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Faculty of Tropical AgriSciences

Department of Sustainable Technologies

Potable Water Sources in Windhoek, Namibia

Bachelor thesis

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Author:	**Supervisor:**
Jiří Rohovský	doc. Ing. Vladimír Krepl, CSc.

Declaration

I honestly declare, that I have written the thesis called Potable Water Sources in Windhoek, Namibia only with my own knowledges and with the literature mentioned in the list of references.

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Jiří Rohovský

I. Acknowlidgement

I would like to say big thanks to all my family members for their never-ending support not just while I was writing this thesis, but during all my bachelor study. Special thanks belongs to my supervisor doc. Ing. Vladimír Krepl, CSc., who helped me to watch the right way and gave me worth advices.

II. Summary

Potable Water Sources in Windhoek, Namibia

This bachelor thesis is a literary research dealing primarily with the quantity and quality of drinking water in Windhoek, the capital of Namibia. In the first part, the thesis dealt with general but related information, whether for example climate or economic aspect of the state.

It describes the water shortage situation in which Windhoek is located, its current sources of drinking water and its quality. There are mentioned the technologies used here for the recycling and reusing of wastewater as drinking water source. Described water recycling processes in thesis are pre-ozonation, flotation, rapid sand filtration, filtration through biological and granular carbon.

The work also noticed the contents of water and the characters of water that determine its quality. These substances are the total dissolved solids, total suspended solids, the electrical conductivity, acidity, fecal coliform, the total and free chlorine content.

In the last part of the thesis offers partial solutions in the process of increasing water shortage, which can be implemented in the future.

Key words: Water, Water purification technologies, Windhoek, Namibia

III. Abstrakt

Zdroje pitné vody ve Windhoeku v Namibii

Tato bakalářská práce je literární rešerší zabývající se především množstvím a kvalitou pitné vody ve Windhoeku, hlavním městě Namibie. V první části se práce zabývala obecnými, avšak s tématem souvisejícími informacemi, ať už například klimatickou, nebo ekonomickou stránkou státu.

Byla popsána situace nedostatku vody, ve které se Windhoek nachází, jeho současné zdroje pitné vody a její kvalita. Jsou zmíněny technologie, které se zde využívají k recyklaci a opětovnému využití odpadní vody, jako zdroje vody pitné. Při recyklaci vody jsou užity postupy pre-ozonizace, flotace, rychlé pískové filtrace, filtrace přes aktivní uhlí.

Práce si rovněž všímala obsažených látek a vlastností vody, které určují její kvalitu. Těmito jsou celkový obsah rozpuštěných látek, celkový obsah organických a anorganických látek, eletrická vodivost vody, acidita, koliformní zněčištění, obsah celkového a volného chloru.

V poslední části práce nabídla částečná řešení při zvětšujícím se nedostatku vody, která mohou být v budoucnu implementována.

Klíčová slova: Voda, technologie purifikace vody, Windhoek, Namibie

IV. Content

V. List of tables and figures

VI. List of abbreviations

BAC	Biological activated carbon
DSC	Dissolved solids content
EC	Electrical conductivity
FCR	Free chlorine residual
GAC	Granular activated carbon
GDP	Gross domestic product
GWRP	Goreangab Water Reclamation Plant
LDCs	Least developed countries
m^3/d	Cubic meter per day
MED	Multiple-effect distillation
mg/l	Milligrame per liter
Mm^3/a	Thousand cubic meter per year
MSF	Multi-stage flash
mS/m	Milisiemens per meter
PAC	Powdered activated carbon
ppm	Parts per million
RO	Reverse osmosis
RWH	Rainwater harvesting
SWAPO	South-West Africa People's Organization
TDS	Total dissolved solids
TSS	Total suspended solids
WDM	Water demand management
WINGOC	Windhoek Goreangab Operating Company
WRM	Water Resource Management

1. Introduction

There is no life without water. Nobody can make this state false. We, humans, need water to exist. A human body includes up to 60 % of water. Without water we can not survive. We can say that supplies of drinking water are all over the world smaller than it used to be. This could be caused by many factors. Polluting water sources, spreading of drought areas, some scientists say it has something to do with global warming.

The human population uncontrollably increases and it brings many issues and unanswered questions. Especially in least developed countries (LDCs) we can observe this trend. Many African families from rural areas have more children, than are they able to sustain. Together with spreading drought, diseases, polluted environment and other factors in Africa they will have less chances to improve the quality of life.

If we focus on Namibia, we find out, that the number of inhabitants increased since year 1988 till 2017 twice, up nowadays more than 2.5 milions people. Other African countries have similar trend of increasing population. And many people does not have basic access to drinking water.

Southwestern Africa is a poor with water sources. Even the cities of central Namibia, Okahandja and the capital Windhoek, which used to be out of the most arid areas, are today stroke by droughts. If there are any water sources, it is needed to use and keep them smartly and in any cases do not waste the water.

There exist some modern technologies, how to get and keep the drinking water. It should be a role of developed countries to impelemnt such technologies to LDCs. To bring modern technologies and knowledges to LDCs and educate local people how to use and provide sustainability of such technologies. There it is not just only question of implementation of technologies. Especially the households in rural areas, which does not have an access to drinking water, should keep some rules and probably change some strategy to sustain better living conditions. Developed countries can bring their know-hows, but the main task is up the local people and the authorities.

2. The Aim of Thesis

Aim of this thesis is to find and collect data related with the lack of water in Windhoek, the capital of Namibia. Thesis will collect the data about water sources and processing the water. There will be reviewed scientific professional papers, articles related to the topic and other relevant sources.

3. Methods

The structure thesis is as follows.

The first part will inform about the background in Namibia in different ways, such as geography, economy, industry and others.

The second part deals with collecting datas about sources and quality of potable water in Windhoek and their analyzation.

The third part will deal with the proposal of an upgraded technology that can be used for this region.

Methods of measuring some parameters like the Total Dissolve Solids (TDS), Total Suspended Solids (TSS), Electrical Conductivity (EC), Acidity (pH), fecal coliform, total coliform, total chlorine, free chlorine and others will be in thesis describe as well.

4. Literature Review

4.1 Background of the Republic of Namibia

4.1.1 Basic informations

South Africa occupied the German colony of South-West Africa during World War I and administered it as a mandate until after World War II, when it annexed the territory. In 1966, the Marxist South-West Africa People's Organization (SWAPO) guerrilla group launched a war of independence for the area that became Namibia, but it was not until 1988 that South Africa agreed to end its administration in accordance with a UN peace plan for the entire region. Namibia has been governed by SWAPO since the country won independence in 1990, though the party has dropped much of its Marxist ideology. Prime Minister Hage GEINGOB was elected president in 2014 in a landslide victory, replacing Hifikepunye POHAMBA who stepped down after serving two terms. SWAPO retained its parliamentary super majority in the 2014 elections and established a system of gender parity in parliamentary positions ("CIA" 2018).

4.1.2 Geography

The country of Namibia spreads on the southwestern shore of Africa sharing the borders with Angola on the north, Zambia on the northeast and Republic of South Africa on the south. The Atlantic Ocean coasline, which stretches in whole west side of Namibia, is more than 1500 km long. The total area is 824 292 km^2 including 1 002 km^2 of the water areas. The country has three broad zones: the Namib Desert to the west; the Kalahari Desert to the east; and the Central Plateau. The plateau, made up of mountains, rocky outcrops, sand- filled valleys and undulating upland plains, covers over 50 % of the land area. It includes Windhoek, the capital, and slopes eastward to the Kalahari Basin and northward to the Etosha Pan, the largest of Namibia's saline lakes. The Skeleton Coast, from Swakopmund to the northern border, is a waterless stretch of high sand dunes pounded by a high surf, much celebrated in tales of the sea. The Kaokoveld Mountains run parallel, covering 66 000 km^2. Shifting sand dunes of the Namib Desert spread inland for 80–130 km, covering 15 % of the land area. ("The Commonwealth: Namibia" 2018).

4.1.3 Climate

We can describe the climate conditions in Namibia as an arid, semi-arid and sub-humid. Prolonged periods of drought are characteristic. There is little precipitation apart from rare thunderstorms in the arid zone of the Namib Desert coast, with rainfall rising to 600 mm or more in the sub-humid north- eastern border with Angola and the Caprivi Strip. Rain falls in summer (October to April). The cold Benguela current gives the Namib Desert thick coastal fog. ("The Commonwealth: Namibia" 2018). Temperature differences in year seasons are not significant.

The impact od the dry climate has the Kalahari Desert on the east of the country as well.

4.1.4 Soils

Over 70 % of Namibia’s surface area can be classified as highly susceptible to erosion activities, making soil development very difficult in general. According to the FAO soilclassification system, out of the 30 major reference soil groups the following do occur throughout Namibia: Acrisols, Arenosols, Calcisols, Cambisols, Ferralsols, Fluvisols, Gleysols, Gypsisols, Leptosols, Luvisols, Phaeozems, Regosols, Solonetz, Solonchaks and Vertisols. By far the most common soils are Regosols, Arenosols and Luvisols. Their main characteristic features include: high sand stratum, low nutrient content, low organic content, alkaline pH-conditions, typical for arid climateconditions with high evaporation rates, as well as high salinity. These soil groups in Namibia almost follow the major geomorphological and geological boundaries. The largest variety of different soil groups such as Cambisols, Luvisols, Acrisols, Regosols, Gleysols, Solonchaks and Solonetz, occurs within thecoastal zone, the Namib and the Kalahari areas, whereas the central mountainous plateau, between the Namib and the Kalahari Basin, is dominated mainly by Acrisols, Cambisols and Luvisols (Christelis & Struckmeier 2011).

4.1.5 Economy

Gross domestic product (official exchange rate) reached in Namibia US$ 12.56 billion with the real growth rate 0.8 %. With only 6.6 % participates the agriculture. Bigger part of the gross economy product makes industry (25.6 %). The services makes the majority, 67.6 %. Namibia’s economy is heavily dependent on the extraction and processing of minerals for export. Mining accounts for about 12.5 % of gross domestic product (GDP), but provides more than 50 % of foreign exchange earnings. Namibia exports worth commodities such as diamonds, copper, gold, zinc, lead, uranium and others mostly to Europe and South Africa.On the other side needs to import foodstuffs, petroleum products and fuel, machinery and equipment, chemicals (“CIA: Africa: Namibia” 2018).

4.1.6 Agriculture

The agricultural area in Namibia was 38 809 ha in 2015. That is a half of total Namibian area ("FAO" 2015). Crop export consists mostly of millet, sorghum, peanuts and grapes. Than Namibia exports livestock and fish. The biggest importer of Namibian livestock is the Republic of South Africa. Cattle raising exists especialy in the central and northern areas, where are better climate conditions. Up to 4 000 farmers is raising the cattle ("CIA: Africa: Namibia" 2018).

4.1.7 Industry

Industry production growth rate was 2.2 % in 2017. In industry works 14 % of Namibians. There are factories for fish processing, meat packing, dairy products, beverages. Probably the most important part of the industry is a mining. Mining of commodities mentioned above – diamonds, gold, silver and other worth metals ("CIA: Africa: Namibia" 2018).

4.1.8 Political and socio-economic situation

Namibia was from late 19th century untill 1915 colony under German government. This year South African Union assumed Namibia and held it untill year 1990, when Namibia became independent. Namibians immediately began to build their own sovereign state. Nowadays, Namibia is a stable country. Most spreaded religion is a Christian (up to 90 %). More than 85 % habitants are black, only 6 % white. There is a plenty of different ethnic groups, tribes. Half of the Namibians belongs to Ovambo tribe. Used languages are English, German, but most of the people speaks Oshivambo and other African languages ("CIA: Africa: Namibia" 2018).

4.2 Windhoek

As it was mentioned above, Windhoek is the capital and the biggest city of Namibia. Situated in the Khomas region in central highlands of Namibia, approximately 1600 m above sea level. The average annual rainfall is 340 mm, while the average evaporation is 3 400 mm. In 2011, population was more than 325 000 citizens ("The Commonwealth: Namibia" 2018). From a social standpoint, the city still reflects the legacy of apartheid, with suburbs classified by housing typology. The low-income population thus tends to be concentrated in the northern and western parts of the city, while the high-income neighbourhoods are located in the south and east (Lafforgue & Lenouvel 2015). The city is a center of a religion representatives, food and heavy industry, business center.

4.2.1 Geomorphology

Windhoek is situated in a valley surrounded by the Auas, Eros and Otjihavera mountains, which form the country's central watershed from where large river systems radiate in all directions. The Swakop and Kuiseb rivers flow to the north and west, while the Oanob drainsto thesouth and the Nossob and Olifants to the east. The Windhoek valley is a geological graben structure bounded by north-south striking fault systems in the east and west. The Khomas Hochland is a deeply dissected mountainland of intermediateelevation, wherethe geomorphology is closely related to the underlying geology. The fracture pattern of the Kuiseb schist determines the direction of the drainage system. The area has a thin soil cover and supports a thornbush savanna, which is ideal for cattle ranching. West-flowing rivers havecarved deep gorges (e.g. Kuiseb canyon) across the Khomas Hochland, especially wherethey break through the Great Escarpment. The central part of the Namib Desert is characterised by gravel plains and rocky outcrops. The dune field along the coast between Swakopmund and Walvis Bay is an extension of the Namib sand sea. Morphologically, the Central Namib is a steeply inclined plain, rising from sea level to 1000 m in less than 100 km. There is a conspicuous gap in the Great Escarpment in this area and in its place areisolatedmountains and inselbergs like the Erongo, Spitzkoppe and Brandberg. Soils are absent on rocky slopes, which are often covered with weathered material, while the soils of the Namib gravel plains are generally rich in gypsum. Calcrete covers a large part of the transition zone between desert and savanna (Christelis & Struckmeier 2011).

4.2.2 Water supply in Windhoek

The water supply for the city is sourced primarily from groundwater, reclaimed wastewater and surface water purchased from Nam Water Company. Due to the strong demographic increase in 1990s was needed to rebuild and modernize the infrastructure of Windhoek. Therefore the city signed a contract with WINGOC (Windhoek Goreangab Operating Company) consisting of companies Veolia, Berlinwasser international and WABAG. The aim of WINGOC was effective water processing and to increase capacity of the Goreangab Water Reclamation Plant (GWRP). Since it has started working (in 2002), the GWRP covers 35 % of the consumption in the city and the suburbs as well. That is 21 000 m^3 daily. The plant of this type was built as a first in the whole world. The process of water purification in GWRP will be described later.

Windhoek owes its existence to the presence of springs, which provided an ample supply of water when the area was first settled. The map below shows the position of springs and the Windhoek aquifer. Since the mostly thermal springs emerged from deep-seated faults in quartzites that form the main aquifer. The spring water contained traces of hydrogen sulphide and high concentrations of salts (890 mg/L total dissolved solids - TDS) (Kirchner & van Wyk 2011).

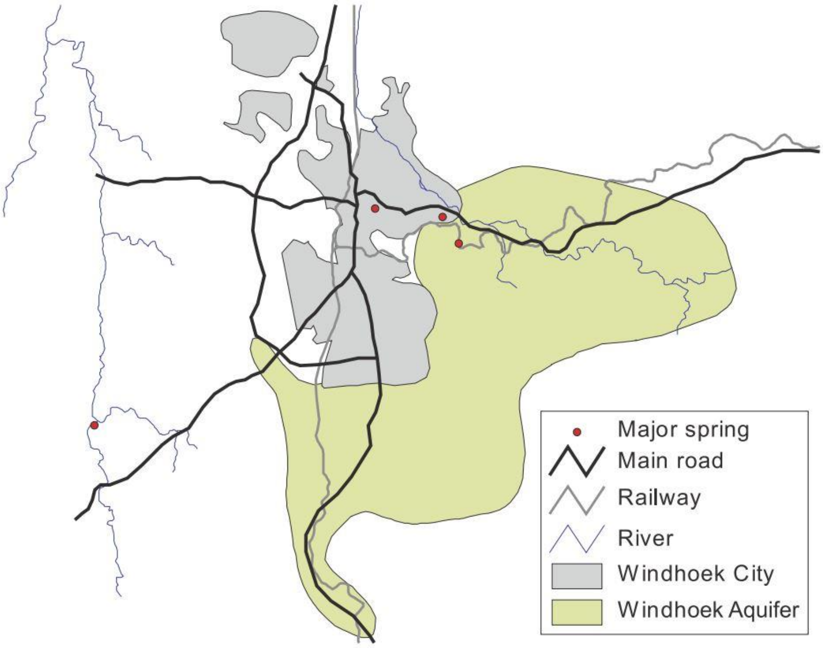

Figure 1: Map of Windhoek city and aquifer

(Kirchner & van Wyk 2011)

In the area of Windhoek, there is more dams. But only four of them work as a water supply for Windhoek and its suburbs. These are Omatako, Swakoppoort and Von Bach located 60 km to 200 km from the city. From the others is water taken for livestock rearing and other needs.

Against this background, water demand is continually escalating (up from 6 Mm^3 per year in 1968 to 27 Mm^3 per year in 2012). But there are very few local resources to cope with this trend: groundwater sources contribute only 1.7 Mm^3 per year to the water supply, annual rainfall is low (360 mm), evaporation levels are high (up to 50% of the dam storage capacity), while the city has no perennial rivers. In the 1960s, the city embarked on a drive to expand its supply sources, which today consist of surface and underground resources, as well as water reuse (Lafforgue & Lenouvel 2015).

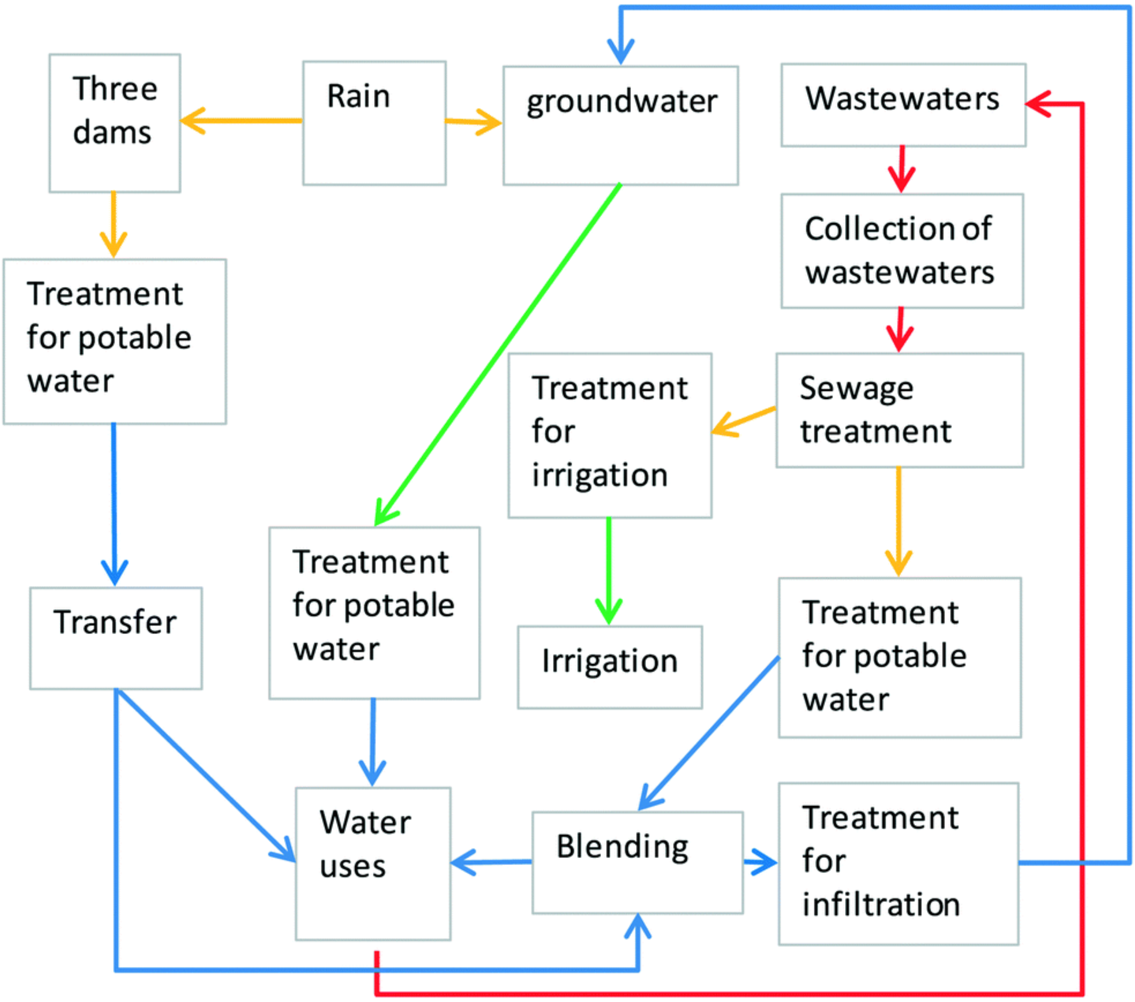

Figure 2: The Urban Water Cycle in Windhoek

(Lafforgue & Lenouvel 2015)

Figure 2 above is a clear scheme, how the water in Windhoek cycles. The fallen down rain water continues as a groundwater, or it is gathered in dams. After treatment of dam water, the water is ready to be used as a potable. After using, the water becames wastewater and there are two options. It can be treated and reused again or modified for irrigation. This is the most important message of the figure.

With normal inflow in the dams the supply capacity of the different sources is: NamWater (three dam system only) 17 Mm^3 Goreangab Reclamation Water Works 2.9 Mm^3 Windhoek boreholes 2.3 Mm^3 (IUCN Water Demand Management Country Study, Namibia).

4.2.3 Water Demand Management

In Windhoek, integrated Water Resource Management (WRM) is a part of a holistic approach towards sustainable development and use of water resources. This involves the implementation of policies for the efficient use of water, for equity, economic efficiency and environmental sustainability.

Water Demand Management (WDM) forms a crucial part of Integrated Water Resource Management with respect to efficient water use and economic and environmental sustainability.

The Namibian Government recognises the need to change the current supply driven approach to water resource management and that existing water supplies are limited and need to be effectively used. This marks an important change, where Namibian decision makers no longer exclusively resort to supply oriented solutions, but also accept new techniques to reduce the actual demand for water.

The WDM policy which was approved in 1996 was implemented over a period of 5 years since 1997. The wide range of demand management measures were classified in Windhoek as policy issues, legislation, technical issues and public education and awareness.

The water demand management programs of the Municipality of Windhoek are financed by a levy on the income from water. At present, this levy represents less than 1 % of the total income from water and is the equivalent of 4.2 cents/m^3. Estimates of the amount of water that are saved as a result of WDM are given in Table 1 (IUCN Water Demand Management Country Study, Namibia).

Water Consumption	1995	2000	2005	2010	2015
No WDM (Mm^3/a)	21,1	26,7	34,6	44,4	57,1
WDM (Mm^3/a)	17,9	20,7	24,1	27,9	32,3
Savings (Mm^3/a)	3,2	6	10,5	16,5	24,8

Table 1: Water Demand in Windhoek, With and Without WDM

(IUCN Water Demand Management Country Study, Namibia)

The driving forces include the resultant increase in demand due to growing population, invariable and unpredictable rainfall that causes drought and high evaporation rates. Policy challenges for integrated water resource management and WDM can be summarised as follows:

- To ensure the efficient allocation and usage of water resources in the face of:
  - Growing water demands.
  - Water scarcity constraining economic activity.
  - The desire for sustainable development.
- To implement the tools of WDM in such a way as to be financially sustainable for the water supply institutions and equitable for water consumers.
- To incorporate WDM in the planning process for countrywide water supply planning.
- To ensure that environmental issues and sustainability are included in the framework for WDM policy. Pertinent environmental issues include:
  - Groundwater linkages to the environment.
  - Downstream effects of abstraction from perennial rivers.
  - Downstream effects of dams on ephemeral rivers.

(IUCN Water Demand Management Country Study, Namibia).

4.2.4 Water treatment plants

Water treatment plants are owned by the city of Windhoek, but trey are operated by private companies.

Von Bach treatment plants, Goreangab Water Reclamation Plant and Ground water boreholes are drinking water treatment plants. Then the waste water treatment plants are Gammans and Otjomuize water care works.

4.2.5 Goreangab Water Reclamation Plant

This plant was briefly described in the chapter Water Supply in Windhoek. Water reclamation plant for the production of potable water for Windhoek, Namibia. The capacity of the reclamation plant totals 21 000 m^3/d. The raw water used consists of treated municipal wastewater.

The municipal wastewater from the region is conditioned in the Gammans treatment plant (nutrient removal with the UCT process) and polished in maturation ponds before being treated in an advanced multi-barrier system (NGWRP). This employs several barriers for all crucial contaminants and thus guarantees outstanding drinking water quality. Since start-up, all the relevant standards have been fulfilled without difficulty. Process steps are:

- Oxidation and pre-ozonation
- Powdered activated carbon dosing
- Coagulation and flocculation
- Dissolved air flotation (DAF)
- Dual media filtration
- Main ozonation
- Biological activated carbon filtration (BAC)
- Granular activated carbon filtration (GAC)
- Ultrafiltration
- Disinfection and stabilisation.

(“WABAG: Windhoek Goreangab, Water Reclamation Plant, Namibia”).

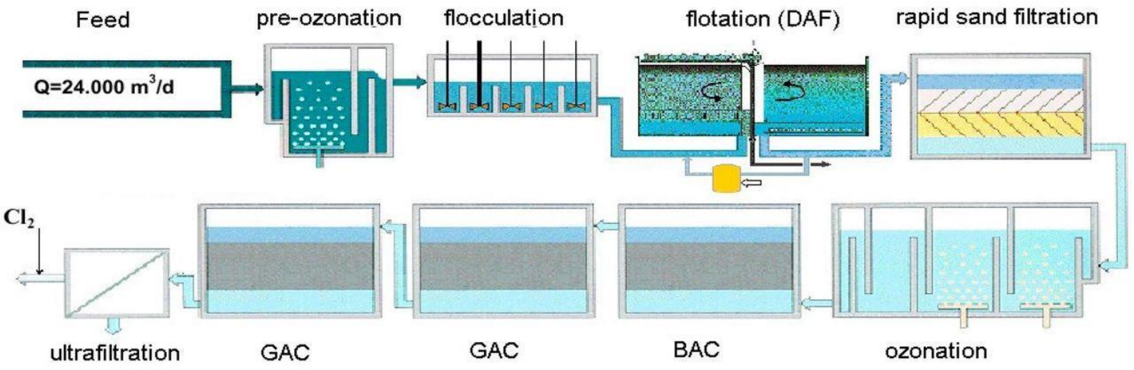

Figure 3: Flow schematic of GWRP

(Law et al. 2015)

4.2.6 Von Bach Treatment Plant

The Von Bach Water Treatment Plant produces potable water for the capital of Namibia, Windhoek, as well as for a number of other consumer points in the central part of the Khomas Region. The plant is situated downstream of the Von Bach Dam and 10 km south of Okahandja.

The Von Bach Water Treatment Plant was designed to produce 72 000 m³/day of potable water, although as a result of a variety of problems which had developed over the years, production was maintained at 55 200 m³/day.

The final analyses showed that the limiting factor on the extent of expansion was the supply capacity of the existing water resources. The design capacity of the upgraded plant was thus set at 156 000 m³/day.

The plant treats water from five different sources. The Von Bach Dam, water from Swakoppoort Dam, Omatako Dam, sub-surface water from Otaki/Grootfotein Karst area and water from Kavango River. Presently water from the first four sources can already reach the plant. Except for Swakoppoort water, which can be directly intercepted at the Treatment Plant before being mixed with Von Bach water, water from all the other sources must first flow through Von Bach impoundment where the different waters will inevitably blend. The following aspects were taken into consideration in the process selection:

- The dams are susceptible to high turbidity during periods of inflow. However, water is generally of medium turbidity and the TDS content is low.

- Algae blooms occur annually in all three dams.
- The water is fairly well buffered (59 to 146 mg/l, alkalinity variation for the three dams together).
- The water hardness ranges from 55 to 124mg/l, for the three dams together.
- Relatively high manganese content is encountered under certain conditions in the Von Bach Dam.
- The chloride and sulphate concentrations are low. Nitrogen and phosphorous are relatively low and the pH is generally in range of 6 to 8.
- Chemical concentrations are generally lowest in Von Bach Dam followed by Omatako Dam and are highest in the Swakoppoort Dam.

Chlorination of the water will kill the algae present but may give cause to the generation of taste and odour if these are not already present. Then the manganese precipitates can readily be removed by sedimentation or rapid gravity sand filtration. The efficiency of Powdered Activated Carbon (PAC) in removing taste and odour is reduced by coagulant dosing and the presence of free chlorine (Von Bach Water Treatment Plant 2018).

4.3 Water Purification Technologies

It is necessary to become acquainted with basic water purification technologies before making choices of adequate purification technologies for polluted water from Kenyan flower farms. This chapter is focused on the most common technologies for water purification and water treatment. There is a basic description of these technologies in the following subchapters. Some of these technologies require the pre-treatment of water. Flocculation, pH adjustment, sedimentation and filtration represent the most used pre-treatment technologies. However, vast majority of water purification technologies can work by themselves (Kraus 2016).

4.3.1 Pre-ozonation

The ozonation is one of the oldest desinfecting methods. Before era of industrial production of chlorine, it was the most used techlology for water treatment. Ozone as a very strong oxidizing agent is not used just for oxidation organic and inorganic compounds, but also for its good desinfecting features (Beneš & Hořava 2018). During the ozonation of water, there are no side unsolicited products, ozon is unstable and very quickly decomposes to moleculs of oxygen. It is used for ferrum, manganese and organic compounds removal (“Ekomonitor: Úprava vody” 2018).

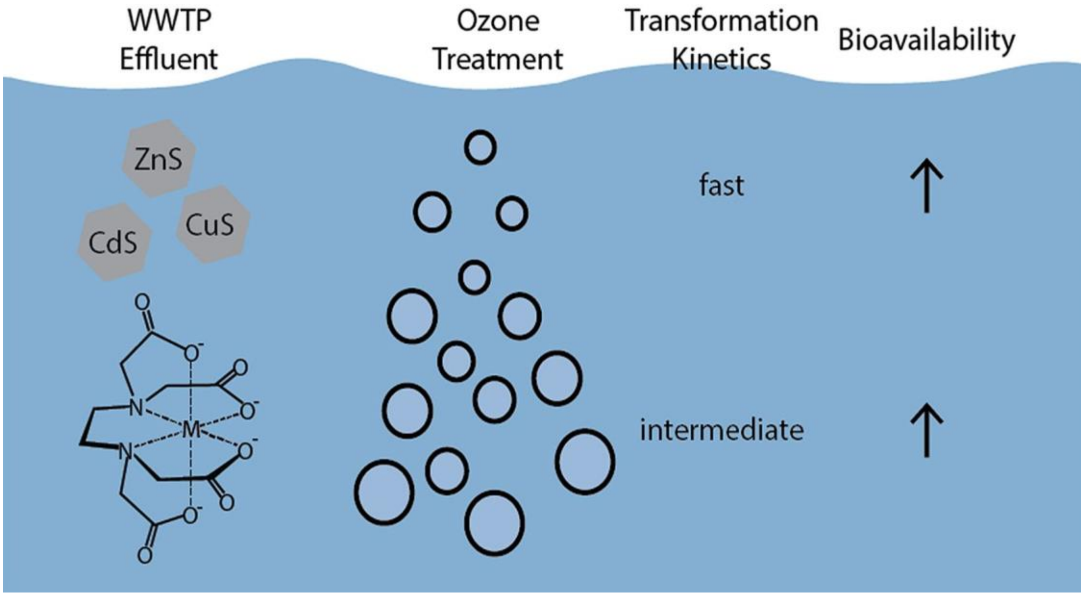

Figure 4: The Schema of Ozonation in Wastewater Treatment Plants

(Thalmann et al. 2018)

4.3.2 Flotation

The principle of flotation is the separation of solid or liquid particles from the liquid phase, which is accomplished by introducing fine air bubbles into the liquid phase. The bubbles adhere to the individual particles, creating bubble agglomerates-particles with a lower weight than the liquid. The buoyancy force of the agglomerates thus formed is large enough to cause the particle to climb to the liquid level. The particles are then removed from the surface by the collecting device as floating sludge (Biela 2012).

4.3.3 Rapid sand filtration

There are two kinds of sand filtres. Slow sand filtre and this rapid sand filtre, operating at higher rate about 25 to 50 times faster than the slow sand filtres. In rapid sand filtres the filter bads are small, ranging about 14 m^2 in small plants to 140 m^2 in large filter plants. These filters consist of a layer of sand or occasionally crushed anthracite coal. It is 45–60 cm deep, resting on graded layers of gravel above an under drain system. Several types of under drains are used in rapid sand filtres, such as perforated pipes, perforated false bottoms of concrete and tile and porous plates. Municipal and large capacity filtres for industry are usually built in concrete boxes or in open tanks of wood and steel. Rapid sand filters are a familiar and mature technology, but the mechanical sophistication they incorporate in industrialized nations limits their sustainable application in developing countries. Conventional rapid sand filters require pumps, elevated tanks, or multiple filter units to generate high flow rates for backwashing. Stacked rapid sand filtration is introduced here as a more robust and sustainable alternative. A stacked rapid sand filter can backwash itself with no additional flow, which eliminates the need for pumps or other expensive equipment (Adelman et al. 2012).

4.3.4 Biological and Granular Activated Carbon

Biological activated carbon (BAC) filtration is used for chlorine removal. Particles of carbon have a huge surface which helps to catch particles of herbicides, pesticides and other undesirable substances.

The biologically enhanced carbon process is an option for many water utilities. Granular activated carbon (GAC) has been used extensively for the removal of dissolved organics from drinking water. In the early seventies, it was reported that bacteria which proliferate in GAC filters may be responsible for a fraction of the net removal of organics in the filter. Following this discovery, pre-ozonation was found to significantly enhance the biological activity on GAC. The combination of ozonation and

GAC is commonly referred to as the biological activated carbon process, or biologically enhanced activated carbon proces (Dussert & van Stone 2000).

4.4 Water Quality

The injected water is fully treated potable water with very strict water quality guidelines that were developed to prevent the deterioration of groundwater quality and to minimize clogging of the boreholes and aquifer. The injectant is blended at a ratio of 3 to 1 from surface/dam water with reclaimed water. On average, its salinity has been 68 mS/m or 456 mg/L TDS and the Dissolved Organic Carbon (DOC) 4.9 mg/L The water blended with the natural groundwater, and to date, the recovered water has had an average salinity of 91 mS/m or 610 mg/L TDS and an average DOC of 1.1 mg/L (Murray 2017).

4.4.1 Total Dissolved Solids

Total dissolved solids (TDS) are made up of inorganic salts (mainly sodium chloride, calcium, magnesium and potassium) and small amounts of organic matter that are dissolved in water. TDS in drinking-water comes from natural sources, sewage, urban runoff and industrial wastewater. Some areas of the world have naturally high amounts of TDS in their drinking-water. Water with very high or low levels of TDS is often called “hard” or “soft” water, respectively. Hard water received this name because it requires more soap to get a good lather and makes the water “hard” to work with. Soap is less effective with hard water due to its reaction to the magnesium and calcium; this leads to high use of soap for laundry and bathing. As well, hard water can leave a residue and cause scale to build up on cooking pots and water pipes. People generally prefer the taste of hard water due to the dissolved minerals; however, very high concentrations of TDS can cause a bitter or salty taste. Soft water is usually preferred for laundry, bathing and cooking. However, water with extremely low TDS concentrations (e.g. rainwater) may be unacceptable because of its flat taste (Household Water Treatment and Safe Storage 2013).

The TDS concentrations of both the dam and reclaimed water fluctuate in accordance with the hydrological situation (annual rainfall), and the reclaimed water TDS standard (TDS = 1 000 mg/L) was exceeded temporarily on several occasions

(Lahnsteiner et al. 2018). Data from the California Mineral Taste Study (CMTS), which established a functional relationship between TDS and taste quality assessed by consumers and taste-panel members, are summarized. The CMTS data indicate that for mineral content a TDS of 450 mg/L will result in a good quality water and that a TDS of 80 mg/L will result in an excellent quality water. A cost comparison between systemwide demineralization and the purchase of bottled water by individual consumers shows that systemwide demineralization may be less costly to the residential consumer. Such information, when developed for a particular utility, can be presented to the community and used to make a propper decision regarding systemwide water treatment for reducing TDS to levels consistent with good or excellent water quality (Bruvold & Daniels 1990).

4.4.2 Total Suspended Solids

Total Suspended Solids (TSS) refers to all solids in a water sample that cannot pass through a 45µm filter. This ranges from dead plant and animal matter to non-biodegradable waste such as metals. High concentrations of suspended solids compromise stream health affecting aquatic life. TSS is capable of reducing the amount of light passing through the water, thus reducing the light reaching the submerged vegetation. This slows down photosynthetic activity, which results in less dissolved oxygen being released into the water by the submerged plants. Low dissolved oxygen in water leads to fish kills. Other effects of suspended solids include reducing clarity in the water (affecting the ability of fish species to see and catch food) and clogging of fish gills, causing morbidity and mortality. To prevent the effects of TSS, coagulation and flocculation processes with agents such as alum or ferric chloride are standard techniques in the water industry for removal of suspended solids during water treatment/ for wastewater treatment (Sibeya 2016).

4.4.3 Electrical Conductivity

Conductivity is the approximate concentration of electrolytes in water. It is ion-solubilized substances, all that meet in the subsoil and dissolve, except for gases. It therefore expresses indirectly the content of minerals („salts“) found in the water. Conductivity limit for potable water is 125 mS/m, which corresponds to the dissolved solids content of about 1 000 mg/l. However, optimaly drinking water should contain less dissolved solids, about 200-400 mg/l (about 25-50 mS/m). Waters with mineralization above 1000 mg/l are considered to be mineral and not suitable for constant drinking. Depending on the composition they may have an unpleasant taste or cause a diarrheal disease. There are often technical difficulties such as reducing the service life of pipes and hot water heaters (“Rozbor vody: Konduktivita” 2004). Electrical conductivity of water depends on geological subsoil as well. It is influenced by contained minerals. In the surroungings of Windhoek are quartzites, where the EC achieves 20–80 mS/m. EC on schichts is much higher (100–200 mS/m) (Murray 2017).

4.4.4 Acidity

pH refers to how acidic or alkaline a solution is; it is a measure of hydrogen ion activity in a solution. During the treatment process, pH allows dissolved waste to be separated from water, thus highlighting the importance of adding acidic and alkali chemicals to wastewater. Water contains positively charged hydrogen ions and a negatively charged hydroxide ions, in acidic (pH 7), contains an excess of negative hydroxide ions.

Different stages of the wastewater treatment require different pH concentrations. It is, therefore, necessary to adjust the pH in the treatment process to make the wastewater neutral. This is particularly important when biological treatment, as the microbes used in biological treatment require a pH in the range of 6-8 and may be killed by highly acidic or alkali wastewater. For example, the value of pH in GWRP is aroud 7.8 (Tredoux et al. 2009). Water pH can be used to kill off bacteria in wastewater, since the most common organic matter and bacteria are best suited to a neutral or slightly basic environment. At the end of a wastewater treatment cycle, pH must be raised back to neutral, as highly acidic water may continue to damage any living cell it comes in contact with (Sibeya 2016).

4.4.5 Fecal Coliform

There is no universal indicator to ensure that water is pathogen free, but there are several types of indicators, each with certain characteristics. Coliform bacteria are most commonly used as indicators because they exist in high ratios to pathogens, making them easier to detect in a water sample.

Most waterborne organisms that are harmful (pathogenic) to humans colonize the gut of humans and certain other mammals and are transmitted through the faecal–oral route. The transmission of common waterborne diseases can thus be interrupted by improvements in sanitation (excreta disposal), personal hygiene (especially hand washing) and microbiological water quality, while those that are water-washed are impacted by improvements in water supplies (quantity and access) for personal hygiene. Improving water supplies can also help prevent water-based diseases, such as schistosomiasis and dracunculiasis, by reducing the need to enter infected water bodies.

As water moves through the water cycle, it naturally picks up and carries many things along its path. Water quality naturally changes from place to place, with the seasons, and with the kinds of medium (rocks, soil, etc.) through which it moves. Water quality is also impacted by naturally occurring contaminants, including animal excreta.

Water can also be polluted by human activities, such as open defecation, improper waste management, poor agricultural practices (e.g. use of fertilizers or pesticides near water sources) and chemical discharges. In developing countries, an estimated 75% of all industrial waste and up to 95 % of sewage is discharged into surface waters without any treatment (Household Water Treatment and Safe Storage 2013).

The NamWater (Namibia Water Corporation Ltd.) has made a guidlines for evaluation of drinking water for human consumption with regard to chemical, physical and bacteriological quality. The bacteriological quality of drinking-water is divided into four groups, namely:

GROUP A: Water which is bacteriologically very safe
GROUP B: Water which is bacteriologically still suitable for human consumption
GROUP C: Water with a bacteriological risk for human consumption which requires immediate action for rectification
GROUP D: Water which is bacteriologically unsuitable for human consumption

DETERMINANTS (COUNTS)	**LIMITS FOR GROUPS**			
	A**	B**	C	D*
Standard plate counts per 1 ml	100	1000	10000	1000
Total coliform counts per 100 ml	0	10	100	100
Faecal coliform counts per 100 ml	0	5	50	50
E. coli counts per 100 ml	0	0	0	10

Table 2: Becteriological Determinants

(NamWater 1998)

* All values greater than the figure indicated.

** In 95% of the samples.

4.4.6 Free and Total Chlorine

When chlorine is added to water, some of the chlorine reacts first with organic materials and metals in the water and is not available for disinfection. This is called the chlorine demand of the water. The remaining chlorine concentration after the chlorine demand is accounted for is called total chlorine. Total chlorine is further divided into combined and free chlorine. Combined chlorine is the amount of chlorine that has reacted with nitrates and is unavailable for disinfection, whereas free chlorine is the chlorine available to inactivate disease-causing organisms. The presence of free chlorine residual (FCR) in drinking-water suggests the absence of pathogens. Thus, for water treated with chlorine products, FCR is one measure of drinking-water safety.

There are five main field methods to test for free and total chlorine residual in drinking-water. They are: 1) pool test kits; 2) paper strips; 3) colourchange test tubes; 4) colour-wheel test kits; and 5) digital colorimeters. Selecting the most appropriate method is dependent on a number of factors, including 1) need for accuracy, 2) cost, 3) number of samples to be tested and 4) how the data will be used. The most expensive methods (digital colorimeters and colour-wheel test kits) are more complicated to use, but provide more accurate quantitative information. The least expensive method (pool test kits) is simple to use, but does not provide accurate quantitative results. Depending on the needs of the programme, a simple presence/absence test may be sufficient, whereas in other contexts, quantitative data are required (WHO 2012).

4.5 Possible Water Sources

4.5.1 Rainwater Harvesting

Probably the most important attribute related to this topic is the average rainfall. As it was mentioned, the region of central Namibia is one of the driest in all country. Windhoek has dry periods in May, June, July, August, September and October. On average, August is the driest month. On the other side, on average, February is the wettest month. The average amount of annual precipitation is: 367 mm (World Weather & Climate Information 2018).

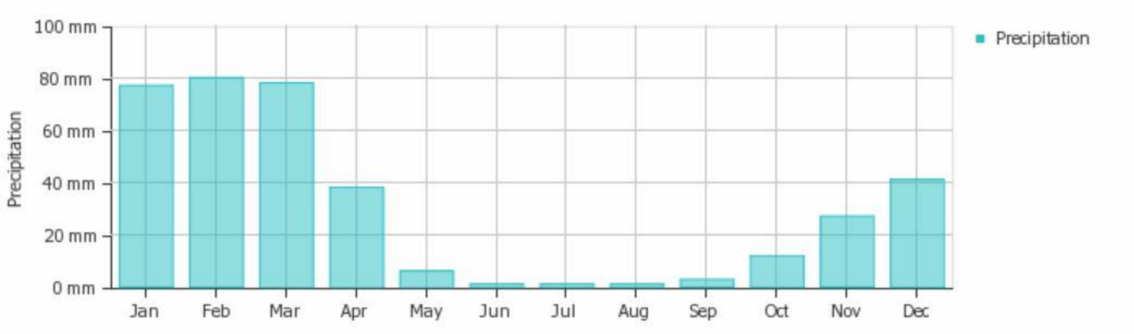

Figure 5: Average Precipitaton in Windhoek, Namibia

(World Weather & Climate Information 2018).

Then the diagram with the rainy days in each single month would look the same. Most rainy days are in January, February and March (up to 10 days), less rainy days are in October, November and December (3–8 months) (World Weather & Climate Information 2018).

The Rainwater Harvesting (RWH) is in some countries a part of the household treating system for getting potable water. In Windhoek, it would not be advantageous because of mentioned poor railfalls.

RWH devices itself could not be complicated for installation. Many houses in Windhoek have a flat roof. These types of houses are suitable for building the water tank on the roof. Than the water will be lead by pipelines inside the house and used for certain purposes such as toilet flushing, irrigation in the house and garden, car washing. The other options of placing the tank are right next to the house or under surface.

This way of storing rainwater could not be probably used during all the year (especially in summer), but in other months would be helpful. The potable water will be used for basic needs and for other things will be here the harvested rainwater.

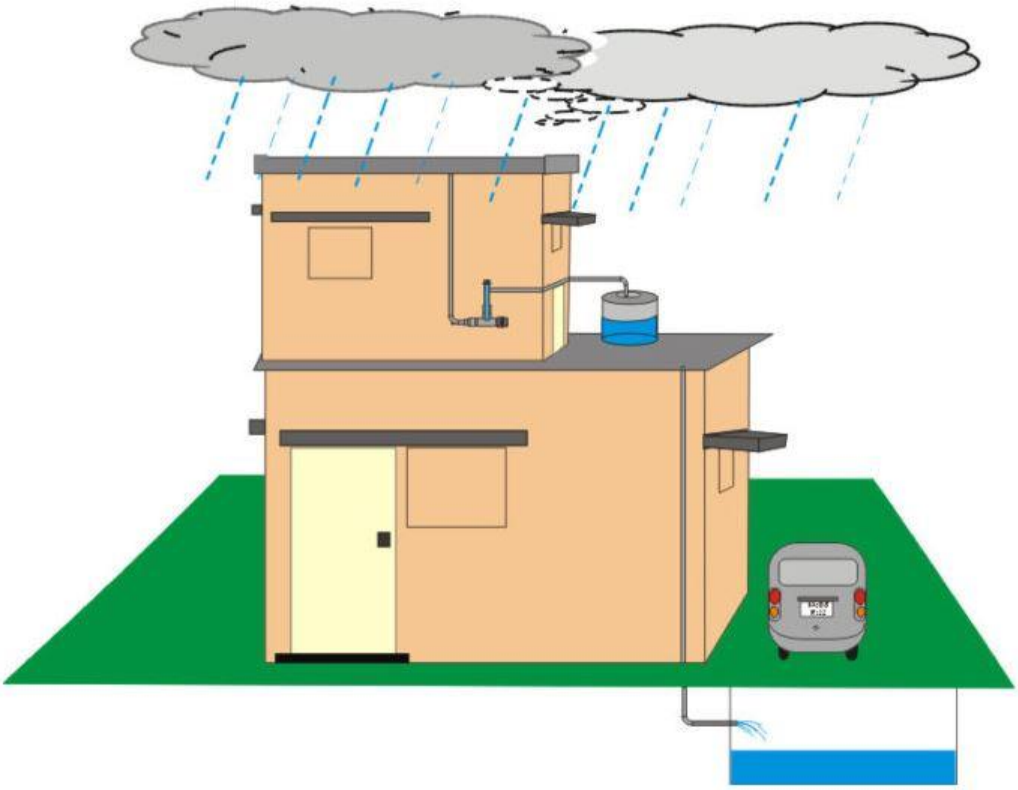

Figure 6: Basic Rainwater harvesting, tank on the roof

(“Relioblix Consulting” 2016)

4.5.2 Managed Aquifer Recharge

The concept of using the Windhoek Aquifer as a water bank was keenly received by the City of Windhoek and by 2004 four boreholes were equipped for recharge, and by 2011 an additional two boreholes had been equipped bringing the combined recharge capacity to 420 m^3/hr. The concept essentially involved transferring treated surface water to the aquifer for safe storage and use when needed. Four borehole injection tests were carried in the pure- and micaceous quartzites between 1997 and 1999 and the water level response showed that artificial recharge is feasible. The success of the injection tests and the historic water level data showed that artificial recharge should focus both in the existing wellfield areas (the micaceous quartzites) and the main natural recharge and storage area (the pure quartzites). Six existing boreholes were converted into injection boreholes and between 2006 and 2012 water was injected into them. A total of 3.3 million m^3 was injected and this resulted in some of the wellfield areas being fully replenished. This is about twice the estimated annual natural recharge rate (Murray 2017).

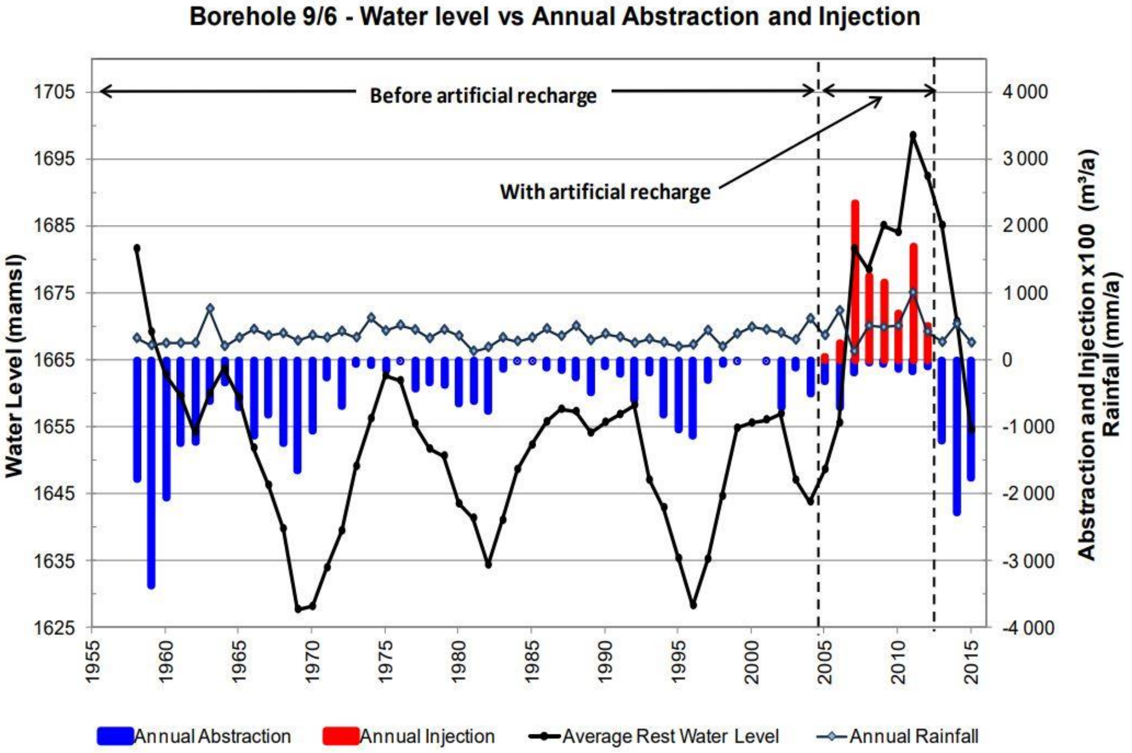

Figure 7: Borehole 9/6 abstraction, injection and water levels with rainfall

(Murray 2017)

In 2014 an Environmental Impact Assessment was conducted and it acknowledged the positive socioeconomic impacts of the project in relation to its significance in creating a sustainable water source for the Central Area of Namibia. This project is therefore considered an essential component for securing the future of the population in the central area and will play a key role in sustaining development and socio-economic health (Murray 2017).

4.5.3 Seawater Desalination

Another way, how to bring water to Windhoek and another dry regions is by seawater desalination and transport to inland by aqueducts. At the first sight this idea may look quite absurd. Of course, this thing has as well negatives. However, maybe one day in future will people of Namibia start think about it. It is estimated, that the Windhoek region will have in 2050 over 700 000 citizens. For example, in Israel desalinated seawater covers 50% of potable water need.

Water desalination plant needs to be situated on the west coast, appropriately close to Swakopmund and Walvisbaai cities. From this part of the shore leads the shortest way to Windhoek, which is approximately 300 km faraway. The biggest obstacle is probably The Kalahari desert. Leading a huge aqueduct through The Kalahari desert would not be definitely easy project. Moreover, water desalination plants could have negative impact on environment. Another issue could be economic part of the project.

Many countries in the world suffer from a shortage of natural fresh water. Increasing amounts of fresh water will be required in the future as a result of the rise in population rates and enhanced living standards, together with the expansion of industrial and agricultural activities. Available fresh-water resources from rivers and groundwater are presently limited and are being increasingly depleted at an alarming rate in many places. A number of seawater desalination technologies have been developed during the last several decades to augment the supply of water in arid regions of the world. Due to the constraints of high desalination costs, many countries are unable to afford these technologies as a fresh water resource. A seawater desalination process separates saline seawater into two streams: a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. The process requires some form of energy to desalinate and utilizes several different technologies for separation. Two of the most commercially important technologies are based on the multi-stage flash (MSF) distillation and reverse osmosis (RO) processes. Although the desalination technologies are mature enough to be a reliable source for fresh water from the sea, a significant amount of research and development (R&D) has been carried out in order to constantly improve the technologies and reduce the cost of desalination. Seawater is unsuitable for human consumption and for industrial and agricultural uses. By removing salt from the virtually unlimited supply of seawater, desalination has emerged as an important source of fresh water (Khawaji et al. 2007).

There are many technologies, how to desalinate seawater based on thermal distillation, membrane separation, freezing, electrodialysis, etc. Commercially, the two most important technologies are based on the MSF and RO processes. It is viewed that three processes — MSF, RO, and multiple-effect distillation (MED) — will be dominant and competitive in the future.

The MSF distillation process is based on the principle of flash evaporation. In the MSF, process seawater is evaporated by reducing the pressure as opposed to raising the temperature. The economies of the MSF technology are achieved by regenerative heating where the seawater flashing in each flash chamber or stage gives up some of its heat to the seawater going through the flashing process. The heat of condensation released by the condensing water vapor at each stage gradually raises the temperature of the incoming seawater. The MSF plant consists of heat input, heat recovery, and heat rejection sections. Although a high temperature additive is commonly used for scale control, an acid dose can also be utilized. The desalinated water produced by the MSF process contains typically 2–10 ppm dissolved solids. Therefore, it is remineralized through the potabilization (or post-treatment) process.

The MED process is the oldest desalination method and is very efficient thermodynamically. The MED process takes place in a series of evaporators called effects and uses the principle of reducing the ambient pressure in the various effects. This process permits the seawater feed to undergo multiple boiling without supplying additional heat after the first effect. The seawater enters the first effect and is raised to the boiling point after being preheated in tubes. The seawater is sprayed onto the surface of evaporator tubes to promote rapid evaporation. The tubes are heated by externally supplied steam from a normally dual purposed power plant. The steam is condensed on the opposite side of the tubes, and the steam condensate is recycled to the power plant for its boiler feedwater. The MED plant's steam economy is proportional to the number of effects. The total temperature range available and the minimum allowable temperature difference between one effect and the next effect limit the total number of effects. Horizontal MED plants have been operating successfully for almost three decades. MED plants can have horizontal, vertical, or submerged tubes. The size of low temperature MED units has increased gradually. Two MED units in Sharjah, UAE have a capacity of 22 700 m^3/day each. A design and demonstration module for the MED process exists for a 45 400 m^3/day unit. Most of the recent applications for the large MED plants have been in the Middle East.

In the reverse osmosis (RO) process, the osmotic pressure is overcome by applying external pressure higher than the osmotic pressure on the seawater. Thus, water flows in the reverse direction to the natural flow across the membrane, leaving the dissolved salts behind with an increase in salt concentration. No heating or phase separation change is necessary. The major energy required for desalting is for pressurizing the seawater feed. A typical large seawater RO plant consists of four major components: feed water pre-treatment, high pressure pumping, membrane separation, and permeate post-treatment. Major design considerations of seawater RO plants are the quantity of flux, conversion or recovery ratio, permeate salinity, membrane life, power consumption, and feedwater temperature. In comparison to MSF, problems arising from corrosion of materials are significantly less due to the ambient temperature conditions. Therefore, the use of metal alloys is less and polymeric materials are utilized as much as possible. Various stainless steels are used quite extensively. Research is focused on development and feasibility studies of new concepts for non-traditional desalination processes and feasibility studies of desalination concepts that have not been fully explored. The following are examples of areas considered for R&D activity:

- New desalination concepts and feasibility studies.
- Coupling of desalination processes with nonconventional energy sources.
- New process design concepts of reported non-conventional desalination processes.
- Development of new designs concepts for process equipment.

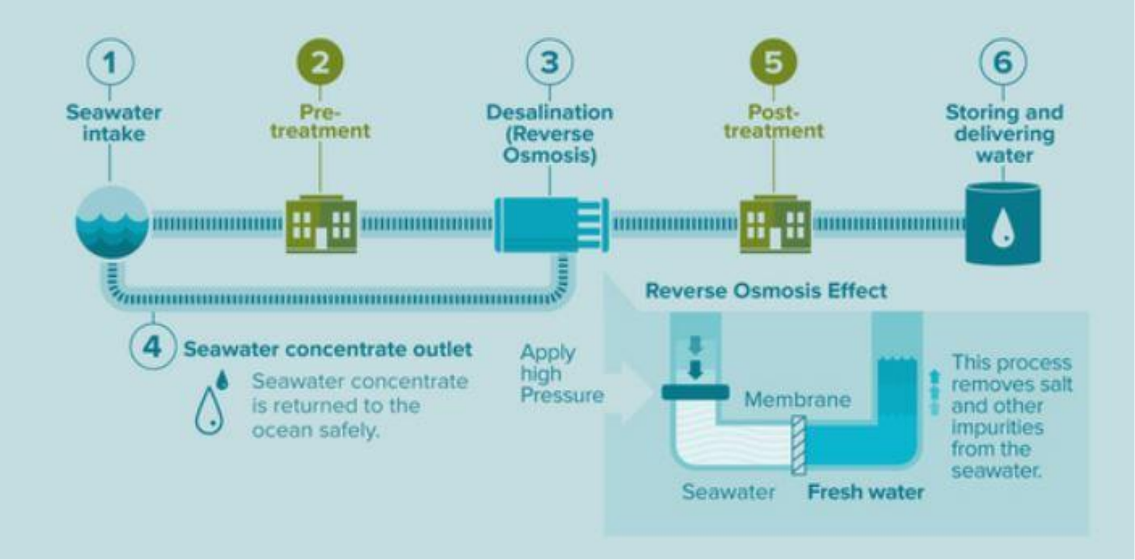

Figure 8: The Desalination process

(“Water Desalination” 2016)

5. Conclusion

Windhoek is situated in one of the driest regions of Africa, between two deserts – Namib and Kalahari. These tough climate conditions have a strong impact on local life and the lack of water. One of the basic humans´need is a water. In 1960s there lived about 50 000 people. In 1990s it was around 150 000 people. And in 2050, the demography predicts 700 000 people living in Windhoek and surroundings.

There are three basic sources of potable water in Windhoek. Groundwater, water from dam system and treated wastewater.

Groundwater does not contribute to total amount of potable water so much like other sources (1.7 Mm^3 per year), but anyways it is important source. Getting groundwater is a quite difficult process. A huge amount is deep under surface and due to this fact it is not possible to get it yet. Nevertheles, local authorities established the project Management Aquifer Recharge, which takes care of getting groundwater with injection boreholes. Therefore the level of water under surface rises and is more available.

Another source of water provides the system of dams. The dams were able to increase water supply from 6 Mm^3 per year in 1968 to 27 Mm^3 per year in 2012. But the climate conditions in this region are slowly getting worse, the land is getting dry. There is an unusually big amout of evaporated water from dams (up to 50 % of dam capacity).

Three most important dams are Omatako, Swakoppoort and the Von Bach Dam. Annual rainfalls are poor (360 mm). There are no perennial rivers.

Significant sources of potable water in Windhoek are water reclamation plant. Two biggest of them, Goreangab Water Reclamation Plant and the Von Bach Reclamation Plan have common full capacity about 177 000 m^3/day. Von Bach Plant is seven-times bigger than GWRP. In these plants are used described purification technologies, such as pre-ozonation, flotation, rapid sand filtration or biological and granular activated carbon.

Finaly, it could be stated, that there is a big lack of water in Windhoek, neverthelss the water is suited for drinking. The quality of potable water in Windhoek is not the best in the world, but it is not definitely harmful for health of citizens. This was submited by ascertainment of content of total dissolvedand suspended solids, electrical conductivity, acidity, fecal coliform and free and total chlorine.

In the last part are suggested some technologies, which could help to developing city handle water lack.

Rainwater harvesting is not so spreaded in Windhoek because of small amount of annual rainfalls. Despite of that, there are some rainy days from October till April, when could be possible to catch some water. This technology is not so expensive and could spare some potable water.

Another possibility was mentioned above – aquifer recharge. Close to Windhoek is a big aquifer, but very deep under surface and borehole technology could help to get closer to water.

Probably most discutable possible water source of potable water for Windhoek is seawater desalination plant. Windhoek is situated about 300 km from nearest sea shore. In addition, between the city and the shore are tough natural obstacles – the Namib desert and highlands. This project would be very expensive and probably with negative impact on environment. Nevertheles, this desalination plants work nicely in Israel and other states.

If will the population of Windhoek increase of 5 % each year, there will be needed much more of potable water. Maybe this sources and help from developed countries could help the Windhoek from water lack.

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7. Appendix

Figure 9: Employee inspecting effluent during the treatment process at the GWRP

(de Villiers, 2018)

Figure 10: Ashkelon Seawater Reverse Osmosis Plant, Israel

("Water Technology" 2018)