SUSTAINABLE USE OF NON-RENEWABLE GROUNDWATER IN NORTHERN NAMIBIA

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Nicole Bolliger

Dr. Schneiderstrasse 2

2560 Nidau

E-mail: n.bolliger@unibas.ch

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Abbreviations

BGR	Federal Institute for Geosciences and Natural Resources
BMC	Basin Management Committee
CEB	Cuvelai-Etosha Basin
COTAS	Technical Water Councils or Aquifer Management Councils
IWRM	Integrated Water Resource Management
KOH	Ohangwena aquifer
mbgl	Meters below ground level
NamWater	Namibia Water Corporation Ltd
RWS	Rural Water Supply authority of the Ministry of Agriculture, Water and Forestry of Namibia
TBA	Transboundary aquifer
WCED	World Commission on Environment and Development

Introduction

Water plays a pivotal role in society; it is critical for economic development, for human health and social welfare, especially for the poor and for environmental sustainability. In Sub-Saharan Africa about 319 million people still lack access to adequate water supplies (WHO/UNICEF, 2015, p. 7). The use of groundwater and its management is a growing debate in the academic and political literature. The central questions turn around the understanding and articulation of groundwater's role and contribution to national and regional development objectives (Braune and Xu, 2010, p. 230). However non-renewable groundwater resources got so far little attention in the literature regarding its contribution, and its utilization is perhaps the greatest discussed philosophic water policy issue.

In Namibia, one on the driest countries in Africa south of the Sahara, where surface water resources are often scare and unreliable, groundwater is the major water source (Christelis and Struckmeier, 2011, p. 6). 300 Mm^3/yr of renewable groundwater (Christelis and Struckmeier, 2011, p. 11) are available in Namibia and the annual national water consumption was about 300 Mm^3 in 2000 (Christelis and Struckmeier, 2011, p. 14). However the renewable groundwater is unequally distributed over the country and does not ensure the water supply for all the regions in Namibia. Some areas have non-renewable groundwater resources, for example the Cuvelai-Etosha Basin (CEB) in the northern Namibia and southern Angola. 2012 a new aquifer with 5 Bm^3 non-renewable groundwater was discovered; the Ohangwena II aquifer contains enough drinking water to supply central and north Namibia for up to 400 years (Kluge, 2012).

This paper aims to investigate how non-renewable groundwater can be part of the solution of sustainable development. What are a) the opportunities and b) the challenges of Ohangwena II aquifer exploitation for a sustainable development? The results will contribute to the discussion of the role of non-renewable groundwater to sustainable and regional development by means of a practical example. The intent of this paper is not to advocate one position neither to present some of the basic philosophical issues related to the utilization of non-renewable groundwater, this has already been done (Maliva and Missimer, 2012), but to discuss one scenario and its implications on the basis of a concrete example.

The theoretical discussion is based on wide academic literature as well as policy paper in the field of groundwater management, governance and development. For the comparison of the potential for development between theory and the case study in the CEB, newspaper articles and geography literature were used in addition.

To allow for a realistic discussion of theses questions, this paper first provides a relevant theoretical background with regard to the combination of sustainable development and non-renewable groundwater as well as the implications for the management. To avoid discussing the contributions and challenges of non-renewable groundwater in a second part in isolation, some background is also provided on the general situation in the northern Namibia before discussing the different options of exploitation. A conclusion rounds finally this paper off.

1 Theoretical considerations of the utilization of non-renewable groundwater

Non-renewable groundwater and sustainable development seems at the first glimpse to be two conflicting pieces of terminology. In the first part of this chapter, the notions will be introduced and brought together. Followed by two examples to point out difficulties related to the use of non-renewable groundwater, before in the last part the implications for the management to create a sustainable development of the non-renewable groundwater will be discussed. The management criteria for a sustainable development form the framework for the analysis of the case in north-central Namibia.

1.1 Non-renewable groundwater and sustainable development

Non-renewable groundwater refers to "groundwater resources which at present are not part of the hydrological cycle since neither precipitation nor infiltration provides recharge" (Polak et al., 2007, p. 2). The criterion of non-recharge has to been seen in a time frame of human planning. Because groundwater occurrence is never strictly non-renewable but some cases take a very long recharge time (over 1000 of years) (Foster et al., 2003, p. 1). If the annual recharge rate is lower than 0.2% of the aquifer capacity[1], the aquifer is classified as non-renewable (Polak et al., 2007, p. 2). The very slow recharge process is thus insignificant and as it exceeds the horizon of human planning, this type of groundwater can be considered as non-renewable. Foster (2003, p. 1) distinguishes two types of low recharge: first, recharge that is very infrequent and also of small volume and second, recharge of a confined section of a large aquifer system, where little active recharge is observed.

As the groundwater map (see Figure **1**) shows, most of the non-renewable groundwater is found in semi-arid and arid zones. It was formed during periods with more humid climate and has been trapped often by an impermeable layer. Due to the high age of these waters they were also called fossil or paleo-groundwater (Polak et al., 2007, p. 2).

[1] Aquifer capacity means the quantity of water that an aquifer contains.

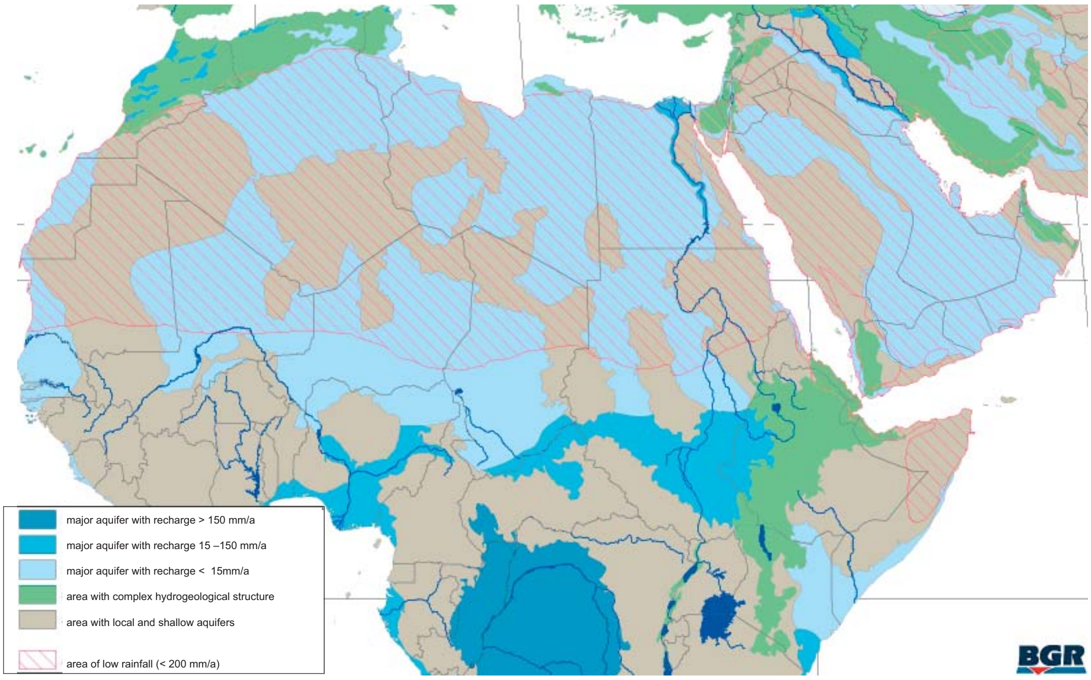

Figure 1: Groundwater map according the recharge rate. Low or non-renewable groundwater aquifers exist in semi-arid or arid area where precipitation level is low (Polak et al., 2007, p. 2)

Being decoupled from the current hydrological cycle means that the groundwater is not connected with the ecosystem. Regarding its management, non-renewable groundwater resources were therefor compared in the literature with mineral or energy resources such as oil. Through the growing recognition of the groundwater importance as a solution to many faced challenges such as irregular precipitation pattern due to the climate change, the current groundwater research focuses mainly on the sustainable management of that resource. How can non-renewable groundwater be part of the sustainable development approach? The base of the international discussion on sustainability is the definition provided by the World Commission on Environment and Development (WCED) (World Commission on Environment and Development (WCED), 1987, p. 51).: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*
According to Khouri (2001), regarding the use of non-renewable groundwater resources the society has to face the choice between:

- Maximize groundwater production to enhance socio-economic development, with the hope of implementing a replacement solution once the water runs out,
- adopt a plan of exploitation that prolongs the period of production, or
- not use or greatly limit the use of the resource.

The last option would be the most obvious interpretation to assure a sustainable development (Polak et al., 2007, p. 3). For the traditional groundwater management, the assumption is used, which suggest using only those quantities, which can be replenished by natural sources of recharge. Regarding non-renewable groundwater resources, this means not to use it at all. Llamas (2004, 2001) weakens this view by proposing that groundwater mining may be a reasonable action if various conditions are met:

- The amount of groundwater reserves can be estimated with reasonable accuracy.
- The rate of reserve depletion can be guaranteed for a long period.
- The environmental impacts of such groundwater withdrawals are properly assessed and are considered clearly less significant than the socio-economic benefits from groundwater mining.
- Solutions are envisaged for the time when the groundwater is fully depleted.

Regarding non-renewable groundwater and sustainable development, several researcher (Foster et al., 2010, 2003; Polak et al., 2007) propose that the use of non-renewable groundwater and the associated decrease of the groundwater level is not a contradiction to the principles of sustainable development. They argue that as the non-renewable groundwater is by its historical formation and deep location in the underground not associated with the ecosystem, its utilization has therefore less adverse effects on the environment. Polak writs further: "The focus on sustainability should therefore be primarily on the affected population, i.e. on their social and economic benefits. A just distribution of benefits from the use of non-renewable groundwater between today's users and those of future generations appears to be the actual challenge at hand for sustainable management" (Polak et al., 2007, p. 3). Forster's argumentation (2003, p. 1) supports this interpretation of a social-sustainable approach. He sees the groundwater in a social rather than in a physical context. According to him, considerations have to be given to the immediate benefits, the negative impacts and to what comes after in a time horizons of 100-1000 years.

In a sustainable development framework, the goal of the non-renewable groundwater use has to be social and economic development of the community as well as to decrease the frequency and severity of threats to society. This by leaving people better prepared to cope with socio-economic stresses associated with increasing water scarcity by generating new, more sustainable water sources or to increase its efficient use as aquifer is depleted.

1.2 Examples

In this part, two different examples will illustrate the broad issues about the utilization of non-renewable groundwater or from aquifers with low recharge.

1.2.1 Jwaneng mines, Botswana: mining of mainly non-renewable groundwater

Near Gaborone, the Jwaneng mine, the richest diamond mine in the world, rely entirely on groundwater (Qiu, 2013). 0.0223 Mm^3 of water are pumped daily in Maboane, a village in the north of Jwaneng, for the mine production.

According to Foster (2006, p. 14), the groundwater in the Kalahari can be considered as non-renewable because the soil-vegetation cover intercepts recharge of the groundwater. Due to the very deep-rooted small trees and grass on sand, with limited bare rock outcrops, most infiltration is intercepted and used by vegetation with only low net contemporary recharge rates from the exceptional rainfall events (400-500 mm/yr) in the region.

By consequences, although the habitants of Maboane have boreholes constructed by the government, often they are dry. According to the area councillor, the Jwaneng's production is at least partially responsible for the depletion of water in the area because the Water act 1968 allows mining companies free and unlimited groundwater extraction within their perimeters (Qiu, 2013, p. 2). According to a local expert, this policy was appropriated after the independence and during the diamond rush to promote economy but today it is not sustainable. In 2000 the Jwaneng mine used 83.7% of the extracted groundwater while Township water supply represented 16.3% (Foster and Loucks, 2006, p. 93). However, according to Qiu (2013, p. 3), many Batswana credit its standard of living to diamond mining. The construction of hospital, shopping centres and infrastructure such as roads and running water is relied to the economic development due to the growing mining industry.

This example illustrates well the difficult balance between the uses of the groundwater for national economic development to the detriment of the livelihood of some rural habitants in the presence. The Debswana Company, the owner of the mine, presented 2011 its strategy to minimise new water intake and impact on the environment (Brook, 2011, p. 18) but real insight looks different than: "The company is not obligated to provide water for the community. We drill boreholes for ourselves. It is the responsibility of the government or council to drill water for them", as a representative of the company said (Qiu, 2013).

1.2.2 Guanajuato, Mexico: Dynamics of unsustainable groundwater use

Surface and groundwater bodies assure the water supply of the State Guanajuato, in the centre of Mexico. 17'000 deep wells provide access to the groundwater sources that is used for irrigation, domestic and industrial purpose (Foster, 2006, p. 18). Therefore the overexploitation of the aquifers, high operational costs, land subsidence and deterioration of the water quality have serious impacts on the population and the economy. The high demand for groundwater could not be covered by recharge. Total groundwater annual extractions fluctuate around 4,100 hm^3 while recharge is around 2,900 hm^3 for the whole state (Comisión Estatal del Agua de Guanajuato (CEAG), 2001) and thus the level of overexploitation is around 40% of recharge. In addition, only a small part of the exploitation is licensed but even the licensed part exceed the sustainable level as the example of the Silao-Romita aquifer shows: 256 Mm^3/yr are consumed although only 118 Mm^3/yr are licensed and only 27 Mm^3/yr of water recharges the aquifer (Foster, 2006, p. 20). The uncontrolled exploitation led to a drop of the groundwater level and a decline of ground level. New aquifers and deeper ones were tapped.

Between 1998 and 2000 Technical Water Councils or Aquifer Management Councils (COTAS) were established in Guanajuato, under the Integrated Water Resources Management (IWRM) approach to reach sustainable groundwater extraction levels in all 18 aquifers. The idea was a "bottom-up process in which the aquifer users would gain a clear understanding of the gravity of groundwater depletion" (Wester et al., 2009, p. 32). However due to struggles between the state and the federal levels these councils become advisory bodies that have not led to reductions in groundwater extractions (Wester et al., 2009).

This example illustrates the importance of a regulated extraction but also difficulties of institutional measurements for a sustainable use of groundwater.

1.3 Implications for a sustainable groundwater management

The above showed examples demonstrate the complex issues of non-renewable groundwater utilization and its consequences for the management. In the present chapter, criteria for sustainable benefits resulting from the extraction of the non-renewable water source will be collected and discussed.

In many countries, especially in North Africa and the Middle East the intense use of non-renewable groundwater is reality (Foster and Loucks, 2006, p. 19). The increasing demand for water due to population growth, increase of irrigation and industrial production will not lead to a reverse of the current use patterns. Therefore the ultimate goal must be to “achieve a change from uncontrolled exploitation towards planned management of groundwater use” (Polak et al., 2007, p. 4).

According to Polak (2007, p. 4) and Foster (2006, p. 28), to transform the utilization of non-renewable groundwater into sustainable development and to ensure social-wellbeing several conditions must be fulfilled:

- **Improving people’s living conditions** and at the same time new socio-economic development chances must be created in order to generate a potential benefit for future generations.
- **Developing a follow-up strategy** for the time, when exploitation can no longer be continued or is not economically acceptable. The economic gains of the present must be invested in the development of an alternative economic structure, which is independent of non-renewable groundwater.
- **Participation of all user groups** will allow adequately distributing the benefits from the groundwater with in the present population and making provisions for the future generations. The participation particularly of the poorest and marginalised groups must be ensured by institutional structure to take into account the power imbalance.
- **Security of access to water supply** is assured if based on regulated access and adequate monitoring, and taking into consideration pre-existing users.
- Potential **economic and social opportunities** have to be considered through an user plan that enhance long-term socio-economic development, which provides opportunities to all stakeholder groups including future generations.
- **Just and effective decision-making** for question such as whether or not and how (to what degree) to exploit non-renewable groundwater means to promote

community right to participate in use decisions – including mechanisms for stakeholder participation in decision-making, just resolution of conflicts and distribution of responsibilities and benefits.

- **Social heritage and identity** (protection of cultural values and life-styles) have to be reconciled with the need to promote economic transformation as regards reduced dependency on scare water resources through the promotion of high added-value activities.
- **Environmental considerations** have to take into account an inventory of ecological services provided by the aquifer and provision for protection of critical elements.

Derived from these conditions several management rules have to be applies to ensure the conditions for a sustainable development. Besides key management needs such as the detailed technical and hydrogeological characteristics of the aquifer, special socio-economic considerations for the management of non-renewable groundwater has to be taken into account (Foster et al., 2003, p. 4; Polak et al., 2007, p. 5):

- Considerations of the **potential alternative uses** (present and future) of the aquifer reserves, the **value of the proposed use** in relation to the in-situ value of groundwater and the "**what happens after**" the depletion of the aquifer.
- Utilization of the groundwater with a **maximum hydraulic and technical efficiency** in order to extent the period of usage and new methods of providing water should be developed.
- Use of the groundwater with a **maximum economic productivity**: This implies a tightly managed demand, e.g. through water pricing. Forms of water use leading to a great increase in value should be given priority. From an economic perspective, agriculture has a relatively low economic value so the cost of pumping water is an important consideration. Progressively increasing groundwater withdrawal results in a lowering of aquifer water levels, which can undermine the economic and social vitality of traditional groundwater depend communities (Margat et al., 2006). Drinking water supply per se is not considered a productive use however due to its high social benefit, the drinking water supply has traditionally priority over economic uses. Economic efficiency means also the full re-use of urban, industrial and mining water supplies and carefully controlled agricultural irrigation is a must.

- Because of the efficiency criteria, it is usually not possible to maintain all types of groundwater utilization. As a result, **compensation** for usage demands must be considered.
- The establishment of a **monitoring system** and the provision of quantitative **data** of the available resource is essential for the management. In case of incomplete data, the **worse case scenario** should be used for plans and water extraction should be kept as low as possible until all required data are available.
- **Public awareness campaigns** on the nature, uniqueness and value of the non-renewable groundwater to create social conditions conducive to aquifer management. This implies also the publication of groundwater data and information on potential of alternatively generated water.
- Non-renewable groundwater in aquifer storage must be treated as a **public-property resource** and by preference taken by the president's, prime minister's or provincial governor's office with an advice from a multi-sectoral committee.

The critical issue for management of non-renewable water is developing a realistic plan for the use of resources that fully considers the volume of recoverable water and extraction rates, alternative water supplies, collateral impacts from groundwater extraction, the economic efficiency of use of the resource, and social, political, and ecological issues (National Research Council, 1997). Good non-renewable groundwater management starts by firmly recognizing that one is dealing with a limited resource.

2 Cuvelai-Etosha Basin and the Ohangwena II aquifer

The first part of this second chapter has the aim to introduce the general situation in north-central Namibia in terms of environment conditions, water availability, population and economic activities for in a second step analyse the possible contributions of the Ohangwena II aquifer to a sustainable development in the region as well as possible challenges.

Namibia is one of the driest countries in Sub-Saharan Africa with an average rainfall of 350 mm/yr (Van Vuuren, 2012, p. 1). However precipitation is highly unequal distributed over the country. The highest rainfall occurs in northeast (600 mm/yr) and decreases in a westerly and south-westerly direction (50 mm/yr). Perennial rivers were only found on the boarders with South Africa, Zambia and Botswana. In the interior of the country, surface water is only available in summer months when rivers are in flood after the rainy season (November until April). During the other months the rivers dry out due to the high evaporation and infiltration in the sand stratum. Desert, savanna and woodland in the more humid north-eastern region make up the major types of vegetation in northern Namibia (Christelis and Struckmeier, 2011, p. 26).

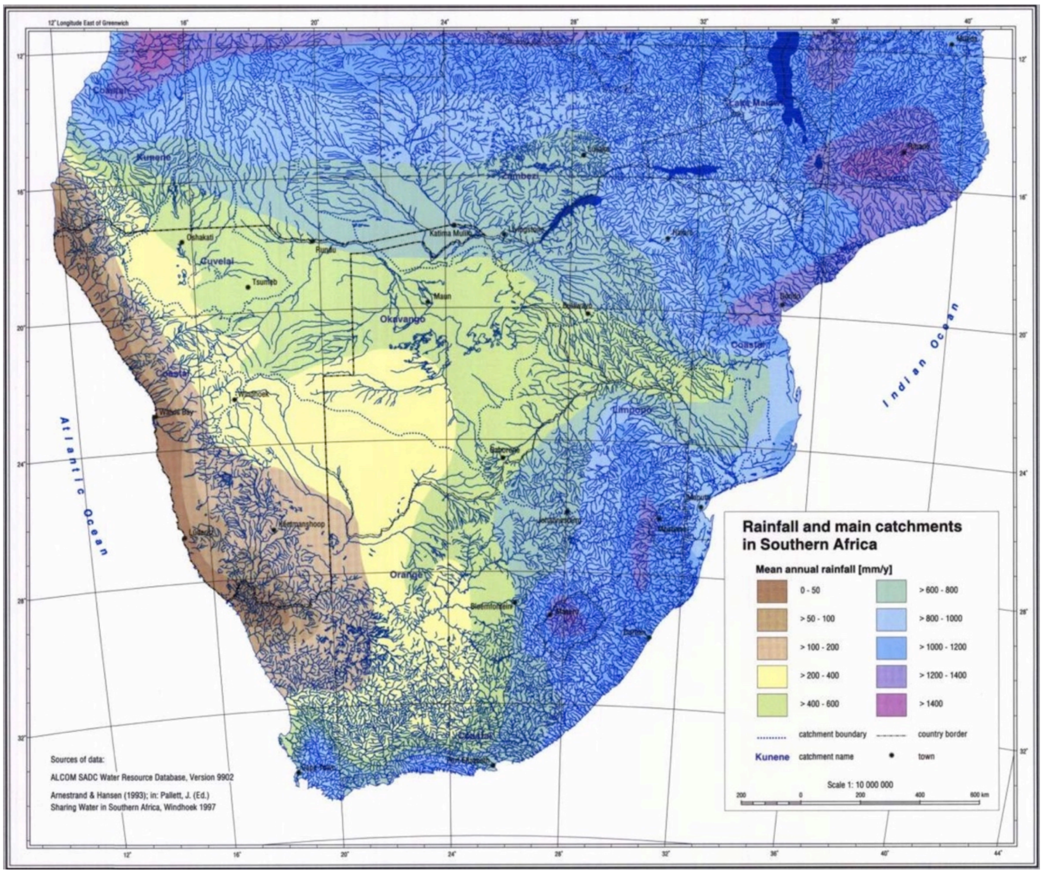

Figure 2: Rainfall and main catchments in Southern Africa (DWA, 2017)

2.1 Cuvelai-Etosha Basin

The Cuvelai-Etosha Basin (CEB) is situated in the north-central area of the country and extends northwards into Southern Angola with a total north-south length of 450km (see Figure **3**). It covers 12.6% of Namibia's land surface (Christelis and Struckmeier, 2011, p. 24).

The following description will be confined to the Namibian part of the CEB as well as the term it self.

Figure 3: Map of the CEB (Mendelsohn et al., 2013, p. 17)

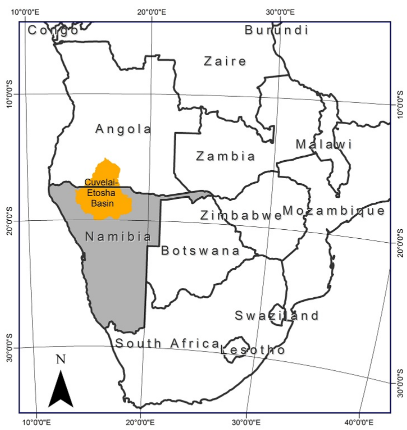

Figure 4: Location of the Cuvelai-Etosha Basin in Angola and Namibia (BGR, n.d.)

2.1.1 Environment (rainfall, climate and vegetation)

Moist air is being pushed into the country from the north and north-east during rainy season, November to April, that is why the CEB is among the regions with the most amounts of rainfall per year (300-600 mm/yr). However rainfall underlies a high degree of variability in timing, amount and unpredictability; western parts of the CEB more than the eastern areas (RAISON, 2011a). In addition, the CEB belongs also to the hottest areas of Namibia. By consequence evaporation exceed several times the annual amount of rainfall, the loss of water is especially high during the months of October, November and December when the sun is intense and only little clouds are there to reflect the sun (RAISON, 2011b). September is the driest months with a humidity level lower than 20% (RAISON, 2011b).

Eight major vegetation types can be found in the CEB (RAISON, 2011c): Cuvelai drainage, Etosha grass and dwarf shrubland, karstveld woodland, mopane shrubland, north-eastern Kalahari woodlands, pans, western Kalahari woodlands and Kunene valley. Problems of overgrazing and deforestation are due to the fact that the wild animal's and livestock's forages are in commonages that are not managed. The basin has been formed 570 million years ago and has been filled and covered by sediments deposits by wind and water. However in recent years, eastern winds have eroded the Etosha Pan rather than filled in with sediments (RAISON, 2011b).

2.1.2 Surface and Groundwater

Water resources are often scarce and unreliable in the north of Namibia. For this reason access to safe freshwater is the main limiting factor for economic and social development of Namibia (BGR, n.d.). The names of Cuvelai-Etosha Basin are characteristics for the two surface water resources in the CEB: the Cuvelai drainage in the northwest of the CEB and the Etosha Pan in the centre. The Cuvelai drainage in the northwest of the CEB is marked by the Iishana flow, a delta-like network of interlinked shallow channels and pans built by the local rainfall and rain in the upstream catchment in Angola. The Iishana channels carries the most surface water in the CEB and is feeding the Etosha Pan. Flooding is normal during rain season in the region and during dry season thousands of small pans remain (RAISON, 2011d).

Figure 4: Flooding in northern Namibia in 2008 (GIZ, 2008)

In addition, the CEB is boarded by two perennial rivers (Kunene River in the north-west and Okavango River on the north-east side of the CEB) (Lindenmaier et al., 2014, p. 1309). The three river systems have their sources in Angola.

Groundwater is the main source of water for people and livestock, especially in the west and north-east of the CEB and south of the Etosha Pan, where surface water is more scare (RAISON, 2011e). The CEB is divided into six groundwater regions: the Otavi Dolomite Aquifer (DO), the Oshivelo Aquifer (KOV I+II), the Etosha Limestone Aquifer (KEL), the Omusati Aquifer (KOM), the Oshana Aquifer (KOS) and the Ohangwena Aquifer (KOH I+II) (BGR, n.d.). The main drilling area is in the KOV aquifer (Christelis and Struckmeier, 2011, p. 58) although there is a risk of saltwater intrusion into the freshwater, especially from the west and from underlying strata. The Ohangwena II aquifer will be presented in detail in chapter 2.2.

The best borehole water is in the eastern and far western areas and south and east of the Etosha Pan (RAISON, 2011e). In the other areas high concentration of fluorides and sulphates are the main dissolved solids that make the water not fit for human and livestock.

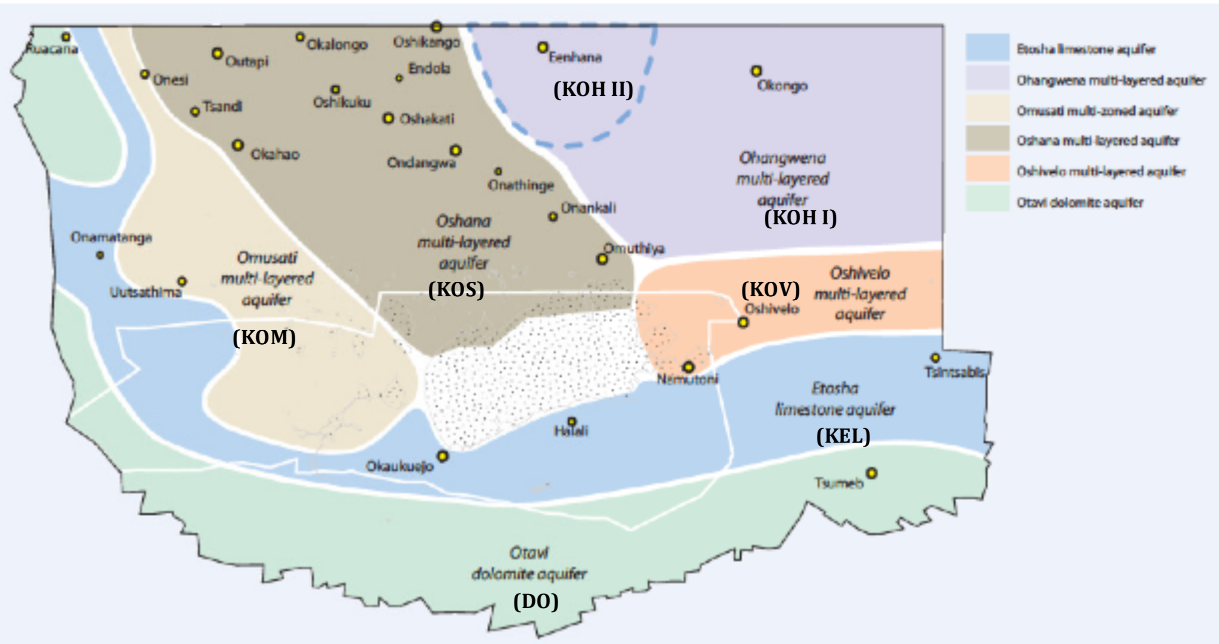

Figure 5: The six main aquifer systems in the CEB (Mendelsohn et al., 2013, p. 87)

2.1.3 Water supply

The current water supply in the CEB is based on a 40 years old and 4'000 km long canal and pipeline system that pumps water from the Angolan Calueque Dam of the Kunene River towards the densely populated central of the North of Namibia where predominantly saline groundwater is found (BGR, n.d.). But the pipeline system needs to be repaired because up to 80% of its water evaporates in the heat or is lost through leakages (Smith, 2012). That is a very high rate of loss, in particular if compared to the main loss target in Europe that is about 15-20% loss of the production quantity (Cottier, 2010, p. 13).

This supply system covers the CEB region only partly (see Figure **6**). In 1991, 30% of the water supply depended on this pipeline system and in 2000, more than 100'000 people (about 15% of the total population of the CEB) still lived beyond the desired 2.5 km from safe drinking water (Christelis and Struckmeier, 2011, p. 58). However water users are required to pay and some prefer to keep their meagre income for other uses (Mendelsohn et al., 2013, p. 145). Where this supply network ends, people are dependent on water from hand-dug wells and seasonal flows of shallow surface water streams (Iishana). Major challenges of using the Iishana water are high evaporation rates and rapid quality degradation of the water due to uncontrolled use by humans and animals.

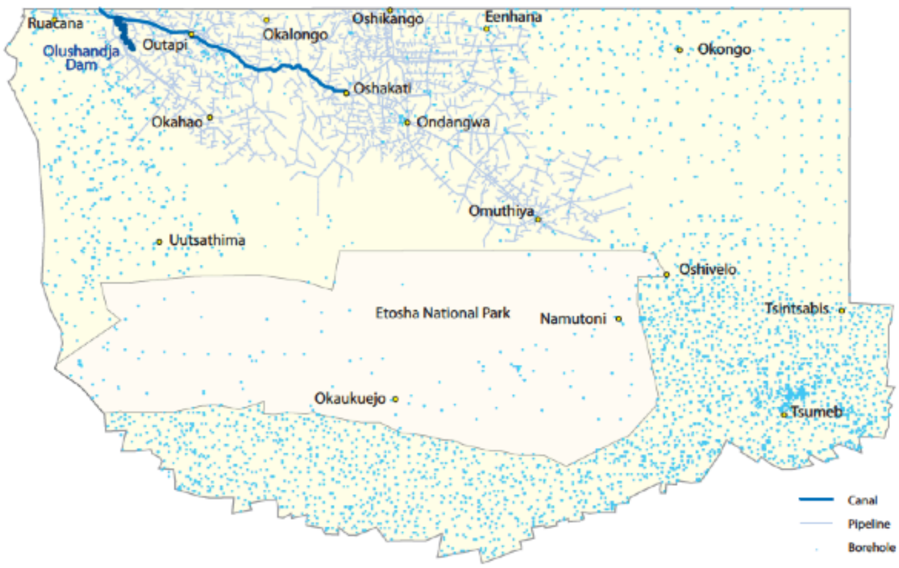

Figure 6: Map of the water supply infrastructure (Mendelsohn et al., 2013, p. 144)

For these reasons the importance of groundwater in the water supply is increasing. Groundwater resources are more reliable, widespread and naturally protected against evaporation. A rather large portion of the basin is supplied by sparsely distributed groundwater wells that tap low yielding, medium deep aquifers. In the last century more than 100'000 boreholes have been drilled in Namibia. Half of these are still in operation and produce groundwater for industrial, municipal and rural supply (Christelis and

Struckmeier, 2011, p. 6). In 1991, 60% of the water supply depended on dug wells and 10% on drilled wells in Namibia (Christelis and Struckmeier, 2011, p. 58). Vast areas in the CEB were provided with water from local deep-water wells. According to Mendelsohn et al. (2013, p. 85), 6'000 boreholes were drilled in the CEB. However many are dry or could produce too little to be used economically. Further high fluoride and salt contents pose a significant problem for using these aquifers (BGR, n.d.) and during dry period, the wells become saltier due to evaporation and hydraulic connection to saline groundwater. In some places, the salt content of the groundwater is three times higher than seawater (CuveWaters, n.d.). But also the contamination of the water in hand-dug wells with algae, faeces and parasites can be significant. By consequence drinking this water can lead to health issues, especially for children.

The advantage of groundwater use is that even isolated communities and those economies located far from good surface water sources like mining, agriculture and tourism can be supplied from groundwater if they are situated above an aquifer.

Government rural water supply projects have the aim to decrease the number of people not having access to safe water by extending the surface water pipeline system and by drilling new boreholes. To improve the situation of salinization, high fluoride content and potential water shortages in drought periods, an additional groundwater source of high yield and good quality would be of great value (BGR, n.d.).

Furthermore, water availability is direct linked to progress. According to Cottier (2010, p. 3), on individual level, 3-5 litres of water per person per day are necessary to survive. Adding domestic needs requires 20-500 litres additional per person per day; 20 litres for a person living in a less developed country and 500 litres in an industrialized country. For agricultural production, services and industry more water is necessary. The world average of water use is between 250 and 300 m^3/yr per person per day. However there is a huge disparity in the world. Applied to the CEB this means by an actual population number of 850'000 in 2011, the actual required water demand is between 212.5 and 255 Mm^3/yr. This is significantly more then what the Namibia Water Corporation Ltd (NamWater) abstract at the from the Kunene River (80 Mm^3/yr) and pumps into the pipeline system (NamWater, 2015, p. 2).

2.1.4 Management

In 2010 a Namibian IWRM Plan was developed to guide the management of Namibia's scare water resources. The overall long-term objective of IWRM in Namibia is to "achieve a sustainable water resources management regime contributing to social equity, economic efficiency and environmental sustainability" (IWRM, n.d.). IWRM is implemented at basin level, linking all aspects of the basin. The CEB has been designed by the government as such a basin (Mendelsohn et al., 2013, p. 21) by consequence decisions on water resources were not only made by centralized authorities but were also addressed at the basin level through Basin Management Committee (Kluge, 2012). In the CEB, as a pilot area, one of the first basins got such Committees to carry out the management at a basin level.

2.1.5 Population

Namibia is one of the most scarcely populated countries worldwide with a density rate of 2 persons/km^2 (Christelis and Struckmeier, 2011, p. 26). Nevertheless more than 40% of the population live in the north-central and northeastern parts. By consequence the CEB is one of the most densely populated area of Namibia. Due to the proximity to Angola and other favourable conditions such as water availability in shallow wells and fertile soils, the CEB is developing rapidly. The annual population growth is with 2.8% higher than the national average of 1.6% (BGR, n.d.). Most of the growth has been around the cities Oshakati, Ondangwa and Oshikango, where 143'000 people are living out of the 850'000 in the CEB in 2011 (Mendelsohn et al., 2013, p. 125; RAISON, 2011f). It is also in these urban centres where the majority of the working-aged people live as well as the majority of men. However the majority of the people (707'000 people) live in rural area. The rural population consists of large numbers of people younger than 20 years and women (RAISON, 2011f). For example the Ohangwena region has the highest percentage of women-headed household due to emigration (Mendelsohn et al., 2013, p. 135).

In the western CEB, theirs homes are, due to the network of Iishana, quite spread evenly and built on higher ground, each household being several hundred meters from its neighbours (RAISON, 2011f). In the Ohangwena region all households were clustered into villages around old pans where water is available and there are soils suited to some crops (RAISON, 2011f). The oldest and biggest farmsteads are usually on the highest areas where the soils are less salty and clayey (RAISON, 2011d). Most of the households are growing crops and have livestock, but obtain most of their income from sources unrelated to farming (Mendelsohn et al., 2013, p. 125).

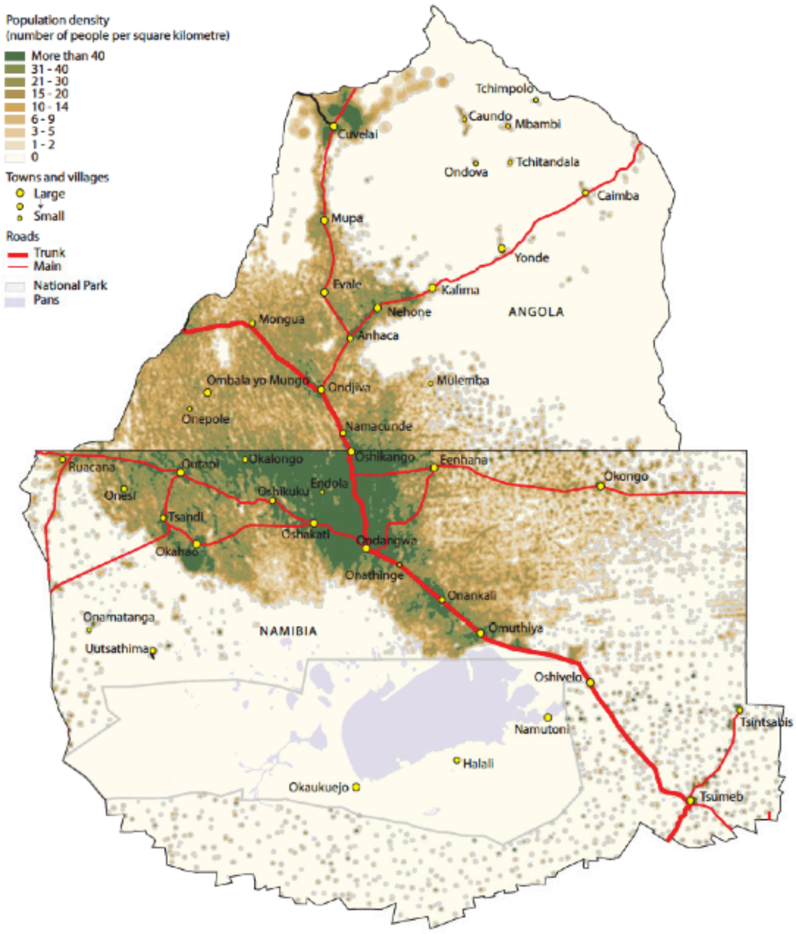

Figure 7: Map of the CEB with the population density (Mendelsohn et al., 2013, p. 18)

Levels of wealth vary widely, the wealthiest people being in the freehold farms in southeasterly parts and in towns, while the poorest households were in remotes areas. They live largely off labour supplied by their few family members while wealthier households live off cash income from large families (Mendelsohn et al., 2013, p. 128). In remote areas of the CEB, the annual expenditure of a person is less than 1’500 N$ compared to large scale farming zone in the south where more than 3’000 N$ are spend per year (RAISON, 2011f). Namibia ranked 2003 on 7th place of the countries with the highest inequality (CIA Worldfactbook, n.d.).

According to government’s figures, “northern Namibia is holding back the country’s progress because of the high rates of maternal mortality, infant malnutrition reaching 38% in 2011” (Smith, 2012) as well as in terms of water use per head and access to sanitation facilities the north is behind (see Table **1**). Ohangwena’s, Omusati’s and

Oshikoto's water use in terms of absolute amount but also per head, is the lowest amount in Namibia (Ministry of Environment and Tourism, 2011, p. 54). The under-development could be due to the presence of malaria, which occurs only in the northern parts and the growing pressure of the population on the health and education services, on environment and on limited water and land resources. For example 15% of the basin population lives more than 10km from a health facility away. According to Mendelsohn (2013, p. 142), a high number for Namibia. Most of these people are in eastern parts of the Oshikoto region and the southern and western parts of Omusati region.

Region	**Water use (m^3/yr)**	**Water (m^3/head/yr)**	**Toilet, flush (% of households)**	**Toilet, bush (% of households)**
Ohangwena	360'097	2	3.2	88.8
Omusati	781'319	3	3.3	83.0
Oshana	3'478'191	22	19.2	49.2
Oshikoto	488'767	3	15.9	70.2
Total:	**5'108'374**			

Table 1: Water use and access to toilets by region in the CEB in 2001 (Ministry of Environment and Tourism, 2011, p. 54)

2.1.6 Economy

A substantial part of the basin's economy is derived from cross-boarder trade (RAISON, 2011g) and is one of the fastest growing areas of Namibia (Expanded Academic ASAP, n.d.). Namibia's economy is constituted of three pillars: Mining, fisheries and agriculture and depends heavily on imports of manufactured goods, technology, while it exports minerals, fish and beef (Christelis and Struckmeier, 2011, p. 28). The CEB's flourishing economy is due to the trade with Angola. The road from Tsumeb to Oshikango is one of the busiest. But also Eenhane is on the trading route from Ohangwena to Okongo in the east (Mendelsohn et al., 2013, p. 146).

i. Agriculture

More than 51% of the households in the four regions of CEB depend on agriculture, except Omusati where it is between 31-50% (Ministry of Environment and Tourism, 2011, p. 68). In addition to the to cattle and small stock farming, dryland crop farming is possible in the CEB due to surface water in the north western parts and the relatively high (more than 500 mm/yr) and reliable rainfall in the south of the area. Most of the rural households live on cash income derived from wages, business profits, pensions and remittance. Nevertheless they continue to cultivate fields and keep livestock for subsistence farming (Mendelsohn et al., 2013, p. 20).

However since surface water is only available for certain periods in the CEB and climate variations like droughts and floods were increasing and their impact on the agriculture is major, people rely on other sources of water, such as groundwater during dry periods (Christelis and Struckmeier, 2011, p. 23). Food security is not always assured. Namibia normally imports about 50% of its cereal requirements (CIA Worldfactbook, n.d.); in drought years food shortages can be a problem in rural areas as for example in 2016 when in the regions Omusati, Ohangwena and Oshikoto 40-50% of the population had survival deficit due to a sever drought (UN Office for the Coordination of Humanitarian Affairs, 2016).

Irrigation is rare and limited to commercial farming because of insufficient, non-permanent, non-reliable and non-saline water sources. Based on Christelis and Struckmeier (2011, p. 58), groundwater based irrigation in the northern part occur especially on two farms on the boarder to Kaokoland in north-west of the country, where vegetables were grown using drip irrigation. The water consumption rate is 10'000 m^3/yr per ha. The sprinkler techniques with surface water used by one other farm, uses twice the amount than the drip irrigation, 15'000-24'000 m^3/yr per ha. In 2000, irrigation from groundwater amounted to 30 Mm^3/yr in Namibia. For only the northern part, no data were available. Further plans to develop irrigation from groundwater are planed to provide food and promote self-sufficiency. Because Namibia still imports more than 80% of its fruits and vegetables from South Africa (Christelis and Struckmeier, 2011, p. 28).

Regarding livestock watering, the water demand in the northern area of Tsumeb is approximately 13 Mm^3/yr and is based on 1998 livestock estimates of 550'000 cattles and 1'325'000 goats and sheeps (Christelis and Struckmeier, 2011, p. 58). Large stock unit demand 45 L/d, wether small stock unit 8 L/d. More southern of Tsumeb 0.6 Mm^3/yr of livestock watering comes from groundwater resources each year. Livestock is the major agricultural activities in Namibia. Since 2000 the number of cattles in the Basin has increased by 66% from 600'000 in 2003 to 1'000'000 cattles in 2012. According to Mendelsohn (2013, p. 161), it is seen as an capital investment. That is also the reason why only 7% of the livestock is sold. Owners sell them only when they have a particular need for cash.

ii. Industry and Mining

Mining companies in the north were mainly located at the boarder of the CEB around the cities Tsumeb and Grootfontein, where water supply is assured trough the water canal coming from the Rundu in the east. In Tsumeb mines copper, lead, silver, gold, zinc, arsenic and germanium were won. Namibia's mining sector contributes 19.0% and the manufacturing 19.6% to the GDP in 2014 ("Namibia GDP," n.d.). Light industries and businesses have been established in towns like Oshakati and Ondangwa (Christelis and Struckmeier, 2011, p. 51). Given its small domestic market but favourable location, superb transport and communication base, the north of Namibia is a leading advocate of regional economic integration (Namibia Government, n.d.). Namibia's industry is high capital-intensive and depend on imports of services and goods from South Africa.

iii. Tourism

The Etosha Pan located in the centre of the CEB is one of the Namibian's most spectacular features and attracts over 200'000 visitors per year (RAISON, 2011h). For the most of the year it is dry, saline wetland, but during the rainy season, it forms a shallow lake covering more than 6000 km^2, the perfect habitat for many animals and plants (RAISON, 2011h). In recent years many new tourism enterprises have started their business in the Etosha National Park, including cultural and craft-based attractions. The people living and working in the National Park use 0.9 Mm^3/yr for drinking water, of which 0.5 Mm^3/yr is supplied to three tourist camps (Christelis and Struckmeier, 2011, p. 58).

Overall, CEB's economy is based for the majority of people on agriculture and small businesses. However agricultural production in rural areas is not enough due to low crop yields, limited access to markets and land rights that have no economic value, so that Basin is depending on cereal importation. Mining and tourism contribute more in terms of income but only a minority can benefit of it. This is illustrated by the high-income inequality in the region.

2.2 Ohangwena II aquifer

In 2012 a new aquifer was discovered in the north-central part of Namibia at the boarder to Angola within a research project of the Federal Institute for Geosciences and Natural Resources (BGR) with the goals "to improve access to safe drinking water and to provide well founded information concerning the groundwater resources in the Cuvelai-Etosha Basin as a basis for Integrated Water Resource Management (IWRM)" (IWRM, n.d.). On the occasion, the Ohangwena II aquifer was discovered in 300 meters depth covering a surface of 15'000 km^2. The aquifer was fed from the mountains in southern Angola over 10'000 years ago (Sorensen, 2013, p. 173). The extent of the resource is estimated at 5 Bm^3 and although the water is ancient, it is of acceptable quality for domestic and agriculture use (Sorensen, 2013, p. 173). The BGR results (Beukes et al., 2012, p. 45) have shown a that the water quality of the KOH II is good for drinking water (300-900 mg/dm^3)[2] because it is protected by a barrier layer from pollution. BGR describes the Ohangwena aquifer as a "multilayer, continuous porous aquifer system of the eastern Ohangwena and northern Oshikoto regions with a groundwater flow from Angola to the south" (IWRM, n.d.). Lindenmaier (2014) refers three aquifers to the Ohangwena aquifer: The uppermost discontinuous aquifer occurs in the Aeolian sheet sands between 1-40 meters below ground level (mbgl) and is named KOH 0. It is an important source for potable water for the local population but yield is limited; thus it is not an aquifer for large exploitation because its spatial and temporal distribution due to closely relation to rainfall as it is fed by direct infiltration. The upper KOH I is located between 60 to 160 mbgl in unconsolidated and partially cemented sand. Its water becomes progressively more brackish as it extends toward the Etosha Pan. It is an important aquifer for decentralised exploitation by means of shallow boreholes. The Rural Water Supply authority of the Ministry of Agriculture, Water and Forestry of Namibia (RWS) drills and maintains most of these boreholes. Particularly during droughts, this aquifer is used as a water supply additional to that of the KOH 0. Yield and quality of water of the KOH I is low and very variable, and, as such, it is primarily used for livestock. KOH II is underlying the brackish to saline western part of the KOH I and consists of fine-to-medium-grained sand with some clay in some parts. It is located between 233 to 350 mbgl, which signify a thickness of the aquifer of 117m. The good

[2] Total dissolved solids (TDS) is the indicator of the water quality. 2'600 milligrams per litre or more is not fit for humans, above 5'000 are detrimental to livestock (RAISON, 2011e)

water quality is due to a clay layer (aquitard) that does not allow the water to pass through it. Figure **8** illustrates the type of hydrological setting of the Ohangwena II aquifer. The aquitard confines the groundwater and increases residence time of the freshwater aquifer, but allows limited leakage and discharge via an overlying shallow saline groundwater system.

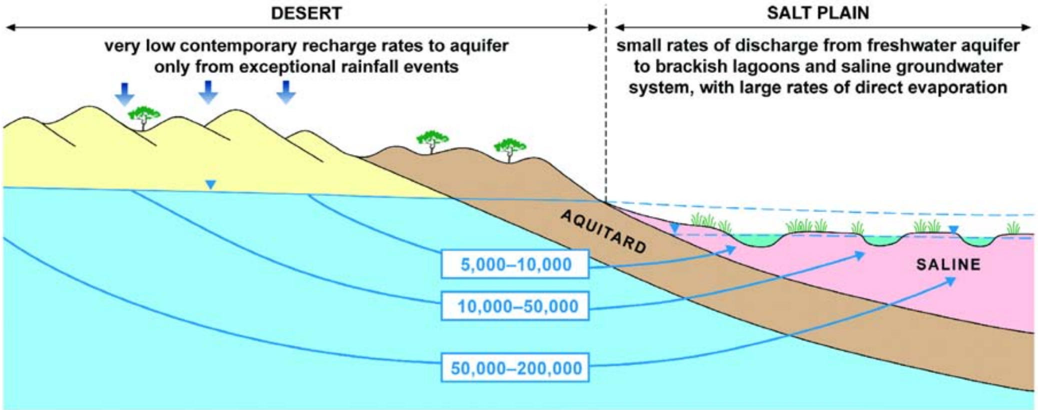

Figure 8: Hydrological setting that illustrates the occurrence of non-renewable groundwater resources in the Ohangwena II aquifer (Foster and Loucks, 2006, p. 15)

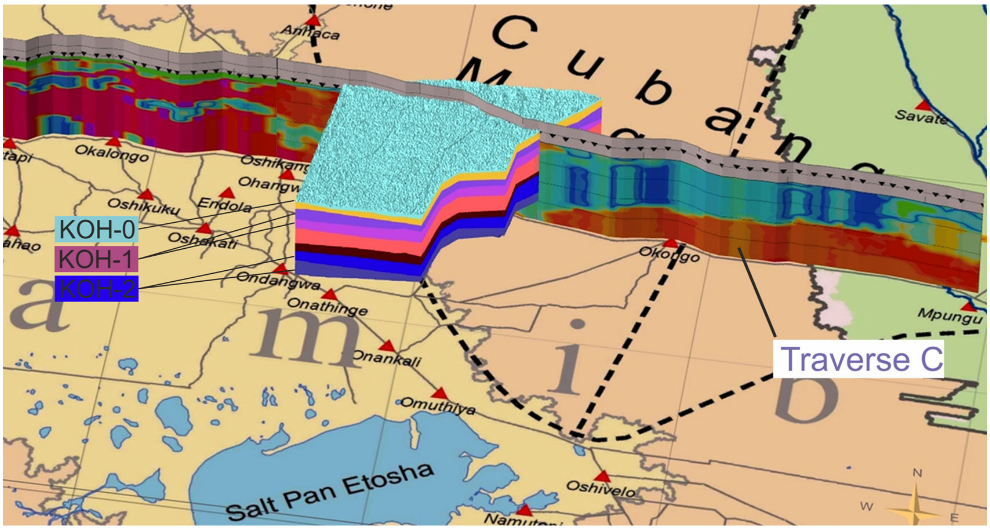

Figure 9: Oblique 3D map of the Ohangwena aquifer (Lindenmaier et al., 2014, p. 1322)

The fact that in some areas a layer of saline water is overlapping the freshwater aquifer is a hinder factor for the exploitation of the groundwater resource because if drilling is mismanaged, the consequence is a contamination of the source (Smith, 2012). In addition, the recharge process of the system of the KOH I and II is not fully understand today. It is important to know because the rate of recharge would determine the sustainability of the water resource. Lindenmaier (2014, p. 1326) proposes three major recharge paths for the KOH II: the first path considered is a top-down recharge through geological window to the north or east of the KOH location. A second path would be regional lateral discharge from recharge in the Angolan Highlands. And the final possibility is from the Okavango River itself. The major recharge process remains unknown but knowledge at date indicates that the recharge rate of KOH II is very low, if there is one. That is why the aquifer can be classified as a non-renewable water resource.

However the investigation to date (BGR, n.d.; Christelis and Struckmeier, 2011; Lindenmaier et al., 2014) have shown that there is a potential for high-quality groundwater resources within the Ohangwena aquifer. In the next two parts, opportunities and challenges for a sustainable development in the north-central part of Namibia are analysed.

2.2.1 Opportunities

The new discovered water resource in the name of Ohangwena II consist an occasion to develop the northern region, to bring into a line with the south and to respond to the increasing water demand. By 2030, demand for water will have increased to 765 Mm^3/yr from 327 Mm^3/yr in 2008 (Ministry of Environment and Tourism, 2011, p. 24), especially by irrigation and by the urban sector. Namibia's plan for development were defined as aiming "at accelerated economic growth, reducing economic dependence, maximising the use of the country's available natural resources, creating substantial employment and promoting equitable distribution of national wealth" (Melber, 2014, p. 114).

In this part possibilities will be ascertained how and to what extent the available fossil groundwater will be able to contribute to regional development by taking into account the criteria for sustainable development elaborated in the theory part of this work. Discussed contributions will be adequate supply, clean and safe drinking water to the rural population, improvement of the water distribution network, increase of the agricultural and livestock production, copping mechanism with climate change, stabilisation of migration to urban centres and support of infrastructure development including possible growth point.

Priority should be given to the increase of the coverage of drinking water. Because of the extent of the of the aquifer, "the resource could supply the population of the whole northern Namibia numbering 850’000 for 400 years” (Sorensen, 2013, p. 173). The main objective of the governmental project in partnership with the German institute (BGR) is to improve groundwater management in the CEB because the lack of a sustainable supply consist a problem in Namibia over the past decade. One of the Namibian development goals is then also to secure access to safe water for all which is a contribution to improve people’s living conditions. According to calculations of the German researchers, 50 wells projected to cost about 2.5 million Euros nor including infrastructure, should be able to supply the northern population with additional drinking water (Kluge, 2012). “In cooperation with the bulk water supplier NamWater and the EU funded Integrated Water Resources Management Project, a pilot scheme for water supply tapping the KOH II water resource is currently being developed” (IWRM, n.d.). The Ohangwena II aquifer is located on the eastern side of the fast growing urban triangle Ondangwa, Okalongo and Ohangwena, between the cities Ohangwena and Eenhana in a rural area where traditional live dominates and access to infrastructure is limited. Using groundwater resource has the advantage that isolated communities can be supplied so that these marginalised and poor groups can benefit. Figure **10** illustrates well the higher presence of boreholes in rural areas where the pipeline system does not reach the population. It is also clear visible (see Figure **7**) that the yields are lower compared to the south although more people are living in the northeast area. According to Mendelsohn (2013, p. 93), 1-5 m^3 per hour is enough to supply a small village, but not for an rising and flourishing city such as Ohangwena or Eenhana.

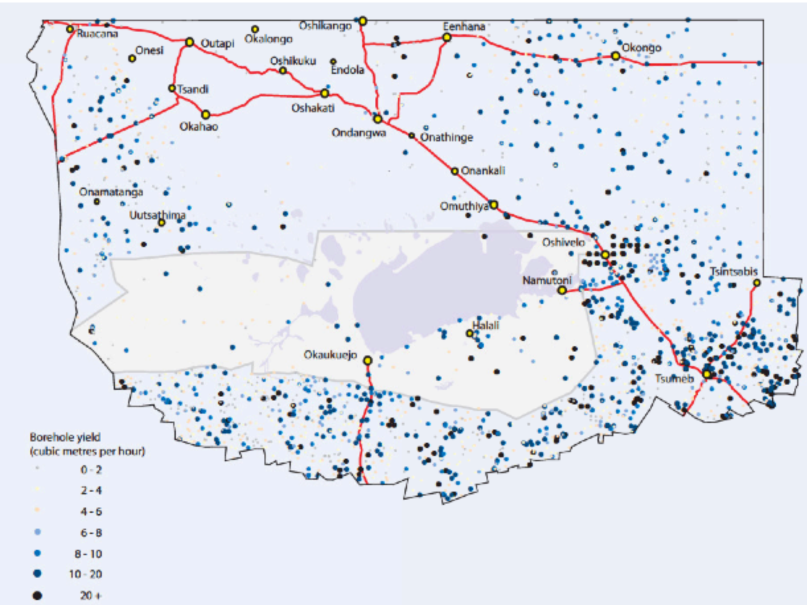

Figure 10: Boreholes yield (Mendelsohn et al., 2013, p. 93)

But for the government this discovery means much more than clean drinking water for the population. The area is marked by unlimited land however agricultural development is restricted to the volume of water available. Head researcher of the project, Quinger says that the new aquifer has great potential to change the nature of the farming in the area (McGrath, 2012). Agriculture could gain in importance besides the livestock farming. Groundwater irrigation can provide much needed food, promote self-sufficiency as well as rural employment. This may be true for the dense populated triangle. Around the urban centres (see Figure **11**), a more stable water supply could be a spur to develop commercial farms in this area, which has a positive impact of the wealth distribution and generates a potential benefit for future generations. At present, freehold farms, which have a significant positive effect on the income, were only found in the south parts of the CEB. In addition, a variety of income increases resilience to effects of drought.

In the northeastern part of the CEB, which is characterised by sand soil that hold little water, and by many small pans with clay soil, better water access would not allow increase productivity because of the infertile grenosol.

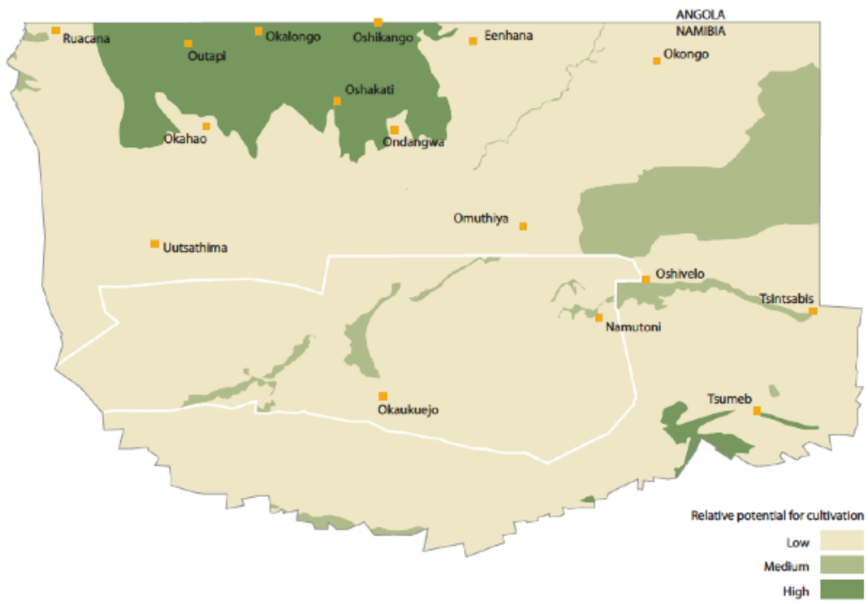

Figure 11: Relative potential for cultivation (Mendelsohn et al., 2013, p. 35)

Irrigation is only suitable along reliable water sources, on suitable soils and where markets are developed (Ministry of Environment and Tourism, 2011, p. 78). These criteria were met in the triangle with the new aquifer, the prospering boarder-trade and a soil mixture of sand and clay, the most fertile soils in Namibia. In addition, the area could benefit of the government-planned project to increase irrigation (green Scheme) [3]. According to Liebenberg (2009, p. 6), there are currently only a few irrigation projects in existence in the CEB but to reach its Vision 2030, the government wants to utilise most of the potentially irrigable land by the year of 2030. In this view, an additional 27'000 ha of irrigated land shall be developed in the next 13 year on the eastern boarder of the CEB to the Kavango region. In addition to the already mentioned factors, Villholth and Altchenko (2016) add other factors, such as distance to surface water, distance to market, drilling and pumping costs depending on depth of groundwater, and access to electricity, which have significant importance for the potential of developing groundwater irrigation. In our case, surface water from rivers and the piped water, is for the most people unreliable. However as the region has a good transport infrastructure of roads and railway (Mendelsohn et al., 2013, p. 146) and benefits of the transboundary trade, access to market is ensured. The abstraction costs are reasonable due to the fact that the water table of the KOH II is around 15 mbgl[4]. Regarding access to electricity, an impressive network of power lines across many areas of the basin was constructed. Nevertheless, according to Mendelsohn (2013, p. 147), the majority of people in rural areas do not have access to electricity, mainly because connections to the grid and usage costs are high.

But also for stock watering, the new water resource is well suited. When surface water becomes unavailable during dry season, abstraction of groundwater assures the investment and food provision. In fact, Giordano (2006) even argues that the use of groundwater for livestock has a greater support to rural livelihood than for the crop production. Although this would speak in desfavour of the groundwater use for irrigation, this can not be evaluated in this paper due to a lack of data for the CEB.

Regard to urbanisation, another contribution is that rural exodus could be contained: an exodus that causes especially in Windhoek problems and depts (FOCUS, 2012). Many people, especially men move to the cities in hope of work, as the recent numbers of population growth in the CEB cities indicates (RAISON, 2011f). But if new income

[3] „Green Scheme Project means an initiative conceptualised and introduced by the Government of the Republic of Namibia (GRN) and implemented by the Ministry to encourage the development of irrigation-based agronomic production within the agro-industry in Namibia with the aim of increasing the contribution of agriculture to the country's Gross Domestic Product" (Hansen and Kathora, 2013, p. vi).

[4] The groundwater in the Ohangwena II aquifer is under pressure. This means if a borehole is drilled, the water level in the borehole will rise up to 15mgbl in this case.

activities can be created and infrastructure expanded in the rural areas, people may stay there.

Another use of the aquifer could be for a back-up of water for an area that is currently supplied mostly by surface water. Because intermittent droughts and unreliable rainfall are normal and to be expected, groundwater should according to Christelis (2011, p. 7), "be preserved and protected as an underground treasure, as a strategic reserve for drinking water supply in prolonged periods of drought and for future generations". Researcher estimate that the Ohangwena aquifer could act as a natural buffer for up to 15 years of drought (McGrath, 2012). Especially as extreme variation between droughts and flooding will be amplified by climate change. The aquifer could be helping people to cope with climate change as groundwater system respond more slowly to climate change than surface water (Ministry of Environment and Tourism, 2011, p. 72). Increasing temperature will affect renewable groundwater replenishment by 30-70% across Namibia (Ministry of Environment and Tourism, 2011, p. 6) and at the same time, water demand by livestock, farmers and nature will increase. In this case having a back-up of stored water is an advantage to assure living conditions and access to water supply as well as guaranty to maintain agricultural production also during extreme weather events.

Altogether the use of the new water source in the respective area signifies security and support to development in the rural north-central region of the CEB by ensuring water supply in case of extreme weather. In addition, it could be a spur and an opportunity to development the infrastructure and markets in the rural north-central region. Higher income generating economic activities for marginalised groups and investment in the infrastructure that relies the rural area better to the urban services and markets are just some possible consequences that creates also for future generation a basis of life.

Extending the scope of analysis, in term of maximum economic productivity and geographic area, the groundwater use for the mining industry seems reasonable to suppose. At the same time in terms of social equality the groundwater use for mining is questionable. At present, the main source of foreign earnings for Namibia is the mining industry, particular the uranium mining. Uranium mines are found in the western parts of the country near Walvis Bay and Swakopmund. They all require water. At the moment, most water comes from the Kuiseb and Omdel groundwater resources (Namibweb, 2012) but also water from the Erongo Desalination Plant is used. A future development of the mining sector is probable, Forsys Metals Corp is planning two new uranium mines (Gordon, 2012), but will depend of the extension of the water resource. NamWater is planning a 50 Mm^3/yr desalination plant (Hartman, 2011). But desalinated water plants need a high investment and are expensive to run. Alternatively, abstracting 50 Mm^3/yr from the Ohangwena II aquifer, the resource could last some 100 years. The necessary knowledge for a 881 km long pipeline construction, is available in Namibia but skirting the Etosha National Park seems prohibitive (Sorensen, 2013, p. 173). According to Sorensen (2013, p. 174), a more reasonable solution would be the supply of the mining town of Tsumeb (320 km by road from the aquifer), at the centre of a flourishing farming area, although they have enough groundwater resources and rain due to the nearby mountains. However chemical used at the copper smelter contaminate the local groundwater around Tsumeb (Mendelsohn et al., 2013, p. 97).

The groundwater could also be a lift for the up swinging tourism industry in the Etosha Pan. New lodges have been installed for the 200’000 overnight guests visiting per year (RAISON, 2011h). Giving the relatively high average water demand of 210 L/day per tourist, the development of this sector depends among other factors, on water availability. The CEB tourism focus on wildlife and recently, also on cultural and craft-based attractions in conservations, community forests and elsewhere, which creates a new income opportunity for the rural population.

For a long time, new water resources were sought to cover the increasing water demand in the CEB. One project, existing since 1970, was a dam on the Epupa Waterfalls at the Kunene River (FOCUS, 2012). It has not yet been realised because the Himba people have formed resistance. The dam would flood and destroy their pastureland and ancestors’ tombs, which have a central role in their religion and rituals. The use of the Ohangwena II water would allow protection of the cultural values and life-style of the Himba people.

The fact that the government promotes Basin Management Committee and conducts the research in cooperation, develop the capacity among young and local Namibians to manage their country’s water resources and raise public awareness on the sensitive topic. It allows to involve users and other stakeholders at the lowest possible level (Amakali and Shixwameni, 2003). Also regional cooperation with neighbouring countries might be attractive (Sorensen, 2013, p. 174). Supplying water to the nearby countries of Angola, Botswana, Zambia and Zimbabwe could be interesting and promote friendly relationships in the south-western and south-central region of Africa by contributing to water safety for all.

In general, society will need to undergo rapid technological advancement with regard to the development of new water resources and the development of more efficient water conservation and re-use practices. Utilization of non-renewable groundwater is viewed as a transitional step in societal development (Issar, 2008, p. 1231).

In conclusion, improving people's living conditions by increasing the security of access to water supply, creating economic and social opportunity and participation of all user group can be fulfilled and by consequence the possibilities that Ohangwena II aquifer opens, are quite massive and real chance for sustainable development. However everything depends on the implementation of the management by the Basin Management Committee and the extraction plans, which are at present in process. Important is that until a realistic plan is presented, abstraction of the fossil groundwater is absent.

2.2.2 Challenges

The discovery of the aquifer is recent and many aspects of the characteristics of the aquifer are still unknown. In this part, some possible challenges such as technical difficulties for exploitation or the demand management should be highlighted. In addition, based on the literature and the practise some solutions will be presented.

First of all the assumption that there is no urgent need at the moment to exploit the groundwater of the Ohangwena II aquifer has to be considered carefully. NamWater (2015) presented a strategic assessment of the CEB and focused on medium to long terms solutions. Their argument is that the current water use from the Kunene River (80 Mm^3/yr) is just 42% of Namibia's allocation (NamWater, 2015, p. 2). According the assumed water use of 145 Mm^3/yr in 2050 (corresponds to 77% of Namibia's allowable off take), the Kunene River should be able to supply the CEB for at least the next 50 years. The exploitation of non-renewable groundwater could allow the country to temporarily continue to rely upon inefficient agricultural operations and retard social, economic and technical development because "too much" water would be available, according the NamWater estimations. Reliance on non-renewable resources could thus potentially be detrimental to a society. However only a small part of the population benefits from that pipeline water and better and more reliable water distribution is needed. A trade-off exists between a short-term groundwater supply to these rural people and time for further investigation to complete the missing geological and technical of the aquifer.

According to Lindenmaier (2014, p. 1326), "much more data on the distribution of subsurface stratigraphic units and about the sedimentological environment under which they formed" are necessary. The Ohangwena aquifer, a complex system of stratified aquifers containing fresh to saline water, has not yet been object of a conceptual model regarding the spatial distribution of fresh and saline water. Moreover, the distribution of depths and potential yields of the different layers are not yet known (Expanded Academic ASAP, n.d.).

Lindenmaier (2014, p. 1326) expects that groundwater resource availability could be increase with further exploration of KOH II towards the east. It is assumed that a slow recharge has been going on since aridity diminished about 1 million years ago and that the saltwater aquifer was slowly refreshed. Kluge (2012) indicates with many raised unanswered questions the knowledge gap that exists around the Ohangwena II aquifer : "Does fresh groundwater flow in i.e. is the renewal rate dynamic and adapts to the degree of use or do we need to wait 10,000 years? Is there the risk of decreasing pressure, accompanied by sinking groundwater levels? How and with the help of what kind of monitoring system can this kind of complex system behaviour be tested and assessed? Might the salty and sweet water mix due to the change in pressure or due to failures in handling the technical equipment?"

As long as the mechanism of groundwater recharge is not entirely understood, fossil groundwater has to be handled with care and a more detailed understanding of the whole sedimentary system of the Kalahari Sediments is required.

These missing data are fundamental for a sustainable management of non-renewable groundwater to assure an ecological and economic assessment of the consequences as well as the determination of the "exit time". The establishment of a monitoring system for the quantitative assessment of the available resource is therefore absolutely necessary. The natural pressure that the water is under means that it is easy and cheap to extract the groundwater because the water will climb automatically up to 15 m under the ground level (FOCUS, 2012). But as a smaller salty aquifer sits on the top of the new discovered one, unauthorised and random drilling could threaten the quality of the water. Quinger warns: "If people don't comply with our technical recommendations, they might create a hydraulic shortcut between the two aquifers which might lead to the salty water from the upper one contaminating the deep one or vice versa." (McGrath, 2012). Therefore a state authority has to monitor the drilling. Random private drilling has to be avoided.

Apart of the technical extraction of the groundwater, impacts of the aquifer development is mainly linked to aboveground infrastructure and logistics. According to an expert report, the major challenge in the CEB is not the availability of the water but the "upgrading and maintaining of the vast distribution network, expanding of the water services network and ensuring that water quality is maintained" (IWRM Plan Joint Venture Namibia, 2010, p. 23). High investments of 2.5 million Euros are required to drill boreholes, to install pump sets and construct wells. On top of this, surface infrastructure has to be renewed or built. As it is mainly recommended by the theory, the national authorities should do the monitoring and management or if done by Basin based committees; activities should be coordinated on higher national level.

Although water quality of the KOH II is generally good, in some areas water treatment will be necessary (IWRM, n.d.). High fluoride content (3 mg/L), affecting teeth and the development of children's bones, were found in water samples in the eastern and southern parts of the KOH II aquifer towards the Etosha Pan and Oshivelo aquifer in the south (see Figure **12**). According to IWRM (2010, p. 36), a solution of unconventional water resources could consist of mixing potable water with brackish water to improve quality.

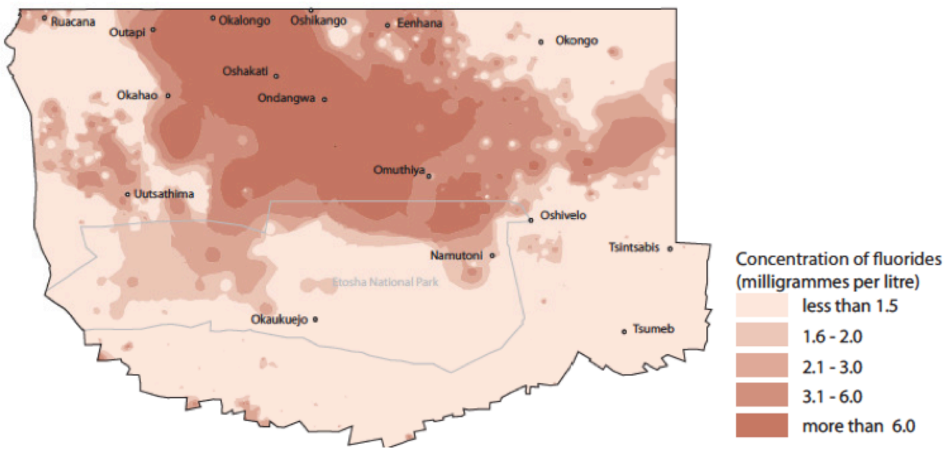

Figure 12: Fluorides content in the CEB (Mendelsohn et al., 2013, p. 95)

But not only the offer has to be managed, also the demand management in the agricultural, industrial, mining and tourism sectors is very important so that water use efficiency can be assured. The Namibian Ministry of Environment and Tourism (2011, p.

74) suggest for example that livestock numbers and their water demand should be closely monitored and large irrigation projects have to be reviewed. Alternatively resources should be allocated to introduce more efficient irrigation techniques such as drip irrigation or the use of grey water for irrigation, and crops that add more economic value.

So far there is no water recycling in the CEB (NamWater, 2015). Water reclamation and reuse should be considered in larger urban areas in the CEB. Windhoek has such a sewage recycle plant (Kings, 2016). Good examples of water recycling processes in the mining industry at large scale can be found in Namibia and applied to the CEB (World Nuclear News, 2013). In the tourism sector, where demand is expected to increase significantly, demand management has to focus on sensitizing staff and tourism operators on water use efficiency. In addition, purified sewage could be reused for golf courses and sport grounds or wastewater effluent standards adjusted to potable water. But also forms of appropriate dry sanitation must be pursued.

Even tough environmental impacts of the exploitation of the non-renewable groundwater can almost be ignored, the increased attractiveness related to the new development, attracts inevitable a bigger population to the Ohangwena region and with it increasing the environmental impacts (Sorensen, 2013). Their land-use practices and intensified irrigation can lead to erosion because of over-grazing and deforestation, which is already now a problem (RAISON, 2011c).

Finally, one aspect must not be forgotten, the Ohangwena aquifer is a transboundary aquifer (TBA)[5]. Although only a few people are living on the Angolan side (30% of the people living in entire CEB), a unilateral extraction of the groundwater could lead to a water conflict with the neighbouring country. No research has been done on Angolan territory so far and little research has been done on the management of transboundary aquifers (Altchenko and Villholth, 2013). However it is acknowledge that a flexible and hybrid institutional model that builds on making basin organisations responsible may be necessary. Namibia has an interest not to annoy its northern neighbour because at present Namibia is dependent on Angola's goodwill for the water supply in the northern and eastern parts of Namibia from the Kunene River, the major water source for the region. Much remains to be defined for instance how duties and responsibilities will be shared between Basin Management Committees (BMC), and how coordination will be

[5] A TBA refers to „an aquifer or an aquifer system, parts of which are situated in different states" (Villholth and Altchenko, 2014, p. 1).

arranged among institutions on a transboundary but also regional and national level (Amakali and Shixwameni, 2003, p. 1061)

In conclusion, it is very important that population's access to clean water does not dependent on just one source and that the precious and future generations' natural resources is not used up irrevocably. New economically and ecologically viable methods of providing water should be developed, such as artificial groundwater recharge, reuse of treated wastewater or mixing of water to improve quality, in order to avoid long-term supply bottlenecks and ecosystem disruption.

Conclusion

The Ohangwena II aquifer contain only on the Namibian side 5 bm^3 fresh drinking water. At the first glance, this huge amount of water represents a unique opportunity for one of the driest countries in Africa, especially the north of Namibia, where extreme weather conditions such as pronounced droughts or floods are normal and where most of the population relies on agriculture and livestock farming. Extreme weather phenomenon can lead to a complete failure of the water supply system in the whole CEB. Several possibilities of water use were discussed in the paper to support a sustainable development of the CEB. However most of them were not reasonable regarding the criteria of sustainability. That is why the groundwater resources of the Ohangwena II aquifer should be used as a buffer for the main water supply by pipelines and canals, as enormous amounts of groundwater are available and as climate change has a limited impact on its disposability.

However a long-term use of the groundwater resource for the regional water supply or for the intensification of the agriculture and industry should not be planned. Because of the very low recharge per year and therefore the sustainable use trough overexploitation and the quality of the resource threaten. This means that non-renewable groundwater can help to fill a lack of water resource in emergency cases and to avoid the worst, however it seems that it cannot be seen as a spur for a sustainable development. In other words, innovative ideas in water use and water purification are required to assure water supply, which is a condition for the country's development. The value of non-renewable groundwater must not be overestimated.

These results contribute to the discussion if and how non-renewable groundwater can contribute to a regional development. Furthermore, it illustrates on a practical example the extent of the analysis. Across the theory and the Ohangwena example, it as been shown, that the discovery of non-renewable groundwater raises hopes for development in the region. Nevertheless the challenges are huge. To create an encompassing abstraction plan is a complex task, as this paper has shown partly. It is linked to many different domains such as economy, society and politics, with the requirement of the specific experience, skills and technical knowledge. The covered aspects in this paper are not exhaustive. For example, the aspect of institutional structure to assure participation of the poorest and marginalised, and just and effective decision-making goes beyond the scope of the paper because of lack time and data. The same is also true for the follow-up strategy.

At the moment, according to Christophe Lohe, Senior Hydrologist of the BGR, the small city of Eenhana (5600 habitants in 2011) uses the groundwater of the Ohangwena II aquifer since 5 years for the urban water supply. An additional well field for emergency supply was installed 2014, however this is not yet integrated to the national supply system. To analyse this case would be a further research topic. BGR is evaluating at presence the consequences of higher extraction rates, which shall be handed over to the Namibian government for further decision about supply options.

It is hoped that the value of the non-renewable groundwater is acknowledged in realistic terms and that a controlled and planned use results as a model practice for other non-renewable groundwater aquifers.

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