LIVING WITH FRESHWATER SCARCITY: MANAGEMENT OF NAMIBIA'S WATER RESOURCES

ÉLET AZ ÉDESVÍZHIÁNNYAL: VÍZKÉSZLET-GAZDÁLKODÁS NAMÍBIÁBAN

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Abstract

Namibia is an arid country in Southern Africa. It frequently experiences a state of freshwater deficit and must employ a range of measures to manage this scarce resource sustainably and equitably. The Ministry of Agriculture, Water and Land Reform coordinates the water sector. A state-owned enterprise, NamWater, is the bulk water supplier and manages large water infrastructure. The country follows a policy of integrated water resource management and has devolved some of the decision-making on water issues to river basin level. Transboundary catchments are managed through legal agreements and multinational permanent commissions representing the basin states. Technologies such as dams in ephemeral rivers, intra- and inter-basin water transfer schemes, reclamation of wastewater to potable standards, artificial aquifer recharge, desalination, and conjunctive use of various water sources are employed to supply water to consumers. Water demand management, particularly education, information, restrictions and tariffs, curbs wasteful use of water.
Keywords: *Namibia, water resources management, freshwater deficit, NamWater, legal framework*
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Összefoglalás

Namíbia egy száraz ország Afrika déli részén. Gyakori az édesvízhiány, és számos intézkedést szükséges alkalmaznia ennek a szűkös erőforrásnak a fenntartható és méltányos kezelése érdekében. A Földművelésügyi, Vízügyi és Földreformügyi Minisztérium koordinálja a vízügyi ágazatot. Egy állami tulajdonú vállalat, a NamWater szolgáltatja a víz többségét és nagy vízügyi infrastruktúrát kezel. Az ország az integrált vízkészlet-gazdálkodás politikáját követi, és a vízzel kapcsolatos döntéshozatal egy részét a vízgyűjtő szintjére ruházta át. A határokon átnyúló vízgyűjtőket jogi megállapodások és a medenceállamokat képviselő multinacionális állandó bizottságok kezelik. A fogyasztók vízellátására olyan technológiákat alkalmaznak, mint a gátak az időszakos folyókban, a medencén belüli és a medencék közötti vízszállítási rendszerek, a szennyvíz visszanyerése az ivóvíz szabványok szerint, a víztartók mesterséges feltöltése, a sótalanítás és a különféle vízforrások együttes használata. A vízigény kezelése, főleg az oktatás, a tájékoztatás, a korlátozások és tarifák visszaszorítják a pazarló vízhasználatot.
Kulcsszavak: *Namíbia, vízkészlet-gazdálkodás, édesvízhiány, NamWater, jogi keretrendszer*

Introduction

The arid climate of Namibia imposes inherent constraints on development. Industries are clustered in the central coastal areas and around the capital, Windhoek, putting much pressure on the scarce water resources. Largescale irrigation is only feasible close to the permanent rivers along the southern and northern borders and near the largest of the surface dams in ephemeral rivers (HEYNS et al., 1998). Dryland cropping is limited to the northeast where the rainfall regime is, at best, marginally to moderately suitable for rainfed production. In most rural areas, livelihoods are based on extensive livestock production (ranching and pastoralism), and wildlife and landscape tourism. Agriculture is by far the largest consumer of water, with 40% used for irrigation and 26% for watering livestock. Urban areas, including households, businesses and industries, account for about 20% of water consumption, rural households for 3%, mining for 5% and tourism operations such as lodges for 6% (ATLAS OF NAMIBIA TEAM, 2022).

Perennial rivers, with their sources in higher rainfall areas of neighbouring countries, play an important role in the provision of water to a large proportion of the Namibian population who are living in the northern regions, as well as for the Ruacana hydroelectric scheme and irrigation schemes. Abstraction of water from permanent rivers has to be negotiated with other basin states. Away from the permanent rivers, surface water is captured in dams in ephemeral rivers and distributed to urban areas, mines and industries through extensive water transfer schemes. These bulk water delivery schemes have to contend with high infrastructure development, 2 maintenance and operational costs, low rainfall, high evaporation rates, few suitable locations for the construction of surface dams, and long distances. About 80% of the territory relies solely on groundwater (IWRMP JOINT VENTURE NAMIBIA, 2010a).

The 2016 Namibia Household and Income Survey (NATIONAL STATISTICS AGENCY, 2016) established that 92.9% of Namibian households have access to safe drinking water, of which 99.4% are urban households and 85% are rural (NATIONAL STATISTICS AGENCY, 2019).

Legal and Institutional Framework for Water Management

Article 100 of the Namibian Constitution (REPUBLIC OF NAMIBIA, 1990) confers ownership, custody and the responsibility for overall management of land, water and natural resources on the State. The water sector is governed according to the Water Resources Management Act, No. 11 of 2013. It is a comprehensive document that covers (1) Preliminary Provisions; (2) Functions of the Minister; (3) the Water Advisory Council; (4) the Water Regulator and Water Pricing Policy; (5) Basin Management Committees; (6) Internationally Shared Water Resources; (7) Management of Rural Water Supply; (8) the Integrated Water Resources Management Plan; (9) Water Supply, Abstraction and Use; (10) Water Services Providers; (11) License to Abstract and Use Water; (12) Control and Protection of Groundwater; (13) Water Pollution Control; (14) Water Protection Areas; (15) Water Related Emergency or Pollution Threats; (16) Water Services Plans and Efficient Water Management Practices; (17) Dams, Dam Safety and Flood Management; (18) Control of Activities Affecting Wetlands, Water Resources and the Resource Quality; (19) Water Services Provided by the State; (20) Servitudes; (21) the Water Tribunal and Appeals; and (22) General Provisions (REPUBLIC OF NAMIBIA, 2013). The development of Regulations and the appointment of the Water Advisory Council, Water Regulator and Water Tribunal had been slow. Implementation and enforcement of the provisions of the Act need strengthening (REMMERT, 2016).

The Ministry of Agriculture, Water and Land Reform (MAWLR), through the Department of Water Affairs (DWA), has the overall responsibility to coordinate the water sector, manage and protect the resource, and supply water to rural areas, in accordance with the Water Resources Management Act (REPUBLIC OF NAMIBIA, 2013) and the Integrated Water Resources Management Plan (IWRMP) for Namibia (IWRMP JOINT VENTURE NAMIBIA, 2010a). The Directorate of Resource Management of MAWLR-DWA formulates water resources management strategies, quantifies the country's surface and groundwater resources, plans at international, national and regional levels, administers the water allocation system according to the Act, and manages the water environment. The IWRMP is currently under review and a National Water Master Plan is being developed (MINISTRY OF AGRICULTURE, WATER AND LAND REFORM, 2022).

The Namibia Water Corporation Ltd. (NamWater) is the state-owned bulk water supplier. It manages supply schemes involving aquifers, permanent rivers, desalination plants, surface dams, water transfer schemes and purification plants. It distributes water through canals and pipelines to regional authorities, local authorities, MAWLR and large commercial customers such as mines and irrigation schemes. NamWater supplies water to the Naute, Hardap and Etunda Irrigation Schemes from dams, and to several other irrigation schemes from the Okavango and Orange Rivers. NamWater operates on commercial, cost-recovery principles. Irrigation water is at present heavily subsidised, but full cost-recovery is envisioned in future. NamWater supplies around 82 Mm^3 a^{-1} treated and 56 Mm^3 a^{-1} irrigation water to Namibian consumers (NAMWATER, 2023). The operational costs of water utilities consume about 3% of Namibia's Gross Domestic Product. The country struggles financially to systematically and comprehensively rehabilitate and modernise existing water infrastructure and to develop key new projects such as desalination plants.

Regional authorities supply water to small settlements in rural areas. Local authorities (municipalities and town councils) are responsible for distributing water to urban households, businesses and industries within their respective jurisdictions. On entering private property, water is metered and fees are charged on a sliding scale according to the amount used. Cross-subsidisation is employed to finance water delivery to informal settlements, where water is not piped to individual homes, but to communal taps. The fees charged by local authorities are not for the water itself, but for the services to acquire raw water, treat it to a safe drinking water standard, deliver it to the consumer, treat and dispose of wastewater, and maintain the reticulation system. Sanitation services, the collection, treatment and safe disposal of wastewater are not only essential for hygienic environments and human health but are crucial for the prevention of pollution and maintaining both surface and groundwater quality. Some local authorities operate small water supply schemes of their own, mainly relying on boreholes.

Namibia has followed a community-based water management strategy since 1997, meaning that rural communities must take responsibility for managing and paying for water services. The Directorate of Water Supply and Sanitation Coordination (DWSSC) of MAWLR-DWA ensures a sustainable supply of safe water to rural communities in communal areas by drilling and equipping boreholes or buying bulk water from NamWater, and installing water tanks and taps. Each water point installation is managed by a Water Point Association (WPA) headed by a locally elected Water Point Committee (WPC). WPAs receive support from Water Supply Extension Officers of the Ministry but have to draw up their own rules on sharing the costs and benefits of water points. WPCs normally collect fees, maintain the infrastructure, and prevent vandalism and illegal water connections.

Private entities such as mines, commercial farms and tourist lodges are responsible for developing their own water supply or reaching an agreement with NamWater if they are near a state water scheme. Generally, farmers obtain water from boreholes, springs and small dams in ephemeral rivers.

Integrated Water Resource Management (IWRM)

Water is the most limiting natural resource for development in Namibia. It has to be managed very carefully to accommodate all economic sectors and to be shared fairly and responsibly. The chosen approach is Integrated Water Resource Management (IWRM), which is defined as "a process that promotes the coordinated development, management and use of water, land and related natural resources in order to optimize the resultant economic, social and environmental welfare in an equitable manner without compromising the sustainability of vital ecosystems" (IWRMP JOINT VENTURE NAMIBIA, 2010a, 2010e). It is based on the four Dublin Principles (from the International Conference on Water and Environment, Dublin, Ireland, January 1992): (a) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; (b) Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels; (c) Women play a central part in the provision, management and safeguarding of water; (d) Water has an economic value in all its competing uses and should be recognized as an economic good.

Bulk Water Supply and Transfer Schemes

NamWater operates 19 large dams in ephemeral rivers. These dams supply water to the larger urban centres, irrigation schemes and mines. The word 'dam' is used in southern Africa to describe both the containment wall and the lake of impounded water. Dams are situated in rivers with large enough catchments to ensure sufficient runoff during the rainy season and where the geology and geography are suitable. As these dams are not necessarily near the urban centres where the water is needed, NamWater operates several long-distance intraand inter-basin water transfer schemes of dams, pipelines, canals and pumping stations.

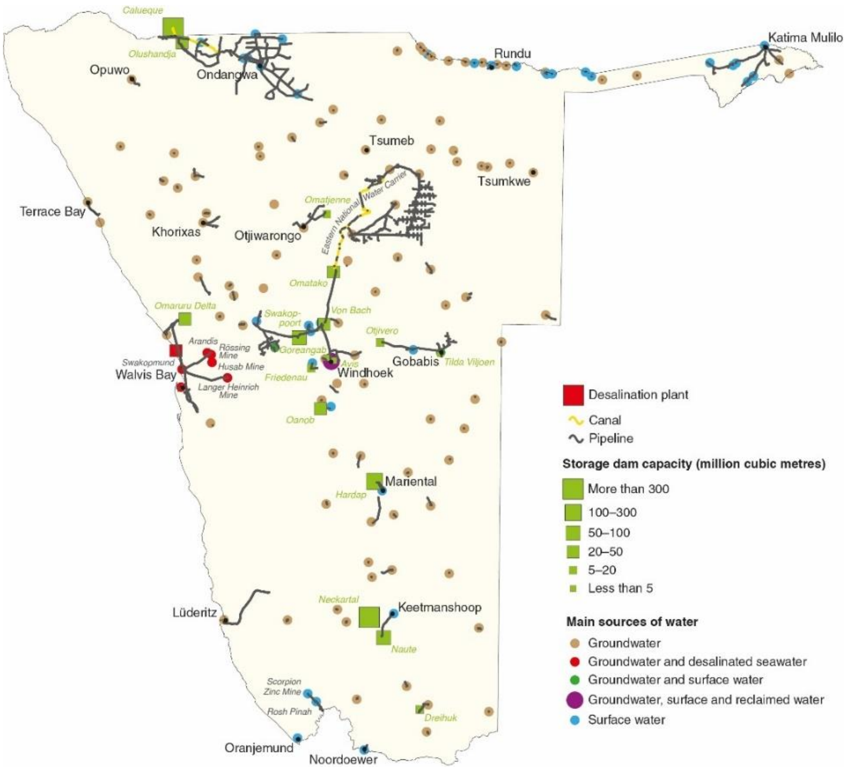

Figure 1. Bulk water supply sources and schemes.
Source: ATLAS OF NAMIBIA TEAM, 2022.

Figure 1 and Figure 2 show the transfer scheme known as the Eastern National Water Carrier (ENWC). Groundwater is pumped from the Karstveld Aquifer and mines in the Grootfontein area to supply the surrounding areas. It also complements the water supply of central Namibia during periods of water shortage (IWRMP JOINT VENTURE NAMIBIA, 2010b, 2010e). Water is delivered to the Omatako Dam by the 300 km long Grootfontein-Omatako Canal, from where a 94 km long pipeline transfers it to Von Bach Dam. Water from Swakoppoort Dam is also pumped to Von Bach Dam over a distance of 54 km, with a reverse gravity flow option for storing excess water in Swakoppoort when Von Bach receives exceptionally good inflows. Raw water is purified at Von Bach Dam and the potable water is piped over 62 km to the city of Windhoek. If the water demand of Windhoek should increase much more, one option would be to extend the ENWC by constructing a pipeline from Grootfontein to the perennial Okavango River (WINDHOEK CONSULTING ENGINEERS, 2000). There are even more ambitious visions of pumping water from the Congo River over the watershed in northern Angola to the headwaters of the Okavango River.

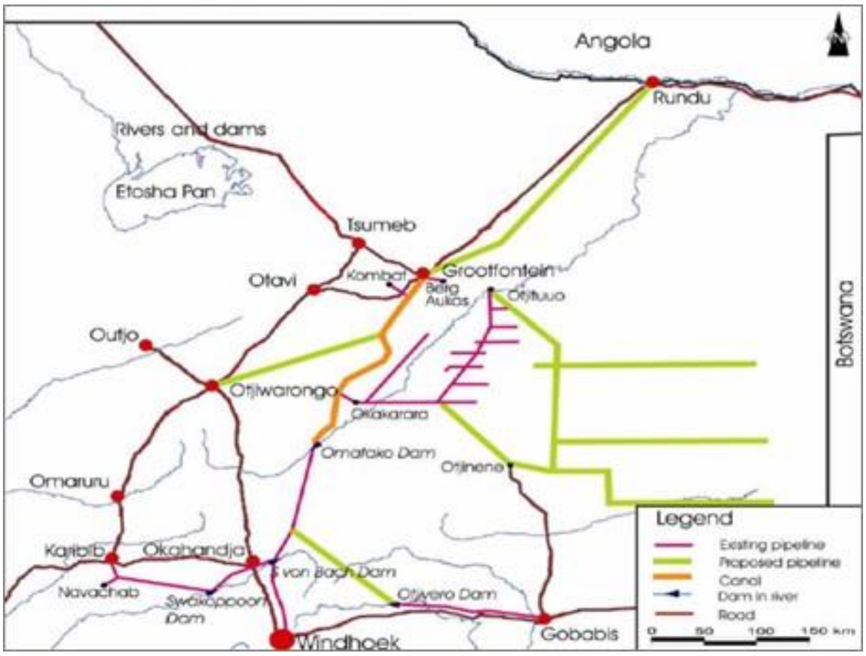

Figure 2. The Eastern National Water Carrier.
Source: IWRMP JOINT VENTURE NAMIBIA, 2010c.

Rosh Pinah town and Skorpion Mine get potable water from the Orange River (Figure 1). The town of Lüderitz is supplied by a 120 km long pipeline from Koichab Pan (Figure 1). This water comes from the fossil Koichab Aquifer which is not recharged anymore. Keetmanshoop and the Naute Irrigation Scheme get their water from the Naute Dam (Figure 1). Potable water is pumped from the Kuiseb Aquifer to the harbour town of Walvis Bay (Figure 1, Figure 3), while the towns of Henties Bay, Swakopmund and Arandis, and the uranium mines Rössing and Langer Heinrich are supplied from the Omaruru Delta (Omdel) Scheme (Figure 1, Figure 3). The Kunene River provides irrigation and livestock water through the 150 km long Calueque-Ogongo-Oshakati Canal (Figure 1). The Calueque Dam is in Angola, about 35 km north of the border. A purification plant at Oshakati delivers potable water to the surrounding area through an extensive pipeline network. The 48 km long Omafo-Eenhana scheme transfers potable water from Omafo to Eenhana. In Zambezi Region, water from the Zambezi River is purified at Katima Mulilo and distributed to settlements by pipeline (Figure 1).

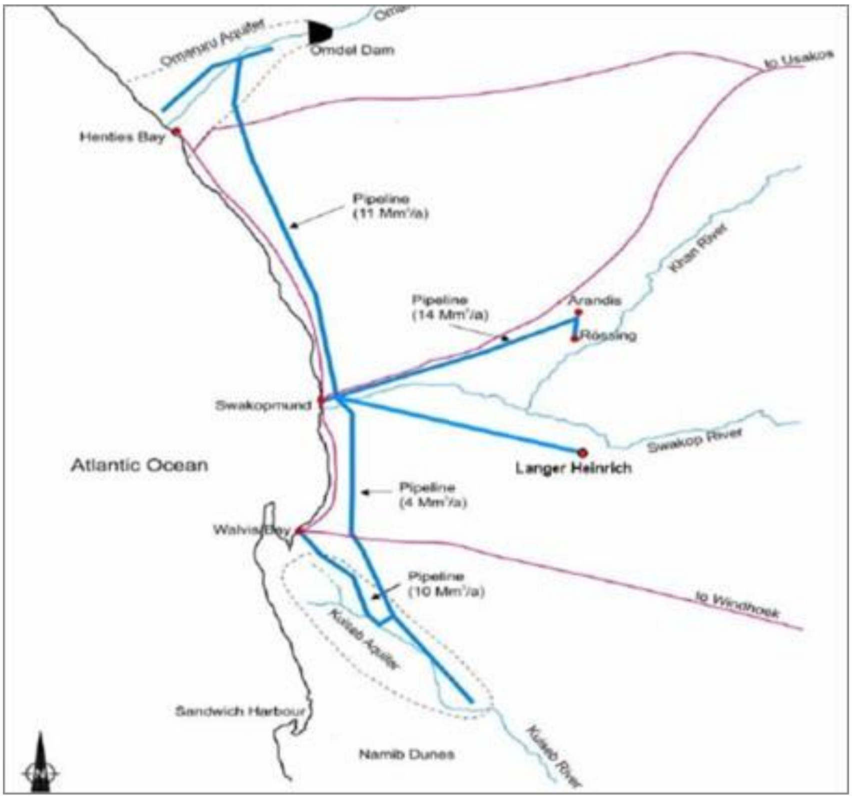

Figure 3. The Central Namib Water Supply System.
Source: IWRMP JOINT VENTURE NAMIBIA, 2010c.

Water Basin Management

In Namibia, IWRM is implemented at catchment (river basin) level to devolve decision-making and management as far as possible and to include the broadest possible group of stakeholders. The country has been divided into 11 water management areas according to common drainage systems, aquifers and water supply infrastructure such as canals and pipelines, each with a Basin Management Committee (BMC) of stakeholders representing various economic sectors, interest groups and communities (REPUBLIC OF NAMIBIA, 2013). BMCs are expected to be involved in the collection and sharing of water data, and the protection, development, conservation, management and control of water resources and its quality. They must promote community participation and self-reliance, contribute to the development of the Integrated Water Resources Management Plan and water research agenda, monitor and report on the effectiveness of policies and measures in achieving sustainable management of water resources and resource quality, help resolve water-related conflicts, and advise the Minister on applications for licenses and the occurrence or threat of serious water or pollution problems within their management areas (REPUBLIC OF NAMIBIA, 2013). BMCs receive technical support from MAWLR and NamWater. Though great progress has been made, not all the BMCs are functioning as intended.

Transboundary Basin Management

The transboundary nature of Namibia's permanent rivers (Figure 4) puts the country in a geopolitically vulnerable position of dependence on the goodwill of neighbouring countries. It could potentially affect the provision of potable water to a large percentage of the population who are living in the northern areas, water delivery to most irrigation schemes and the country's power supply. Up to 40% of the Namibia's electricity is generated by the Ruacana Hydroelectric Power Station on the Kunene River, with the flow regulated by the Angolan Calueque Dam.

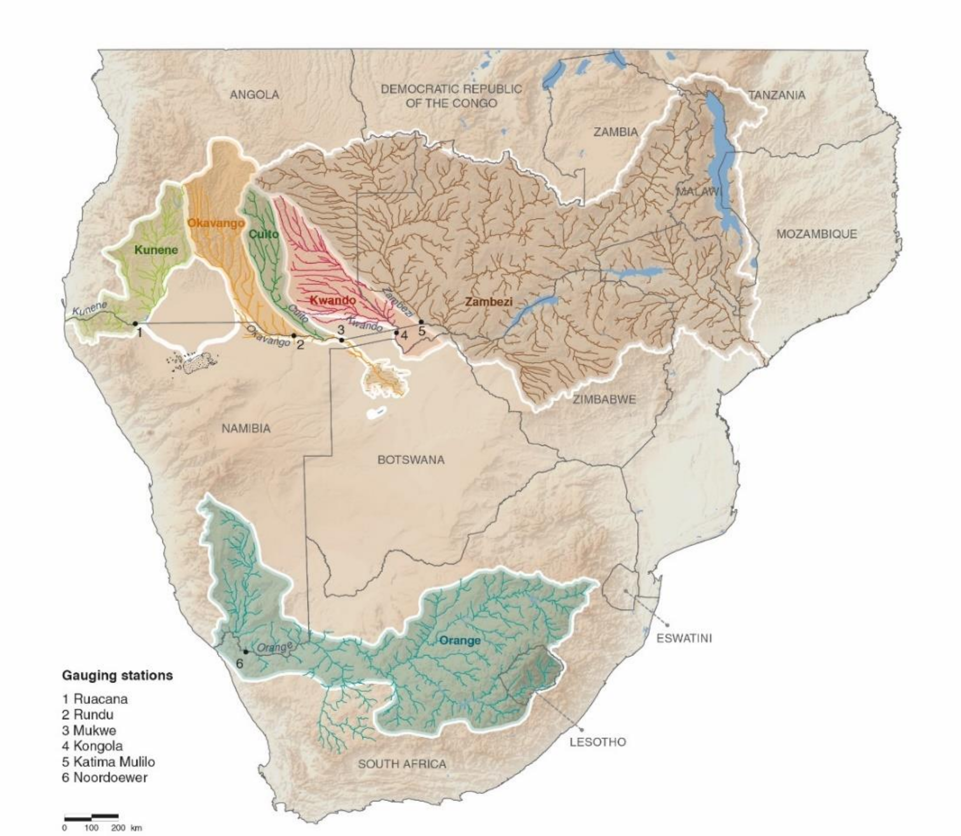

Figure 4. Namibia's permanent rivers and their transboundary catchments.
Source: ATLAS OF NAMIBIA TEAM, 2022.

Namibia has all its transboundary freshwater bodies covered by operational arrangements with the other basin states. It has ratified the 2000 Southern African Development Community's (SADC) Revised Protocol on Shared Watercourses and the 1997 UN Convention on the Law of the Non-navigational Uses of International Watercourses. The country is an active member of transboundary river basin management organisations, namely the Okavango-Cubango River Commission (OKACOM) (with Angola and Botswana), the Orange-Senqu River Commission (ORASECOM) (with South Africa, Lesotho and Botswana), the Zambezi Watercourse Commission (ZAMCOM) (with Botswana, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe) and the Cuvelai Watercourse Commission (CUVECOM) (with Angola) (SHIWEDA, 2022). In general, the permanent basin management commissions have mandates to determine the long-term safe yield and reasonable demand from consumers, prepare criteria for conservation, equitable allocation and sustainable utilisation of water, conduct investigations into existing and planned water infrastructure, and recommend pollution prevention measures (IWRMP JOINT VENTURE NAMIBIA, 2010a). Namibia has started the process to join the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (SHIWEDA, 2022).

Innovative Technologies for Supply-Side Water Management

Freshwater scarcity has forced Namibian water engineers and managers to develop a range of water supply management approaches and tools.

Use of Semi-Purified Water for Irrigation

Wastewater that has been treated to an acceptable standard for discharge into the environment is used to irrigate sports grounds, public parks and vegetable gardens in several urban areas. In Windhoek, part of this semi-purified domestic wastewater returns to the city through a separate reticulation network for irrigation, while the remainder is piped to the New Goreangab Water Reclamation Plant for further purification to potable water.

Direct Potable Reuse (Reclamation of Wastewater)

The capital of Namibia, Windhoek, was the first city in the world to add reclaimed wastewater to its drinking water supply in 1968 (LAHNSTEINER et al., 2018). At present, 10–40% (depending on the availability of surface water) of Windhoek's drinking water comes from the reclamation process. Industrial and potentially toxic waste is diverted to a separate wastewater treatment plant and does not contribute to the reclaimed water. Domestic effluent is first treated biologically at the Gammams Water Care Works (GWCW) to an environmentally safe level, before being purified to safe drinking water quality at the New Goreangab Water Reclamation Plant (NGWRP), which has a capacity of 21,000 m^3 d^{-1}.

A 10-step multiple-barrier treatment process is used, with at least two (often more) removal processes for each potentially dangerous or organoleptically objectionable contaminant:

1. Powdered activated carbon is added to the raw (semi-purified) water for the removal of dissolved organic compounds.
2. After pre-ozonation (O_3), potassium permanganate ($KMnO_4$) is added to precipitate dissolved manganese, followed by destabilisation of particles and coagulation to micro-flocs through the addition of the coagulant ferric chloride ($FeCl_3$).
3. Micro-flocs are given time to grow larger by stirring the water very slowly and sometimes adding a polymer flocculant.
4. Flocs are separated through super-saturation of the water with microscopic air bubbles to which flocs adhere and float to the surface, from where they are removed periodically.
5. Caustic soda ($NaOH$) is added to stabilise the pH, and potassium permanganate ($KMnO_4$) to precipitate iron and manganese. All suspended particles that came past the flocculation and dissolved air flotation steps are removed by dual-media filtration through anthracite and sand filter beds. The scum from the dissolved air flotation and the backwash effluent from the filters are diverted to another effluent treatment plant (Otjomuise).
6. Ozone (O_3) gas is injected into the filtered water to oxidise dissolved organic compounds, including pharmaceuticals, to biodegradable products and to kill all remaining viruses, bacteria and parasites. Any remaining ozone is inactivated by addition of hydrogen peroxide (H_2O_2).
7. Biodegradable dissolved organic compounds are removed by microorganisms living on the surface of biologically activated carbon in filter beds which are periodically backwashed.

8. Granular activated carbon adsorbs any remaining dissolved organic compounds that could be detrimental to human health, such as disinfection byproducts and pharmaceuticals.
9. The final polishing step is removal of any remaining suspended particles, microorganisms and viruses through ultrafiltration membranes, which are cleaned and sterilised regularly.
10. In preparation for blending of the final product with other potable water sources and distribution to consumers, caustic soda (NaOH) is added for pH adjustment and chlorine (Cl_2) for protection during the distribution process (WINGOC, 2023).

The reclaimed water must meet the Group A standards of the Namibian guidelines for drinking water quality (MINISTRY OF AGRICULTURE, WATER AND RURAL DEVELOPMENT, 1988), which are in line with the World Health Organisation's standards. Intensive chemical and biological testing programmes monitor the quality of the reclaimed water, and no negative health effects have been detected since reclamation started in 1968 (IIPUTA et al., 2008).

Conjunctive Water Use

Windhoek is located in the centre of Namibia. It houses about 20% of the country's population, is the seat of Government and it has the highest concentration of public services and industries. The city depends for its water supply on dams built in ephemeral rivers, reclaimed wastewater and a local aquifer. The conjunctive use of these three water sources is managed with a computerised mathematical model that takes account of dam levels, inflows, evaporation rates, aquifer yields, reclamation yields, water quality of all the sources, water demand and costs.

In years of normal rainfall, three surface dams provide about 69% of the city's water supply, with some 26% coming from reclaimed wastewater and about 7% from the Windhoek Aquifer. Surface water is used first to minimise evaporative losses, as Namibian dams can lose 20-85% of their water through evaporation within a year. Water is pumped between Windhoek's three supply-dams, Von Bach, Swakoppoort and Omatako (Figure 3, Figure 5). Whereas the shallow Omatako Dam can lose up to 80% of its full capacity to evaporation in a year, Von Bach Dam would lose about 24% as it has a smaller surface-to-volume ratio. Swakoppoort Dam sporadically turns eutrophic due to pollution in its catchment, and it contains high concentrations of dissolved chlorides and sulphates of magnesium and sodium. These problems are managed by blending it with larger volumes of water from Von Bach before purification.

Groundwater from production boreholes in the Windhoek Aquifer is used to supplement the supply of surface and reclaimed water. The highly variable rainfall regime means that runoff is often too low to fill the surface dams sufficiently. In addition to strict water restrictions for households and industries, hydrological droughts are managed by groundwater abstraction becoming the major supply source, rather than just a supplementary source. In drought years, water is also pumped from the Karstveld Aquifer to Windhoek over more than 500 km via the Eastern National Water Carrier (Figure 1, Figure 2). In 2019, surface water volumes dropped to 11% of the combined capacity of the three dams, and the aquifer supplied 39% of Windhoek's water.

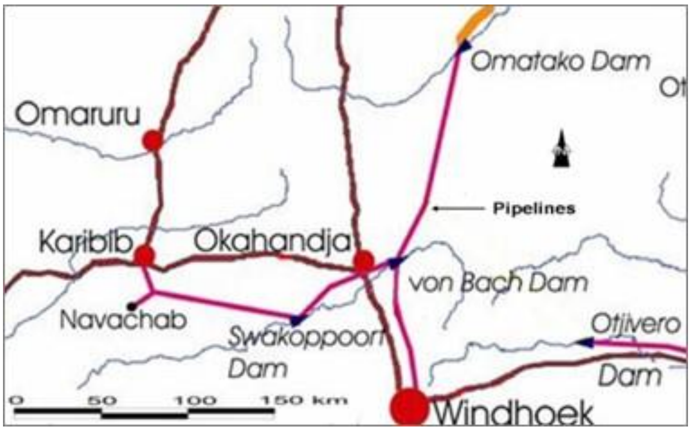

Figure 5. Surface water supply to Windhoek from Omatako, Swakoppoort and Von Bach Dams.
Source: IWRMP JOINT VENTURE NAMIBIA, 2010c.

Managed (Artificial) Recharge of Aquifers

The Windhoek Aquifer is vast, but its natural recharge rate falls short of the high abstraction rates needed in drought years. To achieve a long-term sustainable yield, Namibian water engineers have embarked on an ingenious programme of managed aquifer recharge. In years of high runoff into surface dams, part of this water is purified and pumped into the Windhoek Aquifer through seven recharge boreholes with a combined capacity of 4.2 $Mm^3\ a^{-1}$. By banking the excess water underground, provision is made for times of surface water scarcity, with the added advantage of eliminating the evaporative losses that plague surface dams (COW, 2022).

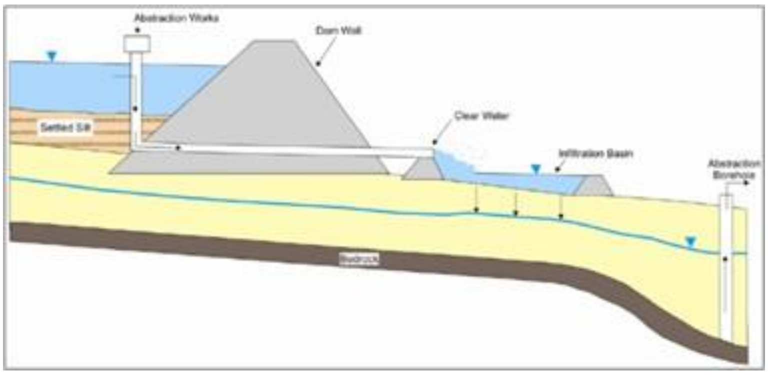

Figure 6. Artificial aquifer recharge at the Omdel Scheme.

Figure 7. Omdel Dam's abstraction tower.

The Omaruru Delta (Omdel) (Figure 6, Figure 7), Omatjenne and Bondels Dams were specifically constructed for another form of artificial recharge. The dams were built in ephemeral river courses, not to keep the impounded water on the surface, but to replenish downstream alluvial aquifers. This method captures fresh water that would have flowed into the ocean or sank into unproductive sands and stores it underground where it is protected from evaporation. After inflow, silt is given time to settle before the clear water is allowed to slowly trickle into constructed gravel beds and then percolate into the natural alluvial aquifers. Groundwater is abstracted through boreholes drilled into the aquifers. The Bondels Scheme supplies water to the town of Karasburg, while the Omdel Scheme supplies water to two coastal towns, Swakopmund and Henties Bay, and to a town, Arandis, and 11 uranium mines in the central Namib Desert (Figure 3, Figure 1). After the Omdel Dam was built, yields of the 40 km long Omdel Aquifer increased from 2.8 to 4.6 $Mm^3\ a^{-1}$, even though significant flows reach the dam only once or twice a decade.

Farmers often construct small dams or berms in normally dry watercourses on their farms. After heavy rain showers, these dams hold drinking water for livestock and game for a few weeks to a few months, while water also infiltrates the sandy and gravelly deposits and recharges local alluvial aquifers. Over time, the dams fill up with coarse sediments that can still store substantial volumes of water, while minimising evaporation. Farmers extract water from the saturated sediments by digging a well or installing a borehole in the 'sand dam' (Figure 8, Figure 9)

Figure 8. A sand dam at Khowarib in the Kunene Region. *Source: M Coetzee.*

Figure 9. A sand dam on the edge of the Namib Desert. *Source: M Coetzee.*

Desalination

The first large desalination plant in Sub-Saharan Africa is situated near Wlotzkasbaken, some 30 km north of Swakopmund. It was built to provide fresh water to a uranium mine, Trekkopje, which is 50 km inland. Low uranium prices have delayed the development of the mine; thus 12 $Mm^3 a^{-1}$ potable water is at present sold to NamWater to supplement Swakopmund's supply. The plant's current capacity is 20 $Mm^3 a^{-1}$, with options for future expansion to 45 $Mm^3 a^{-1}$ (NAMWATER, 2023). Plans are well advanced for the construction of a second desalination plant to provide ~25 $Mm^3 a^{-1}$ water to the central coastal areas.

Blending and desalination of brackish water

In many parts of the country, the groundwater is naturally quite saline, with great variability even over short distances. If yields from good-quality perched freshwater aquifers are insufficient to supply a community, it may be blended with more brackish water from other boreholes to eke out the supply.

Modest desalination plants have been constructed at the small southern towns of Bethanie and Grünau, where the groundwater is particularly brackish. Pilot desalination plants are also being tested in four towns in north-central Namibia (CUVEWATERS, 2023).

Rainwater Harvesting

Many urban homeowners capture and store runoff from their roofs in tanks to provide irrigation water for their gardens. Underground cisterns had been built in some communities in northern Namibia to store harvested rainwater. In the Cuvelai area, small earth dams had been constructed to capture rainwater and overland flow from the efundja (annual flooding), mainly for watering of livestock and vegetable gardens.

Fog Harvesting

The cold Benguela Current and atmospheric conditions over the Namib Desert mean that dense fogs occur for up to 100 days per year up to 100 km from the coast (ATLAS OF NAMIBIA TEAM, 2022). Studies on the harvesting of these fogs agree on the considerable potential of fog as a water source, but it has not yet been upscaled to operational levels (NAGEL, 1959, 1962; SEELY & HENSCHEL, 1998; SHANYENGANA et al., 2001; SHANYENGANA et al., 2002; MAKUTI et al., 2004; OLIVIER, 2004; HENSCHEL et al., 2007).

Water Demand Management

Water Demand Management (WDM) is an important tool to improve water use efficiency by reducing losses and limiting wasteful consumption. It includes legislation and regulations, information, awareness campaigns, inclusion of water-related topics in school and university curricula, cost-benefit analyses and water pricing policies (VAN DER MERWE, 1999; IWRMP JOINT VENTURE NAMIBIA, 2010d). Studies have shown that the need to develop new water supply sources has been deferred by about ten years through effective water demand management measures (VAN DER MERWE, 1999).

The Environmental Management Act, No. 7 of 2007, and its Regulations (REPUBLIC OF NAMIBIA, 2007, 2012) stipulate that any development activity with a potential impact on water resources requires an environmental impact assessment and environmental management plan before the Ministry of Environment, Forestry and Tourism will issue an environmental clearance certificate for the development to proceed. Resource economists quantify and compare the economic returns for the volumes of water required for various activities.

One of the most effective WDM tools is to levy high tariffs for excessive water use. For example, Windhoek domestic water consumption rates are levied on a sliding scale. The first 0.200 kl[1] d^{-1} cost N$[2] 23.36 kl^{-1}, 0.201- 1.000 kl d^{-1} cost N$ 36.20 kl^{-1}, 1.000-1.670 kl d^{-1} cost N$ 72.41 kl^{-1}, and more than 1.671 kl d^{-1} cost N$ 144.81 kl^{-1} (REPUBLIC OF NAMIBIA, 2022). Households with metered water also pay a monthly basic charge, irrespective of consumption, that depends on the diameter of the inlet pipe, e.g. N$ 113.02 for a 20 mm inlet or N$ 184.34 for a 25 mm inlet for an average house.

Windhoek residents living in informal settlements obtain their water from communal standpipes with prepaid meters (Figure 10). Each standpipe serves about 25-30 households (HEYMANS et al., 2014). Standpipe tariffs are fixed at N$ 29.69 kl^{-1}, irrespective of usage (REPUBLIC OF NAMIBIA, 2022). During the Covid-19 pandemic, water delivery to community standpipes was free.

Figure 10. A prepaid standpipe water points in an informal settlement of Windhoek.
Source: HEYMANS et al., 2014.

The City of Windhoek's Water Management Plan rests on three pillars: (a) Supply Situation Indicators, referring to scenarios based on information received from NamWater, the bulk supplier, about the water levels of the three supply dams; (b) WDM Response Actions, which are guidelines for managing water demand according to varying supply situations; and (c) WDM Program Elements, which are guidelines for water uses according to the varying supply situations. Windhoek water tariffs are linked to five levels of water availability: During a 'normal situation' (Category A), consumer awareness is maintained, and realistic demand is

[1] 1 kl = 1 m^3
[2] N$ 1.00 ≈ HUF 23 ≈ US$ 0.05 on 23 October 2022

monitored. A ‘supply alert’ (Category B) requires increased communication with consumers on supply conditions. The water tariffs mentioned above are for ‘normal’ and ‘supply alert’ levels. A ‘scarcity’ classification (Category C) requires that mandatory restrictions are implemented and higher tariffs are levied. Mandatory restrictions intensify when ‘severe scarcity’ (Category D) is reached, and a ‘water crisis’ classification (Category E) results in the rationing of water supplies for essential uses only (REPUBLIC OF NAMIBIA, 2022). During the 2019 hydrological drought, Windhoek residents were banned from washing their cars and watering their gardens. Trees and shrubs could be kept barely alive with water from washing machines, showers and baths, but lawns, vegetable gardens and annual plants had to fend for themselves. Swimming pools had to be covered and no pools, ornamental ponds or water features could be supplied with water. Construction of buildings came to a virtual standstill. Many Windhoek residents switched to water-wise gardens with rocks, gravel and a few hardy indigenous plants and succulents, and bought 5,000-10,000 L water tanks to harvest rainwater from their roofs. Low-flow water-saving taps, showers and toilets were installed in houses, businesses and public buildings.

Namibians are well aware of the value of water and the need to use it sparingly. The first rains are greeted with jubilation. Rainfall figures, dam levels, photos and news of good rains are eagerly shared in newspapers and on social media. People congregate to watch floods in normally dry rivers and on the rare occasions when an ephemeral river reaches the ocean. When the newly built Neckartal Dam reached full capacity for the first time and started overtopping its spillway on 19 January 2021 (Figure 11), thousands of Namibians flocked to the scene. Many drove hundreds of kilometres or chartered light aircraft to witness the historical event.

Figure 11. The first time that the newly built Neckartal dam overflowed, on 19 January 2021. It is the largest dam in Namibia.

Conclusion

Safe potable water is provided to the vast majority of the Namibian population by applying a range of supply-side and demand-side water management techniques. Government, industries, and the general population is well aware of the need to conserve and optimally use every drop of water.

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