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Review

Exploring changes in water use patterns, demand and stress along the Nile River Basin through the lens of Kenya and Egypt

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Abstract. Noting the geopolitical implications of water demand and stress issues on water resources worldwide, this study investigated water demand, changes in water use patterns and water stress developments in the Nile Basin transboundary water resource by comparing Egypt and Kenya. Using an integrative literature review, the study summarises past research, drawing overall conclusions and highlighting unresolved issues. The findings demonstrate increased water withdrawals and a growing unmet demand in both countries. In addition to changing water use patterns towards municipal and industrial use, hydropower development in Kenya and navigation in Egypt are being driven by factors such as heightened upstream use, population growth and settlement patterns, economic development and climate change. In addition, spatial distribution of water stress was demonstrated, whereby downstream countries such as Egypt remain critically vulnerable, although upper riparian countries such as Kenya are gradually also facing emerging water stress problems. This water stress and its spatial distribution are being driven by supply–demand imbalances related to population growth and economic development, escalating upstream water use, deteriorating water quality, inefficient and ineffective water use and climate change. The findings inform a discussion of the crucial socioeconomic, geopolitical and policy implications for riparian countries in the Nile Basin and other transboundary water resources worldwide.

Additional keywords: policies, transboundary resources water demand, water stress.

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Introduction

Approximately 40% of the global population lives in rivers and lakes shared among two or more countries (United Nations Water 2008). A large number of transboundary river basins (~263) and aquifers (~300) account for almost 60% of global water flow. Transboundary aquifers play a critical role in providing water to ~2 billion people globally (United Nations Water 2008). According to United Nations Water (2008), proper transboundary management creates benefits that everyone can share: international trade, climate change adaptation, economic growth, food security, improved governance and regional integration. It has been reported that, because internationally shared water bodies can be associated with cooperative or opposing events, proper water allocation and use management are required (Ravnborg 2004; United Nations Development Program 2006). Moreover, hydropolitics surrounding shared water resources, water stress, climate change, water demand and population increases also required collective water resource management efforts.

The Nile River Basin is one of the most critical transboundary waterbodies in Africa, shared by 11 countries. It is one of the most important basins in the world from a historical perspective and for the water independence of riparian countries. The Nile River is the world's longest river (6695 km), draining 3.1×10^6 km^2 in area and having a catchment basin that covers ~10% of the African continent (Degefu and He 2016). The importance of the Nile River Basin to the riparian countries makes it a central geopolitical issue in the region amid heightened water demand and deepening potential for water conflict (Kagwanja 2007; Adar 2011). Historical, current and emerging water use, water demand and water stress issues are at the centre of geopolitical and international relationship issues in Nile River Basin countries. In a context characterised by growing water demand, changing water use patterns, unevenly distributed water resources, socioeconomic and political asymmetry among riparian countries and the absence of water allocation agreements, there is an urgent need for appropriate management of the transboundary water resources in the Nile Basin. In turn, such informed management requires reliable knowledge and data upon which to base policies and decisions related to regional water resource management. The present study focuses on historical water demand, water use patterns and the spatial distribution of water stress through the lens of Kenya and Egypt, two of the major riparian economies in the Nile River Basin.

Water use and availability

Water availability in the Nile River Basin is on the decline and is affected by several factors, such as variations in precipitation, the hydropolitics of the region and pressure from the rapidly growing population. The renewable water resources of the Nile River are considered almost fully used across various productive purposes. Notably, water utilisation patterns vary considerably among the Nile River Basin countries and sectors. Traditionally, water in the Nile River has been used for domestic, transport, leisure, food security, wildlife and many other activities. According to the Nile Basin Initiative (2012), the main use of water from the Nile River is for agricultural purposes. Currently, most of the Nile run-off is used in downstream countries, whereas upstream countries use relatively little of the river flow (Nile Basin Initiative 2012). Downstream countries use water from the Nile to irrigate over 4.5×10^6 ha of land (Nile Basin Initiative 2012). In contrast, formal irrigation is limited among the other riparian countries in the Nile River Basin, with combined acreage being estimated at a meagre 50 000 ha (Nile Basin Initiative 2012).

Beyond agriculture, various hydropower facilities have been established along the Nile River, albeit with a total installed capacity well below its potential. Unlike agriculture, hydropower is deemed a non-consumptive water use (Nile Basin Initiative 2012). However, hydropower water use still alters the downstream flow regime despite not reducing flow volume. Notably, significant evaporation-related water loss from the establishment of various reservoirs in the Nile River Basin system (including lakes, such as Nasser, Merowe, Jebel Aulia, Kashm el Girba and Roseires) has been reported (Degefu and He 2016). Another area of water use in the basin is for domestic and industrial purposes, which is currently small. Although ~232 million people live within the Nile catchment area, domestic and industrial water use is only estimated 2.0×10^9 m^3 annually (Nile Basin Initiative 2012).

Water use trends and implications

Amid the population growth and economic development unfolding in the region, most of the Nile Basin countries are either water scarce or water stressed in light of growing water scarcity and decline in per-capita water availability in the region (Degefu and He 2016). Within this context, the effect of trends in water use may heighten water stress and intensify competition for water resources in the Nile Basin. Population growth and economic development directly translate to a steady increase in the demand for water (Nile Basin Initiative 2012). At the same time, upper riparian countries, which to date have been barely using water from the Nile River, are planning water investments in areas such as hydroelectric power production and irrigation. Most upstream and downstream riparian countries have hydropower and irrigation development projects underway or planned within the Nile Basin (Degefu and He 2016). These water use trends also have to be considered within the context of climate change, which is affecting water resource availability. Overall, the water use trends and developments translate to potentially heightened water scarcity, with the Nile River Basin coming under immense pressure in the near and distant future (Degefu and He 2016). In turn, heightened water stress has implications for conflict and water sharing cooperation scenarios going forward for riparian countries, including Kenya and Egypt (Swain 2011).

With evidence lately showing decreased availability of water along the basin and a forecast of further water scarcity along the river, key action needs to be taken. Projected water availability per capita in all Nile Basin countries between 2007 and 2025 is on a downward trend, with climate change and variability, population growth and general degradation cited as underlying causes (Nile Basin Initiative 2012).

Egypt and Kenya

Although most literature entails individual analysis (Hamza and Mason 2005; Adar 2011) of Egypt and Kenya or blanket analysis of countries along the river (Keith *et al.* 2013; Kagwanja 2007), the present study uniquely compares two countries along the river. The rationale for selecting Kenya and Egypt stems from their strategic geopolitical positions upstream and downstream respectively in relation to the Nile Basin's water resources. Egypt is heavily dependent on Nile waters, seeking to influence water flow use by other riparian countries (Keith *et al.* 2013). By contrast, Kenya, which is said to have the biggest and most advanced economy in East and Central Africa, is an upstream country that now seeks to use its share of the Nile Basin water resources (United Nations Environment Program 2013*a*). As a result, these two countries provide an opportunity to explore water demand, changes in use and water stress from two distinct perspectives, which contributes to the novelty of the present study. In addition, there has been previous bilateral cooperation between the two countries; for example, in 1996 Egypt granted Kenya US$4.2 million to excavate 100 ground wells in the arid and semi-arid areas of the country to help with water issues in the country (Nile Basin Initiative 2012).

Taking the aforementioned challenges and water aspects into consideration, the aim of this study was to generate insights into historical and developing water use, water demand and water stress patterns based on a comparison of Egypt and Kenya as two important riparian countries in the Nile Basin. This was achieved by a critical review and synthesis of theoretical conceptual and empirical studies published in relation to risk and water management.

The aims of the study were to: (1) compile a time series of water withdrawal and consumption inventories in Kenya and Egypt; (2) identify the driving forces behind changing water use patterns in Egypt and Kenya to highlight the factors determining how both societies have used water resources over time; and (3) reveal the spatial distribution of water stress along the Nile in Kenya and Egypt to provide insights into water stress in the two countries and the drivers of this water stress.

Most interestingly, this paper notes the absence of an authoritative time series of water withdrawal in the Nile Basin, which necessitated the use of a variety of relevant and reliable sources on the topic that, when analysed could provide a generalised picture of water withdrawal to address the aims of this study. Thus, the findings of this study will help fill knowledge gaps regarding the water resources in the Nile Basin and key developments going forward. The study findings will also have practical implications, helping address water security issues that arise from shared water resources.

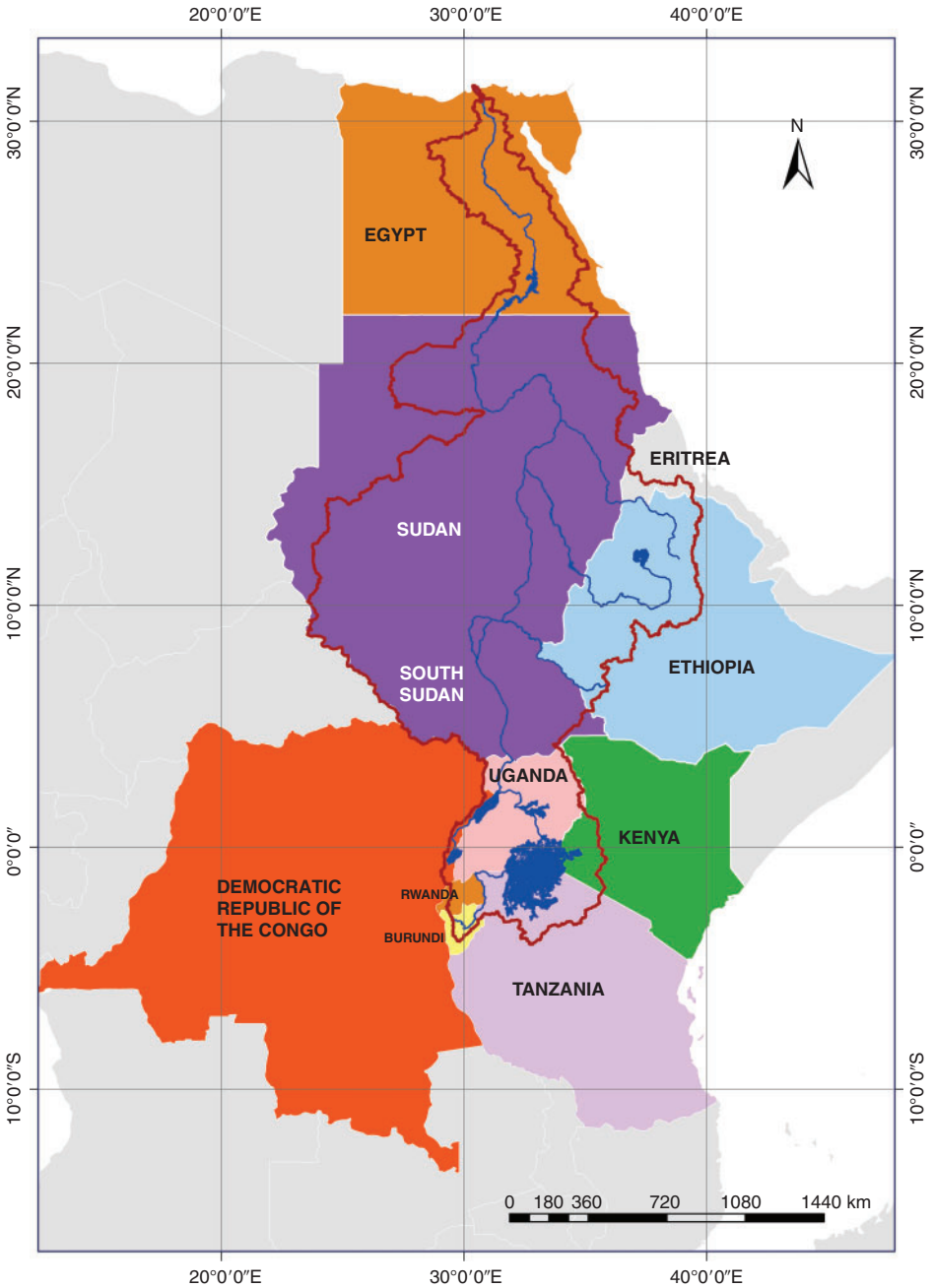

Fig. 1. Map showing the Nile River and the ten countries where the river flows.

Materials and methods

Study area

The Nile Basin covers 10 countries: Burundi, the Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Tanzania, Sudan and Uganda (Fig. 1). The two main tributaries of the Nile are the White Nile and Blue Nile, which converge at Khartoum, Sudan, forming the river's main stream (Swain 2011). The White Nile (which originates in Burundi and flows through the Equatorial Lakes, namely Victoria, Mobutu and Kyoga) contributes 14% of the Nile flow, whereas the Blue Nile (which mostly originates from the Ethiopian highlands) contributes 86% of the Nile River flow (Swain 2011). In terms of surface water distribution in the region, uneven patterns are evident, with Equatorial Lakes countries accessing significant endowments of water resources, whereas downstream countries have a limited water supply.

The Nile Basin's population is ~400 000 000, with over half of these people dependent on the river for water resources (Swain 2011). According to Richards and Syallow (2018) recent massive population growth has been experienced in countries such as Egypt (population 96.98 million as of 2018), Ethiopia

(population 1109.22 million) and Sudan (population 43 million), which translates to rapidly decreasing per capita water availability. Amid such dependence on and a decline in per capita water availability, further issues stem from the Nile River Basin countries being among the world's poorest. Apart from Egypt, Kenya and Sudan, the economies of the Nile Basin countries are among some of the world's least developed (Swain 2011).

Research approach

This study used an integrative literature review method to investigate water demand, water use patterns and water stress in two prominent riparian countries in the Nile River Basin. According to Evans and Kowanko (2000), an integrative literature review summarises past research, draws overall conclusions on the topic in question, highlights unresolved issues and areas and then provides directions for future research. The rationale for choosing to perform an integrative literature review in this study stems from the dearth of research into the research topic. Before empirical or other experimental inquiries can be designed to inform modelling and policy making, it is necessary to have a detailed and reliable picture of the historical and present state of water demand, water use and water stress in the Nile Basin. Further, integrative literature reviews accumulate past endeavours, summarise major issues and provide a pertinent way to disseminate insights generated through individual studies (Evans and Kowanko 2000). In addition, the literature review approach aligns with and is able to meet the purpose and objectives of the present study. Publications identified in environmental and social science electronic databases were critically analysed before inclusion in the study.

Ensuring trustworthiness

The literature review approach necessitates efforts to ensure trustworthiness, given that the rigour and credibility expected of primary research has to be applied to literature reviews (Hawker *et al.* 2002). At the same time, the literature review method should result in an accurate and balanced representation of the research undertaken on the topic of inquiry (Evans and Kowanko 2000). The measures undertaken to ensure trustworthiness in the present study include triangulation through the number and wide-ranging information sources, peer scrutiny and taking into consideration the background and authority of the sources and publishers, as described by Shenton (2004). Triangulation increases validity in qualitative research (Guion *et al.* 2011), and hence is an appropriate approach for research in this study.

Inclusion criteria

The inclusion criteria for sources considered in the present inquiry also contribute to the overall trustworthiness of the study and its findings. The present study restricted inclusion according to date and publication authority. With regard to publication date, inclusion was restricted to studies published in the 21st century in the interest of balancing between the need to exclude dated studies and responding to the dearth of literature on the topic. Inclusion based on publication authority was restricted to peer-reviewed journal articles, conference publications and publications from authoritative sources such as the United Nations Environment Program, the Food and Agriculture Organization of the United Nations, and the Nile Basin Initiative (Table 1).

Table 1. Sources and numbers of articles including in the study based on the inclusion criteria

FAO, Food and Agriculture Organization of the United Nations; NBI, Nile Basin Initiative; UNEP, United Nations Environment Program

Data source	Number of articles
Conference papers	2
Journal articles	15
Authoritative publications (UNEP, FAO, NBI)	6

The analysis revealed gaps in terms of both historical water withdrawal and future projections, signalling areas of focus for future research, especially from modelling and predictions perspectives.

Conceptual framework

The study follows a framework in which the main concepts under consideration are water withdrawal, water demand and water stress. Water withdrawal refers to the quantity of water a country uses for various functions, including irrigation, livestock, domestic and industrial purposes (Wada *et al.* 2011). Water demand is defined as the volume of water required by users in a country to satisfy their needs (United Nations Environment Program 2013*a*). Water stress is calculated as the ratio of water withdrawal to water availability in a country. Here, water use refers to the use of water by various sectors (agriculture, industry, energy production and households) and in-stream uses, such as fishing, recreation, transportation and waste disposal.

In terms of the relationship among the concepts, water demand, water withdrawal and changing patterns of water use may determine the level of water stress a country faces. At the same time, it is important to pay attention to the contextual factors determining changes in water use patterns and the spatial distribution of water stress. The rationale for considering these factors stems from how their effects may skew water demand and withdrawals. Ultimately, the insights gained in terms of water demand, water withdrawals, changing water use patterns and water stress will be crucial in informing policy formulation for improved transboundary management of water resources in the Nile Basin. Based on the aforementioned considerations, the conceptual framework for the present study is shown in Fig. 2.

Results

Water withdrawal in Kenya and Egypt

The baseline for water withdrawal in the Nile Basin is 2005, derived from water use profiles following national studies conducted in the Nile Basin countries by the Food and Agriculture Organization of the United Nations (2011). The other year at which comparable fresh water withdrawal data is available for the two countries is 2009, and projections for 2030 and 2050. At baseline (2005), water withdrawal in Egypt and Kenya was 68.795 and 1.076 km^3 respectively (United Nations Environment Program 2013*b*). In 2009, freshwater withdrawal for Egypt and Kenya was 68.30 and 1.58 km^3 respectively (United Nations Environment Program 2013*a*). Projections for

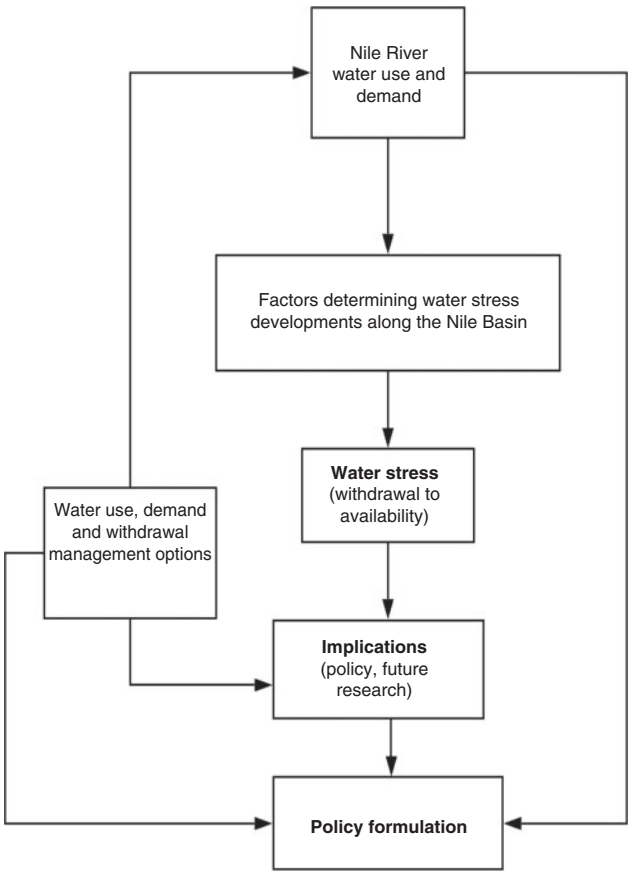

Fig. 2. Conceptual framework of the present study.

2030 indicate a 9.7% increase from baseline in Egypt, increasing water withdrawal to 71.74 km^3, compared with a 37.9% increase from the 2005 baseline in Kenya to 1.48 km^3 (United Nations Environment Program 2013*b*). Projections to 2050 indicate that Egypt's water withdrawal will be 73.64 km^3, compared with 1.89 km^3 in Kenya, equating to 7 and 75.8% increases from baseline respectively.

From the data, it becomes clear that water withdrawal by Egypt and Kenya will continue increasing into the future. At the same time, the Nile Basin Initiative (2017) studies indicate an unmet demand (calculated as withdrawal requirement less actual withdrawal) of $\sim 60 \times 10^6$ and 500×10^6 m^3 for Kenya and Egypt respectively. These observations shed light onto the water resource strain in the Nile Basin from the perspective of these two countries, whereby both face a situation of unmet demand and projected increases in water withdrawals at a time when climate change concerns may negatively affect the availability of water resources in the Nile Basin. The observations regarding withdrawals and unmet demand also have implications for food security and geopolitics in the region, given the geopolitical importance of the two economies in question.

Changing water use patterns

Another pertinent issue beyond water withdrawals and demand is the development in water use patterns. Overall, agriculture-based use remains the dominant area of water utilisation in the basin. However, the percentage of water used for agriculture compared with other areas helps capture the changes water use patterns. In the case of Egypt, the water use requirement for irrigation increases from 53 to 61% between 2005 and 2030 before slightly increasing again to 64% in 2050 (United Nations Environment Program 2013*b*). This captures the initial rise in agricultural irrigation water use from 2005 to 2030, which then plateaus by 2050. No significant spikes are observed in Kenya: the water use requirement is 30% in 2005, 30% in 2030 and 31% in 2050 (United Nations Environment Program 2013*b*). These observations demonstrate that water use dynamics may be more perceptible in other areas such as industry, hydropower and navigation.

Hydropower development is also a major aspect of changing water use in the Nile Basin. In this case, the United Nations Environment Program (2013*a*) highlights the tremendous potential for hydropower development, as well as current gaps, whereby countries like Kenya face 6.8 power outages per month. Despite the massive financial cost required to address gaps in the region's power demands, a notable trend is occurring towards using more of the region's waters to generate electricity, explaining the contribution of hydropower development to changing water use patterns in the Nile Basin. The status of hydropower development in the region can be explored in terms of potential capacity, installed capacity and committed development capacity. The Democratic Republic of the Congo (100 000 GWh) has the highest hydropower development potential capacity, followed by Ethiopia (75 000 GWh) and Egypt (>5000 GWh). Compared with Kenya (1422 GWh potential capacity), Egypt has an immense potential for hydropower development, having only an installed capacity of 2842 GWh (United Nations Environment Program 2013*a*). Although no additional capacity is under development or committed for future development, such potential for expansion of hydropower capacity in Egypt demonstrates the implications for changes in water use in the country. Kenya has an installed hydropower capacity of 761 GWh against a potential of 1422 GWh. Kenya has also committed towards capacity expansion by 63 GWh, which captures the expected changes in water use patterns moving forward (United Nations Environment Program 2013*a*). Despite huge potential for hydropower, underdevelopment has been cited as a considerable barrier to exploiting this sector, with Eritrea and Burundi lagging behind in this sector. Environmental, social, institutional and financial reasons have been cited as reasons for the differences in hydropower exploitation among these countries, as indicated in Table 2.

In addition to hydropower development, industrial and municipal use constitutes an area in which changing water use in the Nile Basin may be explored. Industrial and municipal use currently accounts for relatively small utilisation of water resources in the Nile Basin, at 0.10 km^3 $year^{-1}$ for industrial use and 0.47 km^3 $year^{-1}$ for municipal use in Kenya, compared with 3.57 and 6.87 km^3 $year^{-1}$ for industrial and municipal use respectively in Egypt (United Nations Environment Program 2013*b*). However, projections based on per capita demand following population growth modelling demonstrate the potential for changes in industrial and municipal use. The United Nations Environment Program (2013*b*) reports growth in industrial and

Table 2. Status of hydropower capacity in the Nile River Basin
Committed capacity is that countries or political parties have committed (or pledged, bound or promised) to carry out in future. DRC, Democratic Republic of the Congo

Country	Potential (GWh)	Installed (GWh)	Under construction (GWh)	Committed (GWh)
Burundi	1700	–	–	–
DRC	100 000	2570	–	–
Egypt	>50 000	2842	–	–
Ethiopia	75 000	1534	2087	3016
Kenya	1422	761	–	63
Rwanda	400	55	42	37
Sudan	–	1343	1250	–
Tanzania	4700	561	0	0
Uganda	>2000	>380	310	–

municipal demand in Kenya and Egypt between 2005 and 2010, with the developments in industrial and municipal demand translating to significant changes in water use patterns.

In addition to hydropower development, industrial use and municipal use, navigation is another area of water use in the Nile Basin. In this case, the United Nations Environment Program (2013*a*) notes navigation by sailing boats and shallow-draft steamers as far as Aswan in the south of Egypt, whereas services in other areas are seasonal when stretches of the river can be navigated seasonally. Changes in water levels in the Nile Basin may determine changes in use for navigation in terms of the types of vessels used and the volume of transportation undertaken in the region (United Nations Environment Program 2013*a*). Presently, the various aspects of water use changes, as exemplified by hydropower development, reveal important gaps in terms of potential upstream and downstream expansion. Such gaps mean that decisions and policy making in relation to water use may be taking place in a vacuum, suggesting the need for heightened research attention in water use changes in the Nile Basin.

Spatial distribution of water stress in Kenya and Egypt

The spatial distribution of water stress is a crucial issue in the Nile Basin because it is a system of internally shared sub-basins providing important water resources to vulnerable populations. According to the United Nations Environment Program (2013*a*), the Nile Basin system already suffers water stress in the form of an ever-increasing demand for water amid significant population growth. At the same time, such water stress is bound to be exacerbated by uncertainties associated with the effects of climate change. The United Nations Environment Program (2013*a*) uses the ratio of water withdrawal to availability as an indicator of water stress. This indicator can be used to determine the spatial distribution of water stress in the Nile Basin, especially in terms of downstream *v.* upstream (Egypt and Kenya) considerations. Overall, the pattern of distribution of water stress unfolds in terms of the availability of internal renewable water resources (which determines external dependence), translating to higher water stress downstream than upstream in the Nile Basin (Nile Basin Initiative 2012).

In the case of Egypt, the Basin is home to over 65 million people, with an annual water consumption of ~1008 m^3 per capita, which exemplifies the elevated level of water stress

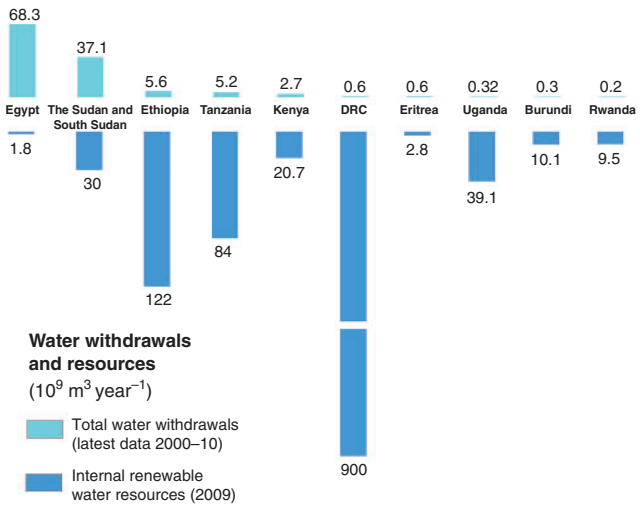

Fig. 3. Water withdrawals *v.* internal renewable water resources in Nile Basin countries, including Egypt and Kenya. Reproduced with permission from the Nile Basin Initiative (2012). DRC, Democratic Republic of the Congo.

downstream in the Nile Basin (Keith *et al.* 2013). Already fully using its share of the Nile flow and having to effectively reuse waste water, the country faces comparatively high levels of water stress, whereby scarcity will potentially leave the country's population vulnerable. Over 95% of the country's water originates from the Nile, which translates to a dependence on water flows outside Egypt's territory, further demonstrating the concerns surrounding water stress (Hamza and Mason 2005). The proportion of total water withdrawals to internal renewable water resources, as shown in Fig. 3, further demonstrates the precarious situation Egypt faces in terms of water stress. With Egypt's withdrawals extremely high compared to the available total internal renewable resource. The country has been classified as a 'very high stress' region on a water stress indicator with gradations from 'no stress' (0-0.1) to 'very high stress' (>0.8), most regions in the downstream Nile Basin, including Egypt, fall under the 'high stress' and 'very high stress' categories, as shown in (United Nations Environment Program 2013*a*). Kenya, however, is falls under 'low stress' region despite its

internal disparities in water stress, with the regions neighbouring Somalia and Ethiopia in the north east of Kenya falling under 'mid stress' and the southern and eastern regions falling under no stress (United Nations Environment Program 2013*a*).

However, although comparisons with Egypt, downstream on the Nile, indicate that Kenya faces lower water stress, the issue is not less challenging or insignificant for this East African country. In this case, Kenya's renewable water resources are insufficient to meet the country's water needs Fig. 3, leading to the general characterisation of Kenya as a water-stressed country (Patel 2013; Mekonnen and Hoekstra 2014). Ultimately, although the spatial distribution of water stress translates to upstream and downstream differences, the observations demonstrate that both countries face significant concerns regarding water stress.

Discussion

Factors driving changes in water use patterns in the Nile Basin

The observations regarding changing water use patterns spark interest in the drivers behind such developments. A report by the Nile Basin Initiative (2012) cites several driving factors behind water use changes, one of which pertains to levels of use among countries upstream and downstream. Historically, the upper riparian nations have barely been using the Nile waters. However, this trend is changing and will continue to change going forward, as the upstream economies plan investments in the water sector in ways that translate to heightened use of the Nile. Such heightened upstream use may explain the changes observed in aspects such as hydropower development (Nile Basin Initiative 2012). In this case, although Kenya's (an upper riparian country) investment in agricultural irrigation plateaus, the planned hydropower capacity expansion contributes to the overall rise in hydropower utilisation in the Nile Basin.

Beyond such developments in upstream *v.* downstream use, population growth constitutes another driving factor identified by the Nile Basin Initiative (2012). Projections from the United Nations Environment Program (2013*b*) also underscore the role of population growth, with use *v.* population models contributing to the changes in municipal use. In such a case, population growth and settlement patterns in countries such as Kenya and Egypt are likely to contribute to a heightened municipal use of water. At the same time, the Nile Basin Initiative (2012) has identified economic development as another important contributor to water use changes. One of the areas in which such economic development-driven change may be observed is increased industrial use. Economic development may also have implications for hydropower and municipal use of water, given the intersections that may occur between development, industrial expansion, population growth and energy demands. Likewise, the observations regarding navigational use being dependent on water levels, as noted in the United Nations Environment Program (2013*b*) report, may point to climate change as a potential driver of changes in the use of water resources in the Nile Basin.

Factors determining the development of water stress

Another crucial consideration in relation to the water resources in the Nile Basin is the driving force behind the water stress patterns in the basin. In this case, the Nile Basin Initiative (2012) report points to concurrent developments that have led to heightened water stress in the region, one of which is the steady rise of the demand curve due to both upstream and downstream countries experiencing population growth and economic development. It is expected that external dependence amid little internal renewable water resources should translate to higher water stress downstream, but upper riparian countries have recently started using the Nile flows more. Such upstream use not only points to water stress becoming an increasingly important issue in the upper riparian countries, but also exacerbates downstream water use owing to the ensuing reduction in downstream flows (Nile Basin Initiative 2012).

Others have highlighted factors beyond heightened national dependence on Nile flows and supply–demand imbalances driven by population growth and economic development. For example, Appelgren *et al.* (2000) cite the rapid deterioration of water quality, especially in irrigation, drainage canals and coastal lagoons, as one of the drivers of water stress in the Nile Basin. Inefficient water use, characterised by high per unit water use and high conveyance losses, constitutes another problem, whereby the Nile valley and the delta use 80% of the Nile flows while contributing only 40% of employment and 20% of Gross Domestic Product. In addition, water stress is exacerbated by ineffective water use, demonstrated by an orientation towards water-intensive crops and wasteful spills to the sea from large quantities of reuseable drainage water (Appelgren *et al.* 2000).

The United Nations Environment Program (2013*b*) has identified climate change-driven changes in flow as another important driver of water stress in the Nile Basin. Di Baldassarre *et al.* (2011) observe that modelling for climate change implications in the Nile River Basin is complicated by uncertainties, with aspects such as changes in precipitation being difficult to pinpoint. Modelling for the effect of climate change through dimensions such as hydrology, hydropower, water management, urban drainage, aquatic ecology and water quality is affected by uncertainty, leaving significant gaps in terms of how the Nile River Basin may be affected by climate change in the future (Di Baldassarre *et al.* 2011). As a result, the effects of climate change and how it may actually affect water stress in the region remains poorly understood, which underscores the need for studies into the topic.

Implications for policy

Observations relating to traditional and changing water uses and the occurrence of water stress alongside the factors driving them have significant implications from a policy perspective. In particular, the developments and trends noted have implications in terms of need to change policies in the areas of water resource sharing and security. For example, Abdulrahman (2019) observes that Egypt's long-time policy in relation to the Nile River has been one related to security, whereby the nation has threatened military action against upstream use of water that may interfere with the Nile flow to Egypt's detriment. However, such a resource-use and security-inclined policy outlook is becoming difficult to maintain as upstream countries become stable, their populations grow (subsequently necessitating the use of available water resources) and geopolitical alignments shift amid the absence of tenable legal obligations not to use the waters and the lack of a central authority to enforce the

colonial-era agreement. For example, Abdulrahman (2019) reports that a 2003 parliamentary declaration in Kenya ruled that it does not have a legal obligation to abide by the 1929 agreement signed at Cairo on 7 May 1929 (see https://www.internationalwaterlaw.org/documents/regionaldocs/Egypt_UK_Nile_Agreement-1929.html) because it was not party to such an agreement, whereas Tanzania has deemed such agreements illegal. Overall, depending on the 1929 agreement to determine water resource use and sharing policies in a much-changed regional context in terms of political, socioeconomic and demographic dimensions is unsustainable and could lead to potential conflict.

With Abdulrahman (2019) pointing to the need for policy rethinking, Allam and Eltahir (2019) demonstrate the possibility of new policy directions in the Nile River Basin. Amid rapid population growth, inefficient resource utilisation, climate change effects and unending conflicts among riparian countries, the Allam and Eltahir (2019) observe that the associated stress in the Nile Basin ecosystem requires new outlooks. Focusing on the upper Blue Nile Basin, Allam and Eltahir (2019) use a water–energy–food nexus outlook to explore the possibility of sustainability and cooperation among the riparian states. Discussing the implications of expansion in rain-fed agriculture, irrigated agriculture and hydropower development, Allam and Eltahir (2019) demonstrate the possibility of cooperation scenarios for win–win outcomes among riparian countries that share the basin's water resources. Such observations reveal that resource sustainability calls for cooperation among the riparian states in terms of use and trade-offs in light of the effect of water stress.

Di Baldassarre *et al.* (2011) approach the policy issue from the unique perspective of modelling in relation to climate change. In this case, there is a need for an informed modelling approach to support fact-based decisions and enable effective policy making. Although insights from modelling are pertinent for equipping decision makers and policy makers with useful insights upon which to base policies, Di Baldassarre *et al.* (2011) note that the different techniques used in modelling may instead lead to contradicting trends and subsequently contradicting recommendations for policy makers. At the same time, relying on one single simulation or modelling approach for climate change predictions may lead to a lack of attention to existing uncertainties, in turn translating to poor policies or wrong decisions (Di Baldassarre *et al.* 2011). Exploring the extent of advances in water resources research undertaken in recent times in relation to the Nile River Basin, Dile *et al.* (2018) highlight gaps in areas such as full understanding of land use dynamics, geospatial soil characteristics, soil and water conservation measures, little multidisciplinary research in water resources and limited data backing modelling efforts. Such gaps suggest that more research is necessary, because policy makers would still be operating in uncertainty even with the present level of research in the field.

Blum *et al.* (2019) demonstrated the usefulness of modelling and forecasts in the policy context in relation to the Nile River Basin. Focusing on the upper Blue Nile flow within the context of the Grand Renaissance Dam in Ethiopia, Blum *et al.* (2019) used statistical and dynamic models to predict a high probability of average to above-average rainfall in the basin, which was, in turn, shared with the public and regional decision makers through a blog. Blum *et al.* (2019) report that Ethiopian decision makers and forecasters found the predictions useful and previously unavailable to them, demonstrating the potential resourcefulness of modelling and predictions in decision making. Ultimately, Blum *et al.* (2019) concluded that publicly available forecasts could foster shared understanding in transboundary water resource management among decision makers, although effective communication and dissemination persist as obstacles. The dearth of wider predictions in areas such as heightened upstream use of water by countries like Kenya and its effect on downstream riparian countries such as Egypt reveals an important gap in scholarship, available data and modelling.

As reflected in the aforementioned studies, policy and decision-making considerations of the Nile Basin water resources, given their transboundary nature, centrally focus on the national and transnational outlook. However, upstream and downstream water stress developments affect individuals and households within communities, demonstrating an area that has received little attention in terms of funding. A focus on community-based natural resource management (CBNRM) can enrich policy discussions towards enhanced conservation and uplifting of community livelihoods. For example, Richards and Syallow (2018) highlight the case of water resources users associations (WRUAs), which are CBNRMs operating within the Mara Basin in Kenya. Such WRUAs constitute local participatory governance structures that seek to manage the Mara River tributaries. Richards and Syallow (2018) also reported considerations such as local knowledge, procedural considerations in instituting and implementing activities and distributional concerns, alongside concerns surrounding elite capture, donor support dependency, lack of meaningful participation and challenges in scaling up. Issues of marginalisation in a context that also involves donors and elites also emerged in that study (Richards and Syallow 2018). Overall, such insights demonstrate the possibility of approaching the Nile Basin water from a CBNRM perspective, which may enrich transboundary water resource use, sharing and management policies and decisions. Notably, the lack of research on the Nile River Basin from a CBNRM perspective underscores the existing gaps in the literature.

Conclusion

Several studies pertaining to water usage along the River Nile have been reported and critically discussed in this study. The focus of the study has been on Kenya and Egypt, determining the interplay between water use, demand and water withdrawal. The findings demonstrate that although water withdrawals are much higher in Egypt than Kenya, both countries are facing unmet demand and projected increases in water withdrawals against a backdrop of climate change concerns that may negatively affect water resources in the basin. Some of the pertinent water use developments are in municipal and industrial uses in both countries, hydropower development in Kenya and navigation use changes in Egypt. The changing water use patterns may be driven by a host of factors, including heightened upstream use by countries like Kenya, population growth and settlement patterns, economic development and climate

change-related factors. The discussion also highlights the spatial distribution of water stress in the Nile Basin, whereby downstream countries such as Egypt are highly vulnerable, although upper riparian countries such as Kenya are also facing water strain. Although some factors contributing to the water strain, such as climate change, are beyond full control, actions such as proper policy formulation, full cooperation, data management and proper resource utilisation are within reach and offer much-needed solutions pertaining to the basin. Such reviews provide a clear picture of the current situation, with the aim of creating awareness and much needed action to achieve sustainability.

Implications

The findings on water withdrawals and demand, changing water use patterns and water stress, alongside their driving factors, have crucial socioeconomic, geopolitical and policy implications. On the socioeconomic front, the importance of the Nile for millions of people in the Nile Basin, especially in Kenya and Egypt, highlights concerns surrounding food security and economic development. The lack of sufficient internal renewable water resources in downstream countries such as Egypt not only has grave socioeconomic implications, but may also spark geopolitical conflicts and security issues among the Nile Basin countries, especially considering recent and projected elevated upstream use of the Nile flows. To avert or pre-empt the aforementioned concerns, national and regional water resource policy making becomes necessary. Such policy making is relevant in areas such as water resource sharing, water quality, effective and efficient water use and mitigating the effects of climate change. In this case, questions surrounding existing water sharing policies alongside opportunities for win–win outcomes through cooperation constitute important policy considerations. At the same time, the role of data and modelling in informing policy and decision making also becomes important, especially in light of uncertainties and the need for strong and effective policies for such critical water resources. The traditional focus on macro-level policy considerations leaves out more localised considerations, with community-based inclinations potentially enriching policy making. As a result of community-based initiatives around the region, such as rangeland management through community based improvements in selected agro-ecological areas in Eritrea, sustainable woodland use that are community based in Ethiopia, etc., that offer solutions faced by countries along the basin (United Nations Environment Program 2013*a*).

Global outlook

According to United Nations Water (2008) there have been ~295 international water agreements negotiated and signed since 1948 as a result of acute conflict over water across the world. With an anticipated decrease in water resources and availability globally, it is important to understand the current status of water resources. This, in turn, helps map out future decisions and, where possible, alleviate problems. Although this study mostly focuses on the Nile River and its environs, it is hard to not to contextualise the problem to a global scale, and thus such an analysis can instigate consideration of transboundary water resources and water resources internationally in an amicable manner. Other studies have proven that a solid framework is important (US and Mexico transboundary water conflicts analysis) in resolving bilateral disputes and promoting cooperation between countries, albeit after multiple conflicts (Neir and Campana 2007).

Future direction and future work

In relation to water resources in the Nile Basin, one of the most important areas for future research lies in developing models for predicting possible case scenarios for per capita demand and changing use patterns, especially in light of the dearth of up-to-date literature on the topic. Another important area to which scholars may pay attention entails current and future sectoral value of the Nile and the implications of water stress for the economies in the Nile Basin. Finally, policy research may focus on proper planning for water use and sharing through understanding the current and future status of the Nile Basin's water resources. Such Nile Basin water resources policy research may focus on both transboundary and local community-centred perspectives to enrich decision making and policy making efforts.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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