**Institution:** University of Aberdeen

**Unit of Assessment:** 7 (Earth Systems and Environmental Sciences)

**Title of case study:** Building capacity for informed groundwater policy and practice in Eastern Africa

**Period when the underpinning research was undertaken:** 2015-2020

**Details of staff conducting the underpinning research from the submitting unit:**

| Name(s): | Role(s) (e.g. job title): | Period(s) employed by submitting HEI: |
|---|---|---|
| Jean-Christophe Comte | Senior Lecturer | 2014-present |

**Period when the claimed impact occurred:** 2016-2020

**Is this case study continued from a case study submitted in 2014?** N

**1. Summary of the impact** (indicative maximum 100 words)

Research led by Dr Comte, School of Geosciences has highlighted the risks surrounding unsustainable use of groundwater resources in Africa and has directly informed governance and planning in Sub-Saharan Africa. This includes a UN development programme led by the Comoros government worth USD60,800,000 with estimated 450,000 direct beneficiaries leading and increased infrastructure for water monitoring. Comte's research findings have triggered a review of groundwater data and model outputs relating to risk of depletion and saline intrusion by the Kenyan national water authority (WRA), which has helped shape training by the Regional Centre on Groundwater Resources Education Training and Research in Africa (RCGW) and crucially, raised awareness regarding the risk surrounding salinisation of aquifers to both policymakers and public.

**2. Underpinning research** (indicative maximum 500 words)

In Sub-Saharan Africa, groundwater resources are undergoing rapid and unprecedented development due to increasing global population growth rates, leading to increased water demand. Groundwater is an important resource due to its abundance and resilience to increasing climate variability compared to surface water. However, poor knowledge and management of an aquifer's local and regional capacity to support large-scale community development often leads to irreversible deterioration by over-abstraction (unsustainable extraction relative to natural recharge from rainfall); particularly in coastal regions, where this can cause salinisation of the aquifers as well as land subsidence.

Due to poorly maintained government-managed monitoring infrastructure (borehole observation networks), there is limited understanding of groundwater response to abstraction and climate variability. This means that use of groundwater through private and community boreholes is either unknown or unregulated despite efforts by the governments to register all groundwater users. This has resulted in significant underestimation of groundwater abstraction, leading to sinking water tables and saltwater intrusion. Intergovernmental agencies such as the Water Resources Agency ('WRA', was WRMA) whilst mandated to regulate the management and use of water resources faces a challenging task given the lack of information on groundwater functioning.

Dr Comte, a hydrologist specialising in the sustainable development and management of groundwater resources, has led research focussing on the impact of rapidly increasing groundwater exploitation on reserves in Sub-Saharan Africa. Since 2015, Comte has built on a body of work demonstrating that government-managed groundwater monitoring networks are inadequate and insufficient to provide meaningful monitoring of the spatial-temporal evolution of the resources (undertaken before he joined the University of Aberdeen). From 2015-18 Comte

has led investigations on the impact of rapidly increasing groundwater exploitation on groundwater reserves, with a focus on depletion and saltwater intrusion in Kenya [1-2], the spatial characterisation of aquifer structures and seawater intrusion in coastal areas, including the impact assessments of volcanic heterogeneity on coastal groundwater salinity through numerical groundwater modelling [3].

Comte's work, presented at the Western Indian Ocean Marine Science Association WIOMSA in South Africa in 2015 [1] showed that human activities (e.g. increasing groundwater development) are more detrimental effect to groundwater resources (depletion and salinisation) than climate change (recharge variability) [2]. He also showed that government-managed groundwater monitoring networks are inadequate and insufficient to provide meaningful monitoring of the spatial-temporal evolution of the resources [2]. In recognition of the value of the research, the WRA part-funded a PhD studentship, enabling secondment of a WRA hydrologist to Comte's team at the University in order to facilitate a source of in-house expertise in Nairobi in groundwater monitoring. The research [3-5], designed and led by Comte, has enabled the development of a strong working relationship with the WRA.

Comte's field research in Eastern Africa (2016 onwards), funded by the Royal Geographical Society has expanded these initial findings [P1] to develop and embed a new conceptual understanding of the response of groundwater resources to climate change and human activities in Nairobi aquifers, relevant to the socio-economic development of Kenya and the wider East Africa region [3]. As part of this project, WRA offices (Nairobi and Kiambu) supplied borehole completion reports and abstraction records. Comte and Oiro then used geophysical surveys and in-situ groundwater measurements along with analysis of available long-term climate and borehole monitoring data in order to assess the water quality of two strategic Kenyan aquifers (the coast and Nairobi), used by over 7,000,000 people [5].

The research highlighted the need to map the extent of seawater intrusion and to understand key driving forces - quality and water levels observed from monitoring wells showed the negative impact of groundwater over-exploitation in both the long and short term. The water quality was found to deteriorate over time suggesting that abstraction acts as a primary driver to saltwater intrusion. [3, 4]. [P1] also examined the use of groundwater through private boreholes in the region. Using climatic trend analysis from seven meteorological stations and land-use change mapping (EarthExplorer website), Comte and Oiro found that the practice and utilisation of private boreholes is incompletely regulated despite current effort by the governments to register all groundwater users, resulting in significant underestimation of groundwater abstraction. Findings also showed that in coastal areas, borehole construction was not adapted to the specific vulnerability of wells to saltwater intrusion, with the narrow, deeper boreholes, which are favoured by drillers more vulnerable to saline intrusion than shallow, large diameter wells. [5].

In 2018, Comte was mandated by the consultancy group AURECON to implement a World Bank-funded, Kenya-wide water resources development project to provide hydrogeological technical expertise. Expertise specifically involves building capacity of the Kenyan Water Authority groundwater staff, through the approach of 'training-of-trainers', in numerical groundwater model application, including model formulation, testing and uptake of a range of long-term (100-years) sustainable groundwater management scenarios for use to policy making [P4].

In 2017, as a result of these findings, Comte was contacted by scientists in Botswana who were keen to apply his findings to the Limpopo river basin (LRB), an arid, water-stressed basin with high susceptibility to floods. The project titled 'Extreme rainfall and floods in arid regions (Botswana): replenishment or contamination of water resources?' [P2] provided the groundwork to develop preparedness and enhance community resilience to flood and drought conditions by building understanding amongst stakeholders of multiscale hydrological processes underlying droughts and floods and combine this with water resource planning. The project aims to forge stronger links between scientists and water management stakeholders including the Water Research Commission (WRC) and Ministry of Public Works and Housing in order to aid local and regional authorities by improving hydrological monitoring networks and strengthening communication

between local and national levels of governance. This research has now been expanded under the flagship 'Connect4WR' project, within the DFID/FCDO's SHEAR programme [P3].

**3. References to the research** (indicative maximum of six references)

**Key references (citations via Scopus)**

[1] **Comte J-C**, et al (2015). Physical and societal challenges in groundwater security in coastal East Africa: case studies in the Comoros Islands, Kenya and Tanzania (conference presentation), 9th WIOMSA Scientific Symposium – Wild Coast Sun, South Africa, 26 – 31 October 2015

[2] **Comte, J.C** et al 2016. Challenges in groundwater resource management in coastal aquifers of East Africa: Investigations and lessons learnt in the Comoros Islands, Kenya and Tanzania. *Journal of Hydrology: Regional Studies*, *5*, pp.179-199. https://doi.org/10.1016/j.ejrh.2015.12.065, 37 citations

[3] Oiro, S., **Comte, J-C,** Soulsby, C. & Walraevens, K. (2018). Using stable water isotopes to identify spatial-temporal controls on groundwater recharge in two contrasting East African aquifer systems. *Hydrological Sciences Journal*, vol. 63, no. 6, pp. 862-877. https://doi.org/10.1080/02626667.2018.1459625, 16 citations

[4] Oiro, S**.** & **Comte, J-C** (2019). Drivers, patterns and velocity of saltwater intrusion in a stressed aquifer of the East African coast: joint analysis of groundwater and geophysical data in Southern Kenya. *Journal of African Earth Sciences,* vol. 149, pp. 334-347. https://doi.org/10.1016/j.jafrearsci.2018.08.016, 5 citations

[5] Oiro, S., **Comte, J.C**., Soulsby, C., MacDonald, A. and Mwakamba, C., 2020. Depletion of groundwater resources under rapid urbanisation in Africa: recent and future trends in the Nairobi Aquifer System, Kenya. *Hydrogeology Journal*, *28*(8), pp.2635-2656. https://doi.org/10.1007/s10040-020-02236-5, 1 citation

**Sources of funding awarded to Dr Comte as Principal Investigator:**

[P1] Royal Geographical Society (with IBG) Environment and Sustainability Research Grant: East African groundwater resources under climatic and human pressure, 2016-2017 (GBP10,000)
[P2] NERC Urgency Grant: Extreme rainfall and floods in arid regions (Botswana): replenishment or contamination of water resources? 2017-2018 (GBP52,064)
[P3] NERC/DFID Research Grant - SHEAR Programme: Connect4 water resilience: connecting water resources, communities, drought and flood hazards, and governance across 4 countries in the Limpopo basin, 2018-2020 (GBP252,352)
[P4] AURECON: Groundwater numerical model, 10/2018-09/2019 (GBP23,585)

**4. Details of the impact** (indicative maximum 750 words)

Comte's research findings have drawn attention to key issues relating to the unsustainability of increasing water demand in Eastern Africa, such as poor monitoring of resources and extensive drilling and pumping rates [3-5]. By engaging with and training water management authorities, policy makers and communities, Comte's research has underpinned new guidelines for water managers, supported decision-making and introduced best practice for local authorities and raised awareness of local communities to the risk of saline intrusion to water quality.

**Contributing to global guidelines for water managers**

In 2016, Comte reported that natural saline intrusion and governance failures were key drivers affecting water quality in the region [1], these findings have been cited as a guideline within the 'Groundwater Management in coastal zones', a handbook (2018) released by the German Federal Ministry of Economic Cooperation and Development (BMZ) [S1]. Germany is supporting efforts of partner countries to balance their water budgets, specifically projects that involve continuous monitoring of water cycle and quality. The handbook outlines the principles of good governance and acts as a guide for water managers in coastal regions globally; Comte's research has been cited as a case study to highlight observed problems in coastal groundwater governance specific to East Africa [S1].

**Guiding best practice in UN-mediated consultancy**

In regions like Comoros where the water table is quite deep (100-200m), a borehole equipped and tested is predicted to cost between GBP5000 and GBP10000. If boreholes fail due to salinisation this means losing tens up to a few hundreds of thousand GBP on borehole cost alone. In order to strengthen water management capabilities relating to water treatment, the Comoros government drew on Comte's research [1] as part of the Terms of Reference of a tender published in 2016 of a major 8-year, USD60,800,000 development project implemented by the United Nations Development Programme (UNDP) under the Green Climate Fund [S2i]. As part of this tender, Comte's research was used to inform the initial feasibility study, with figures from [1] used to illustrate main groundwater salinities of surveyed wells, correlations between borehole/well salinity (Fig 7), geology and distance to coast (Fig 9), pumping schedules for dry and wet seasons (Fig 10) [S2ii].The project, governed by the Comoros Ministry of Energy, Agriculture, Fisheries, Environment, Country Planning and Urbanism (MEAPEATU) was approved in 2018 and is estimated to have 450,000 direct beneficiaries [S2iii]. Comte's research findings [1] were used to focus the project and provided guidance on the vulnerability of sites to saltwater intrusion thereby enabling the Comoros government to make an informed decision regarding selection of the appropriate implementing organisation (e.g. UNDP) with the highest standards for risk-mitigation, thus ensuring long-term cost savings (lower borehole failure rate) and reduced likelihood of salinisation.

**Regional governance, policy and infrastructure**

In Kenya, Comte's research findings [3] have been incorporated into national-scale policy guidelines and have underpinned a terms of reference for national groundwater development project tenders, relating to demand and supply of fresh water and the construction of boreholes by the WRA [S3]. Comte's research [1] has also been cited in the Government of Kenya (2017) 'State of the Coast Report II: Enhancing Integrated Management of Coastal and Marine Resources in Kenya, release by the National Environment Management Authority (NEMA), Nairobi [S4], under section 6.2.2 in order to highlight the imbalance between demand for piped water and supply in Kilifi County.

Comte's research [1, 3] is being acted upon at the national level by the WRA of Kenya to inform the groundwater, water quality and permitting sections of the WRA national office [S5i]. The WRA are using Comte's research findings including new groundwater quality data and model outputs relating to risk of depletion and saline intrusion [2,3,4] to (1) undertake appraisal of existing groundwater monitoring data and redesign their plans and sites for the development of future groundwater monitoring infrastructure, such as observation boreholes [S5ii], (2) improve abstraction metering and water allocation to users [S5ii] and (3) enforce effluent discharge regulations for wetlands [S5ii] in the Nairobi/Rift Valley and South Coast regions. The WRA Technical Coordination Manager confirmed that:

> '*Dr Comte's research work is being used to guide ongoing drilling of groundwater monitoring networks along the south coast costing a total amount of Kenya Shillings 12, 686,920.00 (USD 126,896.2*).' [S5iii]

**Introducing guidelines and training for water authorities**

In the Nairobi region, Comte's expertise and his research findings identifying wetlands as areas of preferential groundwater recharge [2] have heavily informed the WRA's legal office in their development of a new policy to regulate private urban development, enforce new standards for protection of these wetland areas, and provide evidence of ongoing litigations between the WRA and private developers [S6]. Comte's extensive in-field expertise, has led to the WRA's groundwater section seeking his advice on replacement of field instruments best suited for groundwater exploration in Kenya, as well as training for maintenance thereby informing their approach [S6]. Regionally, groundwater salinity maps and models resulting from the research [3] are being used by the WRA's south coast (Mombasa) office to support community water development [S6]. The WRA and are using the salinity maps from modelling to plan water management in accordance with susceptibility to saltwater intrusion as highlighted by the maps to improve models to run management scenarios and salinity modelling [S5, S7].

In 2015-2018 the WRA provided financial support to build capacity for in-house skill development and expertise building in groundwater resources assessment, modelling and management. Comte contributed by providing direct staff training through supervision of the PhD of Samson Oiro, on secondment from WRA's groundwater section. This secondment has been integral to the application of numerical models for management scenario testing, in order to better manage pressures on groundwater resources in Kenya [S5iii]. Comte in association with AURECON [P4] has worked with the WRA to strengthen its 'in-house' capacity in terms of skills and infrastructure including development of a Groundwater and Management Guideline and a National Aquifer map based on geology and surface water catchments [S6]. Through the project, recommendations have been released to support efforts to strengthen water resource management and planning including deployment of systematic monitoring of active boreholes, particularly for users with high water consumption and use of smart water meters in cases of severe depletion [S6].

The training approach, led by Comte, Oiro and the WRA has been praised and deemed exemplary for capacity building by the Regional Centre on Groundwater Resources Education Training and Research in Africa (RCGW) one of the key inter-governmental organisations. Director General of RCGW, stated that:

> *(Comte and Oiro) are providing key reference materials for policy makers currently used to assist the Water Resources Authority in designing their new groundwater management plans. In addition, the current groundwater modelling training project led by Prof Comte for the Water Resources Authority, involving WRA staff placements and training of trainers is exemplary for efficient and long-term capacity building of East African water decision makers* [S7].

**Raising awareness in communities**

Communities in Sub-Saharan Africa (particularly in rural areas) often rely on unregulated groundwater access points, and often lack knowledge of management and safeguarding of groundwater resources, and require training. In Kenya, Comte's research findings [2, 3] supported the introduction of a new collaboration between the WRA and non-governmental organisation, CORDIO, a Kenyan non-profit research institution working at the community level for environmental sustainability [P3]. Although CORDIO initially focused on marine and coastal environments, Comte's findings relating to the effects of inland saltwater intrusion has since 2017 encouraged CORDI to focus efforts on introducing a consultative approach to practice with communities and WRA policy-makers [S8i]. In addition, during engagement with communities in coastal Kenya [P1], Comte and Oiro engaged with private water well owners, local water user representatives, schools and mosques in order to provide technical advice for safe groundwater practices [S8ii].

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

[S1] Groundwater Management in coastal zones' handbook (p53, 55), https://bit.ly/3cPsYhq
[S2 (group)] (i) Funding Proposal FPO94: Ensuring climate resilient water supplies in the Comoros Islands; (ii) FPO94 Annex II – Feasibility Study; (iii) Green Climate Fund project FPO94 page: https://www.greenclimate.fund/project/fp094
[S3] WRA (July 2020) Water Allocation Plan, Nairobi Aquifer Suite
[S4] State of the Coast Report II: Enhancing Integrated Management of Coastal and Marine Resources in Kenya. National Environment Management Authority (NEMA), 2017
[S5 (group)] (i) Government of Kenya, Ministry of Water and Sanitation, (ii) National Groundwater quality report (2017); (iii) Testimonial statement from the Technical Coordination Manager of the WRA
[S6] Groundwater Modelling Reports 1 and 2, Implementation Support Consultant / AURECON / World Bank (confidential, available on request)
[S7] Testimonial from the Regional Centre on Groundwater Resources Education Training and Research in Africa (RCGW)
[S8 (group)] (i) CORDIO data; (ii) photos taken during fieldwork