Systems perspectives on water security: An applied review and conceptual framework

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Abstract

This article proposes a conceptual framework for understanding the resilience of water security at the scale of a river basin, thereby contributing to the ongoing scholarship on water security. Based on literature review, we apply systems thinking and resilience theories to encapsulate water security in a river basin as a system whose behaviour depends on the interaction of the component parts and the environment within which it occurs. The proposed framework has been built on the tenet that the resilience of any system such as that for water security depends on the interactions (the relationships) of the components of the particular system. We have thus argued that there is a relationship between resilience and the configurations of the system of water security. By exploring the Orange-Senqu River Basin, we suggest that configurations of the system of water security that includes the interaction of actors within the river basin, the structure of institutions (including institutional regimes), governance mechanisms, the capacity of actors and so forth generate the changes in the behaviour of the system. This behaviour might enable the system of water security to move into a different regime. Depending on the nature of the regime, the system can be considered to be resilient or nonresilient to disturbances. Any attempt to better understand this system requires us to uncover the configurations of this system and how its parts interact with each other, and this is, therefore, the pathway to unlocking the potential of achieving water security at the scale of a river basin.

Keywords: conceptual framework; resilience; social–ecological system; systems thinking; water security

1 INTRODUCTION

Since antiquity, water resource managers have been confronted by several challenges such as resource depletion, quality degradation, increased demand and uneven hydrological distribution in their attempt to ensure that water users have a continued and sustained access to the resource. Most of these challenges, one might argue, that are a result of the complex interactions that take place at any given scale of consideration. The depletion of water resources, for instance, might occur due to over-withdrawal from the resource by users in a particular river basin. Since water is considered a fugitive resource by some researchers (Anand, 2010; Rogers, MacDonnell, & Lydon, 2009; Smith, 2008; van der Zaag, 2009) as well as a common pool resource (Heikkila, 2004; Sarker, Ross, & Shrestha, 2008), it is quite challenging for a water resource manager to exclude unauthorised users from accessing the resource. Furthermore, when water resources have been polluted, the water users are at high risk of losing their productive use of the resource. We thus argue that the ability of the water user to continue benefiting from a resource whose units are dwindling in both supply and quality lies in the capacity to adequately safeguard, store and transport the resource to the point of use.

Although the calls for a focused debate on improving our understanding of issues of water security have been made for almost over a century now, it is disquieting to note that there has been an overemphasis on metric approaches to studying water security (Global Water Partnership, 2014). While accepting that as an emerging paradigm, researchers do need to quantify the nature of the challenges we now face, we do argue in this paper that water security is a complex discourse requiring a requisite set of novel approaches. It is, however, essential to recognise that leading organisations such as Global Water Partnership (GWP) acknowledges that water security is a concept that is still under development. This provides an opportunity for researchers to set out a research agenda that will challenge our current thinking on water security. In this article, we thus seek to contribute to this scholarship by exploring the application of system and resilience theories. We intend to conceptualise a system of water security and propose some configurations that enable it to be resilient and robust in a river basin.

This article is thus a product of a review and synthesis of previous literature on water security and the theories of systems thinking and resilience. We have used this review to construct a framework that depicts the dynamics within the proposed system of water security. Secondary data have been used to construct and apply the framework in the Orange-Senqu River Basin case study.

2 CONCEPTUALISING WATER SECURITY: THEORETICAL BACKGROUND

2.1 Water security defined

Even though literature is awash with publications on the concept (especially within the last decade), there seems to be a lack of commonly agreed conceptual and theoretical foundations that can be used to explain and understand the dynamics of water security at a scale of a river basin. Despite being a relatively new concept, we find that there has been an inadequate focus by researchers on developing conceptual content as Cook and Bakker (2016) found out in their study that almost 83% of studies on water security were primarily focused on empirical, modelling and lab-based analysis. Without agreed frameworks, Ostrom (2009) fears that all the knowledge that is generated by scholars will remain isolated and hence difficult to be translated and applied by policymakers. Theoretical and conceptual frameworks are essential rubrics in any science. It follows that the study of any complex issue, for instance, requires the use of proper lenses through which one can elucidate the building blocks of arguments and propositions that are made (McGinnis & Ostrom, 2014). According to Cairney and Heikkila (2014), the use of theories as lenses helps researchers to establish these opinions based on tested insights from peers within the scientific domain.

So far, different framings of water security exist, most of which are dependent upon the perspective and interests of the particular scholar or study programme (Cook & Bakker, 2012). Likewise, several definitions have been put forward in literature (Allan, Xia, & Pahl-Wostl, 2013; Bakker & Morinville, 2013; Biswas & Seetharan, 2008; Bogardi et al., 2012; Cook & Bakker, 2012; Everard, 2014; Global Water Partnership, 2014; Grey & Sadoff, 2007; Lautze & Manthrithilake, 2014; Sinha, 2005; Staddon & James, 2014; Tarlock & Wouters, 2009; UN-Water, 2013). Table 1 is a summary of some of the notable definitions and key focus or perspective that each of the definitions present.

TABLE 1. Some definitions of water security

Definition	Key focus and perspective
Adequate protection from water-related disasters and diseases and access to sufficient quantity and quality of water, at affordable cost, to meet basic food, energy and other needs essential for leading a healthy and productive life without compromising the sustainability of vital ecosystems (Pachova, Nakayama, & Jansky, 2008)	Disaster protection and access
An acceptable level of water-related risks to humans and ecosystems, coupled with the availability of water of sufficient quantity and quality to support livelihoods, national security, human health, and ecosystem services (Grey & Sadoff, 2007)	Risk and water availability
'The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality of water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability' (UN-Water, 2013, p. 2)	Access to water

The diversity of these definitions signify the complexity of trying to capture the breadth and depth of water security in one definition (Zeitoun, Lankford, Bakker, & Conway, 2013). While some authors consider water security to be an umbrella of several concepts based on these definitions and framings (Norman, Bakker, Cook, Dunn, & Allen, 2010), we posit that water security is characterised by four dimensions which include capacity, access, quantity and quality (availability), and risks, hazard and vulnerability (Cook & Bakker, 2012; Gober et al., 2014; Goldhar, Bell, & Wolf, 2012). Based on these dimensions, one is faced with a number of questions that should be answered when looking at the concept of water security despite the scale at which it is applied. Some of these questions include the following; Is there enough water of good and acceptable quality for the intended purpose? Is the community of resource users able to have affordable and sustainable access to the resource when needed? Do the actors (users, stakeholders, and governance regime) have the necessary capacity to safeguard the integrity of the resource and its benefits to the population? Is the society adequately protected from the risks and hazards arising because of varying quantities and quality of the resource? Are the benefits of the resource sustainable without degrading the environment?

Attempting to respond to these questions would make one realise the complexity of water security as a concept. According to Zeitoun et al. (2016), reaping the benefits of any conceptualisation of water security at policy level depends mostly on the ability to unpack this complexity which is often exacerbated by political, biophysical and technical dynamics. Two distinct approaches to unpacking water security have been identified by Zeitoun et al. (2016) as reductionism and pluralism, where the former seeks to quantify the risks posed by the dynamics of the water resource at a given scale. The pluralist approach, on the other hand, seeks to integrate the water–society processes and hence seem to be more adaptive in its approach. In both of these two dominant approaches, the authors argue that there are significant deficiencies that fail to translate the policy prescriptions emanating from them to vulnerable local population of water users. We argue that achieving water security is more than having the sufficient quantities of water say for instance in a dam, neither does it mean having sufficient conveyance network for water delivery infrastructure as resource users might still not be able to access the resource. Whether using the reductionist or pluralist approaches to understand water security, one thing is clear to us – water security operates in a system, and there is need to investigate how this system operates to support sustainable access to water despite the scale at which it is considered. As noted by Pahl-Wostl, Gupta, and Bhaduri (2016), an integrative framing of water security is vital for establishing priorities and facilitating analysis of the interaction of competing water uses and users within any given scale such as a river basin.

2.2 Water security from a systems perspective

Although many definitions of systems exist in the literature, a system is defined in this article as a complex of interacting components together with their relationships that permit the identification of a boundary-maintaining entity (Jackson, 2003; Laszlo & Krippner, 1998; Macy, 1991). This definition posits that systems would inherently have three components; the elements or the parts of the system, relationships or interactions amongst the component parts, and a purpose or function the system is made to achieve under given set of conditions. From the different disciplines, examples of systems can include the solar system, the digestive system, a soccer team, an *eco*-system, a family, and so forth. All these systems are built around the component parts, their relationships and a goal to be achieved or purpose. Consequently, Gharajedaghi (2011) posits that in most systems, each element has an effect on the functioning of the whole and is affected by at least one of the other elements of the system. For instance, we find that since democratic dispensation in 1994, the government of South Africa has been attempting to reform water allocation with the aim of enhancing access to water amongst historically disadvantaged users. However, these efforts are hampered by a myriad of factors such as a poor network of water infrastructure (some of which is very old), poor regulatory capacity, social complexities, effects of climate change and lack of an optimised legislative framework (Department of Water and Sanitation, 2015; Faysse & Gumbo, 2004; Movik, 2009; van Koppen, Schreiner, & Fakir, 2010).

As demand for water continues to surge in various river basins just as observed by Bogardi et al. (2012), society is faced with a challenge of meeting development aspirations, while maintaining the integrity of the resource base and this calls for understanding new approaches that would satisfy human needs while securing ecosystem sustainability. One is thus tempted to argue that achieving the goal of water security in this regard shall be very difficult if researchers do not consider the complexity and multidimensionality of water security (Allan et al., 2013). Researchers such as Laszlo and Krippner (1998) have, therefore, argued that the use of systems theory could help in modelling these complex interactions which give us the ability to understand the properties that are relevant for achieving our desired objective in the water security discourse.

Based on the understanding of systems presented thus far in this article, we then define the system of water security as a set of elements that are coherently organised and their interactions that affect water security in a river basin under given set of conditions. It is argued that the aim of this system is to enhance the capacity of actors and users to safeguard their sustainable access to the resource. In line with this argument, we suggest that this system behaves like a social–ecological system (SES). Composed of both an ecological and a social system, we consider an SES in this article as that where a group of individuals (such as water users) have pooled together some effort to build the institutions and physical infrastructure to enable them to generate some outcomes such as access to water for productive purposes (Janssen, Anderies, & Ostrom, 2007).

2.3 Robustness and resilience in a system of water security

So, what is a robust and resilient system of water security? Resilience has been defined in this article as the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain the same function, structure, identity and feedback (Janssen, 2011; Janssen et al., 2007; Walker, Holling, Carpenter, & Kinzig, 2004). However, when a system has the capacity to maintain its performance when subjected to these perturbations, authors such as Janssen and Anderies (2007) refer to that system as a robust system. This suggests that resilience and robustness are closely linked concepts, and we, therefore, use these two concepts together in our discussion of water security.

We first allude to the fact that every system has a specific purpose (and function) (Laszlo & Krippner, 1998). As such, the resilience of any particular system will be determined by the extent to which it can still be able to retain its purpose in the presence of a disturbance (Plummer & Armitage, 2007; Schoon, 2008; Walker et al., 2002, 2006). A robust and resilient system of water security is, therefore, defined as a system that supports water resources users in a river basin and associated actors to safeguard their capacity to sustainably benefit from an existing water resource in the presence of any disturbance.

It should be highlighted that while concepts of resilience and robustness are not new in the water resources discourse, the availability of its application in the study of water security is rather scanty. Nevertheless, proponents of resilience and robustness theories presuppose that the ability to sustainably benefit from any system resides in the thorough understanding of the characteristics that enable that system to be resilient to the disturbances that occur (Bhamra, Dani, & Burnard, 2011; Carpenter, Westley, & Turner, 2005; Gunderson, Holling, Pritchard, & Peterson, 2002; Holling, 1973).

Implausible evidence exists that suggests that the globe is facing unprecedented impacts of climate change across all sectors (IPCC, 2012). This is happening a time when there are a considerable impetus and appetite for achieving water security at all scales. Achieving water security, one might argue, is not a once off target as continually changing global dynamics will have an effect. We consider water security as a volatile phenomenon that will change if the situation within which it was achieved changes. For instance, a river basin might be considered water secure if there is a good rainfall season and hence sufficient and safe available surface and groundwater resource which is accessible by resource users; however, if this year is followed by a drought the river basin might quickly become water insecure.

Now, since water security operates in a system when the favourable conditions change in the basin, the change in the dynamics within the basin renders the system vulnerable. Thus, by using the concept of resilience thinking in this context, we are accorded an opportunity to explore the shocks that the system undergoes in the presence of a disturbance (such as a drought) and be able to predict the responses (of the system to that disturbance) and hence the impact on water security.

Some scholars have argued that there is need to understand the links or relationship that exist between the properties or rather configurations of the system with the behaviour of the system in the presence of any form of disturbance (Gunderson, Holling, Pritchard, & Peterson, 2002). For instance, the presence of good governance regime enables the water users to quickly reduce water use through newly established norms such as water use restrictions during a drought. Instead of the system to completely collapse in response to the disturbance, the nature of the configurations will enable it to either withstand the perturbation or indeed yield to failure. Thus, on the basis of this premise, we suggest that achieving water security requires that we focus on the configurations of the system and their effect on various system regimes to eventually determine the ramifications of changing these configurations on system robustness and resilience. We postulate that understanding the effect of these configurations will enable the water resource managers to develop relevant policies that will help achieve and sustain water security.

3 RECONCEPTUALISING WATER SECURITY: THE ADAPTED CONCEPTUAL FRAMEWORK

Here, we present a conceptual framework whose aim is to identify the configurations and relationships that exist in a system of water security in a river basin. A number of variables that have an effect on the relationships/interactions in the system towards particular outcomes have been proposed. In order to do this, we adapt the SES framework used by Anderies, Janssen, and Ostrom (2004) and Ostrom (2007). We do realise that by using the SES framework as our base framework, our research in water security stands to benefit from a well-established and refined model of inquiry for water security. Furthermore, we do acknowledge that the study of water security is multidisciplinary, and hence requires the use of a framework that has its basis in multidisciplinary research.

The proponents of the SES (Anderies et al., 2004; Janssen et al., 2007; Ostrom, 2009) framework acknowledged that this framework forms the foundation for future work in the study of SESs such as that being examined in this article. Although this framework has been extensively used in SES research and commended for the insights it has provided, the proposed model was still considered by Anderies and colleagues as a minimum representation of elements that comprise the SES suggesting that there are some more elements which were not considered (Anderies et al., 2004). This provides room for reconfiguring the model to fit the context of any problem being investigated. So far, the SES frameworks have been adapted and used in a wide range of systems including lakes, irrigation, forestry and community-based natural resource management just to mention a few. To the best knowledge of the authors, however, no previous efforts exist that attempt to apply the SES framework in water security scholarship at the scale of a river basin despite the increasing efforts and interests by scholars.

3.1 Key features of the conceptual framework

Figure 1 is the representation of the proposed conceptual framework depicting the configurations and relationships or interactions amongst the components of the system in a river basin. A critical characteristic of the definition proposed by the UN-Water (2013) for water security entails that a population (water users and actors) should be in a position to *safeguard* sustainable access to the resource. As such, the key features proposed in this framework relate to the ability it renders us to define a system that is able to contribute to this perspective.

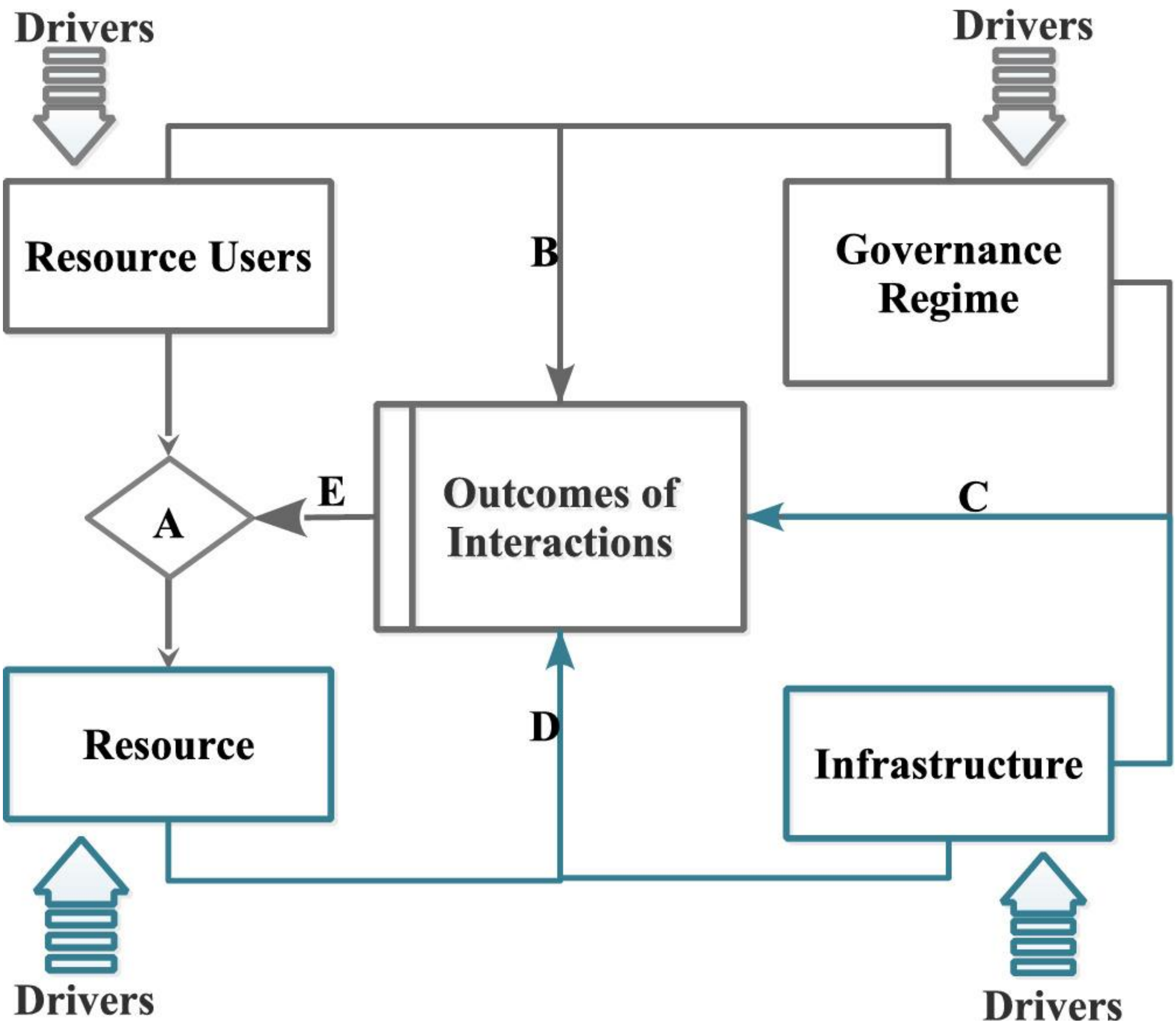

FIGURE 1. Adapted framework revised, November 2019

The framework starts by depicting the primary function of the system of water security which is to safeguard the capacity of actors and resource users to access the resource. In order for resource users to have access to the resource, several factors play a role. These factors influence the manner in which the users interact with each other as well as with the other components of the system within the river basin. By adapting an SES framework, we postulate that this system is composed of four component parts, the resource, resource users, governance regime and infrastructure. The *Resource* and *Infrastructure* form part of the ecological system, while the *Governance regime* and the *Resource users* constitute the social system within the SES. Thus, in this framework, node A represents water security, while E represents the influence of the various interactions of components of the system towards water security in the presence of the drivers.

3.1.1 The resource

Water as a resource is a critical component of the system of water security. It is contended here that water is the central element that brings all other components of the system to interact with one another. From the perspective of water security, the quantity and quality of the water will determine the type of interaction between the actors in the basin and the resource. Authors such as Bruns and Meinzen-Dick (2001) argue that when the resource is in abundance, there is no need for defining rules over its allocation and utilisation. However, as the resource dwindles in quantity and quality, panic and hence competition over the resource emerges necessitating the institution of water allocation rules and norms by the governance regime. It should also be noted that it is not only too little water availability that has an impact on the relationships and interactions of resource users and other actors, but also overabundance and quality of the resource. Janssen et al. (2006), for instance, contend that the activities and interactions of actors and resource users can be influenced by either the physical flow of resources or variability in the physical state of the resource. Too much water might cause flooding thereby destroying various property such as water storage or conveyance infrastructure or indeed agricultural produce on the farms. This might influence resource users to pool their resources and collectively act to respond to the risks posed by the resource dynamics.

3.1.2 The resource users

As indicated previously, the system of water security is built around the presence of water as a resource for use by various users such as irrigation and livestock/dairy farmers, forestry and sugarcane industry, manufacturing and domestic industry and so forth. These users might be self-organised into user associations or cooperatives or operate individually where they pool their resources to facilitate the build-up of their capacity to safeguard their access towards the resource. It has been argued by Anderies et al. (2004) that significant challenges facing resource users include free riding and overharvesting, especially when the resource is common property. This suggests that in order to understand the behaviour of water resource users in the system of water security, it is vital to first understand the types of institutions that are used to govern the allocation and utilisation of the resources. It is argued here that the types of the institutions and resulting water user behaviour will influence the robustness and resilience of the system of water security as a whole in the presence of any disturbance that might occur.

3.1.3 The governance regime

Water governance has been defined by Rodgers and Hall (2003) as ‘the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society’. It thus follows that in order to conceptualise and examine the governance of water resources, the people, organisations and institutions responsible for this functionality should form the critical focus of inquiry (Basurto, Gelcich, & Ostrom, 2013; McGinnis & Ostrom, 2014; Ostrom, 2007, 2009; Pahl-Wostl, 2007). Janssen et al. (2007) contends that the governance of SESs involves enhancing the ability of the system to remain stable or create an opportunity to improve the resource's status. This suggests that understanding the characteristics of the governance regime at a particular scale is essential in trying to understand the influence that governance has on the behaviour of water resource users.

As applied in this research, governance regime refers to the governing authority operating in a given scale or a nested set of governing authorities in polycentric systems (Schoon, 2008). Furthermore, Anderies et al. (2004) also suggest that the governance regimes in the operation of the SESs depend on the social capital – the rules and norms that are used to govern, manage and access the resource. Such being the case, it can be argued here that the governance regimes for the system of water security should include the set of institutions and actors that are drawn from but also outside government to facilitate the interactions between water resource users and the resource. Tarlock and Wouters (2009) argue that transparent and accountable systems of governance are paramount to achieving the required coordination and cooperation in managing water resources thereby improving the ability of resource users to sustain their access to the resource.

3.1.4 The infrastructure

The infrastructure included in the study of SESs has quite often been considered to include both physical and social capital (Anderies et al., 2004). In this study, however, infrastructure refers to the physically engineered capital such as dams, irrigation canals, dykes, water treatment works, pipe networks and so forth, and the ecological infrastructure such as the river system from which the resource occurs. The infrastructure has been considered to be a significant part of the system of water security in this study as it boosts the capacity of water resource users and actors to store and convey water resources for various uses to the point of use on the one hand. In some cases, the infrastructure might be used to improve the quality of the resource to meet the required standards for a specific use such as that for domestic supply. This can be done by either the governing authorities or indeed the resource users themselves or even a private investor. It is argued here that the presence or absence and status of the infrastructure shall have an influence on the interactions between the resource users, the governance regimes, and the resource in the system of water security.

3.1.5 Internal and external drivers

Scholars of SESs postulate that every SES is a complex system that is subject to external or internal stresses irrespective of the scale (Plummer & Armitage, 2007). In one of the works of Hollings, it was thus purported that the future of managing natural resources such as water does not lie in the command and control mechanisms but rather in the ability of resource users to develop self-organizing abilities and leadership for managing the resource in the presence of these stresses (Holling & Meffe, 1996). Our argument in this article is that achieving water security in a river basin requires an understanding of the interactions that take place within the system in the presence of these stressors, some of which might originate from within the system while others are external from the system.

Examples of the drivers include flooding, earthquakes, climate change and so forth which can affect infrastructure as well as the water resource variability while some drivers such as population change, economic dynamics, political dynamics and so forth can have an effect on the dynamics of the resource users and the governance regime. While these drivers are considered to operate at different levels of influence, we further argue that they do not operate in isolation on a particular element of the system. For instance, the effect of climate change on the resource will be exacerbated by the increased water demands due to population increase, and this might trigger some policy changes in the governance space affecting the users' interaction with the resource. A typical example would be that governance authorities change the water allocation principles in response to a prolonged drought while the water resource users change water consumption patterns due to the changes in the economic developments. It is important to note that these drivers will differ from one basin to another.

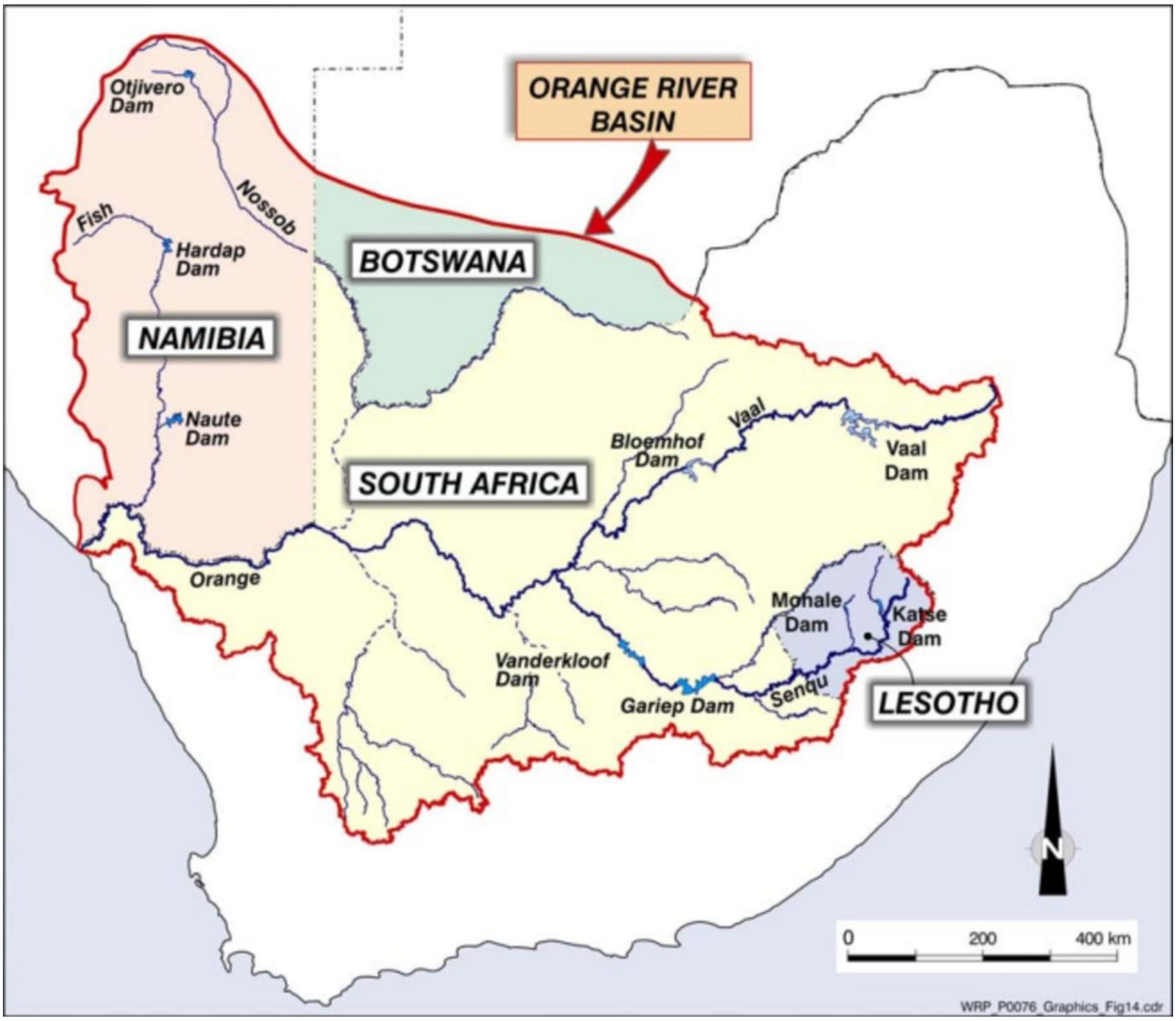

FIGURE 2. Orange-Senqu River Basin

4 CASE STUDY: APPLYING THE CONCEPTUAL FRAMEWORK TO THE ORANGE-SENQU RIVER BASIN

This case study is an example of a river basin whose dynamics are interesting to the study of water security from a systems perspective. This case study is used to explain how the system of water security operates in a river basin. The Orange-Senqu River is a transboundary river that is shared between Botswana, South Africa, Lesotho and Namibia (Figure 2). It originates from the highlands of Lesotho and stretches for about 2,300 km to the Atlantic Ocean draining an area of about 850,000 km^2. The greater part of the river, especially in Botswana and South Africa is referred to as the Orange while the course within Lesotho is called the Senqu River hence the name. The Orange-Senqu River system is regulated by more than 31 major dams with several hundred smaller dams being used to support local demand centres feeding agriculture, domestic water supply, mining and other industries. In order to meet the demand for water by various users, the river basin has numerous large inter and intra-basin water transfers. The river basin is managed by the Orange-Senqu River Commission (ORASECOM) which was established in 2003 to manage the development, utilisation and conservation of water resources in the river basin (Wirkus & Böge, 2006). Due to the spatial and temporal variability of rainfall in the basin, water stress is evident with average per capita availability of just over 1,000 cubic metres annually. According to Falkenmark and Lundqvist (1998) water stress indicator, the Orange-Senqu would be classified as falling between chronic scarcity (500–1,000 m^3/year) and water stressed (1,000–1,700 m^3/year).

In February 2017, the Orange-Senqu River Basin Commission signed an investment agreement of about R48.6 million for improving water security in the river basin with the African Water Facility and the New Partnership for Africa's Development (NEPAD) Infrastructure Project Preparation Facility. This investment is meant to boost water security in the river basin. But what does this mean? We have agreed with several other authors that water security means different things to different authors. However, from a basin perspective, achieving water security depends on a number of factors (drivers) which have been depicted in Figure 3 for this river basin. This figure depicts the organisation or configuration of a system that operates within this river basin with the aim of ensuring that users within the basin have sustainable access to water resources. These factors affect the interaction of various actors in the basin, which affect the status of water security in the Orange-Senqu River Basin. While the framework presents many factors and elements, this article is not able to discuss each and every factor due to space limitations.

4.1 Governance and institutional dynamics

As a transboundary river basin, there are a number of institutions that coordinate the governance of water resources in the basin. According to Savenije and Van der Zaag (2000), management of water resources in shared river basins requires two types of institutions – regulatory and developmental institutions. From a regulatory perspective, each of the riparian states has a Ministry or Department that has direct responsibility of managing the water resources that fall within its boundaries. Prior to the establishment of the ORASECOM, the riparian states established bilateral institutions which were mostly project specific within the river basin. These institutions include the Lesotho Highlands Water

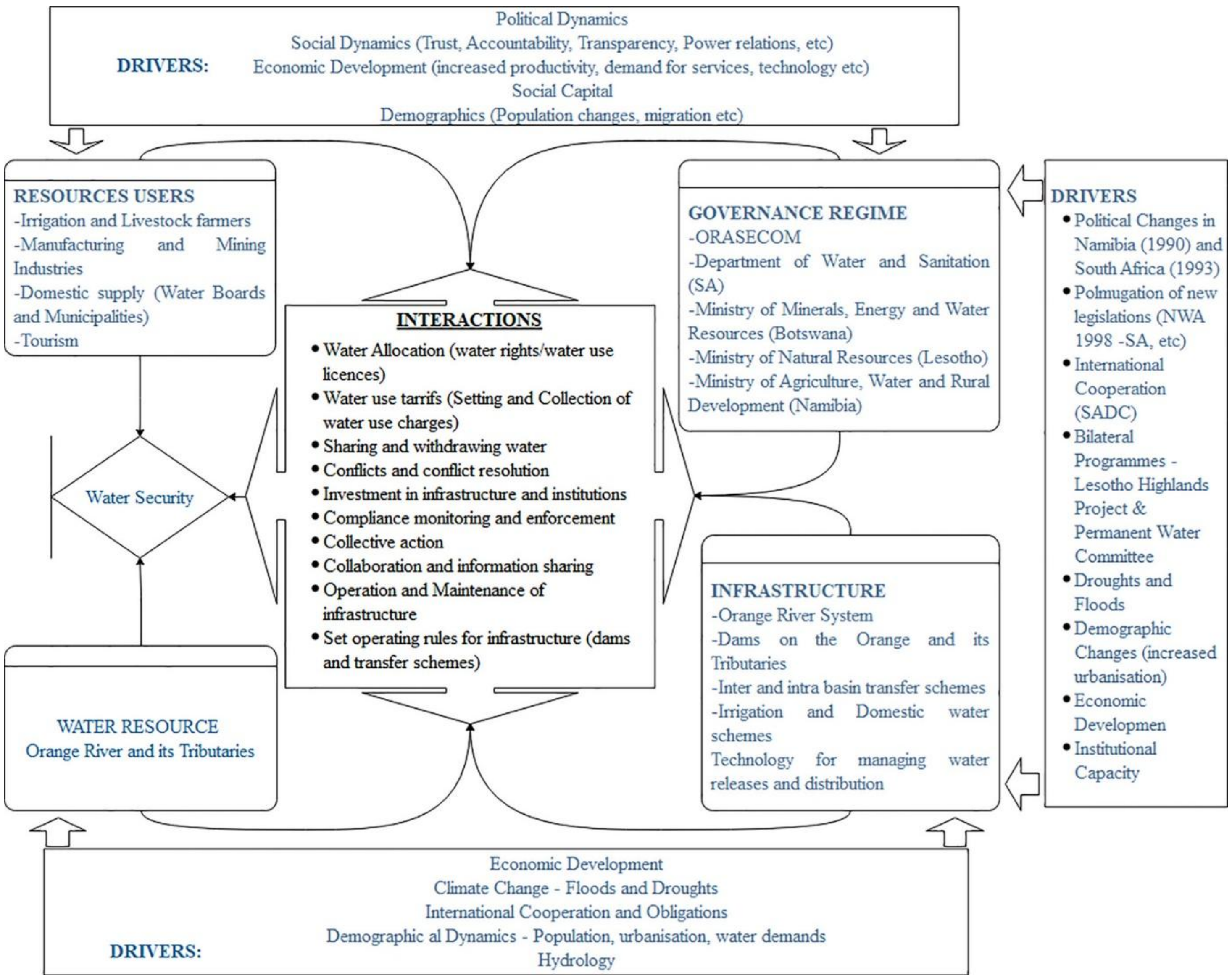

FIGURE 3. Conceptual framework applied in Orange-Senqu River Basin

Commission (LHWC) for Lesotho and South Africa, and the Permanent Water Committee (PWC) for South Africa and Namibia established in 1999 and 1992, respectively. The LHWC was formed in order to provide monitoring and advisory function over the Lesotho Highlands Water Project which was meant to serve the South African province of Gauteng with a reliable supply of water. The PWC was, on the other hand, meant to provide a mechanism through which development in lower Orange River basin could enhance water security for irrigation and other water users on both sides of South African and Namibian border. The establishment of ORASECOM in 2003 was not meant to replace these two bilateral institutions but rather provide a platform through which all riparian actors are involved in the management of the water resources from this basin.

However, it should be pointed out that since the establishment of these institutions in the river basin, their ability to deliver according to their mandates have been affected by a myriad of factors. According to SADC (2009), the ORASECOM has been challenged by the existing bilateral agreements between the riparian states. For instance, it is argued that riparian states would instead dedicate more resources to the bilateral institutions than the multilateral ORASECOM, which eventually undermines its ability to deliver according to its mandate. This can be attributed to the fact that riparian states find it easier to reach consensus on issues of national significance in a bilateral institution than a multilateral institution. To an extent, it can be argued that the ability of these river basin governance institutions to support the management and development of water resources for the benefit of resource users depend on the enabling environment from the riparian states including the political context and policy and regulatory frameworks. Further, since the governing commission of this river basin is multilateral, it ascribes to the international waters governance frameworks such as the Southern African Development Community (SADC) Protocol on Shared Watercourses of 2000 ratified by all countries and the UN Convention on the Law of the Non-Navigable Uses of International Courses which was ratified by only South Africa and Namibia. As a result, the other countries do not always agree with its foundational principles and the manner in which the basin commission discharges its functions.

4.2 International obligations and cooperation

There has been a consensus that water has been at the helm of earliest and modern civilizations. It has followed as such that the nation that has control over water resources has the upper hand in boosting social-economic development within its borders. Due to water scarcity and increased demands, especially in shared water resources, some scholars have forewarned the likelihood of water wars (Fischhendler, 2015) between riparian states. While this might not be the case for the Orange-Senqu River Basin, development and sharing of water resources are dependent on the level of cooperation amongst the riparian states. For instance, the agreement between Lesotho and South Africa on the Lesotho Highlands Water project has ensured that the latter is able to benefit from water resources for its economic and social development in the economic hub of Gauteng. During the drought that hit the more significant parts of South Africa in 2016/17, water from Lesotho Highlands Water Project through Sterkfontein dam ensured that the population within the Vaal sub catchment of this river basin are water secure.

4.3 Demographic dynamics

The Orange-Senqu River Basin has a different demographic profile. As indicated in Table 2, the South African population in the basin constitutes about 85% of the total basin population while Lesotho has the whole of its population making 13.6% of the basin population. It is important to indicate that the whole of Lesotho population dwells in the river basin compared to 30% of South Africa's total population that dwells in the basin.

TABLE 2. Population composition of the Orange-Senqu River Basin) Hall and Jennings, (2007)

	Lesotho	Botswana	South Africa	Namibia
Population	2,127,539	1,680,863	44,819,778	1,830,330
Population in the basin	2,127,539	47,661	13,357,298	163,093
% country's population in the basin	100%	3%	30%	9%
% basin population	13.6%	0.3%	85.1%	1.0%

The population and hence economic activity of the South African population in the river basin has led to a significant upsurge in water demand to such an extent that the South African government has always looked to neighbouring river basins for augmentation options for additional supply. The Lesotho Highlands Water Project, the Tugela – Vaal Transfer Scheme and the Orange – Fish Transfer Scheme are some of the high-profile projects that were a response to the increasing demand for water resources in the basin. Most of these projects were created to feed the economic hotspots of the basin so that it can help develop the capacity to provide sustainable access to water resources by various users, including domestic, irrigation and industries. These projects among others have led to various interactions between many actors in the river basin including funding partners, water user groups such as Irrigations Boards and Water User Associations, Water Boards, Mining Companies and manufacturing Industries.

4.4 Technology and infrastructure development

As indicated previously, the upsurge in water demand in the river basin, especially in the economic hub of South Africa has necessitated the increased assurance of supply of water for various uses. As such, several partners have contributed to the construction of dams in this river basin. To this extent, the river basin has about 40 dams constructed on the Orange and its tributaries. These dams have ensured that there is an improved assurance of supply of water for various resource users. The most recent 2016/17 drought in South Africa is an example of how infrastructure can ensure that water users can continue to benefit from the resource even in the presence of a disturbance where water was released from Sterkfontein dam in Lesotho when Gauteng province was hit with a significant drought and the capacity of the Vaal dam which feeds it was below 25%. In addition, technological advancements have created a plethora of opportunities in the modern era of water resources management. From events prediction to troubleshooting of the associated problems identified, several technicians have invested significantly of their energy to develop tools that can be utilised in the water sector. Biswas and Seetharan (2008) postulate that modern technological advances are most likely going to affect the water-use patterns and hence, the water requirements for various uses. In order to be able to safeguard the access to adequate water quantities safe for various uses in a river basin such as this one and even at a national scale, technology provides some opportunities that can be tapped to enhance the capacity of actors responsible for water resources management.

4.5 Climate change

It is generally agreed that water will continue to be a medium through which the effects of climate change will be profoundly felt across the globe. According to the IPCC (2012), it is predicted that climate change will lead to increased drought incidences in some regions as well as flooding in other geographies. The implication of these phenomena is that there shall be reduced resilience of the capacity of the communities to access, harness and use the resource (Sadoff et al., 2015). For some, the existing infrastructure will no longer be sufficient to contain the hugely variable water resources. On the other hand, the existing governance structures will not be adequate to navigate through the challenges posed by climate change due to its complexity. This entails that water resource actors in a river basin such as the Orange-Senqu shall need to develop mechanisms that enable them to continue benefiting from the resource. In order to do this, the actors might actually need to change the way they interact with the resource, institutions and infrastructure either by increasing the investment efforts or collaboration on self-governance. We have, for instance, seen how the countries sharing the river basin evolved in their relationships over time as they continue to realise that the resource is increasingly being subjected to increased demands and hence infrastructural constraints. Partners have been brought in to provide technical and financial capacity such as the Africa Water Facility through NEPAD.

5 SYNTHESIS AND IMPLICATION ON WATER SECURITY DISCUSSION

We have noted just as other researchers that water security as a concept means different things to different people depending on their interest and area of focus. One of the main challenges posed by this multiconceptualisation of water security has been the inability it has rendered scientists to develop agreeable metrics for its measurement and operationalisation. Despite the proliferation of interest in the concept, some authors argue that water security has been defined in such a way that policy options are defined in a negative way without considering the opportunities that currently exist (Del Moral, Pita, Pedregal, Hernández-Mora, & Limones, 2014). Alternative framing offering policy direction that utilizes the opportunities that exist in the river basin has always been necessary. From the case study, it is apparent that a system perspective offers us an opportunity to learn from the interaction of various components of the system under the various prevailing conditions.

Primarily used in the field of psychology, interaction refers to the ‘dyadic behaviour in which the participants' actions are interdependent such that each actor's behaviour is both a response to and stimulus for the other participant's behaviour’ (Rubin, Bukowski, & Parker, 1998). It then follows that successive interactions between actors bring about what is referred to as relationships built upon the expectations of these actors on one another. Nkhata, Breen, and Freimund (2008) argue that these relationships might develop further especially when actors interact with each other in response to the dynamics within any given environment such as changes in the status of the resource due to any of the internal or external drivers of the system.

TABLE 3. Interactions and variables in the system of water security

System components	Interaction	Effect of interaction	Driver of interaction
Users and the resource (water)	• Sharing and withdrawing water for different uses • Undertaking water management practices • Self-governance	• Improved living standards • Degradation of water resource due to over-withdrawal of resources • Improved water resource due to good water management practices • Collective action/free riding	• Population dynamics • Climate change effects, for example, drought • Economic development/development aspirations • Hydrology • Flood or drought risk
Users and governance regime	• Establishing water allocation norms and standards • Sharing and allocation of water • Payment of water use fees and charges (users) • Collection of water user fees and charges • Compliance monitoring and enforcement • Collaboration and information sharing • Conflicts and conflict resolution	• Collective action • Increased/improved capacity • Improved water resource • Degradation of water resource • Robust/resilient system (un)	• Political dynamics • Good/bad governance • Social dynamics (trust, accountability, transparency, power relations and so forth) • Legislative changes
Governance regime and infrastructure	• Capital investment • Operation and maintenance • Operating rules for infrastructure	• Investment • Increased capacity to support users • Increased transaction costs • Improved resource management	• Climate change risks (floods, droughts and so forth) • Political dynamics • Institutional dynamics • Economic development/development aspirations

System components	Interaction	Effect of interaction	Driver of interaction
			• Demographic dynamics
Users and infrastructure	• Capital investment • Operation and maintenance • Storage capacity	• Improved capacity • Improved productivity • Collective action/free riding • Improved resource availability	• Climate change • Political dynamics • Institutional dynamics
Resource and infrastructure	• Ecosystem maintenance	• Improved resource management	• Climate change • Investment/economy
Resource and governance regime	• Water allocation norms/rules • Compliance monitoring and enforcement • Data collection, processing, and sharing	• Allocation guidelines/norms/rules • Improved management • Degradation of the resource	• Climate change • Political dynamics • Institutional dynamics

From the case study, we have thus learnt that the interactions between the various components of the system under the influence of the drivers shall yield different patterns of interactions. These interactions produce some outcomes that will mostly affect the ability or capacity of the resource users or actors to safeguard their access to the resource, which is the critical feature of water security. In Table 3, we develop some variables that will play a critical role in determining water security in a river basin based on the lessons obtained from the Orange-Senqu case study. It is important to note that this table does not present an exhaustive list of interaction and variables in the system of water security. This is rather the starting point of our understanding of the complex interactions that take place and their anticipated outcomes, all of which have an impact on achieving water security in a river basin.

While looking at the interaction of water users, the resource and the governance regime, it is important to state here that when a resource such as water is in abundance, there is no competition and hence no need for controlled use, and little incentive exists to define the rights over its use (Bruns & Meinzen-Dick, 2003). However, these authors argue that as the resource diminishes in quantity (and quality), competition among users is triggered, and the need for allocation regimes to be defined in the society arises. The status of demand for water resources and its availability in the Orange river basin has necessitated that proper water allocation regimes be instituted by the water governance regimes in the respective countries. These have been deemed necessary to ensure that users both upstream and downstream of the basin can have a guaranteed supply and access to the resource.

In most river basins such as the Orange-Senqu, the governance regime has established norms for water management to be adhered to by resource users and actors. Cook and Bakker (2016) argue that the relationship between water security and good water governance is a symbiotic one whereby the former sets goals for good water governance while the latter catalyses an enabling environment for achieving water security. This is more so as Agrawal (2003) argues that formal and informal institutions have more considerable influence on the behaviour of resource users in a river catchment. We further note that researchers such as Ostrom (2009) confirm that resource users do not have the incentive to self-organise to maintain the sustainability of their resources if the governance regime does not play its role. Resource users and actors within a river basin depend on the governance regime to share accurate information about the natural resource systems, providing the platform where resource users can engage discovery and conflict resolution processes and providing mechanisms to back up local monitoring and sanctioning efforts. By doing this, resource users and the governance regime accumulate capital that can be used to build the much needed capacity to safeguard their interests in the river basin such that even in the times of the various dynamics such as droughts, population increase, political upheavals or indeed power relations, there is still a guarantee that users will have access to the resource for their uses.

While the climate, social and political dynamics within the river basin drives the patterns of interactions amongst the actors, investment in the physical infrastructure to harness the resource is arguably a more critical element. Authors such as Sadoff et al. (2015) debate that there is a significant difference in the status of water security between developing and developed countries. While developed countries have invested a lot in the infrastructure required for capturing adequate water for various uses and instituted relevant governance institutional structures, the developing countries, on the contrary, still lag way behind. Although both developed and developing nations might be facing the threat of water insecurity due to changing climatic and demographic dynamics, we can argue that developing economies face being at more risk especially as demands for catching up and sustaining socio-economic growth escalate. This is exacerbated by the considerable demand for investments in the otherwise complex and poorly researched/understood hydrologies.

6 CONCLUSION

We stated that the objective of this article was to develop a conceptual framework to be used for understanding the resilience of the system of water security at a basin-scale. In order to advance this, we reviewed the relevant literature on systems and resilience theories that assisted us develop a framework representing the system of water security which was adapted from an existing framework – the SES advanced by notable scholars (Anderies et al., 2004; Janssen & Anderies, 2007; Ostrom, 2009; Ostrom & Cox, 2010). We noted with little or no surprise that despite being an emergent concept, there are inadequate efforts among scholars to develop conceptual models for understanding water security except a few. Using this framework in a case study, we were able to show what we believe are the critical elements of the system and interactions that might take place thereby affecting the ability of water users in a given domain/scale to safeguard their access to a given resource for various productive purposes. We have arguably demonstrated that a systems approach to understanding water security offers a better perspective because of the complexity and hence interdependent relationships that take place. It is essential to point out here that being a complex system, the system of water security has several interactions that take place in a given domain suggesting the existence of a variety of variables. It is an implausible job to try to understand the role of all these variables in one single research inquiry like ours. We will thus assume that some variables are constant and only concentrate on some few variables whose choice is purely subjective depending on the availability of data.

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