoir have few negative effects on human water supply, they have a substantial impact on aquatic biodiversity and ecosystems. Such impacts can occur both upstream and downstream of the dam and reservoirs. Essentially, impact occurs consequent upon inundation storage, changes to flow regime, impact on water quality, and changes to the morphology of the river system. Other environmental consideration may be those attributable to climate change. World economic forum 2011, argues that in the backdrop of climate change and climate variability's, how should our water best be stored and which storage should be used to minimize risk due to long term climate variability and change?

Such storage guarantees reliability of water supply, which in turn means food security, electricity generation and industrial growth. Climate change also has an implication for existing dam infrastructure i.e. dams designed in the past without accounting for the increasing variability of climate change are now at risk (i.e. 100 year flood may be more severe meaning that the infrastructure is under designed). Studies carried out by various researchers does suggest that climate change will increase the intensity of extreme weather events (Ehiorobo et al. 2012, 2013) and has the potential to cause mass migration, create food and water insecurity and cause several other environmental and social impacts (Voigt 2009, Khagram et al. 2003, Allonche et al. 2014) .

In practice, some dams may have exceeded their design lives or outlived their original purpose leading to diminished utility; (e.g. Ikpoba Dam in Benin City). In such a case, the dam removal becomes a favorable alternative.

EFFECTIVE UTILIZATION OF DAMS AND RESERVOIRS

In order to increase the effectiveness in the use of dams and reservoirs in Nigeria there is the need to:

- Mitigate environmental impact of these infrastructures;
- Use more efficient irrigation practices to reduce water use in irrigation agriculture e.g. Drip, bed and furrow irrigation;
- Establish better and adaptive cropping pattern in agriculture;
- Adapt rainwater harvesting technique;
- Switch to multipurpose dams usage rather than building new dams;
- Replace obsolete infrastructure such as turbines with modern higher capacity ones to reduce operating cost and avoid the need for constructing new ones;
- Construct sediments flushing gate in dams to remove sediments from reservoirs.

In order to unlock the potentials for multiple utilisations of dams and reservoirs in Nigeria, there is the need to ensure continuous monitoring and evaluation of dams and reservoirs, regarding:

- Provision of sufficient potable and qualitative water from reservoirs;
- Groundwater recharge from reservoirs;
- Effectiveness of dams and reservoirs utilization for hydropower development;
- Study of siltation in reservoirs;
- Effective utilization of dams in flood control and regulation of river flow;
- Monitoring for structural integrity of dams.

CONCLUSION

The demand for water, food and energy is increasing not only in Nigeria and within Africa, but worldwide. In order to cope with the challenges posed by this demand, it is necessary to understand the interconnectivity between the demand and the supply for the three i.e. water, food and energy. Scarcity of water resources as a result of water use from reservoir for irrigation requires continuous studies and monitoring. There is the need for cross-sectorial collaboration between various stakeholders including Government agencies, NGOs, academic and research institutions, policy makers and the end users.

As water becomes scarce as a result of the multiple usages, competition between clean water supply, energy and agriculture arises. Therefore, there is the need to develop cross-sectorial research to address the problem and ensure that decision taken in one sector does not adversely impact other sectors, as well as the environment as a whole.

Finally, the interconnectivity between water, food, energy and climate makes it imperative that the University of Benin Water Centre of Excellence will be working with other colleges in furtherance of research in:

- Acquisition of data on reservoir and irrigation practices in watersheds/river basins;
- Regional flood frequency analysis and disaster management;
- Effective utilization of water from dams and reservoirs;
- Water-Energy-Food nexus in trans boundary river basins/watershed;
- Regional data sharing for climate variability.

With proper collaboration and research in the above thematic areas, we will be able to unlock the potentials for multiple utilizations of dams and reservoirs for water supply, irrigation, flood control, energy (hydropower) tourism, mine tailing, etc.

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Impact assessment and viability of irrigations schemes programs in the Sokoto Rima Basin Development Authority (SRRBDA) project for intensified agriculture and poverty alleviation in Nigeria

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ABSTRACT

Sub-Saharan Africa accounts for 25% of the global estimates of undernourished population. In spite of the relatively abundant arable lands when compared to other parts of the world, the region is unable to produce enough food to adequately feed its rapidly growing population and export for more earnings. Factors such as land and water resources degradation have been identified as causing low agricultural productivity which will seriously undermine efforts to bring about food security and strengthening of foundation for sustainable economic growth in the region. In Nigeria, agricultural and water resources development assumed significantly noticeable dimensions in the 1970s and 1980s with the establishment of eleven (11) River Basin Development Authorities (RBDAs) and construction of large dams and boreholes to harness the country's water resources for sustainable agricultural development, water supply and food self-sufficiency. Despite all the efforts, the sectors performance has not had the anticipated significant impact on national food security, employment opportunities and economic growth. To address these challenges, institutional assessment, dam studies, irrigation systems, groundwater monitoring/piezometer installations and water quality studies have been carried out in the Sokoto Rima River Basin Development Authority (SRRBDA) with the main objective of increasing the water resources management of the basin for better economic growth and poverty alleviation in the basin and Nigeria in general.

INTRODUCTION

The major objective of the research project is to enhance management of water resources for intensified agriculture, food security and poverty alleviation in Sokoto Rima Basin in Nigeria (Figure 1). Specifically, the research aims to:

- Conduct institutional assessment in the SRRBDA and facilitate the development of the organization's institutional capacity development plans;
- Assess sediment deposition pattern and estimate storage loss of some the reservoirs (Bakolori, Zobe dam, Goronyo) as a step towards addressing downstream flooding threat in the basin;
- Carry out basin-wide assessment of surface water quality to ascertain its suitability for irrigation and develop quality control measure(s);
- Investigate factors causing proliferation of algae at Bakolori reservoir and recommend remedial measures;
- Examine groundwater hazard relating to groundwater level lowering and quality issues, and determine actual groundwater behaviour due to extraction and changes in recharge condition;
- Enhance soil and on-farm water management practices through developing suitable model(s) for managing irrigation and drainage water;
- Improve irrigated agronomy through introduction of innovations such as new crops or production techniques and development of standard cropping pattern for efficient utilization of water within irrigation schemes in the basin;
- Enhance active participation of Water Users Association (WUAs) members in maintenance of irrigation facilities through sensitization.

A summary of the projects includes:

1. *Institutional Assessment of the Sokoto Rima Basin Development Authority*

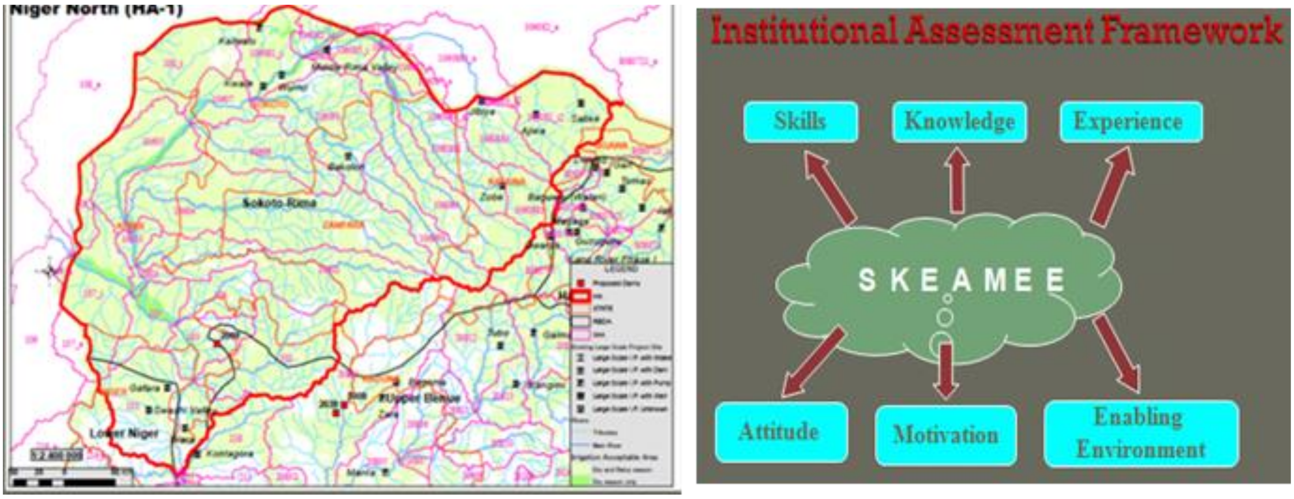

Figure 1: Location of Sokoto Rima Basin (Project Area, left); SKEAMEE Process (right)

The Institutional Assessment entails the following:

- Capacity development to allow the sharing of new ideas and knowledge to strengthen an organization's vision, structure, direction and talent and enables it to contribute to common (development) goals;
- Thus, Capacity development is not just about training, but includes issues such as attitudinal changes, motivation and provision of appropriate enabling environment.

The process utilized the SKEAMEE process as shown above in Figure 1 (right). The Institutional assessment is supposed to:

- develop strategic vision and performance objectives;
- develop an idea of what is needed to reach these objectives;
- identify the gaps between the resources required and current capacity;
- develop a capacity development plan to address the gaps.

The process commences with staff position profiling, position profiling and analysis. It aims to identifying roles, main responsibilities and main activities of a representative staff of the organization. The focus is on the function rather than the individual although some account is taken of the current position holder's capacity needs. Moreover, it is supplemented with group discussion with staff of the organization and review of documents such as job descriptions, work plans, etc. Next is the identification of Critical Accelerators and Potholes: based on the position profiling and analysis, key factors that make various position holders performing efficiently are identified and referred as critical accelerators; key factors that hamper staff performance are also identified and referred to as critical potholes (Figure 1).

2. *Capacity Development (CD) Actions*

CD actions are developed in a participatory manner with the respective institution staff that participated in the previous stages by addressing the identified critical potholes and accelerators to cover three major areas, SKE (skills, knowledge and experience); AM (attitude and motivation), and EE (enabling environment) Fig. 1 (right).

3. *Capacity Development Plans.*

The recommended CD actions are then reported back to key decision makers in the organization and CD plans are agreed in a participatory manner. To each agreed CD action, priority levels are allocated, stakeholders involved are identified and those responsible for implementing the CD action are well noted. The identified CD will also indicate whether budget is required to facilitate the action or not with a given time frame.

Figure 2: Poorly maintained canals and accommodation at the Project areas (left); Drilling at the dam (right)

CASE STUDY 1: SEDIMENTATION STUDY AT BAKOLORI DAM

The Bakolori Irrigation project is located within the Sokoto River Basin and it was first identified by the United Nations Development Programme (UNDP) and Food and Agricultural Organization of the United Nations (FAO) during a soil and water resource survey of the Sokoto Valley in 1969. It was envisaged to implement a series of dams and polders areas of terrace irrigation across the Sokoto River at Bakolori. The Bakolori reservoir is one of the largest dam in Nigeria constructed over thirty-one years to store water for a double season irrigation practices in the project area. The Bakolori dam would feed a terrace irrigation area of 27,000ha, the Yantabaki, Zobe and Zurmi. However, with the construction of the dam both water and sediments being stored in the reservoir and coupled with poor reservoir management practices and lack of full utilization of the reservoir water, sediments accumulation within the reservoir increased, also due to lack of flushing operations. Consequently, over a period of thirty-one year of impounding water, the Bakolori reservoir's morphology undergone significant changes arising from deposition and accumulation of sediments, which obviously must have implications on the available active and dead storage. The overall objective of this study is to investigate the loss in storage capacities of the Bakolori reservoir occasioned by the siltation processes in the reservoir over the period of impoundments with a view to assess the capacities of the reservoir to meet all the demands dependent upon it. The main objectives of the project were as follows: to carry out the bathymetric survey of the entire reservoir area using acoustic depth measurement system synchronized with a GPS and determine the revised storage capacities at various operating levels of the reservoir at the time of the survey. More in detail, specific objectives of the study are to gather data needed to:

- determine the amount and distribution of sediments deposited in the Bakolori reservoir;
- develop the Bakolori Reservoir underwater bed surface topographies;
- estimate storage depletion at each operating levels of the reservoir by sediment deposition since impoundment of water in the reservoir commenced after completion of the construction of the dam in 1982;
- compare the 2014 and 1982 preconstruction bed topographies using the GIS methods;
- provide the bathymetric and topographic information in a format that would facilitate their use in the management and protection of land and water resources of the lake;
- build the capacities of the staff of the Institute on reservoir sedimentation survey techniques.

Methodology

Bathymetry Surveys

- Bathymetric surveys of the reservoir depth was carried out by depth sounding using Garmin-GPSMAP-546 echo sounder. Garmin GPSMAP 546s offers Dual-frequency (50/200 kHz) sonar capabilities for improved shallow water performance, measured the depth to the bed of the reservoir up to 1500ft as the survey boat moved along track lines spaced at 10m interval covering the reservoir area and running parallel to the dam crest alignment from shoreline to opposite shoreline and perpendicular to the direction of inflow into the reservoir.

Water Sampling for Physio-Chemical Analysis

- Water samples were collected at several locations over the reservoir area using the 250ml wide mouth glass stoppered bottle. The water samples were analyzed for physio-chemical parameters immediately on the field in a field laboratory set up near the reservoir.

- The physio-chemical characteristics of the water samples were compared with the Nigerian Standards for Water Quality and the results indicated that the reservoir water is acceptable in all measured parameters except turbidity.

Suspended Sediment Concentration

- The water samples were also analyzed for suspended sediment concentration. The results of the suspended sediment analysis indicated the mean suspended sediment concentration of 7.69g/l and mean density of 1.01g/cc.

Bedload Sampling

- The bedload samples were collected randomly at the bottom of the reservoir using the suction dredger locally fabricated to collect bedload samples at depths as much as 100m. In generally, the samples contain about 80% to 85% particles finer than 0.08mm.

Results of the Survey

- The present study has partially corrected the designed reservoir capacity at spillway crest level of 334m masl (425.84MCM vs 443.00MCM) and the survey has also established the revised reservoir capacity at the spillway crest level of 334m amsl as 269.18MCM (NWRI 2014).
- Consequently, the total storage capacity loss over the thirty-one (31) years of service by the reservoir is in the order of 156.66MCM or an annual storage loss of 5.05MCM/year.

CASE STUDY 2: GORONYO DAM (PIEZOMETER INSTALLATION FOR MONITORING – DAM SAFETY)

The overall objective of the project is to provide additional seepage monitoring infrastructure at Goronyo Dam site, for the proper management of the safety of the same.

The first Piezometer borehole was drilled with compressed air and mud drilling was later used due to the fact that material used for the construction of the dam are loose and unstable (Figure 1, right). 42 piezometers were constructed within the dam area and will be used to monitor the dam on a regular basis to ensure the safety of the dam. A geological section of the dam shows intercalation of sand, silt and clay as shown in Figures 3 (left) while Figure 3 (right) shows the design of one piezometer installed at location FA 08 on the main axis of the dam.

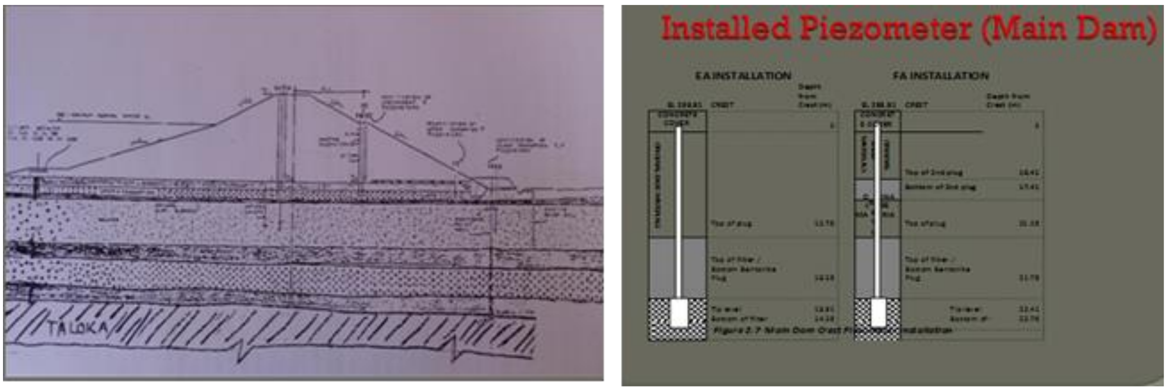

Figure 3: Geological section across the main dam axis (left); Installed Piezometer on the main dam at Goronyo (right)

CONCLUSION

The Integrated approach in the studies is expected to increase the effective utilization of the irrigation facilities for adequate food production, security of lives/properties and poverty eradication in Nigeria. These projects are expected to reduce crime rate and better national security through mass employment especially for the youth in the area and in the country in general.

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Baseline IWRM information – an interdisciplinary project approach

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Since the enactment of South Africa's current water law in August 1998, one of the priority initial activities was to confirm how much water is being used in the country, as part of a national audit process. As a dry country, this information is important to inform policy, management and planning in the water and its associated sectors in the environmental, social and economic domains. Although the starting point is consumptive water use (abstraction, storage and stream flow reduction activities – particularly commercial afforestation) water quality and riparian zone impacts are equally important audits, but methodologies are more difficult to standardize and implement. Accordingly, these latter audits have not yet commenced and their impacts are currently assessed using other instruments. The high-level water management context of the water use audit process is shown in Figure 1.

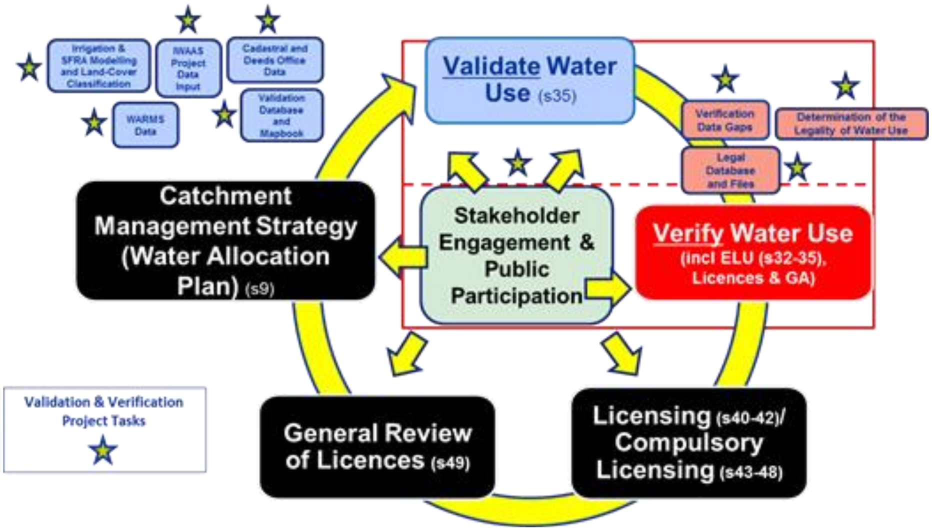


Figure 1: Schematic showing key aspects of water resources management and linkages with relevant provisions in South Africa's National Water Act (No.36 of 1998). Water use audits are described in the red box as validate and verify water use with project activities displayed in the smaller boxes next to the (★) symbol. Validation is a technical exercise to determine the nature and extent of the water use; Verification is confirmation of the lawfulness or legality of the water use. (Seetal, 2011).

There are multiple benefits from the national scale consumptive water use audit and these include, among others:

- Confirming existing lawful water use that inputs into future water allocations planning and reforms through licensing;
- The eradication of unlawful water uses. Compliance, monitoring and enforcement cases will have a clear factual basis and water use contraventions more effectively dealt with in courts of law;
- Better and more inclusive local water management (across all water use sectors), especially if these functions are delegated to, and performed by, local institutions;
- More efficient billing and water use revenue management;
- Improved management of water allocations during times of water scarcity and droughts (fewer and better managed disputes among users);
- Local, regional and national water planning and allocations can be undertaken with greater certainty, especially where water is a critical input for social and economic development needs.

Currently, there is a suite of water use audit projects being undertaken in the nine (9) water management areas (WMA) in the country (Figure 2)

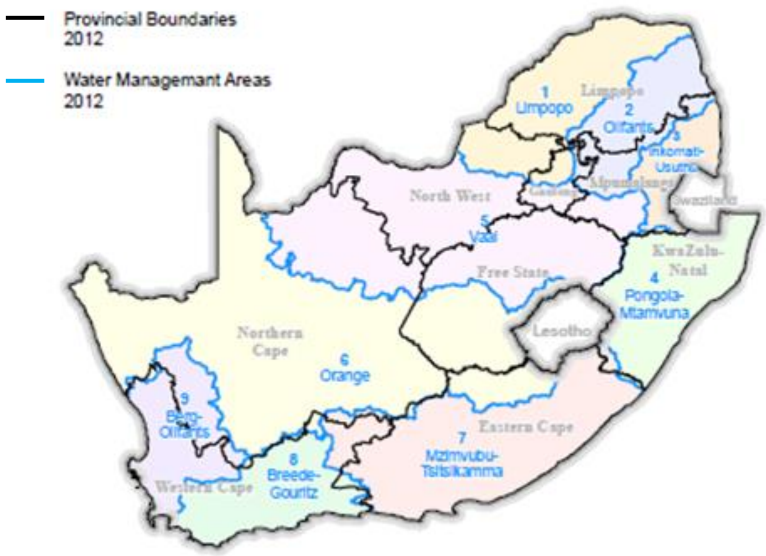


Figure 2: South Africa's nine water management areas. These are hydrological areas where the catchment boundaries differ from political and administrative (provincial) boundaries.

The initial project framework and methodologies were developed in 2003, tested and completed in 2006. There were subsequent minor refinements to the processes and procedures, based on incremental implementation experiences. An example of one such customized current project plan schematic is shown in Figure 3.

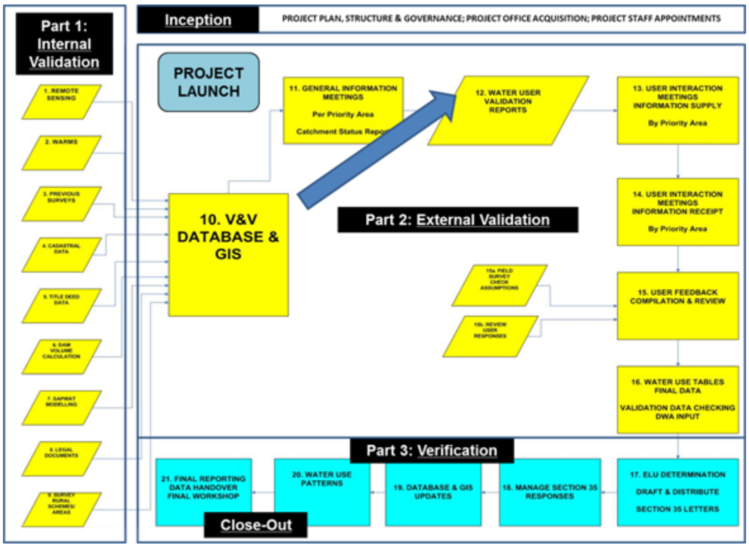


Figure 3: Water use audit (validation and verification) project plan for the KwaZulu-Natal Region, South Africa project. There are five phases in the project (black boxes), namely: Project Inception, Part 1 – Internal Validation, Part 2 – External Validation, Part 3 – Verification and the Project Close-Out.

The frameworks and supporting project plans describe internal and external procedures, systems and methodologies to be used, and are multi-disciplinary in nature. Project methodologies include earth observation (satellite imagery and aerial photography), water use and hydrological modelling, legal assessments and land surveys, where necessary and required. Illustrative results from the remote sensing analyses (Landsat 5 and 8 images), crop water use and dam volume modelling and calculations are shown in Table 1 and Figures 4 (a) and (b).

The land, water user and water use information was consolidated and summarized in a GIS format for ease of reference for individual land parcels or water users (Figure 5), and used during the water user engagement phase of the project where the user and property details, nature and extent of water uses were confirmed.

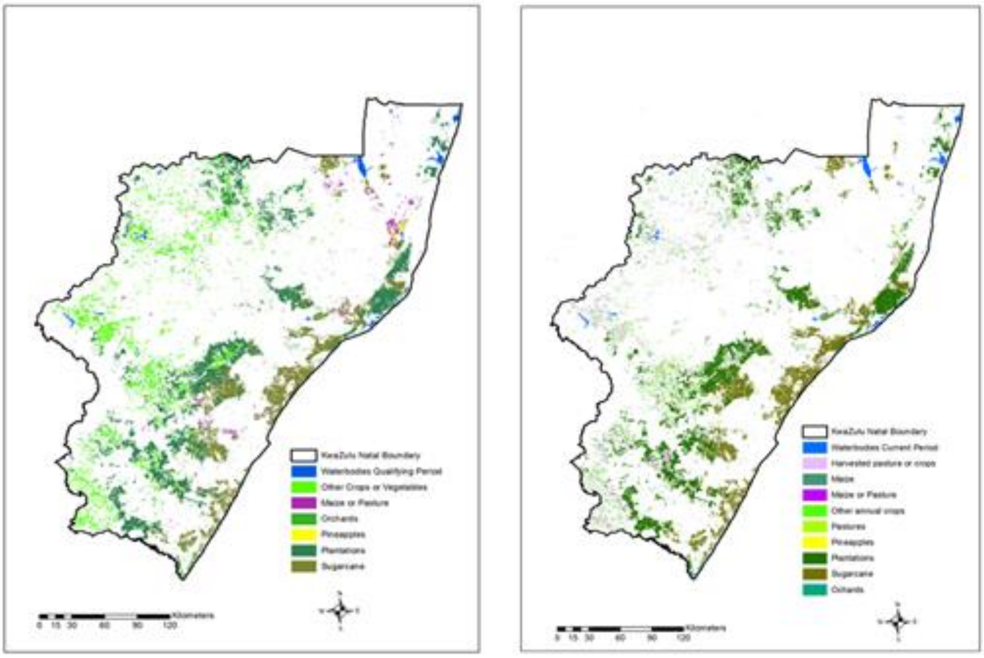


Figure 4(a): Distribution of some of the crop types, plantations and waterbodies in KwaZulu-Natal in 1997-99 (left) and 2014-15 (right).

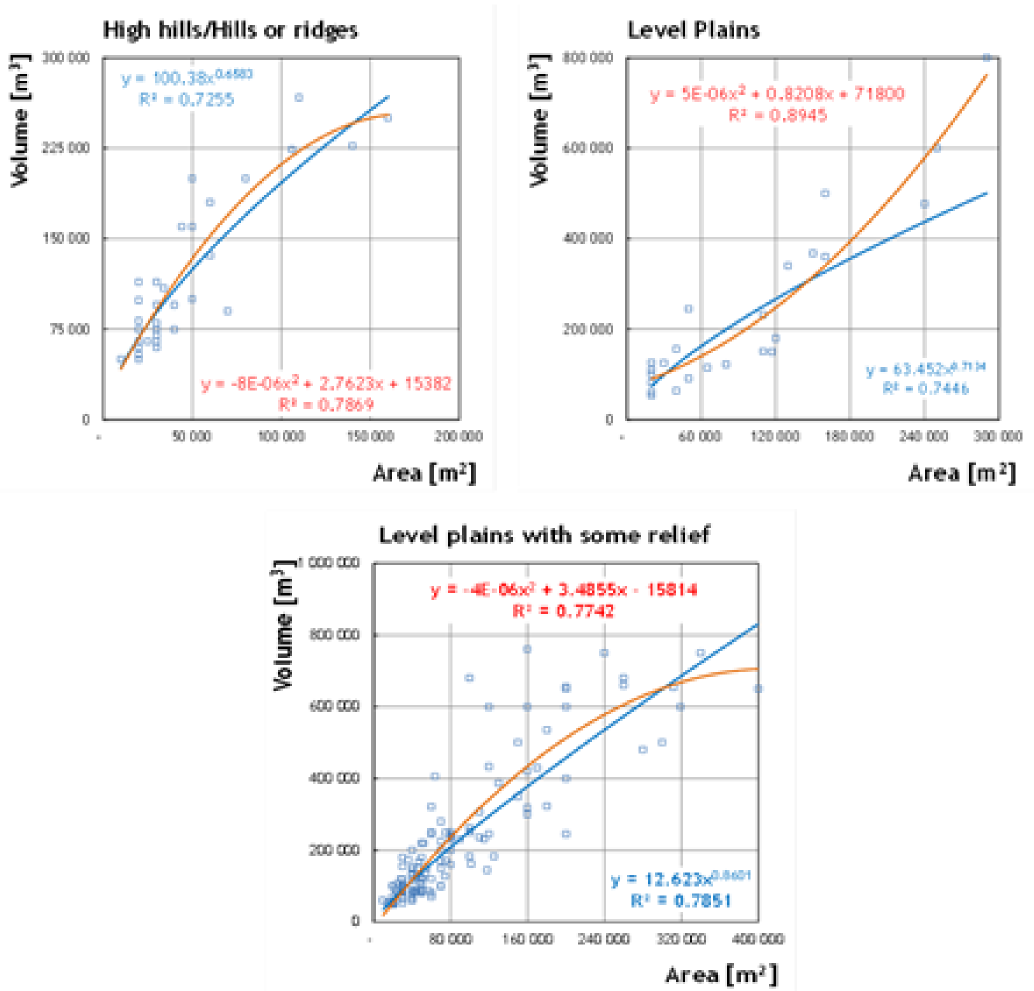


Figure 4(b): Results of the Capacity-Area relationships established for various reliefs in KwaZulu-Natal Province for farm reservoir/dam storage (Mwenge Kahinda, 2016)

Table 1: Summary results of crop water requirements using the South African Plant-Water programme (SAPWAT) based on evapo-transpiration (ET) and gross irrigation requirements for selected crops (Dzikiti and Kapangaziwiri, 2016)

Crop Type	ET (mm)			Irrigation (mm)		
	Max	Avg	Min	Max	Avg	Min
Avocado[1]	1543	1205	141	1360	631	54
Beans	575	439	326	400	215	30
Butternut	640	312	233	420	139	40
Cabbage	485	388	220	480	211	80
Carrots	534	375	283	520	330	120
Chillies[1]	1508	583	321	1020	438	60
Citrus[1]	1476	1093	100	1020	529	100
Cucumber	961	529	399	500	272	80
Maize	816	668	360	960	302	22
Perennial pasture[1]	1263	783	101	1040	337	60
Seasonal pasture[1]	1175	723	454	920	598	180
Pine apples[1]	699	605	345	560	297	160
Potato	599	449	356	500	292	20
Soybean	843	539	360	700	262	60
Spinach	996	763	65	880	474	160
Sugarcane[1]	1468	1150	126	1160	643	80
Sunflower	1141	434	350	560	181	40
Tomatoes	960	579	220	860	312	60
Watermelon	780	393	291	460	167	40
Wheat	758	526	25	720	479	40

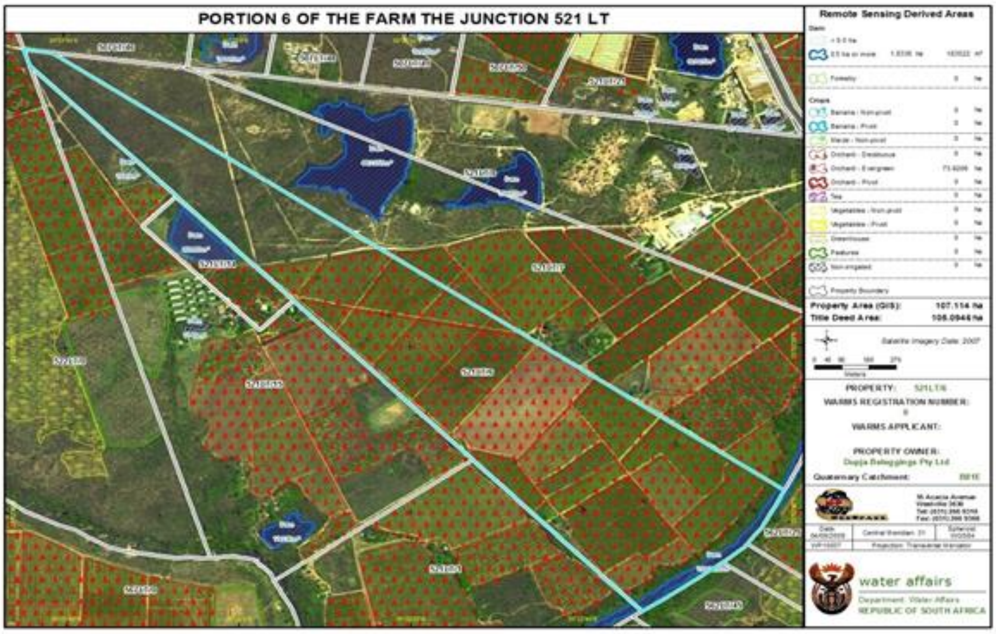


Figure 5: GIS information sheet showing the consolidated water user and property details as well as crops and water use information derived from remote sensing and hydrological analyses.

Figure 6 is an example of a comparative assessment of irrigation water use by one single user for two different periods. This unauthorized expansion (the regulatory authority had no documented records of the extended area under irrigation in 2011) may be the result of unlawful/illegal water use or increased water use efficiency and would be subject to confirmation following discussions with the water user concerned.

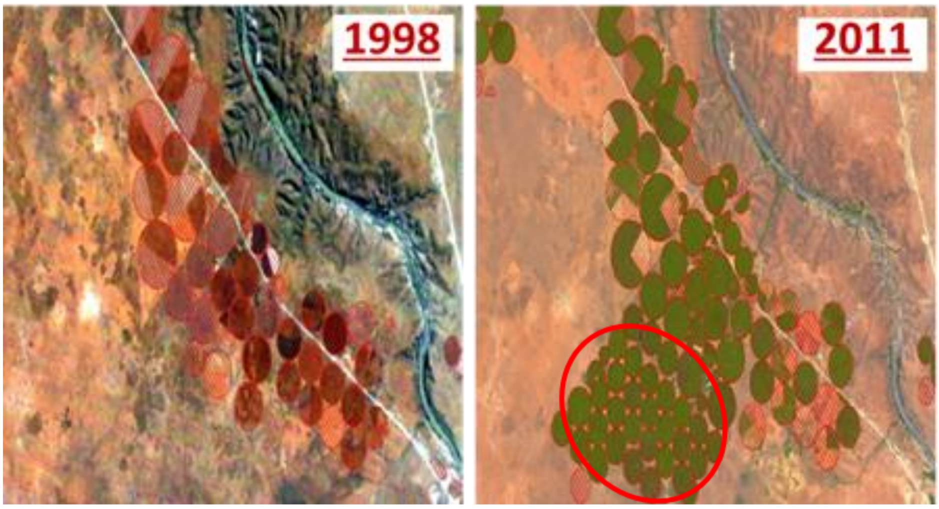


Figure 6: An example of irrigation expansion on the same property for two different time periods.

Balancing water availability with demands for its use is critical for all aspects of maintaining and sustaining resource protection and socio-economic development (Figure 7). In particular, water use audits support the evaluation of efficiencies in water use and the contribution and value of the use to environmental sustainability, social well-being and economic prosperity. These are important considerations in the context of the water-energy-food nexus, climate change impacts, socio-economic development and socio-political stability.

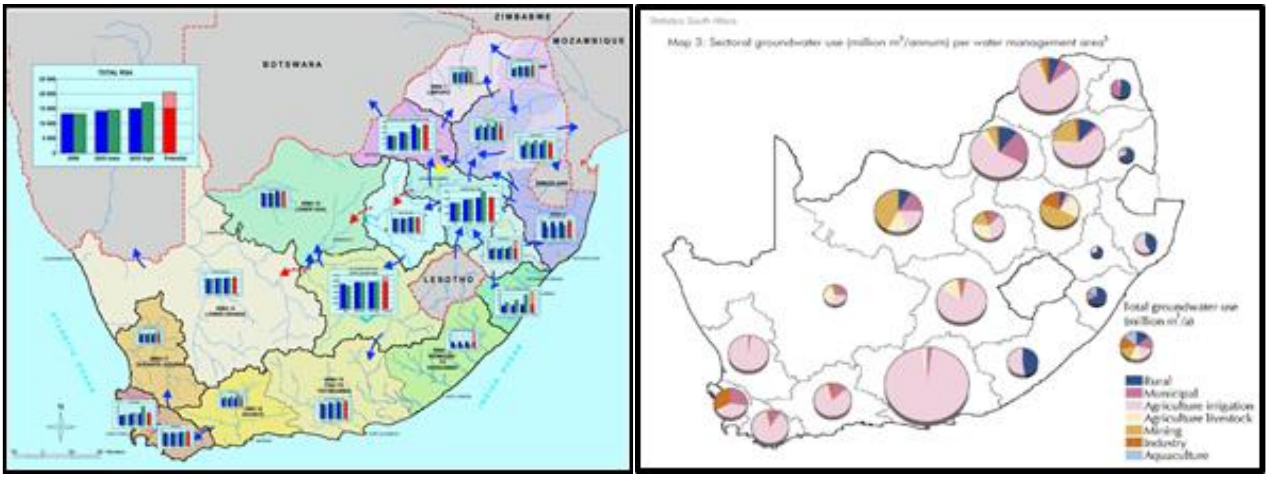


Figure 7: South Africa's water reconciliation scenarios in each of its water management areas, for surface and groundwater resources. (National Water Resources Strategy, 2004 and 2013)

At a shared watercourse scale, the benefits of synchronizing water use audits could have immense value to member countries, particularly through maintaining effective management, control and oversight of water uses and optimizing respective country water use benefits on an agreed and standardized basis.

Activities of AMCOW on groundwater

Charles NGANGOUE, AMCOW Secretariat, Nigeria

AMCOW mission is to provide political leadership, policy direction and advocacy in the provision, use and management of water resources for sustainable social and economic development, poverty eradication, regional integration and cooperation and protection of African ecosystems. In the context of the international, regional and national Goals, attention should be devoted to:

- Africa Water Vision 2025: *equitable and sustainable use and management of water resources for poverty eradication, socio- economic development, regional cooperation and integration and environmental protection*;
- Africa Agenda 2063;
- SDGs (Sustainable Development Goals) and particularly SDG 6 "*Ensure availability and sustainability of water and sanitation for all and sustainable water resource management*";
- N'gor declaration on water security and Sanitation, a key vehicle to achieve the SDGs 6 .

Particularly, '*Africa Water Vision 2025*' focus on Water Resources Availability and Use in Africa, highlighting:

- Human Right for Water and Sanitation: Sustainability of access to safe Water and Sanitation services to meet basic needs;
- Water has become one of the primary factors for sustainable socio-economic development, eradication of poverty and protection of ecosystem;
- Water contributes to cooperation, regional integration and peace through Hydro Diplomacy.

In such a framework, groundwater plays a key role in human development, by:

- Providing drinking water to at least 70% of African's population;
- Providing water used for agriculture at least 43% in rural areas;
- Sustaining the base flow of rivers and aquatic systems (flood and river management);
- Supporting Industry development, agriculture, forest, biodiversity;
- Water security at national, basin and international levels;
- Being a critical resource for adaptation to climate variability and climate change;
- Promoting cooperation and integration;
- Addressing WEF (Water, Energy and Food) nexus (i.e. OMVS - Organisation pour la Mise en Valeur du fleuve Sénégal).

COOPERATION AND REGIONAL INTEGRATION

Transboundary Water Resources raise even more challenge Cooperation and Integration issues (Figure 1). There are more than 38 transboundary aquifers in Africa. Some aquifers and Basin Organizations are shared by two or more sub-regions and countries like Congo Basin shared by Central Africa, Eastern Africa and Southern African countries, Niger Basin Authority shared by countries from Western and Central Africa and Lake Chad Basin Commission shared by Central Africa and Western Africa by Cameroon, Chad, Nigeria, Central Africa Republic and Niger; Nile Basin Initiative; other basin Organizations are shared within the sub-region countries like Senegal River Basin Development Organization (OMVS), Gambia River Basin Organization, Okavango River Basin Commission, Initiatives as Zambezi River Authority, and Lake Victoria Initiative.

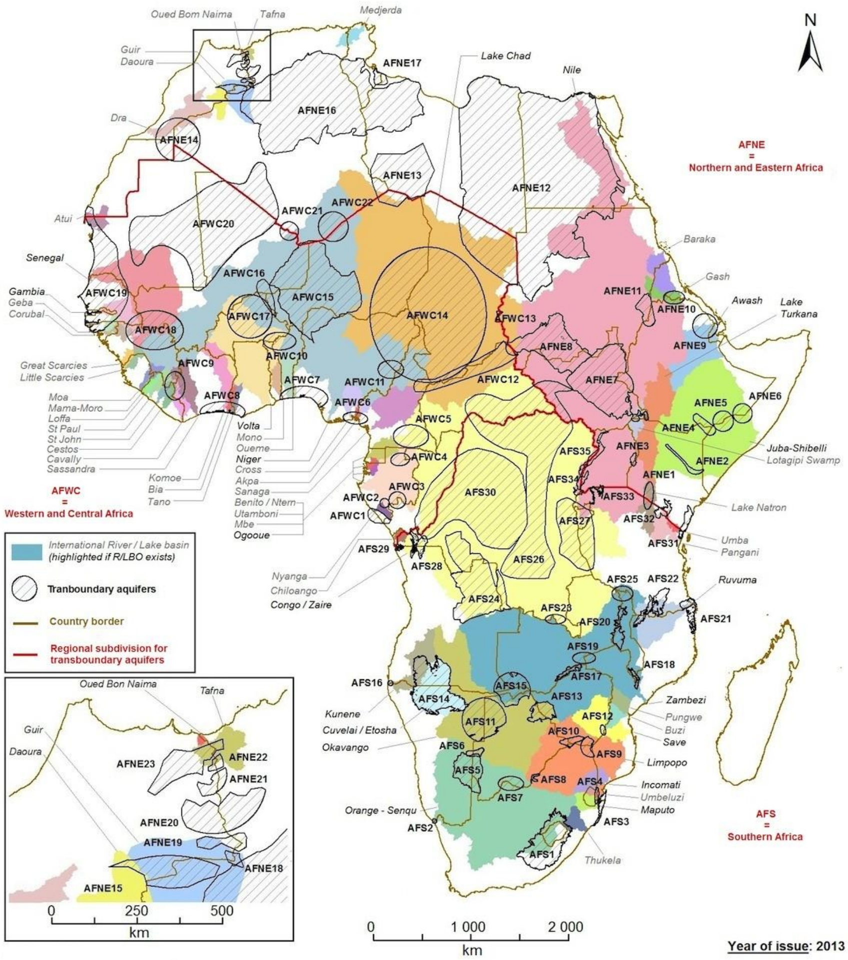


Figure 1: Transboundary Aquifer Map of Africa (source: CGIAR Research Program on Water, Land and Ecosystems)

GROUNDWATER CHALLENGES IN AFRICA

Face to AGWC vision, "*an Africa where groundwater resources are sustainably utilised and managed for the benefit of all*", groundwater management poses many challenges, as follow:

- Groundwater should be recognized, utilised and protected as an integral part of Africa's water resources framework: integration of Groundwater management into Basin Institutions (AMCOW Decision) by planning, meetings, training, AMCOW events such Africa Water Week;
- Groundwater governance: Framework for Groundwater Governance, legal and institutional aspects for participative management in systematic planning, financing and implementation;
- Poorly understood resource (few attention, few recognized);
- Explosively abstracted (intensive use of groundwater, not enough taken into account in planning, development and coordination, extraction agreement);
- Knowledge and information management: building institutional and technical capacity and skills because few specialists, education, capacity building, research, training centres, innovation by scientific research, technology, training manual (recommendation of Ouagadougou Workshop 2013);
- Monitoring groundwater quality and quantity: inadequate sanitation system (wastewater and industrial waste, use of pesticides in agriculture), aquifer management, resource protection, environmental aspects;
- Cooperation agreement: cooperative management of transboundary aquifers at basin, regional, national levels;
- Financing and mobilizing financial resources;
- Groundwater governance for better and sustainable management at local, national, basin, RECs and trans-boundary levels is still poor despite efforts made by some RECs (SADC), countries (South Africa, Libya, Kenya) and Basin Management Organizations (ORASECOM – Orange-Senqu River Commission).

ACTION TAKEN ON GROUNDWATER: POLITICAL WILL

Water is increasingly being recognized worldwide as a critical factor of social and economic development and has been addressed in Africa at Summits of Heads of States and Government, in AMCOW decisions and by involvement of partners and Institutions:

- 2000: Africa Water Vision 2025;
- Abuja 2002: Creation of AMCOW;
- Johannesburg, 2002: Integrated Water Resources Management (IWRM) and water efficiency plans incorporating all IWRM components;
- Syrte, Libya, February 2004: Water for Agriculture;
- Brazzaville May-June 2007: AMCOW Declaration on Groundwater Initiative;
- Sharm-El-Sheikh, Egypt, July 2008: for accelerating the achievement of water and sanitation goals. Water and sanitation are and must remain a key to sustainable development in Africa;
- Nairobi, November 2008: establishment of the Africa Groundwater Commission (AGWC);
- Syrte, Libya 2008: Water for Energy and Agriculture, a challenge in the achievement of food and energy securities nexus;
- Addis Ababa 2014: African Union (AU) summit decision on a Study on groundwater for agriculture;
- Dakar 2014: N'gor declaration on Water security and sanitation;
- Involvement of partners: AfDB, UN-Water (UNESCO, UNICEF), BGR, AGW Network, IAH, IGRAC, RWSN;
- Engagement of African countries and RECs: Libya, South Africa, Kenya, SADC.

AMCOW ACTIVITIES ON GROUNDWATER

- Implementation of the AU (African Union) and AMCOW decisions on Groundwater;
- Full operationalization of the AGWC and achieve its vision;
- Promote, facilitate, coordinate platform for African and international water community to work together for development, implement and monitor the AMCOW Work programme and the SDGs and targets at regional, basin and country levels;
- Coordination of Platform for Data & information management, results of scientific research knowledge, best practices sharing between regional institutions, organizations, countries (RECs, RBOs);
- Promote groundwater governance (framework for transboundary aquifers management and cooperation);
- Financial resources mobilization;
- Capacity Building (Training, Seminar, meeting, AWW).

AMCOW IMPLEMENTATION PARTNERS

- AfDB/AWF
- In the framework of AMCOW Project on Support for the Establishment of a Monitoring and Reporting System for the Water Sector in Africa, develop indicators on groundwater issues and implement at basin, RECs and countries levels;
- UNESCO: Operationalization of the AGWC, capacity building program, transboundary aquifers management and cooperation;
- NEPAD Water Centres of Excellence (Capacity building, Research, scientific and technology aspects);
- RECs: SADC, ECCAS, ECOWAS;
- ANBO and Basin Organizations;
- GWP: IWRM, promote benefit sharing in transboundary aquifers, strengthen Institution of ANBO;
- OSS: data information, Aquifer, regional cooperation;
- BGR, AGWNetwork, AGRHYMET: data, information sharing;
- RWSN on rural water supply ;

As a general conclusion, it is worth to recall Governing Council Decision on Operationalising the African Groundwater Commission (GA/10/2016/Dar/11) and the Governing Council calls on Member States and Partners to financially and technically support the operationalization of the AGWC. As Africa has to face common Challenges, Common Objectives towards Sustainable Groundwater development and governance in Africa should be shared as well.

UNESCO CHAIR in Hydrogeology as a center of excellence of Southern Africa at the forefront of capacity building, research and development of groundwater professionals

MENGISTU Haile Arega, University of Western Cape, South Africa

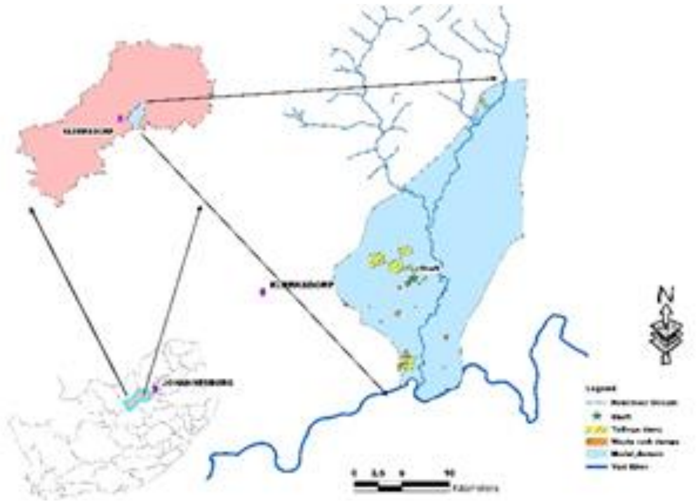
UNESCO CHAIR in Hydrogeology is an institution devoted to groundwater research and development under the University of Western Cape, South Africa. UNESCO CHAIR center is striving to continue, lead and implement its projects through three full time and three extra ordinary emeritus professors so far awarded 15 Ph.D. and several masters' graduates since its inception. The center provides nationally and internationally recognized expertise in groundwater resources assessment and management in developing regions including: conceptualization of groundwater flow systems: recharge, storage and discharge in hard rock aquifers; assessment of groundwater pollution due to agricultural and mining activities including acid mine drainage and fracking process; environmental flow requirements, especially groundwater resources directed measures, integrated water resources management in South Africa, and groundwater governance. The center has been providing various short-term courses, collaborated with several national and international organizations and lead regional and continental projects. UNESCO CHAIR in hydrogeology also provides essential advisory of national water resource management policies to the South African government; it also leads African Groundwater initiative for groundwater commission and China-Africa Water Forum. Going forward, the UNESCO CHAIR in Hydrogeology is focusing towards fulfilling universal access to water and sanitation by introducing smart integrated water management schemes, which incorporates accelerated capacity development of water storage schemes by increasing recharge (artificial recharge), improved monitoring strategy and delineating and controlling pollution sources including the issue of saltwater intrusion into coastal aquifers. The center also envisages setting up aggressive educational forums, and empowering rural women leadership in groundwater governance and management.

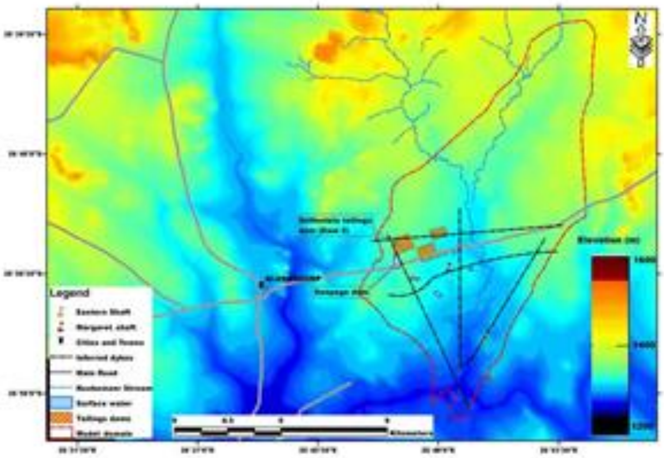
The center currently operates full-fledged water analytical laboratory, which measures major and trace metal concentrations with high accuracy using spectrophotometric technology. The laboratory hosts equipment and expertise towards the measurement of environmental stable isotopes of hydrogen and oxygen. The hydrogeology laboratory has models for show casing Darcy flows, sand boxes for aquifer presentation, and various capacity pumps for field aquifer test demonstrations, portable multipurpose water physico-chemical probes and various water samplers. There is also a real-time meteorological data receiver, which supplies real-time weather data at no charge for the greater Cape Town area, a Geographic Information System laboratory equipped with the state-of-the-art ESRI software (ArcMap 10.1) and spatial database of South Africa including satellite images for remote sensing applications. The UNESCO Chair in Hydrogeology Center can access facilities of the Applied Geology Department of the various laboratories including petrographic, geochemistry and sieve analyses, to mention a few.

The center has expertise in isotope hydrology, water quality, quantitative hydrogeology, mine hydrogeology and environmental hydrogeology. The center is composed of a team of skilled man power in spatial data analyses using GIS software (ArcMap 10.1™) and remote sensing data analysis (DRASTIC Model™), aquifer test data analyses (AQUETSOLV™), Groundwater flow and contaminant transport modeling (MODFLOW based Groundwater Modeling System, GMS™), Tracer Tests analysis (Efficient Hydrologic Tracer-test Design, EHTD), Geochemical modeling (Geochemical Workbench™, GWB and FITEQL), Water analytical data interpretation software (AQUACHEM™), Visualization software (Environmental Visualization System (EVS™), and SURFUR™) and statistical data analyses.

PROJECT 1: CATCHMENT LEVEL NUMERICAL MODELING WITH IMPROVED CONCEPTUAL MODELING USING ENVIRONMENTAL STABLE ISOTOPE AND WATER CHEMISTRY DATA IN A DEFUNCT MINE, WITWATERSRAND BASIN, SOUTH AFRICA

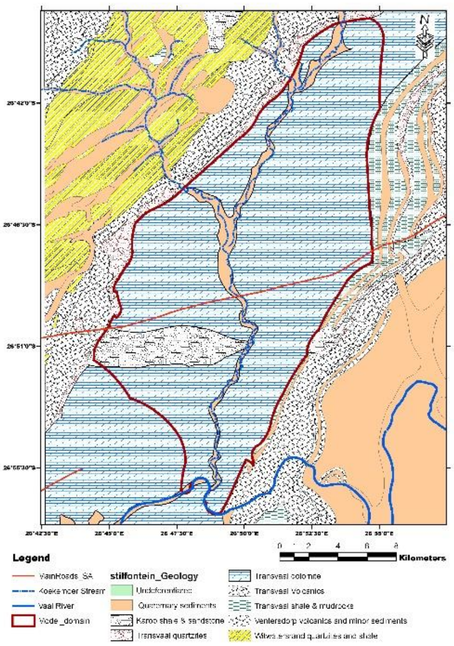
Recently, a successful project was completed by one of the staff members using integration of various data sets (Environmental stable isotope and water analytical data) to refine and recalibrate conceptual groundwater flow model on sub-catchment level in the Witwatersrand Basin (Figures 1 and 2). The conceptual groundwater flow model was used as a basis for developing a numerical groundwater flow in a defunct mine. An old mine shaft is being used for dewatering of excess groundwater to prevent downstream active mines as the best mine water management option and keep vital mining operations continue without compromising the safety of the miners. The catchment based numerical modeling provides updated site information (Figures 3 and 4) to decision makers whether or not the current dewatering scheme is the best management option, helps to conduct scenario analyses using various conditions and predict what happens if the current condition continues or a condition whereby there is a cessation of dewatering in the next 50 years (Figures 5a and 5b).

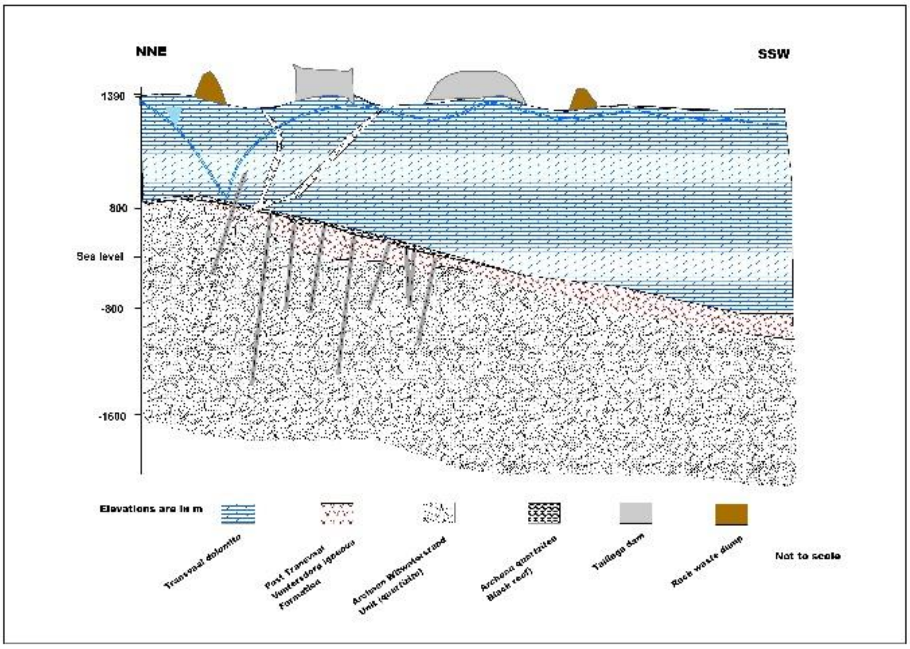




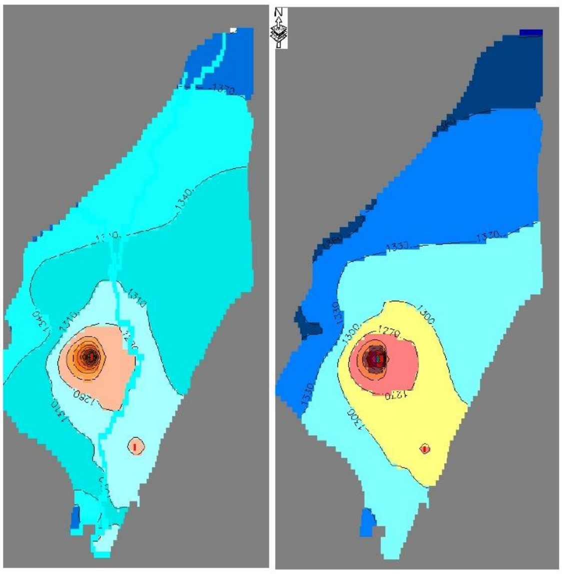
Figures 1 and 2: Site location map and site topography

The numerical model predicted that provide that the current conditions remain unchanged, many shallow farm boreholes would be dried in 10 years-time and the zone of influence of one shaft dewatering would expand to merge with another shaft dewatering in about 50 years. The 50-year prediction shows that the merge in the two cons-of-depression would cause various impacts including formation of sinkholes, interception of highly polluted water from a new tailings dam, which was under construction and possible catastrophic dam collapse due to local subsidence triggered by dewatering (Mengistu et al. 2015).





Figures 3 and 4: Site geology and cross section



Figures 5: Model run results of in layer 1 (left) and layer 2 (right) after 50 years of pumping.

PROJECT 2: APPLICATION OF MULTIVARIATE STATISTICAL ANALYSIS TO INVESTIGATE THE HYDROCHEMISTRY OF GROUNDWATER UPPER BERG RIVER CATCHMENT, WESTERN CAPE, SOUTH AFRICA

A multivariate statistical analysis (MSA) has been used to characterize groundwater quality in the Upper Berg River Catchment (Fig. 6) and to establish the evolution and suitability of such waters for agricultural use. Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (CA) have been applied to groundwater physicochemical data that were collected from several boreholes by following the sampling standard procedure. Piper Diagram showed that Na-Cl water types were the predominant groundwater facies (Figs. 7, 8 & 9). Furthermore, PCA extracted five major factors that explained 83.11 % of the variation in the physicochemical characteristics of groundwater. Cluster Analysis extracted three major groundwater clusters based on dissimilarities in groundwater physicochemical characteristics in different sites. Groundwater quality in the Upper Berg River Catchment mainly reflects the influence of natural process of recharge, rock-water interactions and microbial activity.

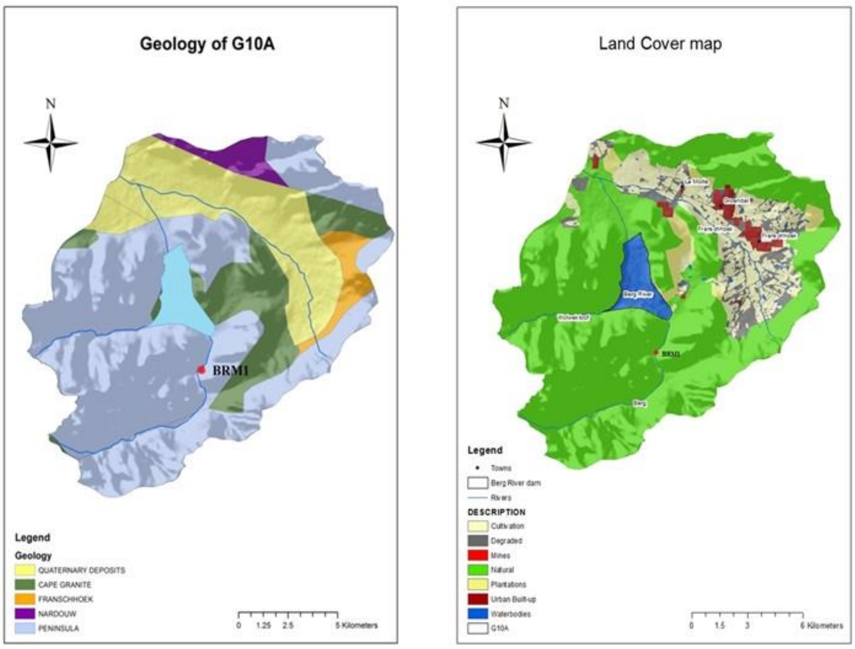
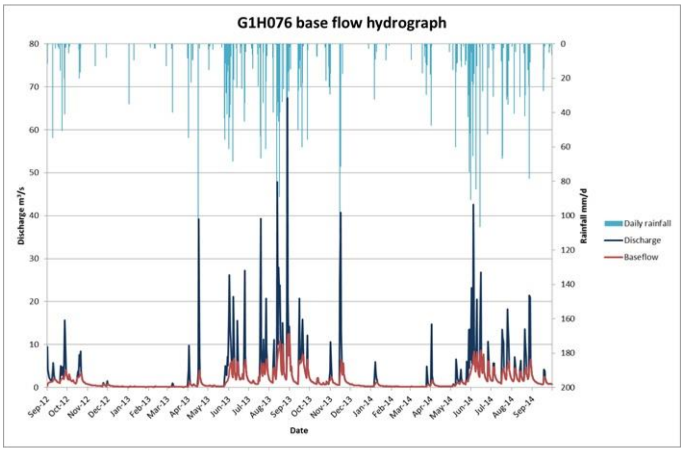
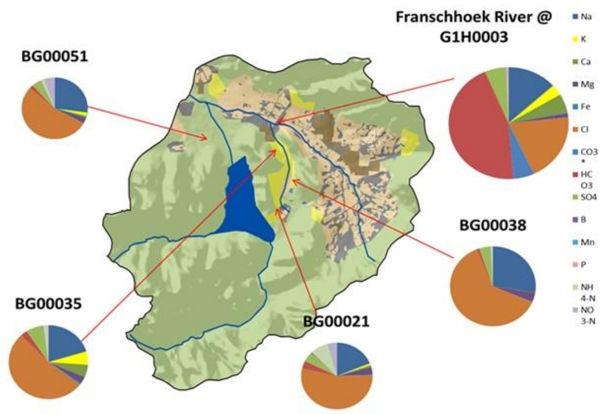


Figure 6: Site geology and land cover map





Figures 7 and 8: Surface water – groundwater interaction, water quality map

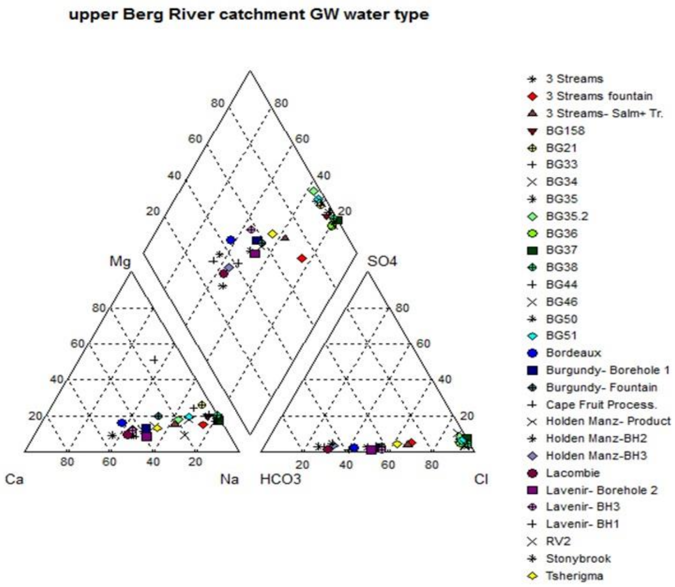


Figure 9: Piper plot of groundwater chemistry

The project successfully determines the groundwater quality situation of the area as well as average annual recharge, both critical for sustainable management of the groundwater aquifer in this (wine producing) region of South Africa.

At the same time, the outcome provides a platform to design effective monitoring strategy and select areas where additional monitoring points are required. More importantly, the research outcome helps the local department of water and sanitation bureau to manage water use licensing and permits in a way that do not compromise the quality as well as the quantity of the local groundwater resource in the Berg River catchment.

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Specific interests for water resources management and development for Zambia

NKHUWA Daniel, University of Zambia

It is universally accepted that Water and Sanitation comprises two sub-sectors, namely, (i) Water Resources Management and Development (WRMD), and (ii) Water Supply and Sanitation (WSS). Along its quest to acquire Middle-Income Status through its Vision-2030, Zambia has identified agriculture, mining, industry, housing and energy as growth sectors. Close examination of these sectors reveals that they require access to adequate water and sanitation services for their effective development. However, developments in each of these sectors, in turn, will affect both the quality and the quantity of available water resources as follow:

- Pressures induced by land use changes and socio-demographic dynamics (i.e. population growth, urbanization, governance);
- Reduced flow downstream of surface impoundments – impacts created by man-made infrastructures and policies on the availability and quality of water;
- Accumulations of fertilizers and pesticides resulting from agricultural practices;
- Waste water discharges from industrial and domestic activities;
- Excessive pumping of groundwater for mine dewatering purposes.

The greatest challenge that must addressed is the availability of adequate and credible monitoring data to enable informed decisions to be made with regard to sustainable development, utilization and management of the country's (but also continent's) water resources. The following express our specific interests and needs as a country:

1. Research and Development – the imperative for developing innovative approaches and appropriate technologies for effective management of the nation's water resources cannot be over-emphasized, and must involve:

- Strengthening the country's hydrological network for water resource surveys;
- Enhancing professional competency in borehole drilling and acquisition of hydrogeological and aquifer data;
- Strengthen the country's institutional capacity for hydro-meteorological and groundwater monitoring;
- Conducting systematic applied research in water development, utilization and management.

2. Climate Change/Variability Adaptation - strengthening national capacity for adaptation (and mitigation) to effects of climate change, as well as manage disaster risks. To attain this objective, the following strategy should be adopted:

- Develop pilot projects to improve water conservation infrastructure against climatic change/variability including reduction of flooding;
- Implement climate change adaptation projects countrywide; and
- Enhancement of capacity in disaster risk management.

3. Integrated Water Resources Management – to ensure effective water resources management at various levels in the country by means of:

- Provision and implementation of appropriate policy, legal and institutional frameworks for integrated water resources management;
- Development of skills at different management levels – river catchment, basin, regional and national;
- Water information – there is need to place value on water information in order to ensure that water data from drilling and monitoring networks feeds into efforts to improve resource's evaluation, development and management.

The critical and effective icing to the attainment of all these specific interests lies in the development of capacity – in terms of skills and knowledge – and effectively coordinated and regulated sectoral activities.

Shallow groundwater irrigation for food security in northern Ghana

BOUBACAR Barry, WASCAL – AFRIALLIANCE, Burkina Faso

The majority of Sahel inhabitants are rural, and small-scale rainfed agriculture is the dominant economic activity, employing roughly two in three inhabitants (nearly 9 out of 10 in Burkina Faso). Livelihoods vulnerability, food insecurity and poverty are major problems. Agricultural productivity is low, roughly 1 metric ton of cereal yield equivalent per hectare.

Given the extremely unreliable rainfall pattern, irrigation development is seen as an obvious strategy to increase agricultural production. One irrigation development pathway involves the utilization of small reservoirs, found throughout the Sahel. However, the performance of many of these systems is adversely affected by management problems and the economic benefit relative to the investment is characteristically low and only benefits a limited number of farmers.

The use of hand-dug shallow wells and dugouts, enabling the utilization of shallow groundwater for irrigated production of vegetables and cash crops during the dry season provides an alternative source of income for farmers and poor households. Shallow Groundwater Irrigation (SGI) has developed without any government or donor involvement. In the last decades, hand-dug shallow wells have been spreading throughout in the Sahel and are located mainly in inland valleys. SGI systems are farmer-driven and have developed without any government or donor involvement. They frequently emerge in areas where some minor form of traditional dry season gardening existed or where migrant workers introduced the techniques. Production of vegetables during the dry season has become an alternative source of income for farmers and poor households in the dry season. "Well gardening" is a long-standing method of cultivation practiced in Niger, possibly for hundreds of years (Morris et al. 1984). Hand dug shallow wells, usually only a few meters deep, are located in shallow alluvial aquifers, usually associated with active stream channels or beneath floodplains. These are regularly recharged by perennial stream flow or by annual flood waters, and long term depletion is not thought to present a problem (Owen and Rydzewski, 1991).

Despite its wide spread practice and immense contribution to food security, information on SGI, their extent and contribution to livelihoods support remains very limited. SGI is practiced by many small scale farmers in the informal sector, and contributes immensely to livelihood security and poverty reduction. Although it is increasingly becoming widespread, crucial information such as the spatial extent of use, physical and economic efficiency, socio-economic drivers and potential impacts of SGI on groundwater resources remain largely undocumented. This paper examines SGI in detail and discusses its performance in the Atankwidi basin – a representative sub-basin of the White Volta in northern Ghana with the highest per capita use of groundwater.

IWEGA past and ongoing water-related activities in Southern Africa region and potential contribution in the framework of ACEWATER2 project

FALCAO Mario Paulo, IWEGA, Mozambique

The International Center for Water Economics and Governance in Africa (IWEGA) is a center of excellence in Africa for applied research and training in the field of water economics and governance. The main activities of the center are research, training (graduate and post graduate), and policy support actions. The center is hosted at the Faculty of Agronomy and Forestry Engineering of Eduardo Mondlane University (UEM).
The mission of IWEGA is to develop "knowledge and skills in Africa in water economics and governance by enhancing the capacity of African researchers to conduct inquiry of relevance to African problems. IWEGA aims at increasing managers´ and policy makers´ awareness about water economics and governance for sustainable development".
IWEGA plays a crucial role in terms of catalyzing and coordinating research and training activities on water economics and governance issues. In addition to the faculty of Agronomy and Forestry Engineering of UEM, the faculties of Engineering and Law work in close collaboration with the IWEGA staff in terms of both research and training. Some courses of the Regional Master in water economics and governance offered by IWEGA are part of the curricula of the faculties of Agronomy and Forestry Engineering, Engineering and Law of UEM.

IWEGA had been implementing several research projects regarding water-related activities, namely:

- Analytical Framework on the Institutional Analysis of Water Management and Governance in three African Countries (Mozambique, South Africa and Zimbabwe);
- Water Governance and Decentralization in Africa: A Framework for Reform Process and Performance Analysis. An Application to three Southern African River Basins;
- The politics of water payments and stakeholder participation in Limpopo river, Mozambique.
- Quantifying the Process and Performance of River Basin Water Management Decentralization in Sub-Saharan Africa;
- Water governance decentralization in Sub-Saharan Africa: between myth and reality.
- Rethinking stakeholders' role for flood prevention and maintenance in the context of climate change: the case of the irrigated scheme of Chokwè, Mozambique;
- Economic valuation of natural resources in Mozambique;
- Farmer associations' perceived appropriateness and practicability of role playing games for maintenance of Chókwè irrigation scheme in Mozambique; and
- Climate Change: Assessment of Institutional Systems and Government Organizations in Mozambique.

IWEGA is willing to contribute to the framework of ACEWATER2 project, based on our available expertise and research interests, at national and regional levels on the following issues:

- Climate Change / Variability
- WEF (Water-Energy-Food nexus)
- Agriculture
- Socio – demography
- Politic – Governance.

Coupling for Coping, CoOPLAaGE: an integrative strategy and toolbox fostering multi-level hydrosocial adaptation

Nils Ferrand & the CoOPLAaGE group[7], UMR G-EAU, France

ABSTRACT

We introduce CoOPLAaGE, a meta-strategy and the related toolbox, supporting effective transformation in multi-level hydro-social systems, through participatory decision and implementation. Building on a set of international and diverse case studies over 15 years (Daniell et al., 2010)(Emeline Hassenforder, Ferrand, Pittock, Daniell, & Barreteau, 2015)(Legrand, Ducrot, Van Paassen, Monteiro, & Rousseau, 2014; Pommerieux, Bourblanc, & Ducrot, 2014)(Ferrand, Hassenforder, Ducrot, Barreteau, & Abrami, 2013)(Magombeyi, Rollin, & Lankford, 2008), selected principles, methods and tools have been improved and harmonized to support transformative processes at all governance and operations' scales. (Re-)Coupling scales, sectors, actors and perspectives, issues, methods, decision' steps is a complex challenge, with technical, social, procedural, methodological dimensions (see e.g. Saravanan, Mcdonald, & Mollinga, 2009). Through an integration and implementation focus, it can enhance the efficiency of public intervention and the mutual benefit from all actors' efforts. In this note, we summarize the key principles and expose an overview of this strategy. We develop the different components of CoOPLAaGE: PrePar for participatory engineering of decision procedures, SMAG for baseline governance assessment, Just-A-Grid for distributive justice dialogue, Wat-A-Game for participatory modeling and simulation, CooPlan for participatory planning, ENCORE-ME for monitoring and evaluation and Scoolplaage for capacity building.

COUPLING-FOR-COPING: RATIONALES & APPROACH

Isolation, sectoral "silo-ing", segmentation, disciplinary attachment, stakeholders' exclusion, social des-integration or segregation, methodological specialization, mono-specific productivism, horizontal concentration, short-term-ness, science-society gaps, reductionism, etc., are all forms of protective specializations, often driven by "optimization" and control issues (Mitchell, 2005; Serageldin, 1995). While being promoted by several strategic and systemic drivers, they restrain adaptive capacity, synergies, creativity, coordination, common pool resource management dynamics, low-cost low-intervention social transformation (Pahl-Wostl, 2009). Such situation is clearly paradoxical in a context of economic globalization and wide "networking", but it does also mirror top-down "divide-and-rule" strategies and bottom-up individuals' willingness to simplify, master self' complex dependencies and desaturated from information overflow.

When acknowledged, the coupling-for-coping target dimensions are diverse: actors (participation), scales (vertical integration), issues or sectors (horizontal integration), methods (complementarity and methodological independence), disciplines (interdisciplinary), decision steps (from normative to cognitive, operational and relational), solutions' types (technical & non-technical). Each has its own rationale and attached approaches, while the transversal coherency also has to be improved among them. Conversely, in a context of reduced public (top-down) intervention capacity, general decentralization and search for resilience, local autonomy has to be strengthened (Andersson & Ostrom, 2008). This may appear first as a decoupling attempt, but by cutting external links and dependency, it de-facto should lead to re-coupling internally inside the social groups and the environment, looking for local and mutual (circular) solutions.

In such context, our strategy has been to engineer and promote a proactive and multi-dimensional coupling dynamic (Daniell & Barreteau, 2014), using series of tools supporting the key decision and implementation needs, in a coherent manner. Designed and tested case after case, they constitute together a versatile solution environment for water and land management, with all stakeholders.

[7] Géraldine Abrami, Emeline Hassenforder, Benjamin Noury, Raphaële Ducrot, Stefano Farolfi, Patrice Garin, Bruno Bonté, Sylvie Morardet, Delphine L'Aot

THE OVERALL PARTICIPATORY DECISION CHAIN

Before introducing the detailed steps and methods, we describe the overall re-coupling process in the decision chain. The typical steps are as in Figure 1, combined with monitoring and evaluation.

Figure 1 : Participatory decision steps in Ethiopia & Uganda (Afromaison FP6 project) - Hassenforder, 2015

They follow a classical framework procedure, but include at least two specific stages:

1. An initial participatory decision about the participation itself, used to establish the common procedural rules (recoupling procedural and substantive decision making);

2. A coupled use of participatory modeling, simulation (role-playing games) and explicit planning, with dual exchanges between them: games used to foster creative and coherent action and strategy design vs. integrated plans to be tested in games.

In the current design procedures (PrePar, see below) we push 8 main decision steps to be addressed: building a participation plan, diagnosis, scenario exploration (incl. modeling), setting goals, values and constraints, identifying actions and plans, choosing, implementation, monitoring and evaluation. By making stakeholders parsing these and setting their preferred participation intensity, we get them to consider the diversity and complementarity of decision stages, and recouple issues, values, information and other actors' perspectives.

THE STEPS AND TOOLS OF THE COOPLAAGE FRAMEWORK

1. Planning participation with PrePar

In this initial step, participants have to agree their future participation plan and rules: who will participate to which decision step, and how. By addressing openly the procedure and common rules early, it recouples participants with their own commitments, their roles and collaboration conditions. Open to all citizens it supports new forms of complementarity between representative and participatory democracy (e.g. Kohler-Koch, 2007; Trenz, 2009). It also elaborates on warrants and participation charters[8].

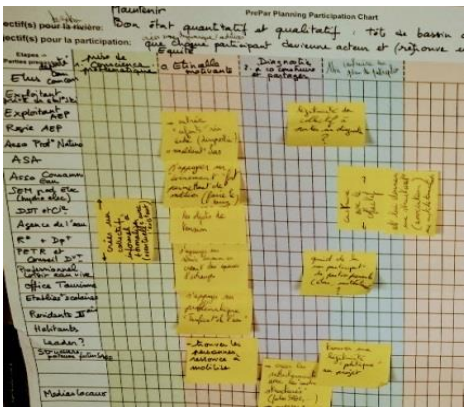

Figure 2 : A PrePar pre-participation plan

In PrePar ("Pre-Participation"), all participants (including citizens), using reference information on participatory decision and methods, discuss participatory aims,

[8] See e.g. the Public participation Charter developed by the French Ministry of Environment, Energy and Sea at the following link: www.developpement-durable.gouv.fr/IMG/pdf/16227_Charte__participation__democratie__participative.pdf

stakeholders, decision steps, participatory actions, roles and finally rules. They build a participation program, which will guide them later. This is crucial for future mutual trust, respect between citizens and elected bodies, and reference for procedural arbitration.

2. Learning to participate with SCoOLPLAaGE 2nd order training

Learning to participate or to "let-them-participate" requires training, access to practical exercises, simple references and time. In this step, participants are guided together in simulated participatory processes, directly mimicking their real situations, and using the proposed methods. They are directly challenged by having to become immediate trainers (or "traineers") of other groups, associating their own practical learning with an actual participatory process, which they steer and facilitate. This recouples small initial "traineers" groups with larger social assemblies, and triggers trust in their autonomous capacity for the process. The SCoOLPLAaGE training toolkit includes classical material and online support websites, which "traineers" have to follow and fill step-by-step as in real operations. More than 60 training cases have been implemented. A very online training course for groups (MOOC "TerrEau & Co", AgreenCamp 201--2017) is currently being developed, to replace in-person group training.

Figure 3 : A SMAG mapping process (Interreg SPARE 2016)

3. Assessing past governance with SMAG

Looking toward the past of management and governance is a way to enlighten the future. Next step offers some selected participants to reanalyze, model and map the past water governance. It is based on participatory modeling techniques, but applied to past decision processes.

With SMAG (Self-Modeling for Assessing Governance), participants assess the scope of past decisions, the main actors, the most important decisions, their causes and impacts and look at key factors to analyze the governance regimes. They build a transferable map of the history and infer key findings for future changes. Thereby it couples the past and the future.

4. Modeling and playing for changing together with Wat-A-Game

Participatory Modeling is a key process for coupling the used reference models with the reality and the perceptions, and for coupling very diverse issues: environment, society, technologies, current and future activities (ComMod, 2005; Voinov & Bousquet, 2010). All stakeholders can participate in the design of their own models which become appropriate with their own life and decision cycle. In a second stage these models are used for open multi-level participatory simulations, or role-playing games, where all participants can explore and understand, change, test and normalize practices and policies. Between lay people and intermediary stakeholders, they enter in virtual change and can tackle individual and collective conditions.

Figure 4 : Participatory Modeling in Kenya

Figure 6 : an INIWAG model for irrigation scheme

Wat-A-Game (WAG) is an open versatile toolkit for hydro-social systems modeling and role-playing games. INI-WAG is a robust simple physical kit used for initiation, dialogue and opening phase for future specialized modeling. It's combined with online model editing tools, and knowledge management for the users' community. WAG has been used in more than 110 cases (Geraldine Abrami et al., 2012)(Géraldine Abrami et al., 2016).

Figure 5 : The INIWAG kit

5. Framing distributive justice principles with Just-A-Grid

Sharing resources requires coupling various stakeholders' expectations, based on fundamental justice principles. By letting stakeholders express, share and recouple their justice principles before addressing the operational dilemmas, we help framing the "deep" social and policy orientations (Neal (Patrick), Lukasiewicz, & Syme, 2014; Venot & Clement, 2013). Just-A-Grid is a simple adaptable protocol by which participants can formulate first individually then share collectively their distributive justice principles, and search for compromises. A debate is organized to share arguments. Later this farming can be referred to for assessing the final strategies. Controlled experiments have been used to assess the coupling with other participatory tools (Ferrand, Hassenforder, Abrami, & Daniell, 2014).

Figure 7: A Just-A-Grid process in Ethiopia

6. Integrative multi-level planning with CooPlan


Figure 8: Participatory modeling in Uganda

Participatory planning is a central re-coupling process for sectors, scales, actors, temporalities, technical and social realms (Ridder, Mostert, & Wolters, 2005). All stakeholders, from citizens to governments, are expected to formulate and structure actions' proposals, technical, social or political, to share them, and later to choose among them "strategic bricks" which can be used to build common action plans. These candidate strategies are assessed for coherency, feasibility and efficiency, and finally adapted and chosen. CooPlan is a protocol developed since 2004 which supports anyone in such process, using simple adaptable frameworks, but providing capacity to recouple very diverse actions and visions, to get really integrated territorial strategies. CooPlan meta-models address needs, impacts and uncertainties. It can use Wat-A-Game for testing the plans, or to trigger creativity.

7. Monitoring & Evaluation with ENCORE-ME

Monitoring and evaluation (M&E) is usually decoupled from the process' participants (externalization for neutrality)(Datta, 1999). We argue that for fair piloting and enlightened engagement of participants it has to be recoupled, and taken as a reflexivity trigger, opening to adaptive management (Boyd et al., 2007). We especially focus on impact M&E to tackle efficiency of the process (Williams, 2015). Meanwhile most M&E are driven by an analytical disciplinary or political perspective. But processes are hybrid, complex and multi-dimensional. Hence M&E has also to recouple disciplines and change' dimensions.

ENCORE-ME (Ferrand, Le Bars, 2004) stands for "External / Normative / Cognitive / Operational / Relational / Equity" dimensions, which have to be monitored. Each requires a different disciplinary perspective and the attached tools. The entire procedural cost of such recoupled M&E can be high, but it does provide a comprehensive assessment of what changes. It can be done implemented either by external observers or led internally by the groups themselves (participatory M&E). Hassenforder (2016) has improved the framework to account for institutional change (E. Hassenforder, Pittock, Barreteau, Daniell, & Ferrand, 2016; E. Hassenforder, Smajgl, & Ward, 2015; Emeline Hassenforder et al., 2016).

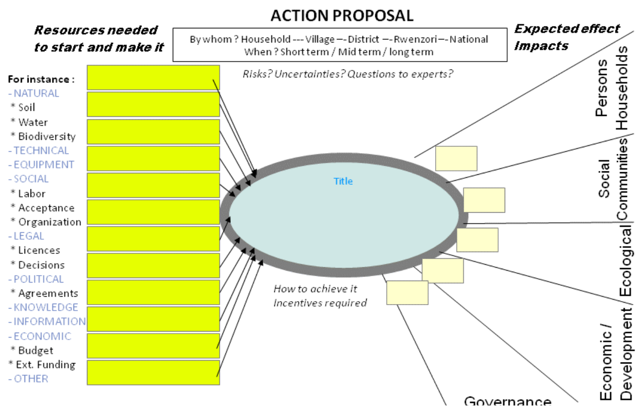

Figure 9: a CooPlan action meta-model

CONCLUSION

PrePar, SCoOLPLAaGE, SMAG, Just-A-Grid, Wat-A-Game, CooPlan, ENCORE-ME constitute a comprehensive and coupled set of methods covering a wide scope of decision needs and steps for participatory water and land management. They have been tested in many countries worldwide and by coupling them we have shown are it can actually recouple actors, issues, scales, needs, in order to improve real sustainability of socio-environmental systems.

In current international projects, we try to strengthen robustness and full transferability of these tools, with the perspective of rapid second Order Transfer. Online tools are being developed to support process design and piloting (procedural workflow) and improve capitalization throughout the case studies.

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The BeWater Project: making society an active participant in water adaptation to global change.

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GLOBAL CHANGE IN THE MEDITERRANEAN REGION

Global change and socio-economic developments are affecting the availability of and access to water for drinking, agriculture, ecosystems and industrial activities. These evolving conditions are posing challenges for the optimisation of freshwater supply, they demand and highlight an urgent need to adapt current water management strategies and practices towards more integrated approaches. Threats such as water scarcity are particularly acute in the Mediterranean region, where the degree of pressure from human activities on natural resources is already high (EMWIS, 2007). Therefore, new management approaches are needed, able to cope with the uncertainties and complexity that characterize the challenges of global change on the ground and the possible solutions ahead. Social awareness, citizen empowerment and joint responsibility are key ingredients for successful adaptation strategies (Pahl-Wostl et al., 2007). As a response, the BeWater project provided innovative tools to facilitate the adaptation of river basins in the Mediterranean region to global change via an active engagement of local societies. In fact, the project has adopted a bottom up approach, enabling dialogue and collaboration between science and communities to co-produce four river basin adaptation plans as a pilot for jointly facing the challenges posed by global change impacts.

ADAPTATION IN WATER MANAGEMENT: THE BEWATER PROJECT

The BeWater project, funded by the European Commission's 7th Framework Programme, offered a unique opportunity to contribute to adaptation policy design and practices with experience-based knowledge. Coordinated by CREAF at the Autonomous University of Barcelona, the project was developed by a Consortium of 12 partners form 11 countries, with different background and complementary expertise. The BeWater project consortium has been working together with local communities towards the collaborative development of adaptive water management approaches at river basin scale in Mediterranean region. Four research institutes located in the cardinal points of the Mediterranean region collaborated with expert organizations and members of the local communities to elaborate local adaptive water management plans for the different rivers, such as Tordera (Spain), Pedieos (Cyprus), Rmel (Tunisia) and Vipava (Slovenia). In these river basins, BeWater applied an innovative, stakeholder-driven method to promote societal transition towards a less vulnerable, more sustainable and adaptive river basin management, facilitating a truly collaborative process. This approach promoted mutual and multi-directional learning among partners, entities and actors within and between the river basins and with the broader society. In all case study river basins, the project enhanced social participation into the design of water management policies and concrete proposals to build societal resilience to the impacts of global change. The results of the project, as well as the lessons learned from its development, are formulated to facilitate its transferability into adaptation management and policies of similar river basins, in Mediterranean and beyond.

THE PROCESS OF DEVELOPING RIVER BASIN ADAPTATION PLANS

The BeWater approach developed within the project focused on creating a shared definition of challenges to be targeted across the river basins and then developing, assessing and prioritizing a broad range of potential water management options to address these points along with pathways for their implementation. While each of the four Mediterranean river basins experienced the process slightly differently, all shared the common aim of introducing adaptation principles into water management at the basin scale. In all the case studies, BeWater adopted an adaptive management strategy that prioritizes the creation of a feedback-driven dynamic engaging local communities at all stages: analyzing the current state, defining the challenges ahead, as well as designing, following up and evaluating the effectiveness of the actions taken to reduce the vulnerability to the impacts of global change in their territory (Rist et al., 2013). This management strategy establishes a continuous learning process, allowing to update the information feeding in decision-making and to adopt the adjustments accordingly. Therefore, the project developed a methodology fostering dialogue and collaboration between local actors and the scientific partners through an iterative approach:

workshops, events, interviews and meetings alternated desktop work by the project consortium in subsequent moments. This iterative process is both a method and a result itself, as the process may be used as a reference for other basins when developing similar processes, in other environmental decision-making processes or scaled up to develop guidelines of national and international relevance. The BeWater participatory and stakeholder-driven approach applied in four case studies entailed the development of 16 co-production workshops and 25 complementary events with the participation of several hundreds of actors representing: public administration, academia, education, private sector, NGOs, civil society. The direct interaction between actors allowed to move forward on issues with a high degree of conflict, such as the allocation of the resource between competing uses and contrasting goals. The Project designed the interactive sessions taking into account this challenging context, and made use of diverse tools and methodologies in order to provide adequate comfort and conditions for participants to express themselves and participate actively. The BeWater method allowed to develop a participated diagnosis of the current and future state of the different basins, combining scientific formation, such as meteorological data, climate projections, land use changes and social and economic vulnerability and impact analysis, with information provided by the stakeholders, such as the drivers of global change in the basin, climate change impacts and regional and local policy developments. The first stage of the iterative process allowed to build a shared understanding on the desired state of the basin and the main challenges the adaptation plan should address. All case studies identified water quality and water quantity as crucial challenges, but also other aspects were identified, such as the urgency to recover the health of forest and water ecosystems and the need to strengthen human resources and employment.
The basin's dynamics was jointly depicted, both with graphical tools, such as fuzzy cognitive maps (Penn et al., 2013), and in a narrative text, allowing a better comprehension of the leverage factors in the basin's dynamics and the relationship between them. Thanks to appropriate IT tools, it was possible to build an analytical model of the information mapped, generating a reference state of the basin that enabled analyzing the impact of the water management options developed by the project in a semi-quantitative way. Indeed, the reference state of the basin indicates the relative importance of each factor with respect to others and the intensity of the influence of the factor in the system. Subsequently, the iterative process aimed at developing concrete proposals to tackle the challenges identified. A series of water management options were formulated, based on a first outline of proposals developed together with stakeholders, including a specific description of the action and classification of the measure. The whole set of proposals was then clustered and fine-tuned thanks to the addition of complementary information, such as a rough cost estimation and implementation oriented factors. All together, the four case study river basins produced 102 water management options.

Further steps of the BeWater process involved the evaluation of the water management options that were produced, by validating its formulation, evaluating its impact through the analytical model and by developing a multi-criteria analysis. In fact, the definitive list of water management options was validated in a specific workshop, making sure these effectively represent stakeholder's understandings. The project technical expert team developed an impact analysis that allowed comparing the reference state of the basin with a new state of the basin's dynamics indicating the changes induced by the different water management options. This exercise allowed assessing the impact of each measure on the factors it addressed as well as indirect effects on the basin's dynamics. Finally, participants were invited to select evaluation criteria, indicate their preference and jointly analyze the results of its application to the model. Outcomes were discussed throughout as to deliver a comprehensive framework of proposals and ranking of priorities. In order to prepare the river basin adaptation plans, the set of validated and evaluated water management options was then analyzed with an implementation oriented focus, prioritizing the most urgent measures, bundling them into groups to enhance co-benefits, take into account conflicts and inter-dependence of options, as well as identifying eventual preconditions and elements concerning windows of opportunity for up-take into on-going plans and programs. The latter was further underpinned with information regarding the policy framework and stakeholder willingness to further pursue the implementation of the actions proposed, as well as concrete references and lessons learned from similar cases, identifying barriers and opportunities, for example taking into account aspects related to funding. During a specific workshop, participants designed the best combination of water management options as well as sound timing to implement them according to synergies and opportunities previously identified. This allowed elaborating an implementation pathway, useful for envisioning the best timing for the development process of the actions, taking into account current policy developments and opportunities for fund allocation. All the information gathered and developed during the iterative process described, was later formulated within four river basin adaptation plans, including detailed information on the single water management options and synthetized information sheets for optimizing dissemination and acknowledgement of the results by the target audience. All background information is available on the project's website, were a detailed description of the methodology and intermediate results for each basin are available.

PROMOTING INCLUSIVE GOVERNANCE

BeWater offered a very important opportunity to gain insights on the performance of innovative governance practices and to identify room for improvement. Different challenges need to be overcome for inclusive governance for adaptation to be consolidated. Firstly, for participatory processes to be successful, the level of interest of participants is crucial. The BeWater project experience clearly demonstrates that stakeholders reveal an high degree of interest and are willing to contribute to pursue the solutions formulated to address the impacts of global change.

Through its approaches and methods, the BeWater experience has contributed consolidating the framework of references and confirms the positive effects of bottom up and mutual learning approaches to face uncertainty and complexity. Being applied in four different case studies at river basin scale, the approach represents a sound reference for developing other similar processes. Moreover, BeWater faced the challenge to combine scientific information with knowledge gathered from local societies and communities, to evaluate vulnerability and uncertainties patterns across the river basins. Given that social – ecological tradeoffs are generally the main obstacle for adaptation to global change, the problem-solving process induced by BeWater proved to be particularly relevant, allowing to reach compromises between local actors and agree on the goals ahead and actions to be taken. The BeWater process also proved the importance of engaging public authorities at different levels from the very beginning and so to foster better uptake of outcomes as well as establishing new governance relations encouraging intense and active involvement of societies. Nevertheless, the adaptation policy agenda should promote strong institutional changes to allow consolidation of inclusive governance practices. The BeWater river basin adaptation plans aim to contribute to this goal, and different proposals included in the plans were designed to support this process at basin level. For example, participants indicated that open-citizen participation processes (promoted by different policy sectors) are crucial for capacity building and empowerment of society as a whole. In order to improve the dialogue between the administration and stakeholders, specific tools were formulated, such as the creation of Water User Associations and specific Management consortia. Furthermore, by targeting the administration at different levels, governance could be improved through the creation of new organs for deliberation, such as coordination boards (i.e. Municipalities) or interdepartmental groups. Along with this approach, policy implementation observatories could improve transparency, follow up and treasure results from monitoring the performance of policies adopted. Social learning processes are key factors to move forwards for better water governance and adaptation to change.

CONCLUSIONS

Adaptive management poses challenging questions that need to be tackled through methods and practices with solid theoretical framework to be integrated into ordinary management procedures and policy design. Knowledge sharing and mutual learning between scientists, experts, decision-makers and local society have provided the needed basis for a truly participatory approach, offering a solid ground for capacity building, awareness raising and the development of concrete proposals for action. The process of co-production has proven to be able to deliver results with a high degree of social acceptance, political relevance and technical interest to tackle the uncertainties and complex nature of global change. BeWater promoted inclusive governance by identifying key actors and developing targeted engagement strategies. Workshops and events allowed to link actor groups and to create opportunities for interaction to foster citizen's empowerment and awareness. By enhancing inter-sectoral knowledge sharing, it is possible to increase transparency (access, format, timing) of relevant information and delivering key messages to decision makers.

From the BeWater experience, some recommendations can be made to further pursue the consolidation and improvement of inclusive governance practices at river basin scale. For active and effective citizen participation to be mainstreamed, new regulations and new institutional structures need to be designed. This process should foster increased collaboration between competent authorities and policy makers so to improve the coherence and harmonization of policies, in particular as far as their combined impact on reducing societal vulnerability are concerned. In this framework, it is fundamental to introduce mechanisms to increase transparency of decision-making processes, including all citizens into processes and ensuring continuity of the deliberative spaces. Special efforts are needed in order to institute sound monitoring protocols and practices, as to allow full accountability on uptake and implementation of the actions.

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