Ephemeral river systems and their ecosystem provisions to the local populations: A review of the Huab and Ugab Rivers, Namibia.

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ABSTRACT

Ephemeral rivers have been the source of domestic and livestock water for millennia in Africa. In Namibia, crystalline and alluvial groundwater aquifers in ephemeral rivers are the only source supporting livelihoods. The aim of this paper is to review the existing literature on these two ephemeral river systems, with a specific objective to investigate the knowledge gaps in these arid areas of the Huab and Ugab ephemeral systems. These rivers lie in proximity of the marginal populations and support a great number of livelihoods, and economic activities. The aridity dynamics are fundamental factors that influence ecological aspects of the ephemeral rivers that support at least one- fifth of the Namibian population. The rivers only flow for a period of two weeks per year, and in wet years, some may flow for three weeks. The rivers have a highly evolved ecological system that is sustained by the high hydrologic variation which is the main ecological driver. These ephemeral rivers transport sediment, fine particulate matter, and organic matter in form of tree and woody matter that is generally deposited downstream as a result of hydrologic decay. The study found that knowledge on hydrological and ecological patterns of the Huab and Ugab ephemeral rivers are limited, in spite of their catchments being the main supportive systems to the economically marginal populations. There is also a lack of understanding on how the ecosystem provision influences the livelihoods of the local populations. The study recommends further research on ecological reserves, linking to ecosystem provision of these natural systems (natural future bank of resources).

1 Introduction

Namibia is one of the driest countries in Africa, is bordered by two deserts, the Kalahari on the east and the Namib on the west, and relies heavily on ephemeral river systems for the sustenance of rural and urban centres. Typically of the arid environment, the country is characterised by high rainfall variability and long periods of droughts. The country is also the most arid country south of the Sahara, with only ephemeral rivers in its interior as perennial rivers only occur along the northern and southern borders of the country. Ephemeral rivers that flow to the northern and eastern part of the country, flow largely towards regions with high rainfall, while those that flow southward and westwards, largely traverse the arid and hyper arid regions, with rainfall varying from $0\check{}100mm$ per year (Jacobson et al., 1995). For the western flowing ephemeral rivers in Namibia, the average potential annual evaporation is estimated to be 3000 mm (Stols, 1993), whereas the observed evaporation is estimated to be six times higher than the mean annual rainfall in the inland headwaters and more than 100 times higher in arid areas, leading to saline soils and to the growth of only saline tolerant vegetation around the springs

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(Jacobson et al., 1995; Seely et al., 2003). Water flows sporadically and for short periods following heavy rains, some for hours and others for some days (Seely et al., 2003). According to Jacobson (1997), ephemeral rivers' measurable discharge are less than 10% of the year, but there is also usually a significant volume of water stored beneath the channel (Jacobson et al., 1995). Climate variability is found to be strongly correlated with aridity (Seely et al., 2003) and is a major factor influencing ecological, economic and social sustainability of ephemeral rivers (Molles et al., 1992).

Despite the low annual rainfall amounts, and the high evaporation rates, the limited water resource is able to maintain the natural ecosystems and support livelihoods within their catchments and the surrounding environments. Consequently, the ephemeral rivers are one of the focal points for human settlements and development, supporting at least one-fifth of the Namibian population, as well as commercial activities, small scale subsistence farming, mining activities and wildlife in their catchments (Seely et al., 2003). By design, ephemeral river system catchments are fragile and sensitive to disturbances, as such they can only support a limited number of people. The increase in population or tourism activities is likely to lead to increased water demand, vegetation removal, increased soil compaction, and increased runoff, which in turn reduce infiltration rates. These factors influence the flow regime, physical habitat patterns, and the recharge on the stream beds as well as changes in the amount of nutrient load that is carried. Alterations of such processes therefore, affect the fragile balances and ecological processes (Seely et al., 2003; Jacobson and Jacobson, 2013). Commonly, many studies of ephemeral rivers have largely focused on the fluvial geomorphologic, the hydrologic regimes and how it naturally influences other related aspects such as sediments, fine particulate matter, infiltration and the health of the riparian forests. Similarly, although limited, some aspects have been studied for Ugab and Huab rivers (Jacobson et al., 1995, 1999; Sarma, 2016; Dansie et al., 2018). Our study focuses on the Huab and Ugab catchments, providing an overview and identifying the knowledge gaps.

2 Methodology

2.1 Evaluation of hydrological load and drainages

Much of the hydrogeological and stream gauge data is from the 1970's and 1980's, when most stream gauges were still in good working order. In this review, we have tapped on both historical data and recent data from publications, especially on the Kuiseb, which is better studied. Literature and data on the catchment has also been gathered and combined with historical rainfall data. This assembly of data over a long period of time helps to establish patterns of hydrological variation in these ephemeral river systems. Derivation of catchment characteristics was achieved using the criteria of Alexander (1990); as these control flood hydrology. The catchment characteristics are derived from the thematic maps of Namibia on geomorphology, geology, DEM data and the rainfall data (Mendelsohn et al., 2002) and from the Namibian Meteorological Department, in Windhoek. From these data the mean annual rainfall and the mean catchment slope can be established for each ephemeral river basin. These are presented as figures and maps for clarity.

2.2 Evaluation of ephemeral rivers' ecosystem provision

The ecosystem provisions rendered by each river can never be fully quantified, as they affect different aspects of interrelated facets from riverine ecological life systems, to catchment scale flora and fauna in addition to the support of human populations. Our methodology was to investigate the ecosystem services rendered to human populations, livestock, wildlife and vegetation by these non-perennial river systems.

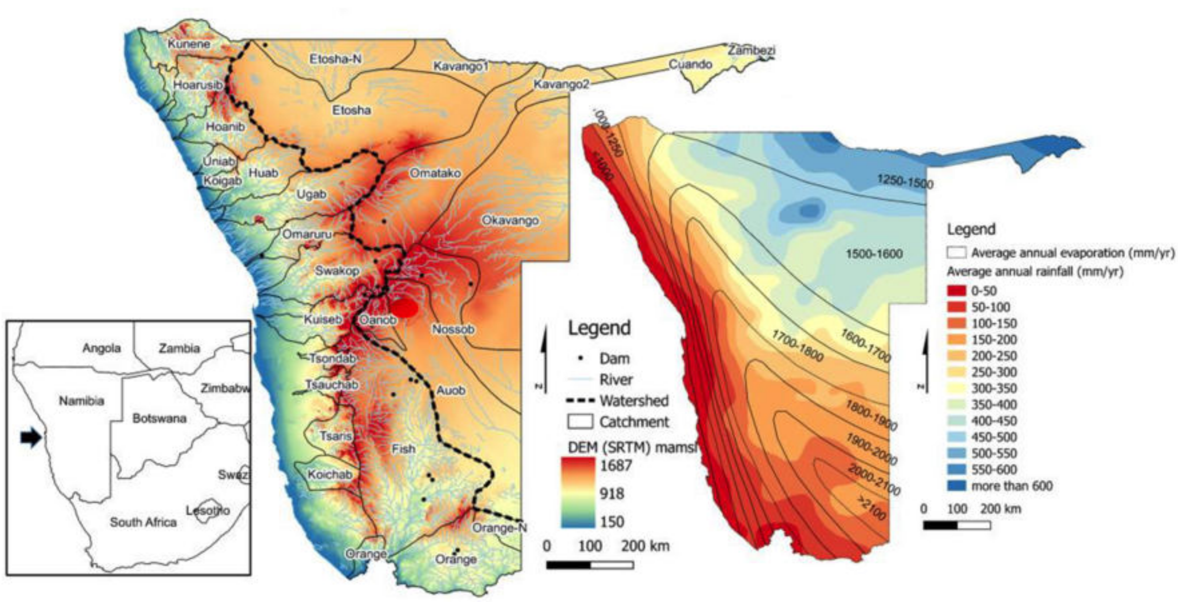
2.3 Evaluation of social-economic issues of the local populations

Climate change impacts on water resources have been inferred to become more pronounced in the near future than previously thought (Intergovermental Panel on Climate Change (IPCC, 2007)). These impacts will have a direct impact on the quantity of water available for domestic and agricultural use as well as induce a systematic decimation of the biophysical environment central to the economic survival of marginal populations living in the semi-arid to arid regions of Namibia. The gathering of social economic indicators from both the Namibia Statistics Agency (NSA) and the Ministry of Agriculture, Water and Land Reform (MAWLR) sheds light on the vulnerability of these marginal populations. This data has been combined together to show how urgent and necessary it is to adapt new management policies so as to sustain populations supported by these ephemeral river systems.

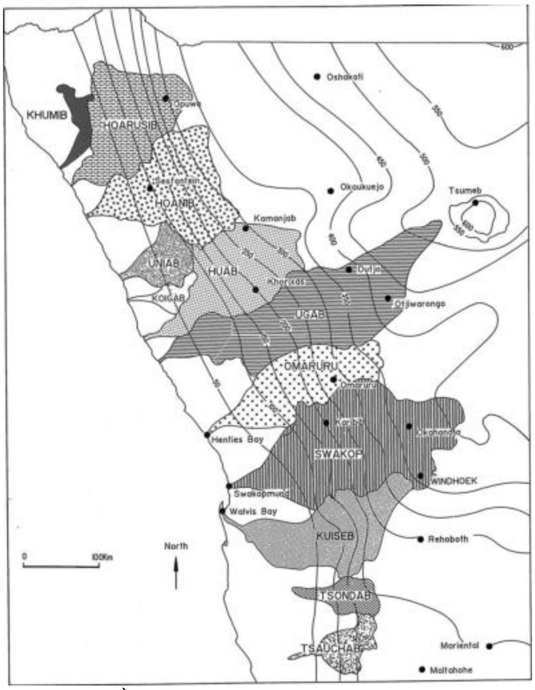
3 Regional settings

3.1 Landscapes and catchments

Namibia consists of twelve (12) ephemeral river basins that flow westward, with ten (10) of them eventually reaching the Atlantic Ocean (Fig. 1a). The annual rainfall decreases progressively westwards towards the Atlantic Ocean (Fig. 1b). The catchment areas range from $2200\,km^2$ to almost $30\,000\,km^2$ (Fig. 1c and d). The Huab and Ugab are among the five biggest west flowing ephemeral rivers in Namibia, and the two are separated by $50\,km$ at their closest point (Ahmed et al., 2009). The ephemeral rivers start in the steep mountains, pass through the valleys of the high escarpment at an elevation of $900-1300\,m$ above the sea level (Fig. 1a), as they flow to the coastal area of the country (Mendelsohn et al., 2002). Ephemeral Rivers are typically identified by the absence of regular flow. The average annual rainfall amount received in the rivers upper stream is $300\,mm$, with an exception of the Ugab River that receives up to $500\,mm$ (Fig. 1b and c). At the mouth of these rivers the annual rainfall amount received decreases to zero and for those that do not reach the ocean (Tsondab and Tsauchab Rivers) up to $100\,mm/a$, while for the other rivers, the amount reduces to $100\,mm/a$ (Mendelsohn et al., 2002; Garzanti et al., 2014);Fig. 1b.



a) b)



c)

Catchment	Area (km^2)
Khumib	2 308
Hoarusib	15 240
Hoanib	15 760
Uniab	3 960
Koigab	2 320
Huab	16 470
Ugab	29 360
Omaruru	11 580
Swakop	21 010
Kuiseb	15 500
Tsondab	3 844
Tsauchab	4 431

d)

Figure 1: a) Ephemeral rivers and their catchments, b) Rainfall amounts & evaporation rates, adapted from Sarma (2016), c) Twelve (12) westward flowing catchments, and d) their estimated area, complied from Strohbach (2008) and Garzanti et al. (2014).

3.2 Geological and recharge aspects

The Huab River lies on a Proterozoic basement (Goscombe et al., 2003; Garzanti et al., 2014) (Fig. 2). It starts from some of Namibia's oldest rocks in the Kamanjab Mountains and ends in the Etendeka Group that was formed from Damaraland igneous eruptions following the breakup of the Atlantic Ocean around 132 million years ago (Miller, 2008). It consists of greenschist-facies and siliciclastic metasediments, and granite rocks; geological materials that subsequently form levisols in the upper stream of Huab, lithic lepsols in the mid-stream and eutric leptosols in Etendeka Plateau (Mendelsohn et al., 2002; Miller, 2008). Material deposited at the end includes basaltic pebbles with litho-feldspathic quartzose sands (Garzanti et al., 2014). The Ugab River is found in the Neoproterozoic rocks of Namibia (Goscombe et al., 2003; Garzanti et al., 2014) (Fig. 2). The Ugab starts from the Kalahari and Namib sands, passes through the Damaran granites and ends in the Swakop Group of the Damara Super Group mobile belt that formed around 600 million ago (Jerram et al., 2000; Mendelsohn et al., 2002). The geological material contains granitic float and sediments, schist, dolomite rocks that gave rise to eutric regosols soils in the upper stream, lithic leptosols soils in the middle stream and ends in soil layers of pertic gypsols (Mendelsohn et al., 2002). The Ugab deposits are metapsammite and carbonate rock fragments, and also litho-feldspathic quartzose sands (Garzanti et al., 2014).

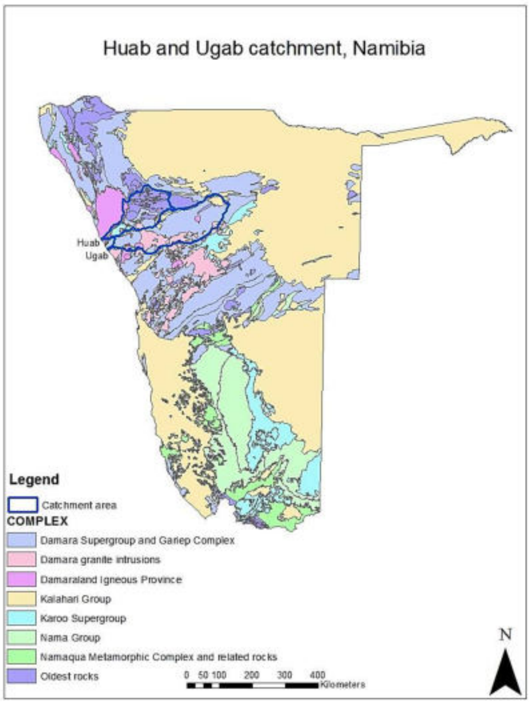


Figure 2: Geology of the Huab and Ugab catchments (Data source (Mendelsohn et al., 2002))

The western part of the country is characterised mostly by V and U shaped valleys, large open plains, escarpments and mountain landscapes. These landforms resulted from the distinctive geological evolution that lasted for millions of years and has effects on the ephemeral river regimes and classification (Seely et al., 2003). Most of these soils are relatively poor and thin, and found to have little potential even for irrigated agricultural activities, but at the same time do support dense stands that are used as fodder for livestock and wildlife (Seely et al., 2003) and support the recharge of the alluvial sand aquifers. However, there are no recharge values for these catchments and no data is documented for the Huab and Ugab Rivers; which is a major gap in research of the ephemeral rivers of Namibia. Recharge values of the two river basins cannot be inferred from neighbouring basins that are well documented (e.g. Kuiseb, Swakop and Omaruru). First, the two rivers are pristine, unlike the Swakop and Omaruru that are dammed and no longer flow naturally. Secondly, the two river systems lack the high gradient that the Kuiseb River possesses. Figures 3a and 3b show the longitudinal profiles of Huab and Ugab. The highest elevation point at the headwaters is $535 mASL$ for Huab and $1200 mASL$ for Ugab, while the highest elevation point for Kuiseb headwaters is around $2100 mASL$. The Kuiseb has one of the steepest slopes in the world and results in a rapid water discharge downstream (Jacobson and Jacobson, 2013). The slope gradient of Huab and Ugab are gentler, giving time for water to infiltrate in the alluvial aquifers.

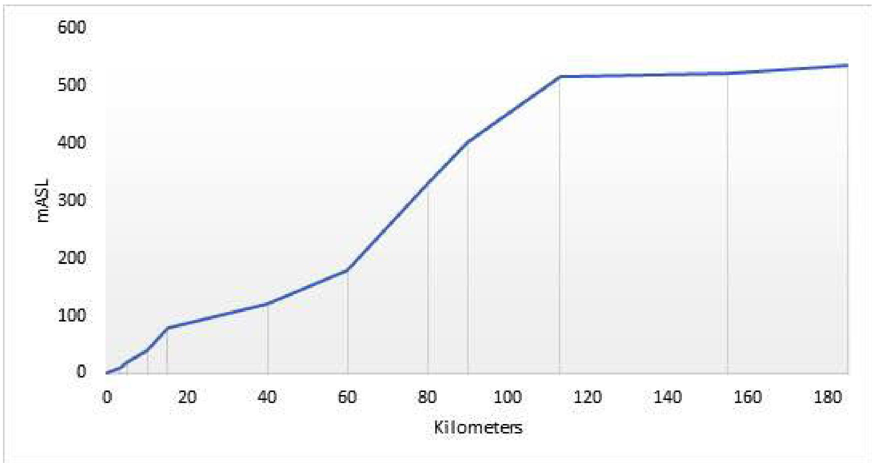


Figure 3a: Longitudinal profile of Huab River. (Kilometres from Ocean at Huabmond, sea level to the start of the Aba Huab south of Khorixas; Y- axis metres above Sea level).

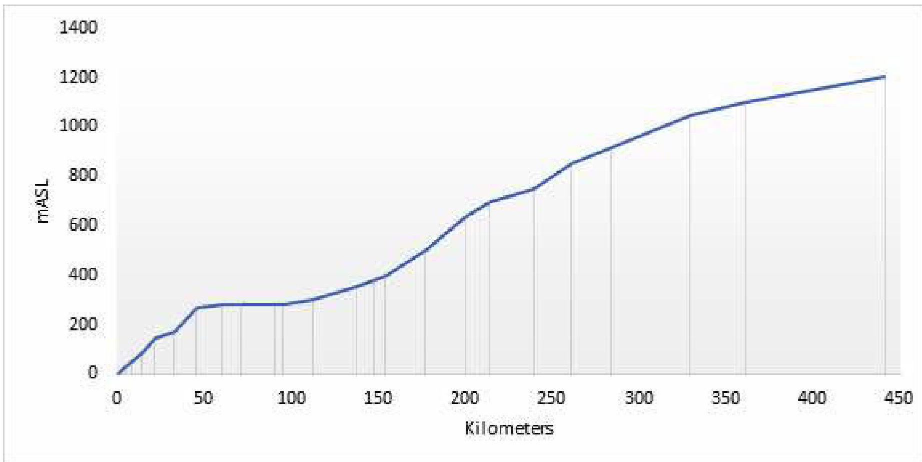


Figure 3b: Longitudinal Profile of Ugab River. (Kilometres from the Ocean at Ugabmund, Outjo is at 360 km from the Ocean).

3.3 Groundwater - Alluvial aquifers

The geology of the alluvial aquifers is directly related to the underlying geology and the nature of the tributaries. Alluvial aquifers are unique in the arid desert of Namibia. They have a dual function, firstly they are very efficient at storing water than surface rivers and dams. When the groundwater table in the alluvial aquifer is 1 m or deeper below the surface, no effective evaporation takes place and this helps to store large volumes of water over long periods of time below ground. Ephemeral river systems experience a flooding event once or at most twice in the rainy season, and this lasts as surface water for a period of two weeks. The flood waters are gently filtered through an effective porosity of the sand in the river, which leads to good and excellent filtration, cleaning the water of organic contaminants and muddy particles. These alluvial aquifers have more complex hydrologic regimes than surface waters streams. These difficulties are compounded by the extreme variability of flooding regimes, making modelling more complex.

Precipitation in arid and semi-arid regions is very variable, sporadic and of short duration (Graf, 1988). As a result, run-off is variable, both among storms within a year and among years. The rate of rise of hydrographs in alluvial aquifers is typically very rapid, with peak discharges being reached in minutes. Water flow in the ephemeral rivers is characterised by the passage of well-defined peaks, often of only a few hours duration. Downstream reductions in flow occur due to infiltration into channel and flood plain sediments, the extent of which is highly variable and due to evaporative losses. This downstream attenuation in flow volume is perhaps the best known characteristic of ephemeral rivers and has been reported worldwide (Leopold and Miller, 1956; Leopold et al., 1966; Picard and High, 1973; Sharma et al., 1984; Crerar et al., 1988; Walters, 1989; Hughes and Sami, 1992). Run-off may be generated over small areas, as these systems may have several channels within the main channel. Tributary and even main stream flow may occur while large portions of the channel system remain dry. This lends the ephemeral rivers to complex modelling approaches.

3.4 Hydrological influence on sediments, organic and inorganic particulates and solutes

The flow of the ephemeral rivers serves as a source for the existing and replenishing of alluvial sediments. The flow regime of the ephemeral rivers is the most significant aspect in their ecosystem, as it influences the patterns and the processes of the dependent flora communities, the spatial and temporal distribution of various related habitats, the interactions of abiotic and biotic dynamics and recharge (Loutit, 1991; Jacobson and Jacobson, 2013).

The catchments have less coarse channels and flood events manage to deposit sediment at its coast (Dansie et al., 2018). Some flooding events are of an abrupt nature and have been documented in Namibian ephemeral rivers, mostly for Kuiseb, Swakop and Omaruru (Stengel, 1964, 1966; Heyns, 1990; Loutit, 1991; Dansie et al., 2018) and found to result in change in run off that often last for a short period ranging from few days to less than six weeks, but only occurs when localised cloud burst that is able to yield enough runoff to pass the escarpments (Loutit, 1991). Generally, the magnitude and duration of flood depends on the amount of water, the speed and on the type of geological material that keeps more water flowing as runoff than infiltrating, whether or not the runoff reaches the ocean also depends on whether or not the river has been dammed. For instance, the Tsondab and Tsauchab Rivers never reach the sea as a result of sand damming (Turpie et al., 2010), whereas the Swakop River has resulted in fewer years in which the river manages to reach the ocean as a result of two major dams, the Von Bach and the Swakopoort on the water course. This has also increased salinity levels in the lower reaches of the Swakop River, due to less frequent flood flushing the salt into the ocean.

Commonly, the floods transport large loads and compositions of sediments, dissolves solids and fine particulate of organic matter (Jacobson et al., 2000; Jacobson and Jacobson, 2013; Dansie et al., 2018). Jacobson et al. (2000) noted that based on their flows, the most expansion of the rivers takes place at the lower reaches, where high amounts of alluvial material are deposited and are associated with broader channels and flood plains. The magnitude and duration of the flood also determine how far and where deposition is mostly made, however, the high level of dissolved and particulate material normally ends up downstream of the river systems (Dansie et al., 2018). Consequently, the solute loads increases downstream, and leads to a higher level of salt concentration in the river that is left behind after evaporation. In these parts of the river with high salt concentration, only halophytic species of plants survive as they are able to with stand the salts such as *Tamarix usneoides*. Wetlands of salty marshes and lagoons, serve as habitats for migration and breeding birds as is the case for the Kuiseb and Swakop Rivers.

3.5 Vegetation

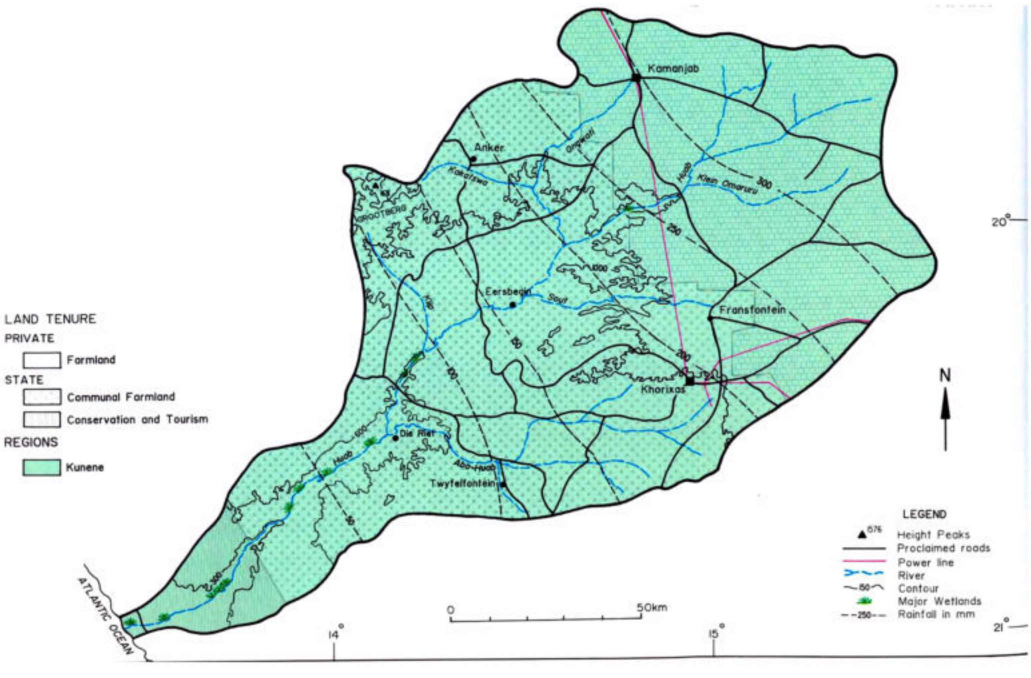
A combination of climate, topography and soils influence the type, pattern, processes and vegetation biomass production on ephemeral riverine systems. For Namibian western ephemeral rivers, these conditions differ from headlands to downstream. Vegetation varies greatly from inland where topography is defined by high mountains and rainfall is slightly high ($300 - 500\,mm/a$) (especially in the upper stream of Ugab in the Otavi area), to the lower reaches of the Namib Desert, where rainfall is close to zero and the scattered vegetation is mainly grass and very few shrubs that withstand the hyper-arid conditions (Jacobson et al., 1995; Mouton et al., 2000). The riparian forests are found in the ephemeral river banks, supported by the soil deposition resulting from the floods, which increase the soil moisture, ground water storage, and providing the essential nutrients, compositions and productivity of the ecosystems (Jacobson et al., 2000; Seely et al., 2003).

The Huab and Ugab go through mainly three biomes: in the upper catchments, the acacia trees and shrub Savanna biome which consist of grass land and scattered trees dominate, the Nama Karoo biome covers the middle streams with mostly few scattered shrubs and grass, while the Namib Desert flora covers the downstream part of the rivers with only sparse grass (Mendelsohn et al., 2002; Namibian Association of CBNRM Support Organisations, 2010). Typical vegetation species found within the catchments of the Huab and Ugab include *Senegalia fleckii, Vachellia reficiens, Vachellia erioloba, Dichrostachys cinerea, Colophospermum mopane, Faidherbia albida, Combretum imberbe, Terminalia prunioides, Stipagrostis uniplumis, Stipagrostis ciliate, Stipagrostis hochstetteriana* in Huab catchment, whereas in Ugab catchment vegetation such as *Ficus sycomorus, Vachellia erioloba, Vachellia reficiens, Vachellia tortilis, Combretum imberbe, Tamarix usneoides, Arthraerua leubnitziae, Salvadora persica and Stipagrostis* species such as *hirtigluma , hochstetteriana, obtusa, ciliate, and Eragrostis nindensis* (Giess, 1971; du Pisani, 1978; Mouton et al., 2000; Juergens et al., 2013).

3.6 Population along the catchments

Growth in human population in arid environments have led to greater pressure on ephemeral rivers globally, while at the same time attracting more tourism, based on biodiversity and scenery (Seely et al., 2003). Namibia's limited water resources are under immense pressure, with 50% of the population dependent on groundwater and ephemeral rivers (Heyns, 1990), the situation is expected to get worse with a drier climate envisaged over the next five decades (IPCC, 2007). In the year 1991, the estimated urban population of the two catchments was 49 222 (Jacobson et al., 1995), and over 50 000 by the 2011 (National Statistics Agency, 2011a). The population for other surrounding settlements including the rural areas have been estimated to be 25 600 inhabitants, with a livestock population (cattle, goats, sheep and donkeys) of at least 385 300 (MAWF, 2010). Wildlife include animals such as elephants, lions, leopards, spotted hyenas, cheetah, black rhinos, black jackals, giraffes, mountain zebra, kudus, duikers, warthogs, steenboks, klipspringers, ostriches, oryx and springboks (Namibian Association of CBNRM Support Organisations, 2010). All these are dependent on the water resources of the two ephemeral river systems.

The catchments have private farmlands, communal farmlands, parts of National parks, and also flow through proclaimed conservation and tourist areas (Jacobson and Jacobson, 2013). Of the total areas of the Huab (Fig. 1d), private lands take up at least 36% (at least 237 private farms) and 60% (at least 647 private farms) in the Ugab catchment (Jacobson et al., 1995; National Statistics Agency, 2010) (Fig. 4) whereas communal land makes up 62% and 38% respectively and only 2% in each catchment belongs to the National Park (Jacobson et al., 1995). There are eight (8) individual conservancies in the Huab and seven (7) in Ugab (National Statistics Agency, 2014). The Doro !Nawas conservancy, which covers around $3978\,km^2$, lies in and is shared between Huab and Ugab but is counted as part of Ugab. Within the catchments, lie quite a number of tourist attraction points such as the Petrified Forest, White Lady, Brandburg, Messum crater, Groot Paresis (Fig. 4) and this has led to several developments in the surroundings for accommodation places, with 33 lodges in Huab and up to 70 in Ugab catchment (National Statistics Agency, 2011b). All these developments have put added pressure upon the water resources within the catchments.



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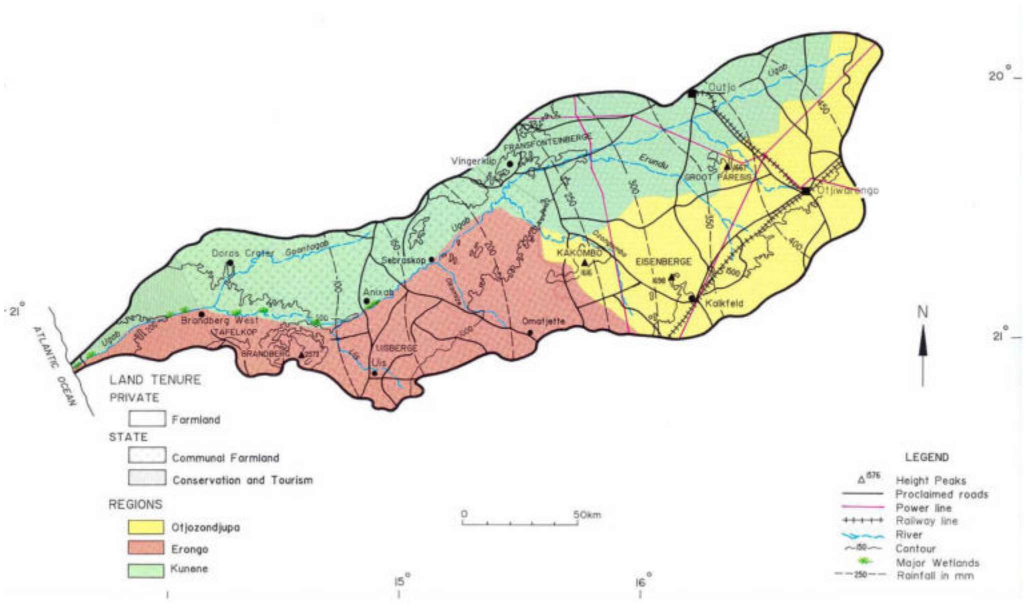

b) .

Figure 4: a) Huab catchment, and b) Ugab catchment (Jacobson et al., 1995).

4 Huab and Ugab catchments as sources of water

4.1 Water for domestic and farming activities

The rivers drain from the higher rainfall areas in the headwaters towards the dry desert environment in the west. In the middle to lower reaches, the rainfall allows the rivers to create linear oases along their ecosystem. The draining of the headwaters areas favour the groundwater recharge patterns in the middle to lower stream where the catchment is mostly flat and covered with alluvial sand soils. The upper part of both catchments is steep and has high runoff, and it is also largely covered by dolomites. However, the dolomites in Ugab River are part of the karstified zones in the plains areas and has significant yield whereas the meta-sediments and granites in the Huab Complex are overlain by the volcanic rocks and leave the area with little potential for groundwater (Christelis and Struckmeier, 2001). The generated sub-flows and the subsequent alluvial sand aquifers are the focus of the human settlements and of the survival of their livestock and wildlife, and the mining, tourism and agricultural activities. The source of water is exclusively from these ephemeral river systems. Most of human activities are in the upper (commercial farming) to middle (communal farming) part of the catchment, where vegetation is available and rainfall is also slightly higher than the lower catchment.

The water usage is prioritised for domestic use, which includes the livestock (both subsistence and commercial farming), and then for economic activities that includes mining, industries and irrigation (MAWF, 2010). Livestock take up the highest amount of water. As a result of the short flow duration, most of the water is abstracted from the alluvial sand aquifers through boreholes, several excavation of dams, springs and hand- dug wells. At least up to $37000m^3$ in the Huab and $52160m^3$ in Ugab is pumped from the groundwater to the irrigation schemes (Christelis and Struckmeier, 2001). The potential of surface water for Ugab - Huab Basin is estimated is up to $7.5MCM/annum$ and $19.5MCM/annum$ for the alluvial sand aquifer, and the usage from the aquifer is up to a total of 73% per year (Sarma, 2016). At least 19 boreholes exist in Huab and 37 in Ugab catchment, with the estimated yield of $91m^3/h$ and $612m^3/h$ (National Statistics Agency, 2010). According to (Christelis and Struckmeier, 2001), the groundwater quality in the Ugab is still principally of good quality water in category B (insignificant risk). The Huab had already deteriorated from category B (insignificant risk) to C (low risk) as of 2001 (Christelis and Struckmeier, 2001). Category D represents the high risk unsuitable water for human consumption. The deterioration of the water quality is partly dependent on the frequency of floods and the volume of abstracted water each year.

4.2 Potential effects on ecological systems

With natural rural population growth, and the rapid population growth in urban centres, the population of the catchments are growing steadily. As such there has been a shift from semi-nomadic way of living to animal husbandry and sedentary livelihoods, and this has resulted in a significant observable ecological changes that could qualify to be classified as land degradation and desertification (MAWF, 2010; Seely et al., 2003). Commonly, the high number of livestock, combined with wildlife negatively affect the vegetation. Their grazing and browsing can contribute to degradation of the riparian forest, and cause damage to the seedlings and juveniles (Pettit and Froend, 2001; Moser-Nørgaard and Denich, 2011). River channels that have enough alluvium consist of species that respond to scour, to root damage and root suckering (Jacobson and Jacobson, 2013). Good example are the *F. albida, V. erioloba*, and *T. prusnioides*. These trees and other similar ones are key resources of fodder for livestock and wildlife as they provide pods for feeding, wood and leaves for browsing and are also used as a sources of building material, medicine and as valuable organic matter (Moser-Nørgaard and Denich, 2011). Reduction in riparian forest coverage therefore has implications in the availability of fodder for livestock and wildlife on habitats and food for many reptile, bird and mammalian species, and ultimately on the human settlements. In the Kuiseb River, trees like *F. albida* reflects high amount of moisture and nutrients content in soil, and it is found to be a resource for livestock and wildlife, especially during drought periods (Jacobson and Jacobson, 2013). Although these trees utilise mostly the shallow soil moisture during the rainfall period, they also draw from the groundwater resource (Roupsard et al., 1999), a trait similar to *S. mellifera* (Bester, 1993; Sweet, 1998; Shikangalah et al., 2020). In addition, vegetation such as *C. mopane, C. imberbe, F. sycomorus*, and *S. persica* significantly depend on groundwater. This vegetation is also found in the Huab and Ugab catchments, and their effects could be similar to those in Kuiseb.

Moreover, the presence of invasive species in the upper catchments means more reduction in the groundwater as they consume high amounts of water, affecting the ecosystem. Invasive species such as *T. prunioides, C. mopane, S. fleckii, D. cinerea*, and *S. mellifera* are encroachers (Bester, 1999; Curtis and Mannheimer, 2005; Marais et al., 2015; Hauwanga et al., 2018) and are associated with the decline in functions and processes of the ecosystems (Van Auken, 2009; Archer, 2010; Eldridge et al., 2011). The process leads to a decline in green grass biomass production if not controlled and ultimately in a reduction of grazing capacity (de Klerk, 2004; Espach, 2006; Lukomska et al., 2010). The irreversible loss of biomass productivity is one of the typical sign of desertification (Whitford, 2002). While the process is natural, its impacts can be detrimental in ephemeral rivers, and affects the processes and patterns of river hydrology and in turn fodder resources that impact upon the activities of communities along the ephemeral rivers. Results of bush encroachment, include reduced recharge that has gone from 8% to less than 1% in Platveld aquifer, an area drained by Ugab River (MAWF, 2015). Those selected vegetation species outlined above exist also in Huab and Ugab catchments, and the extent of their effects on the two catchments are yet to be fully understood. Currently, only bush encroachment and loss of biodiversity as a result of wood harvesting has been noted as problem in the Huab – Ugab catchments (MAWF, 2010).

5 Gaps and implications

5.1 Management implications

The neighbouring river basins such as Kuiseb, Omaruru and Swakop are well documented and researched. However, the peculiarities of the Ugab and Huab River basins cannot be extrapolated from the neighbouring basins, because of the differences in hydrological gradients and flow patterns; for instance, the Ugab and Huab Rivers are lacking the unusual high gradient of Kuiseb River. The Kuiseb River delivers its water load much quicker to the lower reaches of the river due to its high gradient at the upper catchment. Furthermore, the Ugab and Huab are still pristine ephemeral systems which have not been dammed, unlike the neighbouring Swakop and Omaruru Rivers. The Swakop River cannot be also used as a comparison for the Huab and Ugab Rivers, as it is no longer a natural flowing system due to the dam effect. The Swakop River was dammed in order to supply water to the towns of Karibib and mining companies in the Swakop River catchment area. The Omaruru River is equally dammed for the purpose water supply schemes to the Omaruru, Uis and Henties Bay areas.

This study also shows that there are research gaps that need further work. These include the lack of recharge values from the two river systems, even though the recharge plays a big role on recharging the aquifers, and the impacts on the ecosystem provision and as a water resource for livelihoods in the face of climate change. Low rainfall is a major driver as it implies that there will be less water and fewer flood events, thus reducing recharge for the aquifers and increasing competition for ecosystem resources between human and wildlife, hence increasing human-wildlife conflicts, leading to a decline in wildlife and therefore resulting in reduced tourism activities and decline in mining and agriculture. All these factors lead to reduced income levels among the catchment populace which lead to a high level of poverty. Low recharge also means poor recovery of riparian forests and increase in desalination in lower reaches of the rivers when the water does not reach there. The poor recovery of riparian forests leads to the desertification process.

5.2 Effects of climate change on the Ugab and Huab River systems

In the context of global change, there is a grave danger that the services provided by these two important ephemeral systems can degrade. In Namibia, the decrease of rainfall and prolonged drought have become a common phenomenon, and the ephemeral rivers lie in areas with lower annual rainfall (Mendelsohn et al., 2002;

Seely et al., 2003; Jacobson and Jacobson, 2013). With decreasing rainfall in the headwaters (Table 1), this translates into reduced flows in the river systems. Table 1 represents the newly installed rainfall stations by the Southern Africa Science Service Centre for Climate Change and Adaptive land Management (SASSCAL) in a bid to close the gap on climatological data collection. However, more stations are required to adequately cover the catchments for both rivers.

a) b)

Figure 5: a) Ugab and Huab Rivers (Food and Agriculture Organization , FAO), and b) three stations (16, 20 & 26) closest.

Table 1: Rainfall (mm) trends over the last three years from 3 stations in Figure 5b (SASSCAL, 2020). For 2016, only for months were recorded after installation.

Year	Khorixas (Station 16)	Konop Pos (Station 20)	Mopanie (Station 26)
2019	57.2	102.7	52.5
2018	117.3	141.9	178.3
2017	119.6	166.3	250.8
2016	Incomplete data	Incomplete data	Incomplete data

These west flowing ephemeral rivers have a much higher annual coefficient of variation (CVMAR) among 28 stations representing seven rivers at 1.55, while the range is from 0.88 to 3.32, compared with a world average of a CVMAR of only 0.45 (Jacobson, 1997; Jacobson and Jacobson, 2013). In particular, the mean peak discharge, flow volume, and days of flow per annum exhibit a marked decline in the lower reaches of the rivers, after a mid-catchment peak. The frequency of the floods, in these rivers determine the ecosystem provision of these systems. The less the frequency of floods, the greater the damage to the ecosystems.

Climate change will also have a direct effect on increasing the human-wildlife conflict. With decreasing water resources, lions and elephants tend to access water points in human settlements. While the elephants are usually problematic in the Ugab, in the Huab Catchment, lions have been reported to be problematic (Desert Lion Conservation, 2018). When lions do not find their natural prey (wildlife), they target livestock and as the drought wears on, they become habitual livestock killers (Namibian Association of CBNRM Support Organisations, 2012; Tourism Supporting Conservancy, 2012). In 2018, the lions were reported to have been roaming in the

Ugab catchment and caused problems associated with killing of livestock (aggressive behaviour) (Desert Lion Conservation, 2018). Preying on livestock is a disadvantage to the local populations, fuelling the human-wildlife conflicts. As such climate change is a major issue that should alert us to adopt methods of protecting these fragile ephemeral river systems for both human and wildlife survival, especially with regard to the abstraction volumes.

5.3 Management challenges and future outlooks

The rivers provide a unique world class opportunity to study the hydrogeology and ecology of large ephemeral systems; especially as they respond to global change, and changes in carrying capacity, nutrient input and salinity variation over time. These issues are well studied for Kuiseb, Swakop and Omaruru (Jacobson and Jacobson, 2013). However, managing these ephemeral river systems is more complex than other riverine systems, and requires more than just studying these aspects. What is more critical in ephemeral systems is to ensure that even in times when the rivers are not flowing, there is some baseflow below the sand. That baseflow is sufficient to provide required water for the riparian vegetation and human populations that depend on this resource. The Huab and Ugab catchments provide livelihoods to a population of about 50089 inhabitants in urban centres, and around 25600 inhabitants in rural areas as well as over 385000 animals (Jacobson and Jacobson, 2013; MAWF, 2010). The urban centres are growing rapidly with accompanying tourism developments; 33 lodges in the Huab and 70 in the Ugab (Jacobson and Jacobson, 2013; MAWF, 2010) implying that pressure on water resources will continue to grow. These are likely to put a significant pressure on critical water resources, and carrying capacity of the land for livestock.

Groundwater abstraction is likely to lead to hydrological alteration as this is the case for Kuiseb, Swakop and Omaruru ephemeral rivers (Jacobson and Jacobson, 2013). Therefore, in years of drought, water abstraction levels need to be reduced systematically to an ecologically safe threshold, which allows the rivers to continue flowing. It is not easy to enforce such regulations. However, these can be enforced by the local populations if they are made aware of the dangers associated with over abstraction. Groundwater abstractions in these systems when exploited beyond a certain critical threshold affect the riparian vegetation that lines the river systems. This vegetation has a significant impact on the health of these ecosystems, it maintains the channel width and substantially reduces evaporation from the river channels due to canopy cover. In Kuiseb River, the overly abstraction of the alluvial sand aquifers does not only lower the water table and affect the springs, but it also reduces the dependant riparian forest, a pattern that has been observed over the years (Jacobson and Jacobson, 2013). Furthermore, in the Kuiseb, most of the woody trees such as *F. albida* died as groundwater availability combined with low rainfall amounts to produce enough flood events dwindled in drought years (Jacobson and Jacobson, 2013). The lowering of the groundwater system coupled with the annual rainfall decreases over time, could also lead to the economic hubris of these catchments being gravely affected. Tourism, subsistence and commercial farming, and mining will all be affected. Another important issue is the cutting of trees in these environments. The cutting of fire wood as a source of income and for contributing to building structures, have of late become a problem, leading to probable land degradation. Certain tree species provide a complete nutrient and food source for certain wildlife, such as elephants, oryx, springbok, rhino and kudu. It is important to design policies and methodologies on how the riparian forests can be managed in a more sustainable manner for the developments of the livelihoods and for the benefit of both domestic animals and wild life.

Climate change and the increase in socio-economic activities in ephemeral river systems such Kuiseb, Swakop and Omaruru has led to significant impacts on their ecological systems reducing their productivity. The Kuiseb is still marginally fresh, but both the Swakop and Omaruru have degraded significantly due to over abstraction, mainly by commercial farmers and industry.

The future outlook of these rivers in the context of climate change require concerted efforts in management of various aspects that contribute to the whole ecosystem of the ephemeral rivers. That includes the management of water resources, forestry, wildlife, tourism establishments and agricultural activities such as land carrying capacity for livestock.

6 Conclusion

Ephemeral rivers have been the source of domestic and livestock water for millennia in Africa and will continue to do so for the foreseeable future if they are appropriately managed. The potential impacts of both climate change and population pressure on the ephemeral river ecosystems need to be understood in order to be able to manage the resources in a way that both humans and fauna can co-exist with minimal impacts on the groundwater resources especially in conservancies. The Huab and Ugab catchments support a great number of economically marginal populations. The excessive use of riparian forests has been observed in the Huab catchment and it poses a great threat to the ecosystem reserves as it contributes to desertification that significantly affect the arid and hyper arid regions of the middle and the lower reaches of the rivers. As such forestry protection is critical and needs to be understood, and to be controlled to sustainable levels. With a forecasted decrease in the annual rainfall amounts, flooding events are likely to become less frequent, which can translate in less recharge to the groundwater system. The reduced recharge will necessitate deeper boreholes which might affect the riparian forests that produce fodder for livestock. The increase in population and new tourism developments are likely to add pressure on the groundwater resources. These interlinked factors need to be understood for Huab and Ugab catchments. There is therefore an urgent need for research focusing on understanding the current ecosystem, its functional parameters in the context of ecosystem services provision and the impacts on ecological component. These are fundamental in guiding the management approaches for Huab and Ugab catchments, and other neighbouring catchments that might be in a similar situation, and for informing related regulations and policies.

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