Chapter 4

Water, Ecosystem Dynamics and Human Livelihoods in the Okavango River Basin (ORB): Competing Needs or Balanced Use? A Review

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Abstract

Freshwater is essential to life, and its availability poses a significant challenge to developmental needs and environmental sustainability globally. Due to increasing populations, global water requirements have increased in the twentieth century, and the trend is similar in the Okavango River Basin (ORB). With a total annual flow of 11 km^3, the ORB is characterised by a flood pulse regime that drives and supports a diverse eco-sociological system. The Okavango River is a potential water source for the development of the semi-arid nation states of Botswana and Namibia. Therefore, there is a need to ensure that the water resource of this system is managed effectively to ensure water sustainability in the basin. Current water demand in the basin is less than 1% of the current total discharge, while projected demand over the next 10 years also falls below the total discharge. Moreover, the ORB is characterised by multi-functional use, where riparian communities have adapted to change hydrological conditions. While the ORB is relatively pristine, there are potential threats in this system, which can affect its water resources. We conclude that there is a need for a harmonised legislative framework in the basin to ensure that the ethos of water sustainability is maintained.

Keywords: water scarcity, water management, water governance, transboundary water resources management

1. Introduction

There are 214 transboundary river basins in the world [1], which cover large parts of Arica, Europe, Asia and the Middle East, and were inhabited by 58% of the world population in 2010 [2]. This makes transboundary river basins critical foci of human livelihoods. They are a source of freshwater, which is essential for life [3, 4]. The world's land and water resources are finite and under pressure from population growth [5], climate change and pollution [6]. Water resources management becomes more challenging when water resources straddle international boundaries [2], such as in the Okavango River Basin (ORB). Floodplains have always played a key role in human livelihoods [7] and also have the ORB [8]. According to Junk [7], hydrology is the key "environmental forcing factor in wetlands"; therefore, maintenance of natural flow conditions is critical for the environmental sustainability of the ORB. Hence, management of the ORB is critical towards sustenance and maintenance of human life among the basin states. However, humans have always withdrawn freshwater from sources such as rivers, wetlands and lakes for various needs such as agriculture, energy and industrial activities, at the exclusion of ecosystem needs [3]. Therefore, ensuring water sustainability in the ORB will require finding a balance between competing human needs and ecosystem functioning.

The waters of the Okavango River are a potential source of development for the semi-arid nation states of Namibia and Botswana [8]. Therefore, water is both a key and a limited resource in the ORB [9]. Because of its uniqueness, national socio-economic development polices have added pressure on the water resources of this river system [10] in their endeavour to uplift the socio-economic status of the basin's impoverished communities. However, water sustainability becomes more urgent and acute in transboundary river systems because of the diverse hydro-political and socio-economic drivers that exist. Munia et al. [2] highlight that transboundary rivers create hydrological, social and economic interdependencies among societies, which make transboundary water resources management challenging.

Some of the key transboundary management areas of concern identified by OKACOM [10] in the ORB are variation and reduction in hydrological flow, changes in sediment dynamics, changes in water quality and changes in the abundance and distribution of biota. These issues are driven primarily by population dynamics, land-use change, poverty and climate change. According to OKACOM [10], the major transboundary concern is that increasing populations in the basin will result in increased demand for food crops with subsequent pressure on land, which will invariably result in changes in water quality. Undoubtedly, well-managed water resources can be a significant driver of growth with benefits for human livelihoods and ecosystem functioning [11]. Therefore, the main goal of this chapter is to contribute knowledge that will contribute towards a water resources framework for the ORB with the aim of achieving water sustainability.

2. Description of the study area

The ORB is located in central Southern Africa (**Figure 1**) and covers a broad climatic gradient from a high rainfall zone in the Angolan highlands, through a semi-arid Namibia and ends in the semi-arid Northern Botswana [12]. It covers a total surface area of between 20,000 Km^2 [13]

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and 690,000 km^2, with a population of approximately 900,000 [5, 10, 14]. According to Barnes et al. [15], the population in the basin is predominantly rural and remote and has higher population growth rates than national averages. The basin's population is expected to grow to 1.28 million people by 2025 with 62% of the population living in Angola, 22% in Namibia and 16% in Botswana [10]. Assuming a medium variant growth, the river basin population will increase to 5.1 million people in Angola but will plateau in Botswana and Namibia by 2050 [16]. This is expected to increase pressure on the ORB, especially in Angola [9].

According to Wolski et al. [12], the ORB is composed of an upper part (in Angola) characterised by a typical river catchment and a lower terminal part (in Botswana) consisting of the Okavango Delta and terminal rivers, where the "water's ultimate sink is evaporation to the atmosphere". The ORB has four catchment areas, which the Angolan headwaters (in Angola), the middle reaches (in Namibia) and the Botswana portion, which consists of the panhandle and the delta ([10, 17], Figure 1). This system is drained by the Okavango River, which is one of the largest rivers in Africa [13]. Because of its location in an arid area, the Okavango River is a major source of water in the region [13].

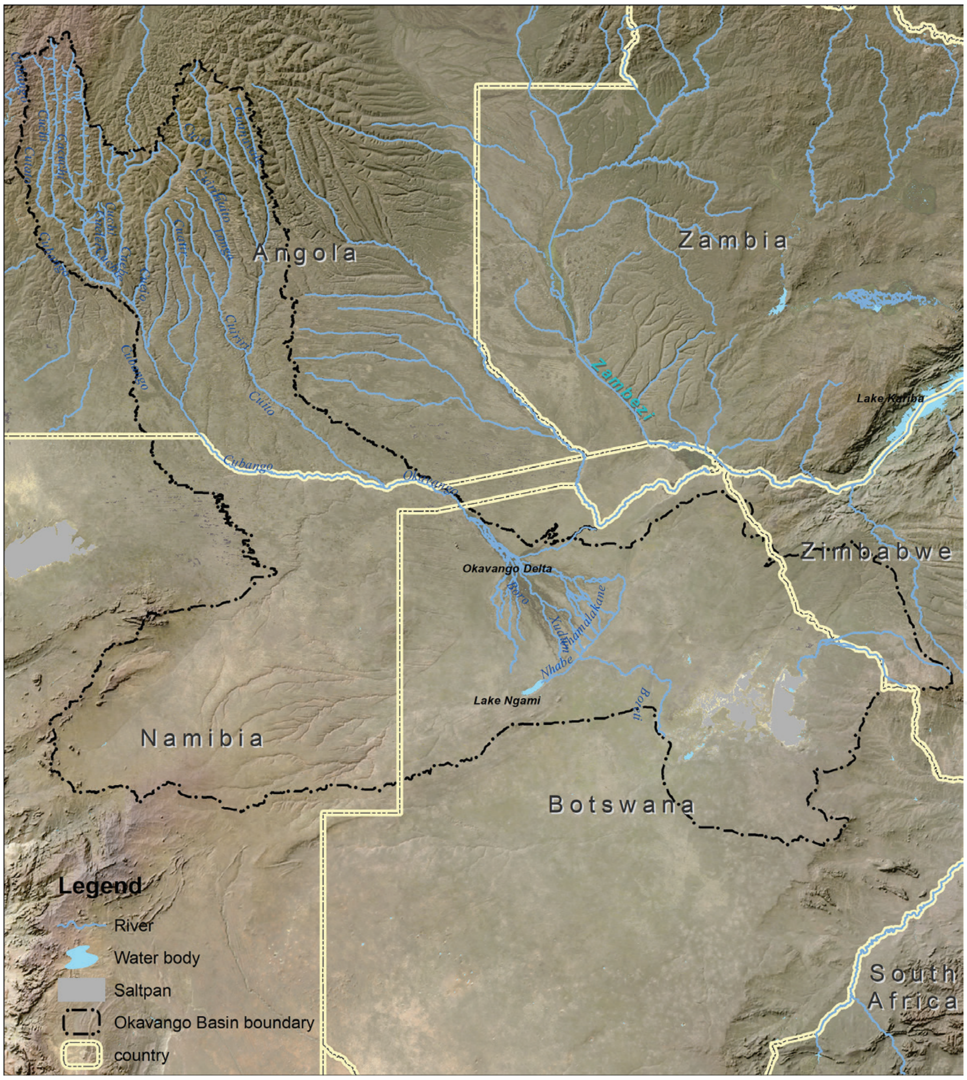

Figure 1. The Okavango River Basin (ORB).

Total annual water inflow in the ORB, characterised by an annual flood pulse, is approximately 10,900 Mm^3 [18], while that of the lower basin is 9600 Mm^3 [10, 18, 19] and drought flow is 3120 Mm^3 [18]. Peak flow of this flood pulse from the Bie Plateau in Angola reaches the delta in Botswana between February and April [19, 20], which coincides with the end of the rainy season in Botswana [20]. All the water flow in the system is generated upstream of the confluences of the Cubango and Cuatir Rivers in the west and the Cuito and Longa Rivers in the east [10], with a combined area of 38,700 km^2, contributed 5185 Mm^3/annum of water into the system, which is 48% of the total water volume in the ORB [10]. In fact, the Cuito River is the most important for downstream flows into Namibia and Botswana [18], hence any changes to water flow in this river system will have a significant impact on discharge into these two countries. Overall, the Angolan catchment is approximately 13,000 km^2 and contributes about 95% of the water inflow into the system [14]. There is multi-decadal-scale variability in rainfall, temperature and discharge characterised by 30-year non-overlapping periods in the basin [21].

According to Pröpper et al. [22], woodlands on Kalahari sands are the major land cover type in the ORB, followed closely by Miombo forests. Other land cover classes in the ORB are thorn-bush savanna and shrub and grasslands, while wetlands constitute 7.3% of the land cover in the basin. Furthermore, SAREP [23] observed that Miombo woodlands dominate the upper catchment of the basin, which graduates into deciduous woodlands in the middle reaches (Namibia), which then turns into mixed acacia and mophane woodland in the lower reaches (delta). The delta, a key biodiversity hotspot in the basin [20, 24], hosts approximately 1300 plant, 444 bird, 122 mammal, 64 reptile, 33 amphibian and 71 fish species [19].

The ORB is one of the least developed basins in Africa [4, 10, 13] and supports predominately rural communities [10] with a relatively low population density [4]. It is relatively pristine, possibly due to a strong conservation ethic in Botswana, which is focused on tourism, poor agricultural soils and a civil war that ravaged the catchment area (Angola) from 1970 until 2000 [10, 12]. However, the end of the civil war has resulted in a rapid population build up in the catchment [12], which might result in development pressures on the basin in the future. Poverty rates among communities living within the ORB are much higher than the national average among the three countries [5]. Generally, poor people depend more on natural resources as social safety nets than communities in urban areas, which can invariably lead to environmental degradation [15].

3. Theoretical framework

This study used primary and secondary data, which was then integrated with literature review to produce a state-of-the-art analysis of water sustainability in the Okavango River Basin. The transboundary water assessment programme [25] framework was used in this study to assess water sustainability in the ORB. There are five core elements of the framework, which include water quantity, water quality, ecosystems, governance and socio-economics. These core elements have 15 indicators associated with them as summarised in **Table 1**. We added a 16th indicator, which reflects the importance of climate change as a major factor that needs to be incorporated into water resources management.

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3.1. Water quantity

The global population is growing steadily, and this will result in a corresponding increase in water demand for food production, especially from wetlands [26]. Invariably, this may result in water scarcity, which is defined by Matlock [27] as a function of available water resources for the human population, where the *Falkenmark* indicator is a widely used indicator of water stress. The different *Falkenmark* categories are shown in **Table 2** and range from no stress to absolute scarcity.

African growth is expected to be driven largely by primary and secondary (economic) sectors, which are heavily reliant on water, with irrigation as a key food production activity [6]. However, agricultural water demand (agricultural water stress) in the basin includes livestock water and irrigation [5]. Indicators of agriculture-induced water stress in some global basins include "closed basins, reduction of groundwater resources, loss of wetlands and habitat fragmentation" [26]. Therefore, there is a need to ensure that agricultural water demands are balanced against ecosystem water needs, which are often defined as environmental flows. According to Forslund et al. [28], these refer to the quantity, quality and timing of flows that are needed to sustain ecosystems. These flows are partitioned between ecosystem needs and other key users such as agriculture, power generation, domestic use and industry [29].

Core element	Indicator
Water quantity	1. Environmental water stress
	2. Human water stress
	3. Agriculture water stress
Water quality	4. Nutrient pollution
	5. Wastewater pollution
Ecosystems	6. Wetland dis-connectivity
	7. Ecosystem impacts from dams
	8. Threats to fish
	9. Extinction risk
Governance	10. Legal framework
	11. Hydro-political tension
	12. Enabling environment
Socio-economics	13. Economic dependence on water resources
	14. Societal wellbeing
	15. Exposure to floods and droughts
Cross-cutting	16. Exposure to climate change

This is adapted from UNEP-DHI and UNEP [25].

Table 1. Summary of the five core elements and associated indicators of the transboundary waters assessment programme (TWAP) that underpins the theoretical framework for this study.

Index (m^3 per capita)	Category
>1700	No stress
1000–1700	Stress
500–1000	Scarcity
<500	Absolute scarcity

Table 2. Summary of *Falkenmark* categories used in the assessment of water scarcity in the ORB.

3.2. Water quality

River catchment degradation is a key issue of concern in contemporary river basin management in tropical systems. This degradation is driven by increasing population pressures, which place a heavy burden on natural resources [30]. Therefore, water quality management in river systems is critical towards controlling river pollution in which land use is a critical component of water quality in river basins [31]. The key land-use types that affect water quality in river basins are urban and agricultural activities, whose key indicators are elevated concentrations of bacteria, pesticides and nutrients [32]. Failure by governments to preserve water quality of surface waters, especially in river basins, may enhance fragility of communities [33].

3.3. Ecosystems

Wetlands are a key source of goods and services but are threatened by unsustainable use, both within wetlands and also in the upstream catchments [34]. They are biodiversity hotspots and foci of high biological production at the water-land interface [35] and are critical for biodiversity conservation [36]. Some key wetlands' resources include freshwater for human livelihoods, fish and flood protection [37]. Wetlands play an important role in river basins, while human activity within those river basins can have a negative impact on wetlands [36] usually driven by population growth [38], land-use change and climate change [10]. Because wetlands provide benefits to basins [39], there is a need to integrate their management into basin management [36] to ensure that this beneficial relationship is sustained.

3.4. Governance

Proportionally, water crisis is the top most important issue among the top five (i.e., water crises, failure of climate change mitigation and adaptation, extreme weather events, food crises and profound social instability) global risks of the highest concern for the next 10 years [33]. Therefore, governance of water resources, especially in river basins, is critical towards achieving water security. Governance considers multi-level participation beyond the state and includes the private sector, civil society and society in general [40]. Orme et al. [41] propose the Good Transboundary Water Governance Matrix (**Figure 2**) as a key tool in water governance of shared water courses. This matrix incorporates the sustainable development goals (SDGs) and is also based on the United Nations Watercourses Convention [41]. According to Sadoff et al. [33], the fragility of basin communities can be heightened by failure of governments to preserve transboundary water resources, usually underpinned by weak institutions. Therefore, good water governance should include shared water courses [6], which will ameliorate any hydro-political tensions among basin states.

Sustainable transboundary water management is anchored upon substantive and procedural criteria ([41], Figure 2). The substantive criteria are circumscribed by three legal obligations. The "equitable and reasonable utilisation" criterion is the cornerstone of international water law and is the anchor for transboundary water governance, while the "duty not to cause significant harm" criterion refers to limiting pollution or over-exploitation, which might have a negative impact on the environment. The "protection and conservation of ecosystems" criterion is self-explanatory. The procedural criteria are anchored on four key obligations. The "notification and information exchange" criterion is implemented when parties notify others of planned developments that might negatively affect other users. The "environmental impact" criterion refers to a process of making informed developmental decisions based on a thorough analysis of anticipated environmental impacts. This criterion also provides a platform for community participation, which is also explicitly stated in the "public participation" criterion, and refers to the obligation to consult the public. When the "access to justice" criterion is upheld, then "information exchange and public participation rely on enforcement and review mechanisms to ensure efficacy and equity" [41]. Furthermore, this framework can create an enabling legislative environment that can reduce/minimise hydro-political tensions between the basin states, through by creating an enabling environment.

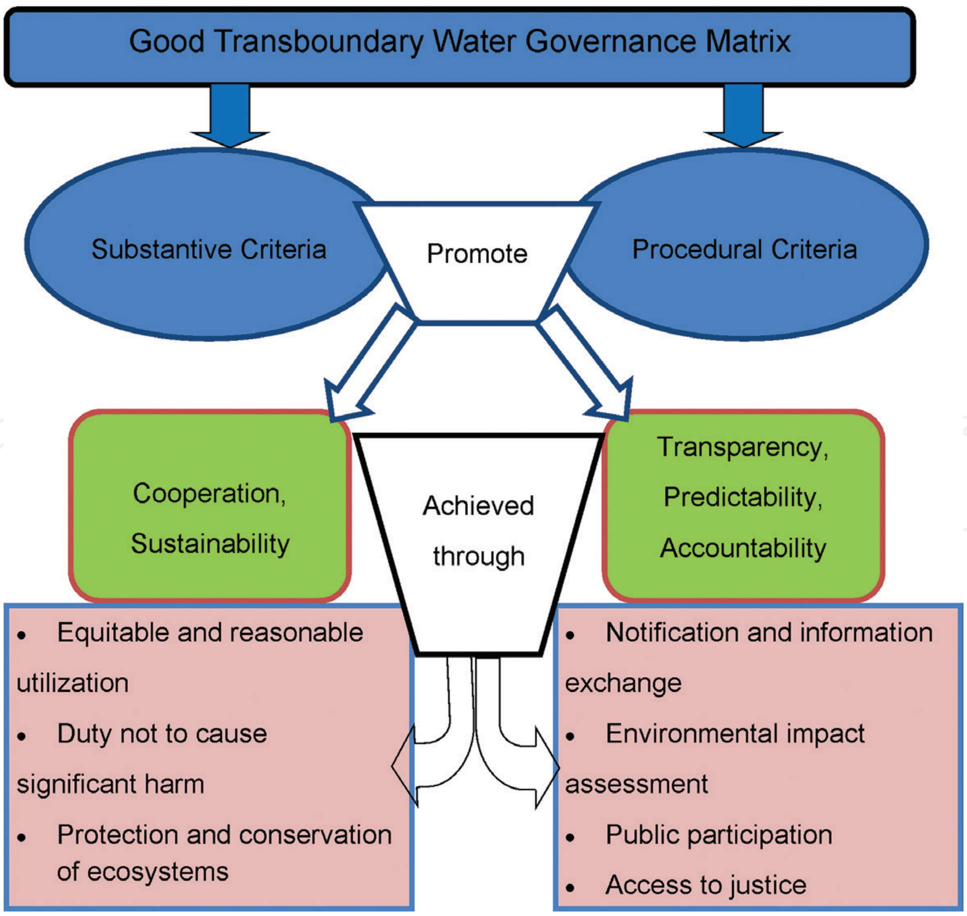

Figure 2. The Good Transboundary Water Governance Matrix reproduced from Orme et al. [41].

3.5. Socio-economics

The livelihoods of the majority of rural African populations are intertwined with water [6]. This is because water is the basic foundation of human livelihoods [26], and water scarcity can have a profoundly negative impact on economic growth [42]. According to UNEP-DHI and UNEP [43], the key components of the coupled human-environment system used in the assessment of river basins are "economic dependence on water resources, societal wellbeing and exposure to climate-related natural hazards". This suggests, therefore, that the observation of water being not only a key resource but also a limited resource in the ORB [9] makes it vulnerable to future population growth in the basin.

3.6. Economic analysis

Water resources management initiatives at macro and micro levels are faced with positive transaction costs [44, 45]. The economic considerations of allocation, efficiency, equity, production and pollution have significant influence on water-related decision-making, water resources management and water policy formulation. However, because it assumes a world of zero transaction cost, neoclassical economics "is incapable of handling many of the problems to which it purports to give answers" [46]. There is, therefore, a need to develop, define and apply economic analyses that not only factor in the positive transaction costs involved in water resources management but also serve as a guiding tool for sustainable water resources management. Subsequent to the 1992 Dublin Conference on Water and Environment, water has widely been accepted as an economic good [47]. Regarding water as an economic good is vital for shifting the behaviour of water users towards efficiency [48]. It is also important for creating a basis for cost recovery related to water access, use and management [48, 49]. However, in defining water as an economic good, there is a need to appreciate the role of water as an environmental, ecological, social, financial and economic resource. A combination of these uses and the multi-sectoral use of water resources have stimulated the consideration that water is complex or "at least very special" [50] compared to other economic goods.

3.7. GIS and remote sensing

To calculate water volume in the basin, the digital elevation model was downloaded from the Japan Aerospace Exploration Agency (Earth Observation Research Centre); http://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/html_v1804/s040e000_s010e030.htm. This dataset has a resolution of approximately 30-meter mesh (1 × 1 arc second). Tiles were downloaded and mosaicked to the study extent (i.e., Botswana, Namibia and Angola). A clipping tool from ArcGIS desktop was used to clip each country to allow easy calculations for the water volume. The surface area tool within the ArcGIS 3D Analyst extension was used to calculate the area and volume of the region, the water surface and the terrain. In order to establish a reference height of the water along the channels of the Okavango Basin, shapefile data for maximum extent of open water for 1984–2015 by Pekel et al. [51] were downloaded, mosaicked, clipped to the basin extent and then converted to a polygon in ArcGIS for desktop. The water extent polygons were then used to extract height values from the digital elevation model. Whereas the original basin DEM had elevations ranging from 695 to 2278 m, the extracted water extent raster showed that the maximum water level reached in the 30-year period used by Pekel et al.

[51] was 1822 m. The mean area of water reached was 7×10^5 km^2, and mean volume reached was 6×10^8 Mm^3. All required datasets were converted into Universal Transverse Mercator projection before calculations were done [52].

Population projection data were taken from OKACOM [10], a shapefile was created and a heat map was created in ArcGIS Pro 2.0 [53] for data visualisation to show density points as a continuous colour gradient.

4. Results and discussion

4.1. Water quantity

Water availability in the ORB is driven by a 30-year multi-decadal variability [5] driven primarily by natural variability [12]. The effect of this variability is more pronounced downstream [5]. This variability translates into years of high floods and years of low floods in the Okavango Delta [5]. Lake level variability in Lake Ngami (in the Okavango Delta) is a good illustration of this multi-decadal variability, where the lake has been more dry than wet between 1880 and 1993 [54, 55]. Therefore, any water developments in the Okavango Delta should account for this multi-decadal variability in water availability.

Arntzen and Setlhogile [18] estimated water abstraction in the ORB at 100 Mm^3, which is less than 1% of the mean annual run-off (MAR). This estimate compares well with FAO [5], who estimated water abstraction in the basin at 90 Mm^3, while water use was estimated at 133 Mm^3. The ORB is a major source of water among the three basin states, and the growing socio-economic needs of an increasing population "are likely to result in greater development of the basin's water resources" [13]. OKACOM [10] revealed that 3428 Ha of land were under irrigation in the basin, while an estimated 490,000 Ha are planned for in Angola, at an estimated water demand of 6400 Mm^3 under future development scenarios. Livestock population in the ORB was estimated at over 1.4 million livestock (i.e., cattle, goats, sheep, etc.), where 67% were in Botswana, of which 65% were cattle [10]. Therefore, the water resource of the ORB is currently underutilised, and water use can be expanded within the limits of the available development space [18]. The two major drivers of water demand in the basin are domestic, industrial and agricultural [16]. Overall, water demand in the ORB is expected to increase gradually to 1857.8 Mm^3 in 2020 to 3871 Mm^3 in 2025, driven mainly by irrigation agriculture [10]. This demand is expected to increase in Angola and Namibia due to water shortages and increased agricultural demand [14].

Water stress is "the ability, or lack thereof, to meet human and ecological demand for water" [56]. According to Gassert [57], the Okavango Basin users have low overall Baseline Water Stress Average Scores of 0.6 [0–5 low–high]. This indicator measures the ratio of total water annual withdrawals to the total available renewable supply, considering upstream uses and depletion of water, and therefore measures the underlying factors that drive water quantity-related risks across basins and countries. Although the overall Okavango Basin's risk scores are much better than the Limpopo and Orange River Basins at 2.7 and 1.9, respectively, all three basins score similarly for interannual variability and flood occurrence. The low basin risk scores are consistent with the *Falkenmark* index (**Table 3**), which suggests that there is

Country	Index (×10[8])	Category
Angola	83.6	No stress
Botswana	3.4	No stress
Namibia	6.2	No stress
Overall basin	1.8	No stress

Table 3. Summary of the *Falkenmark* index for the ORB states.

no water stress in the basin. Munia et al. [2] also observed that there is no water stress in the ORB either to local or to upstream water uses. This is also in agreement with UNEP-DHI and UNEP [43] global transboundary assessment, which revealed that the ORB has a "very low risk" of transboundary human water stress. Global assessment projections to 2030 indicate no significant changes in human water stress in the basin [43].

An average of 23% of the total discharge in the ORB is needed by the environment to keep it in fair condition [29]. Therefore, this suggests that 2507 Mm^3 of discharge from a total discharge of 10,900 Mm^3 in the basin is needed for ecosystem functioning. Using the mean volume of water available in the basin over a 30-year period (1984–2015) suggests that environmental water needs for the ORB are approximately 1×10^8 Mm^3. Taking into account water withdrawals, it follows that only about 24% of the discharge (or mean volume) in the ORB is utilised for both human use and ecosystem needs. About 76% of the water remains unutilised. Therefore, there is a room for water use expansion in the basin without any concerns of environmental water stress.

4.2. Water quality

Global studies emphasise the need to protect quality of freshwater rivers because they are few, and water demands are exacerbated by the global stressors such as climate change, population growth, industrialisation, economic growth and land-use activities [58]. For some river basins, deteriorating water quality might be as a result of lack of monitoring protocols aimed at protecting the integrity of the wetland in early stages of planning [36]. Therefore, it is critical to continuously monitor water quality in river ecosystems for sustainability of the wetland. The Okavango River water quality is relatively pristine [10, 22], which makes sense given the low human development impact in the basin. The basin's wetland vegetation is partially responsible for the waters' purity, while the substrate of the Kalahari sand also contributes significantly to water quality [10, 17]. Furthermore, wetlands are capable of removing nutrients from surface water resulting in freshwater [59].

Improved surface water quality status of the Okavango Delta is as a result of evapotranspiration and chemical precipitation [60]. Land-use activities such as mining, agriculture, industrialisation and settlements affect the quality of water [61], although slight effects were observed in Maun for pH, total nitrogen and dissolved oxygen [62]. Agricultural activities in the basin result in low nutrient enrichment because of minimal use of fertilisers, herbicides and pesticides. Generally, water quality studies show that waters are aerated and are within the Environmental Protection Agency (EPA) standards [62, 63]. However, there were times when dissolved oxygen (DO) ranged below the minimum of 2.4 mg/L DO as a result of decomposition from organic matter loadings, which resulted in annual fish kills at some parts of the delta [24]. pH levels in the delta are mostly within acceptable guidelines for aquatic life set by EPA and World Health Organisation (WHO), respectively (6.5–9.5 and 6.5–8.5). Few studies looked into major and trace elements and were generally within acceptable limits [63], except for beryllium and aluminium, which exceeded the Botswana Bureau of Standards (BOBS) for drinking water [64]. Although locally the effects of pollution are felt as a result of global stressors, these effects are negligible on the entire delta. Capitalising in good water quality and improved sanitation results in improved human health and economic productivity [65]. Generally, there is localised water pollution around human settlements in the basin [10].

4.3. Ecosystem dynamics

The ORB is internationally important due to its biodiversity and biological productivity [10]. It also contains the Okavango Delta, which is the world largest Ramsar site [4, 13], the world's second largest inland wetland [4] and a key World Heritage Site [66], with a high beta diversity [4]. Due to a low population density, OKACOM [10] revealed that about 90–95% of the basin's natural habitat remained intact. Pröpper et al. [22] also observed that the ORB remains in a "near natural state" due to low development in the basin, where 90% the basin is still covered by natural vegetation. Therefore, ecosystem integrity has remained largely intact because it has remained unaffected by human development due to its remoteness [15]. Therefore, there is high ecosystem connectivity in the ORB, which is a core indicator on transboundary river assessments as described by UNEP-HDI and UNEP [43].

While the ORB is a key source of various natural resources (e.g., firewood, reeds and fruits) for riparian communities, fish is a key source of livelihoods for the basin's communities [17]. According to Ramberg et al. [19], there are approximately 86 fish species in the basin. Fishing is practised on a small-scale commercial in Botswana [15, 67], while it is predominantly artisanal employing crude fishing gear in the rest of the basin [10, 15, 22, 23, 68]. Several studies in the Okavango Delta have shown that the delta's fish stocks are not yet over-exploited [69], where fishing behaviour [70] and fish community dynamics [71, 72] are driven primarily by seasonal flooding. A biodiversity survey in 2012 [23] revealed five previously undescribed fish species in the upper catchment of the ORB, while an earlier survey in 2003 [73] discovered an undescribed fish species in the delta. While earlier studies [19] estimated that there were 86 fish species in the ORB, these recent studies suggest that there are currently about 92 fish species in the system. These observations attest to the pristine status of the Okavango River system as observed by Todd et al. [4].

Despite its pristine status, 330 macro-invertebrate species are either vulnerable or near threatened, 10 fish species are red listed, 3 wetland bird species are considered vulnerable, while another 3 wetland bird species are near threatened in the basin. The common hippopotamus and the African elephant are also considered to be globally vulnerable, but not in the ORB [10] and certainly not in the delta, which have high elephant populations [10, 19]. In fact, the delta was found to be the most productive among several global wetlands due to the seasonal flood pulse [74]. Aquaculture is still at infantile stages in the basin, with small-scale operations in Angola and Namibia [10]. However, it is possible that some entrepreneurs in the upper catchment might decide to farm Nile tilapia, which is fast growing and reaches big sizes, ostensibly to generate higher economic returns. This will have a negative impact on the ORB's ecosystem functioning.

4.4. Governance

Globally, about 145 states share an estimated 286 rivers and lakes and around 200 aquifers [75]. Transboundary freshwater resources are prone to international conflict, especially if not managed properly [76]. These conflicts include economically and verbally hostile actions, which are capable of raising tensions mainly when upstream and downstream interests clash [77]. The institutionalisation of transboundary water management principles can be traced to the Helsinki Rules on the Uses of International Rivers, which are a nonbinding code of conduct for states to follow [78]. They are credited with making the first effort at counter-hegemonic strategies by introducing equity criteria for shared use of international rivers [79]. This then formed the basic foundation for the SADC Protocol [80], which led to the establishment of OKACOM [81]. This agreement replaced the bilateral agreements that existed between the parties [82].

Therefore, OKACOM became a key institution in the basin critical towards management of conflicting interests over common water resources. It sets out rules of the game and mechanisms for the resolutions of potential conflicts. It addresses various issues related to sustainable development, especially on water security and sustainability. In terms of Article 1.4 of the OKACOM Agreement, the commission is an organ responsible for advising the contracting states on the criteria to be adopted for the equitable allocation and sustainable utilisation of water resources in the ORB. Therefore, the commission is obliged to apply principles of "equitable allocation and sustainable utilisation" or the Helsinki Rules [82]. There are, however, several transboundary challenges that OKACOM is faced with. These include lack of harmonisation of water quality standards; insufficient basin-wide cooperation, especially at the local level; and lack of a harmonised land-use planning framework among the basin states, which would facilitate integrated basin planning [10].

Therefore, OKACOM faces both political and structural challenges, which will affect its effectiveness and its ability to ensure that there is sustainable utilisation of the ORB water resources. This will imperil the future of water sustainability in the basin. Pröpper et al. [22] argue that OKACOM is weak and poorly funded, which perhaps attests to lack of political will among the basin states to ensure sustainability of this institution. It is perhaps due to this lack of political will that Pröpper et al. [22] observed that OKACOM recommendations are generally ignored in national decision making among the basin states. Moreover, this lack of effectiveness by OKACOM, underpinned by poor political will, makes the legislative environment unaccommodating to coherent and coordinated policies in the ORB. This observation conforms to Malzbender et al.'s [83] conclusion that there is insufficient integration of environmental policies in the ORB. Generally, this suggests that OKACOM is not fulfilling its mandate as a transboundary river basin management entity. Issues of water sustainability in the future are then potentially imperilled unless the basin states recognise OKACOM's relevance to water resources management in the basin.

4.5. Social systems

The total population in the ORB is approximately 900,000 over 195,000 households and a mean household size of 5. Angola has the smallest household size at 4, while Namibia has the largest household size at 6, and all these depend on the basin for their key livelihood activities [10]. Major livelihood activities in the ORB include subsistence agriculture, harvesting of natural resources, tourism and fishing [10, 15]. The predominant land use in the basin is subsistence agriculture characterised by arable agriculture and pastoral farming, where the largest livestock herds are found in Botswana and Namibia [10]. Flood recession agriculture is common in Botswana and Angola and is relatively more productive than dryland farming [9]. OKACOM [10] further posits that each country has invested in irrigated agriculture, where Namibia has the largest investment in irrigated land, while Angola has planned large future-scale irrigation schemes. Conversely, Botswana has limited irrigation schemes. Harvesting of natural resources includes fisheries, firewood, reeds and grasses, fruits wild foods and medicinal plants. Tourism, whose products are attributable to the wetland, is predominantly non-consumptive and of high value to Namibia and Botswana economies [15]. Aquaculture is yet to reach full potential in all the basin countries [84]. The ORB also contributes to livelihoods through provisioning services [10].

It is evident that most of the basin's communities derive direct use of the basin's resources [15] and that the ORB has a significant contribution to national economies [10]. Anticipated climate change impacts, which include changes in precipitation and temperature, will affect the basin's ecosystem and run-off, which would in turn disturb the availability, allocation and sharing of the ORB water resources [16, 85, 86]. This will inevitably affect the livelihoods of communities that are dependent on these resources. For example, anticipated changes such as loss of habitat, wildlife disruptions, increased wild fires as well as pests and disease vectors would affect the tourism industry [21]. In terms of agriculture, high temperatures will affect both arable and pastoral agriculture, which would force farmers to change the animal breeds and crop varieties [21]. Climate change effects will accentuate poverty in the basin, which is already widespread, and would subsequently increase the vulnerability of communities to socio-economic shocks. Therefore, there is a need to implement adaptation strategies at basin level in order to enhance community resilience. Inadequate basin-wide climate change adaptation and mitigation strategies are a big challenge, while at the same time, there is insufficient long-term policy formulation with respect to climate change adaptation, a common problem in all basin states [10, 83]. Transboundary water resources like the ORB should be protected from potential impacts, even though it is difficult to assess them due to uncertainty inherent in the General Circulation Models (GCMs). This will also fulfil the SDGs, particularly Goal 1 on "no poverty" and Goal 13 on "climate action".

4.6. Water economics and management in the ORB

Factors such as emerging diverse demands for water resources, increasing population, increased urbanisation and rapid evolution of environmental and climatic problems pose future threats to the ORB. It has been projected that the current basin population will increase to about 1.3 million by 2025 [10]. This increase in population will add pressure to the natural water resources. The scarcity of and pressures on water resources in the basin will make the lower basin sharing states vulnerable. This creates interdependencies, which are often perceived as threats [77]. Within the basin, the nation states are faced with attaining a balance between ecosystem function and sustainable resource use by communities dependent on the water resources.

Various modelling techniques for balancing human and ecological water resource needs have been developed [87, 88]. These techniques range from quantifying ecosystem services spatially, to tracing, quantifying and analysing the trade-offs between the ecosystem services. Theoretically, these techniques are needed to inform policy decisions for effective, efficient and secure water resources use and management. Hence, FAO [5] conducted a water audit for the ORB, while Arntzen and Sethogile [18] conducted a water allocation study for the basin, where the goal was to find the balance between human water requirements and ecosystem water needs.

According to FAO [5], a valuation of the Okavango Delta revealed that tourism has the highest direct use value in the delta, the highest contribution to the gross national production and the largest contributor to natural resource rent. Carbon sequestration and wildlife refuge were the largest contributor to indirect use value of the delta [5]. Furthermore, valuation results show that agriculture was less valuable than ecological services in the delta. Annually, the basin's natural resources contribute approximately US$60 million to household income, over US$100 million to the national economy in the form of gross national income and just over US$234 million to the "broad economy in the form of gross national income, including the effect of the national income multiplier" [15]. The largest contributor of this value is tourism activities [5]. However, these economic benefits will reduce basin household income by 50% to approximately US$30 at a low development scenario, to US$10 million household income under a high development scenario [10]. These development scenarios are based on water use in the basin and would mostly involve dams in the upper catchment, which would reduce tourism activities in the lower basin.

One major challenge regarding economic value and benefit in the basin is that Angola is the largest contributor to discharge in the basin but benefits the least, while Botswana contributes the least discharge and derives the largest economic gain [10, 18]. This dichotomy in benefits sharing among basin states is a major transboundary management challenge. Another key challenge in the basin is that while non-consumptive tourism is the most valuable economic activity, agriculture is the biggest source of livelihoods for the majority of households in the basin [5, 18]. This makes water allocation in the basin a challenge. However, the absence of water stress in the basin makes the development space large enough for these activities to occur concurrently. There is a need, however, to intensify data collection in Angola and to enhance management of the water resources of the ORB. This will also provide enough data for development of econometric models as a part of a suite of economic-based models to aid in decision making of water allocation in the basin.

4.7. Climate change

Generally, the ORB is characterised by high inter-annual and multi-annual variability, which makes it resilient to climate variability [13]. GCM's predict increased temperature and decreased rainfall across the ORB with a consequent drop in dry and wet season flows by

49–54% in 2050 and by 68–73% in 2080 [16]. However, Folwell and Farqhuarson [16] conclude that human abstractions will have a minimal impact on both dry and wet season flows. This agrees with OKACOM [10] that water for human abstraction will have a minimal impact on water flows in the system based on future development scenarios.

Generally, climate models consistently project an increase in temperatures over the ORB. The greatest increases in temperatures are associated with high emission scenarios used to force

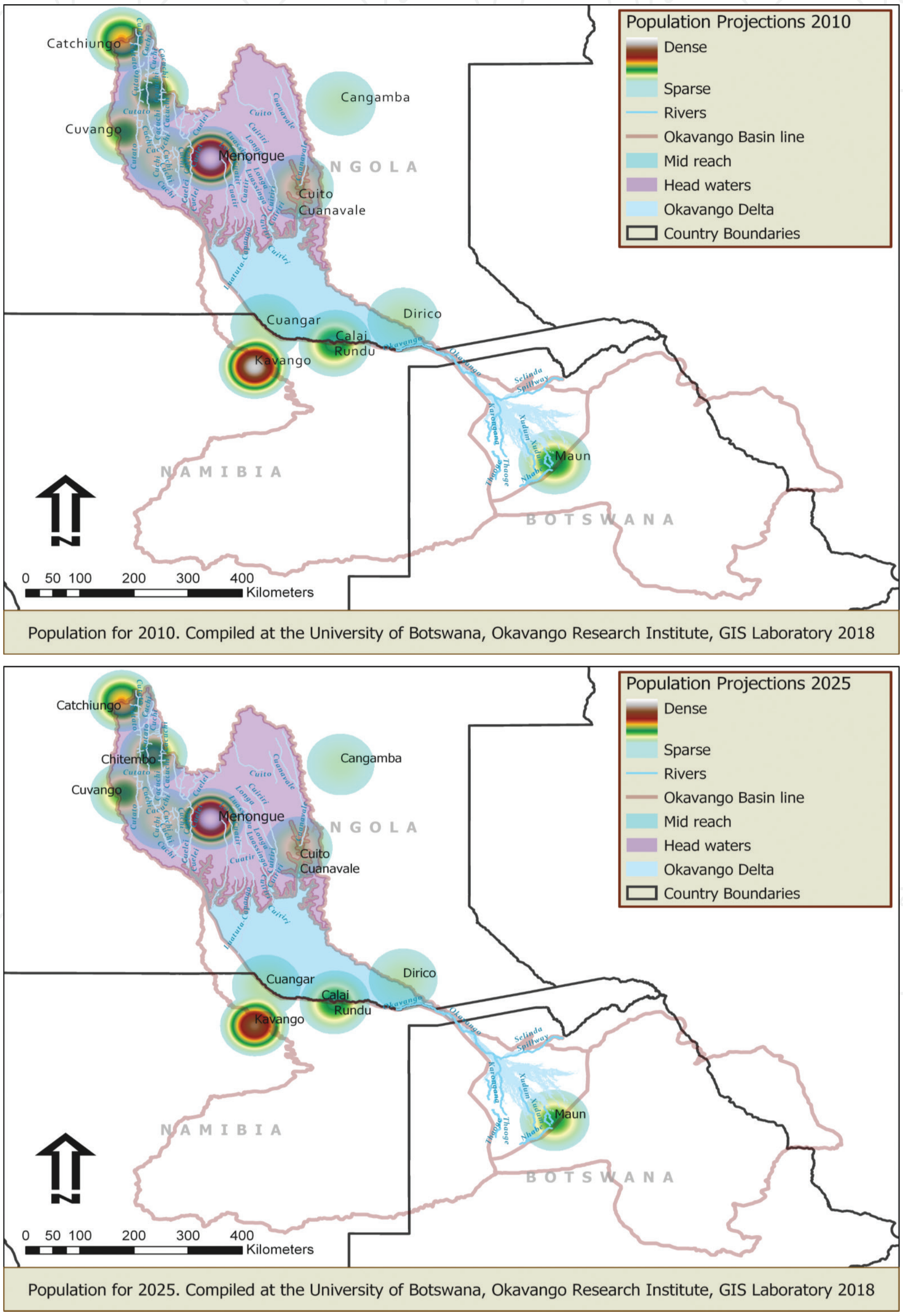

Figure 3. Population growth in key settlements of the ORB.

the models, while the lowest increases are associated with low emission scenarios. For rainfall, the models are inconsistent in projecting the direction of the change (some project wetter, while some project drier future conditions). These predict a negative rainfall change in the future, but the inconsistency in direction of change reduces confidence on the impact of climate change on the ORB. There may also be an increase in heat waves, prolonged dry spells, thunderstorms, localised flooding and damaging winds, which is consistent with other studies (e.g. [86, 89, 90]). The uncertainty in these models makes it difficult to assess the direction of impact, although there is general agreement that the upper basin will receive more rainfall, while the lower basin will receive less rainfall and will experience increased temperatures [18].

4.8. Population growth

Figure 3 shows that there is a relatively higher population density at Menongue and Kavango in 2010 than at Cangamba and Dirico. Population projections for 2025 (**Figure 3**) show that there will not be a major change in population density in the other basin's urban areas, while there will be a negligible increase in population density in Maun. However, this observation is inconsistent with OKACOM [10], which shows that Angola has the highest population growth rate (2.7%) compared to Botswana (0.9%) and Namibia (1%). Furthermore, Angola has the highest fertility rate among the basin states [10]. However, Botswana has the lowest death rate and infant mortality rate among the basin states [10], which may account for an overall negligible increase in Maun population compared to the other urban areas in Angola and Namibia.

5. Synthesis and conclusion

The livelihoods of most of sub-Saharan Africa's rural poor are closely intertwined with water [6], which make water security and water-related issues the most pressing global concerns in the next 10 years [33]. Subsequently, water sustainability becomes a core issue of concern in river basins of developing countries, where future population pressures will conceivably increase water stress in these systems. Lack of preparation to this reality and poor water resources management within this context will invariably lead to fragility, which might trigger simmering tensions among and between the communities [33]. Moreover, comprehensive water resources management is critical towards achieving water security in developing countries. According to Sadoff et al. [33], failure to achieve water security usually occurs through failure by governments to (i) provide its citizens with basic water services, (ii) provide citizens from water-related disasters and (iii) preserve surface, ground and transboundary water resources. Population-driven development pressures will become more of a concern in Angola than downstream states.

Due to low development in the ORB, most of the water needs in the basin is used for ecosystem purposes [91]. Hence, currently, there is no competition for water between human needs and ecosystem requirements. Therefore, this suggests that current consumptive water needs in the system, compared to environmental needs, provide baseline conditions upon which future needs can be assessed against. Clearly, there is a need to conserve the catchment of the Cubango and Cuatir Rivers in the west and the Cuito and Longa Rivers in the east of the

ORB and to ensure that water sustainability is achieved in the basin. Upstream developments, especially dams in these areas, will affect not only water flow dynamics in the entire basin but also sedimentation in the system. However, development pressures in Angola, where 62% of the population is expected to reside by 2025, are realities that need to be addressed within a configured OKACOM. Pröpper et al. [22] argue that multiple uses of ecosystem services in the ORB (e.g., agriculture, fish, water supply, etc.) will possibly result in over-utilisation and commodification with unknown consequences on the ecosystem. Invariably, this may affect water sustainability in the basin.

Yang's et al. [92] six major water management strategies for the Texas State Water Plan can also be applied to the ORB to enhance water resources management in the basin and hence increase water sustainability. These include "water conservation, surface water development, groundwater development, re-use, desalination and conjunctive use" [92]. Similar to the Texas situation, it is envisaged that implementing some of these management strategies in the river basin will in the long term alleviate pressure on surface water resources, especially for uses other than ecosystem needs. Ultimately, this will release more water for ecosystem functioning. Some of these strategies, especially re-use and water conservation, can be codified into law to ensure that they become part of water governance in the ORB. Moreover, OKACOM should be the key driver of this envisaged policy formulation among the basin states. There is no harmonised policy framework in the ORB that deals with water legislation among the basin states [83].This is a major weakness of the OKACOM policy framework because this suggests that there is potentially lack of coordination in water resources management among the basin states, which might result in unsustainable water use.

The water allocation problem for ecosystem needs on one hand and for human livelihoods on the other hand will increasingly become more of a political issue than an economic activity in future [3]. This observation is premised on the fact that increasing population size in the ORB will undoubtedly place more pressure on water resources in the basin, and basin states will increasingly be faced with the political pressures of providing services to their populations, at the expense of ecosystem needs. Currently, however, Pröpper et al. [22] observe that economic pressures among the ORB states are currently the key drivers of water resources management policies. Nonetheless, the basic question then remains, how do we achieve water sustainability in the ORB as we move into the future? Currently, OKACOM is ill equipped to deal with these political questions that underpin water use and allocation in the basin, in the face of the inevitable increasing population pressures. What implementable and practical measures have been implemented in the basin states to deal with these future threats?

Water is the basic foundation of the SDGs and is hence the key determinant of their successes [42]. There is a need to ensure that the water resources of the ORB are used sustainably, through finding a balance between ecosystem needs and human livelihoods. This will ensure that the basin states achieve the SDGs. Future major potential threats on the basin's water resources are issues related to water quality and habitat fragmentation caused by dam construction in the upper catchment. While these future development scenarios will cause an overall reduction in ORB household income, this will be related primarily to loss of tourism activities in the delta. Therefore, OKACOM needs to create a decision support system (DSS) to facilitate benefit sharing in the basin. Hopefully, this will assist the basin states to find the balance between ecosystem dynamics and human livelihoods, which will reduce or eliminate competition for water requirements. This will contribute to water sustainability in the ORB.

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