A TALE OF FRESHWATER SCARCITY: WATER RESOURCES OF NAMIBIA

AZ ÉDESVÍZHIÁNY TÖRTÉNETE: NAMÍBIA VÍZKÉSZLETEI

MARINA E. COETZEE
mcoetzee@nust.na

Abstract

This article introduces the various water resources available to Namibia, an arid country in southern Africa. With low and extremely variable annual rainfall and high evaporation rates, surface water is scarce. Permanent rivers are only found along the southern and northern borders. Ephemeral rivers flow for short periods after thundershowers and few reach the ocean. Many ephemeral rivers sink into the gravelly and sandy riverbeds, where they feed alluvial aquifers. Groundwater is the only water source for about 80% of the territory. Dams were built in ephemeral rivers to create artificial lakes that play an important role in water provision for urban areas, irrigation schemes and mines. Despite the extreme aridity, Namibia has a variety of wetland habitats, including five Ramsar sites.
Keywords: *Namibia, water resources, freshwater scarcity, dams, groundwater*
JEL code: *Q25*

Összefoglalás

Ez a cikk bemutatja Namíbia, egy dél-afrikai száraz ország különféle vízkészleteit. Alacsony és rendkívül változó éves csapadék és magas párolgási arány mellett a felszíni víz szűkös. Állandó folyók csak a déli és az északi határ mentén találhatók. Az efemer folyók rövid ideig folynak zivatarok után, és kevesen érik el az óceánt. Sok múlékony folyó süllyed a kavicsos és homokos folyómedrekbe, ahol táplálja a hordalékvíztartó rétegeket. A terület mintegy 80%-án a talajvíz az egyetlen vízforrás. Gátakat építettek az átmeneti folyókban, hogy mesterséges tavakat hozzanak létre, amelyek fontos szerepet játszanak a városi területek vízellátásában, az öntözési rendszerekben és a bányákban. A rendkívüli szárazság ellenére Namíbiában számos vizes élőhely található, köztük öt Ramsari terület.
Kulcsszavak: *Namíbia, vízkészlet, édesvízhiány, gátak, talajvíz*

An Arid Climate

Namibia is the most arid country in sub-Saharan Africa. The median annual rainfall varies from less than 50 mm in the Namib Desert along the west coast to a maximum of 650 mm in Zambezi Region in the northeastern tip of the country (Figure 1) (ATLAS OF NAMIBIA TEAM, 2022). The rainy season is concentrated from December to March, but may start in October and continue until the end of April (ATLAS OF NAMIBIA TEAM, 2022). In addition to being low, the rainfall is highly variable both spatially and temporally. Rainfall variability, expressed as the coefficient of variation in annual rainfall (Figure 2), increases from northeast to southwest (ATLAS OF NAMIBIA TEAM, 2022).

Namibia's aridity is the result of straddling the Tropic of Capricorn and being located on the west coast of a continent in the Southern Hemisphere. The northward-flowing cold Benguela Current constitutes the eastern limb of the South Atlantic Gyre. It exhibits strong upwelling along the Namibian coast and greatly inhibits evaporation. Except for overnight and early-morning coastal fogs, there is no appreciable influx of moisture over the country from the west. Positioned within the Subtropical High-Pressure Zone, the South Atlantic Anticyclone and the Botswana Anticyclone dominate during winter. The dry, descending air of these high-pressure systems precludes winter rainfall over most of the country. Only the far southern parts of Namibia receive low amounts of winter rainfall from Temperate Zone cold fronts and low-pressure systems sweeping from west to east over southern Africa. In summer, the anticyclones weaken and the Intertropical Convergence Zone (ITCZ) shifts southwards. This low-pressure belt follows the sun, carrying warm, moist air from equatorial regions towards the Tropic of Capricorn in the austral summer and towards the Tropic of Cancer in the boreal summer. The interplay between the ITCZ and the anticyclones determines when and how much rain Namibia will receive in a rainy season (ATLAS OF NAMIBIA TEAM, 2022). This is influenced by long-distance atmospheric teleconnectionssuch as the Indian Ocean Dipole (IOD), the Subtropical Indian Ocean Dipole (SIOD), the South Atlantic Oscillation Dipole (SAOD), and the El Niño Southern Oscillation (OGWANG et al., 2020). El Niño events generally result in poor rainfall over Namibia, while La Niña increases the probability of good rains.

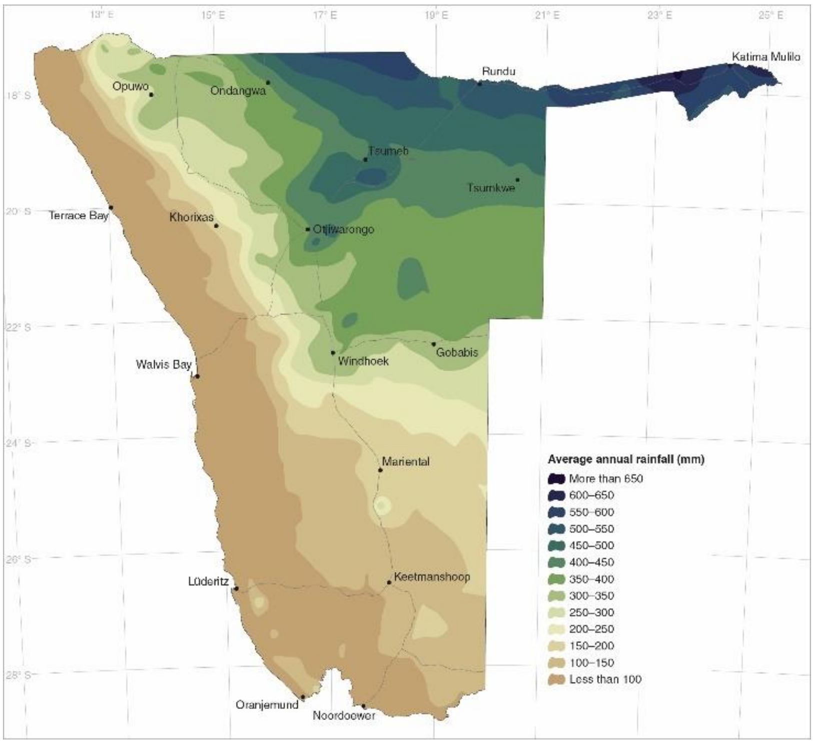

Figure 1. Average annual rainfall (mm).
Source: ATLAS OF NAMIBIA TEAM, 2022.

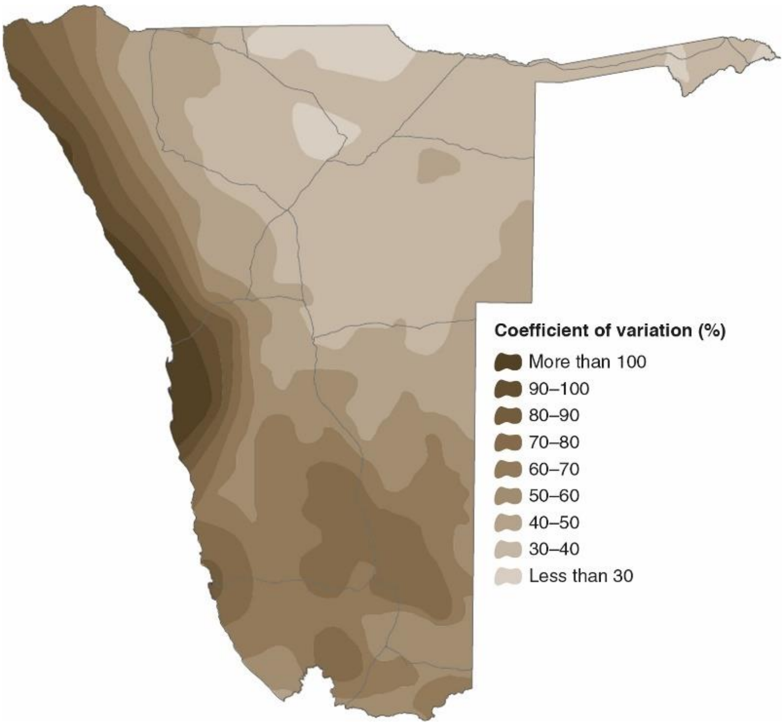

Figure 2. Coefficient of variation (%) of annual rainfall.
Source: ATLAS OF NAMIBIA TEAM, 2022.

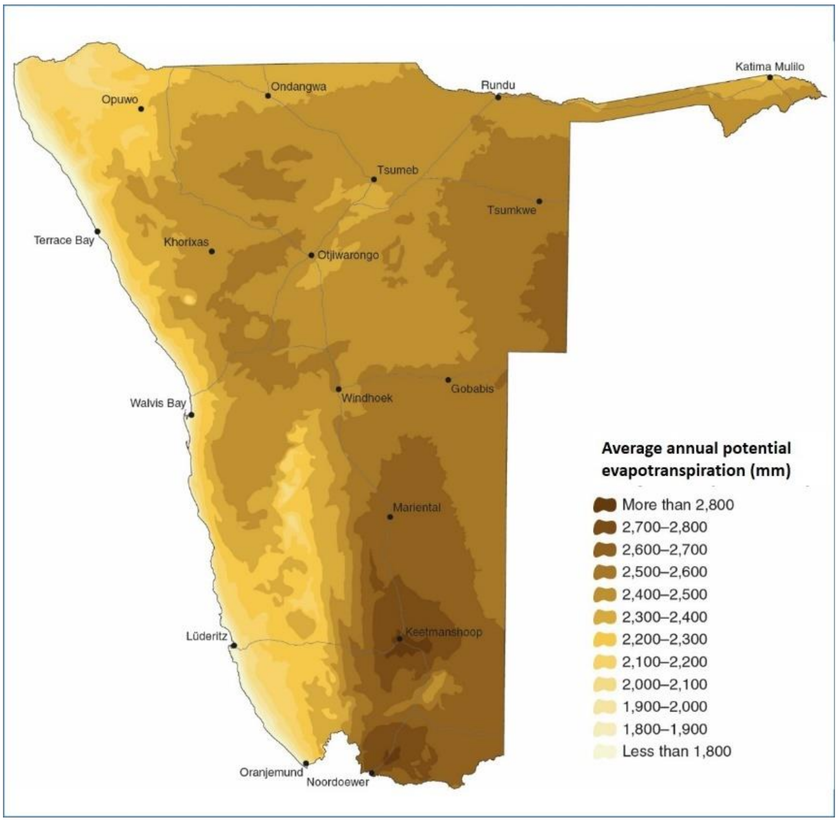

Figure 3. Average annual potential evapotranspiration (mm).
Source: ATLAS OF NAMIBIA TEAM, 2022.

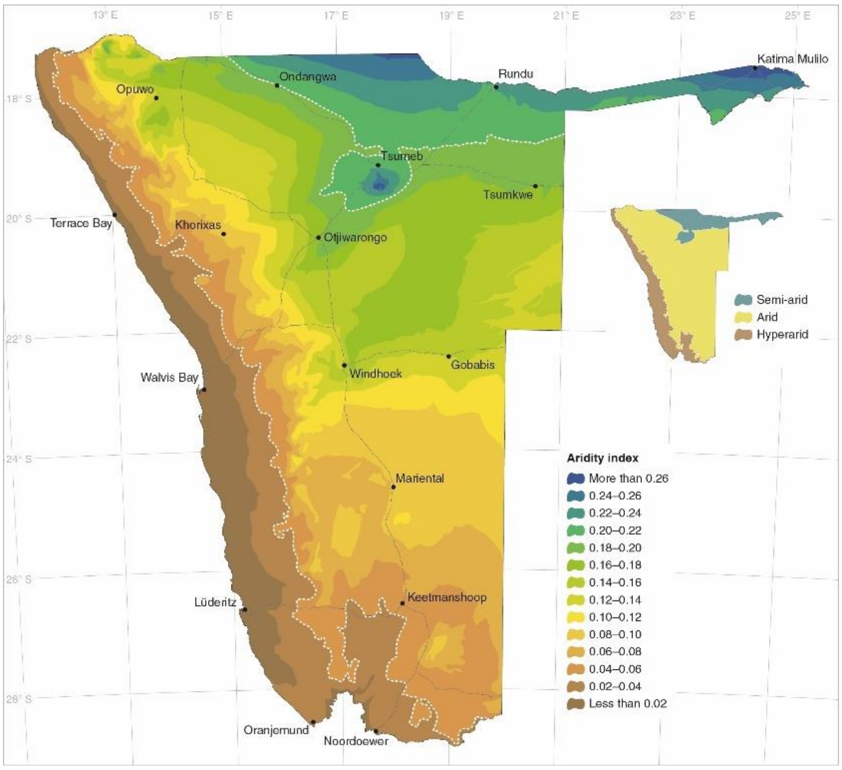

Figure 4. Aridity index.
Source: ATLAS OF NAMIBIA TEAM, 2022.

The evaporation rate is among the highest on the continent. The annual potential evaporation ranges from 1,800 mm a^{-1} along the foggy coastline to more than 2,800 mm a^{-1} in the south-central and southeastern areas (Figure 3) (ATLAS OF NAMIBIA TEAM, 2022). Evaporation is highest during the hottest months with low cloud cover, from October to December. Of all rainfall, 83% evaporates directly from surfaces, while 14% returns to the atmosphere through transpiration. Only 2% of rainfall ends up in the country's ephemeral watercourses as runoff and about 1% recharges aquifers (IWRMP JOINT VENTURE NAMIBIA, 2010).

Using the Global Aridity Index (GAI), the Namib Desert on the Atlantic Coast is classified as hyper-arid (GAI < 0.04), the far northern and northeastern areas are semi-arid (GAI 0.20-0.28), and the bulk of the country is arid (GAI 0.04-0.20) (Figure 4) (ATLAS OF NAMIBIA TEAM, 2022).

Permanent (Perennial) Rivers

The only permanent rivers are along the northern and southern borders, with their sources in the higher rainfall areas of neighbouring countries (Figure 5). The Orange River originates in the highlands of Lesotho, where it is known as the Senqu River, before traversing South Africa and forming the border between Namibia and its southern neighbour.

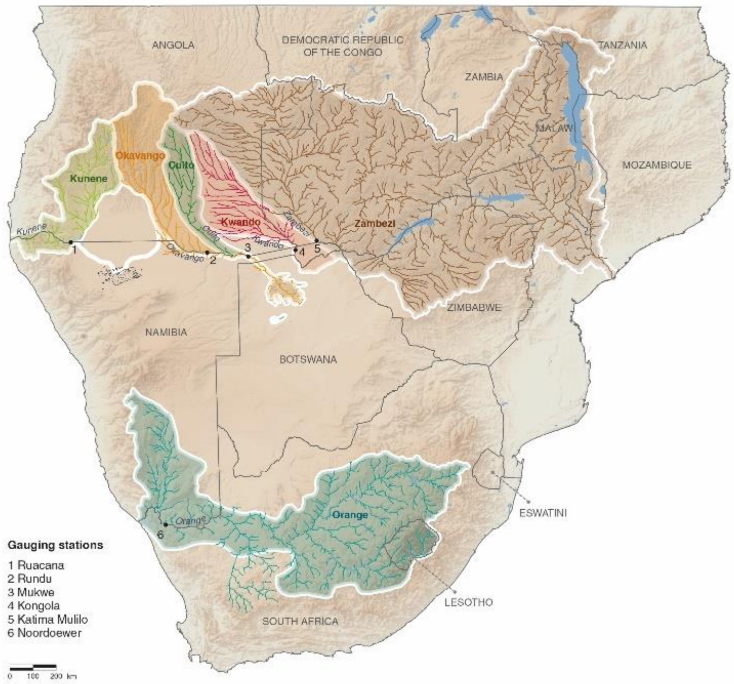

Figure 5. **Namibia's permanent rivers and their transboundary catchments**.
Source: ATLAS OF NAMIBIA TEAM, 2022.

The Kunene (or Cunene) River originates in Angola, forms the northwestern border between the two countries and debouches in the Atlantic Ocean. It is the source of up to 40% (depending on flow volumes) of the country's electricity supply from a hydroelectric scheme at Ruacana, which is supplied with water from an impoundment at Calueque across the border in Angola. The Kunene boasts waterfalls at Ruacana and Epupa. The Ruacana falls are only active after exceptionally high rainfalls in the catchment, as the flow is normally diverted through the hydroelectric scheme. The endorheic Okavango River starts in the Angolan highlands (where it is known as the Cubango), flows along the Namibian-Angolan border for 424 km, and is joined by the Cuito (or Quito) River. The Okavango then crosses a narrow strip of Namibian territory and terminates in the Okavango Swamps in Botswana. The only Namibian stretch of river with rapids is at Popa. The Zambezi is southern Africa's largest river and the fourth largest in Africa. Figure 6 highlights its vast flow volume compared to the other Namibian permanent rivers. The Zambezi River flows through Zambia and Angola, then forms the border between Namibia and Zambia for 170 km before continuing its journey eastwards to the Indian Ocean. The Zambezi floods extensive areas of eastern Zambezi Region every year, compelling the local inhabitants to migrate seasonally with their livestock to higher land and often causing losses of unharvested crops.

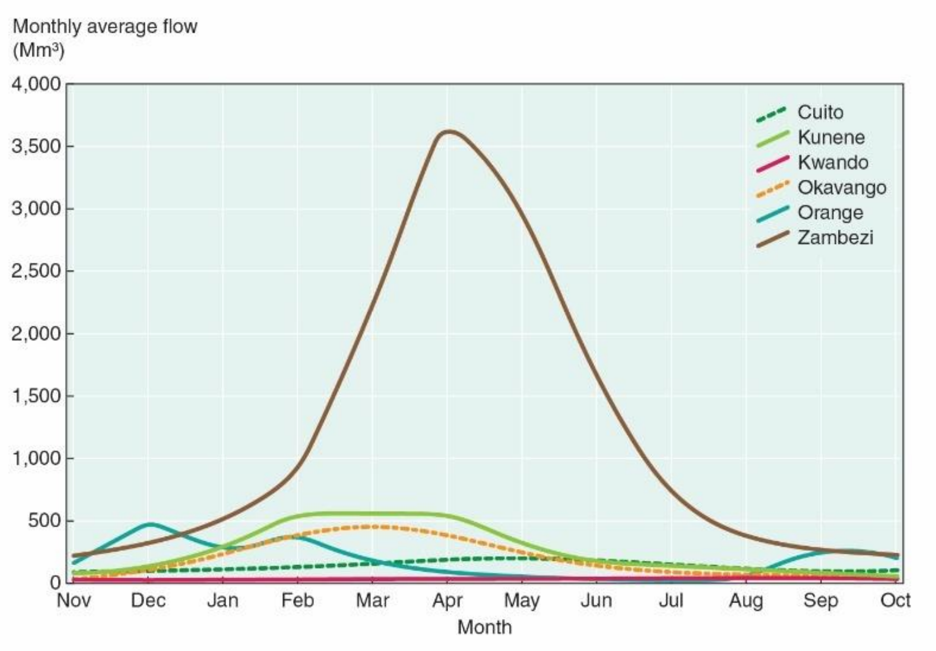

Figure 6. **The average flows of Namibia's permanent rivers, in Mm^3/month. The Zambezi dwarfs the other rivers**.
Source: ATLAS OF NAMIBIA TEAM, 2022.

The Kwando (or Cuando or Quando) River starts in southeastern Angola where it drains deep Kalahari sands. It initially has a well-defined channel within a wide floodplain vegetated by grasses, reeds and sedges when it crosses into Namibia, but eventually spreads out into the swampy Linyanti wetland where a geological fault changes the river course to the east. The Linyanti Swamps have a tenuous, poorly defined link to the Chobe River further east. The Linyanti River emerges from the swamp and flows into Lake Liambezi, which is normally a dry, vegetated depression that is farmed in parts. When it does contain water from floods in the Kwando or Zambezi or from high local rainfall, water emerges from Lake Liambezi's southeastern corner to join the Chobe River. The Kwando-Linyanti-Chobe system joins the Zambezi at the border of Namibia, Botswana, and Zambia[1]. The Chobe drops very little in elevation from west to east. Though it normally flows eastwards, its flow direction reverses when the Zambezi is in full flood. At those times, the Zambezi also pushes water through the Bukalo Channel, a broad, shallow depression, into Lake Liambezi.

Ephemeral (Seasonal or Intermittent) Rivers

The interior rivers of Namibia flow for only a few hours to a few days after heavy downpours, and flash floods are common. Runoff usually disappears into the gravelly and sandy riverbeds long before it reaches the ocean or inland termini.

[1] Contrary to popular belief, Namibia does not directly adjoin Zimbabwe. There are two tri-point borders close together: Namibia, Botswana and Zambia, and Botswana, Zambia and Zimbabwe.

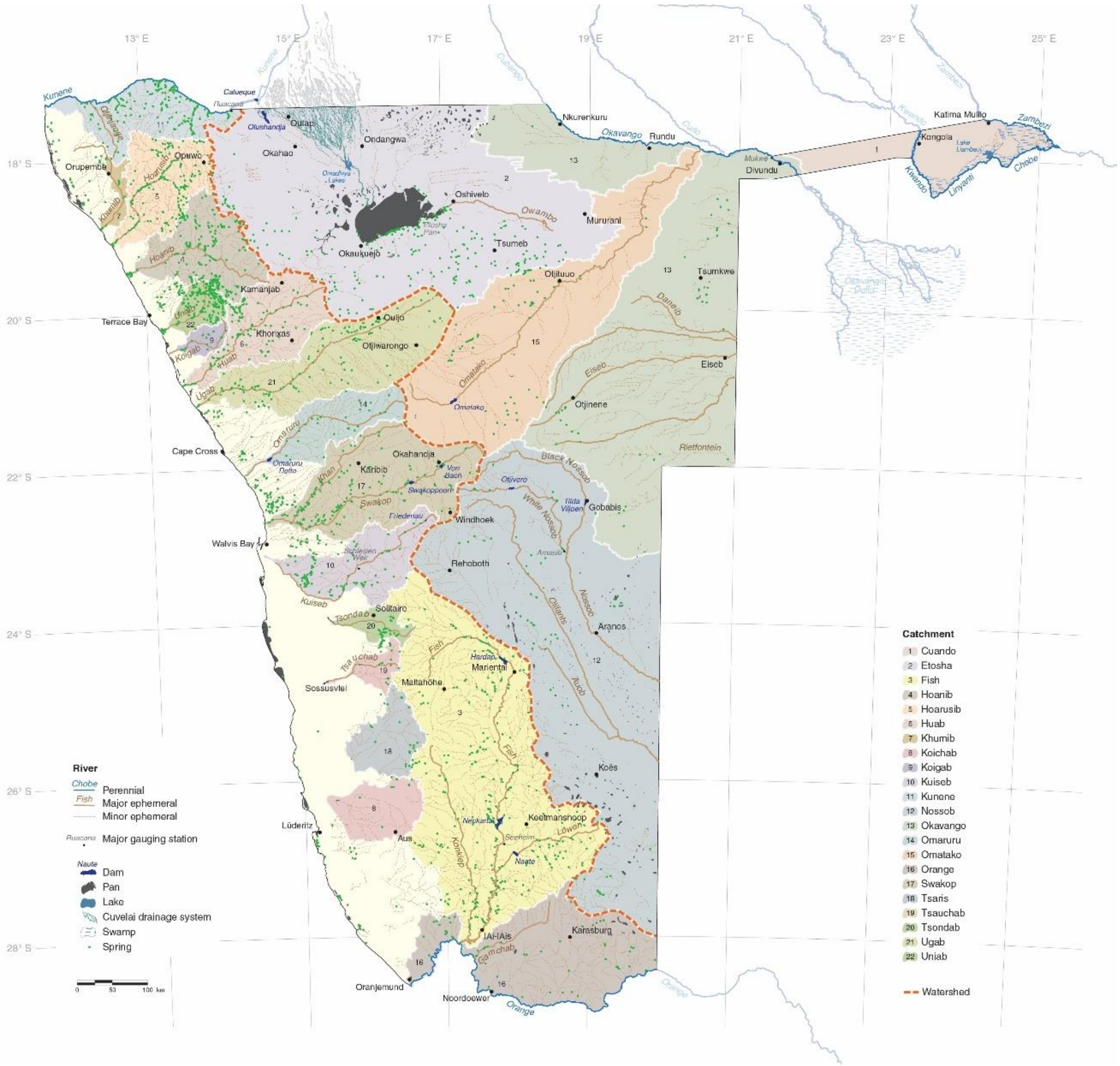

Figure 7. Namibia's surface waters and river catchments.
Source: ATLAS OF NAMIBIA TEAM, 2022.

To the east of the watershed (broken orange line in Figure 7), the ephemeral rivers have gentle gradients and are endorheic: they disappear into the sands of the Kalahari or end up in shallow seasonal pans that hold water for a limited time. Some watercourses so seldom carry any water that they are almost indistinguishable at ground level. Decades may pass without any flow in these omiramba (singular omuramba), as they are locally known, or they may only flow for a few kilometres after a localised shower (ATLAS OF NAMIBIA TEAM, 2022).

To the west of the watershed, the ephemeral rivers have well-defined, rocky channels eroded by high-energy flows. The difference in elevation from the central highlands and western escarpment to the low-lying coastal plain creates steep gradients. As they cross the Namib Desert on the coastal plain, the watercourses become shallow and wide with sandy and gravelly beds into which the water seeps. Only the Hoanib and Hoarusib Rivers reach the Atlantic Ocean in most years, with the Swakop and Ugab Rivers managing it less frequently and the Khumib, Huab and Kuiseb Rivers rarely. The other westward-flowing ephemeral rivers are barred by dunes, with flows that terminate in flat inter-dune playas or active fan systems, forming short-lived wetlands. Only exceptional floods in those rivers with large catchments can break through the dunes, such as the Hunkab in 1995 and the Uniab that broke through about seven kilometres of dunes in 1982 (WARD & SWART, 1997; ROBERTSON et al., 2012; SWART & MARAIS, 2009; GOUDIE & VILES, 2015). Seasonal flows, usually from February to April, bring water, sediments and nutrients to the lower reaches of the ephemeral rivers and are vitally important for supporting biodiversity in the hyper-arid environment of the Namib Desert. They recharge relatively shallow groundwater in alluvial aquifers, which occasionally surface as springs and seeps. The river courses create habitats and movement corridors for both resident and migrating wildlife and provide dispersal routes for plants, thus they are considered to be ‘linear oases’ (JACOBSON et al., 1995). They even support small populations of desert-adapted lions and large herbivores such as desert-adapted elephants, black rhinoceroses and giraffes.

The Fish River flows for more than 800 km southwards from its origin in the central highlands to its confluence with the perennial Orange River. It has a large enough catchment to flow a few times per rainy season and to accommodate three dams: Hardap Dan near the town of Mariental, Neckartal Dam near Keetmanshoop, and Naute Dam in a tributary of the Fish River, the Löwen River.

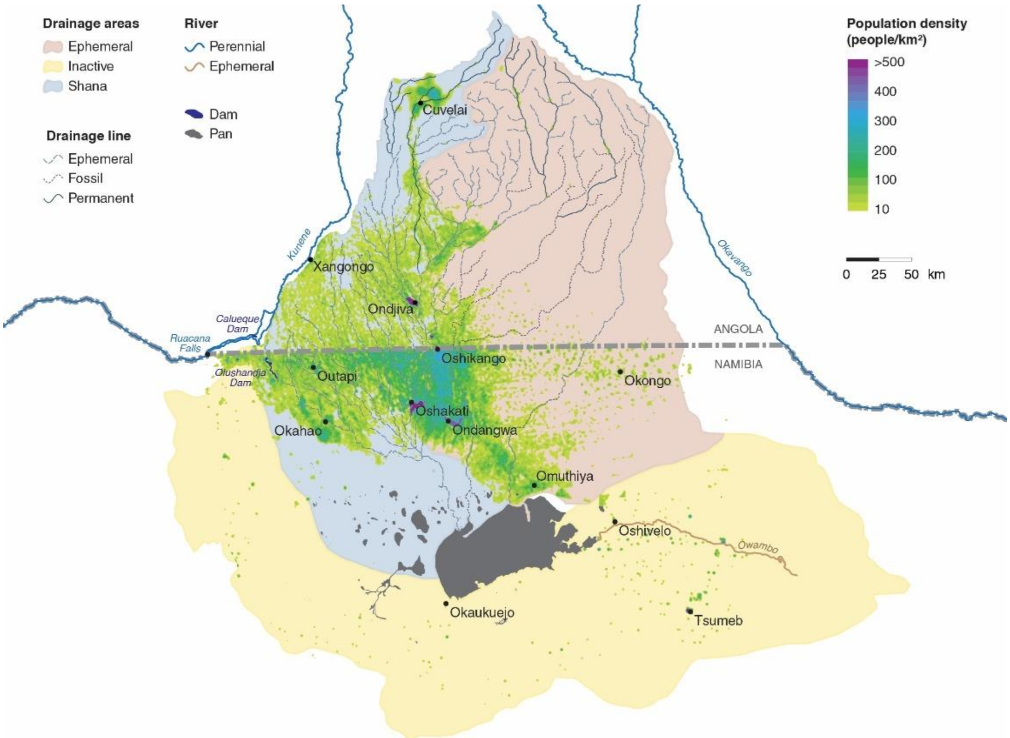

Figure 8. Cuvelai Drainage System.
Source: ATLAS OF NAMIBIA TEAM, 2022.

The Cuvelai (Figure 8) is a large, flat, ephemeral, transboundary drainage basin in southern Angola and the central northern regions of Namibia. Most of its seasonal water originates in the Angolan highlands between the headwaters of the Kunene and Okavango Rivers. It forms an intricate, low-gradient network of anastomosing channels known as ‘iishana’ (singular ‘oshana’). Though the area is covered by deep sandy soils of the Kalahari, the channels are underlain by clayey, saline and sodic soils of low permeability. In good rainy seasons, a large volume of water from local rainfall and inflows from Angola flows from north to south through the Cuvelai system. The event, known as the ‘efundja’ or ‘omafundja’, turns the entire basin into a vast shallow wetland. It brings fish, frogs and nutrients, but also displaces people, damages infrastructure, inundates crops, drowns livestock and occasionally people, and causes major disruptions in lives and the economy. The water eventually seeps into the sand, evaporates or may reach the Omadhiya lake complex (with Oponono as the largest lake) and, less frequently, Etosha Pan (ATLAS OF NAMIBIA TEAM, 2022). The Cuvelai system includes habitats of iishana, pans, seasonally flooded grasslands, palm tree savanna, woodlands and dry bush savanna. It supports 45% of the Namibian population through subsistence farming and fishing in the seasonal wetlands (RAMSAR, 2023).

Dams

Namibia has a handful of large dams, built to impound the sporadic flow in ephemeral rivers, and some 7,900 small earth dams on private farms, to catch the runoff and provide water for livestock and wildlife for a few weeks to a few months (ATLAS OF NAMIBIA TEAM, 2022). These dams are mainly located in the center of the country, as the Namib Desert to the west is not farmed and the deep Kalahari sands to the east and northeast absorb rainwater so efficiently that there is very little overland flow.

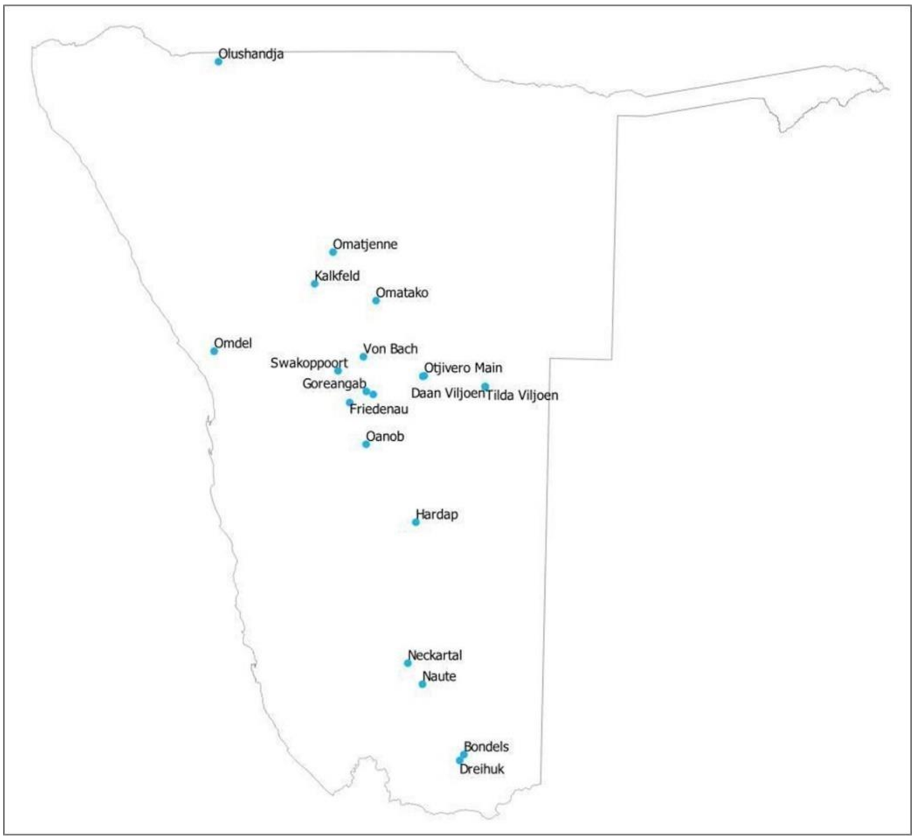

Figure 9. Large surface dams.
Source: NAMWATER, 2023.

Figure 9 shows the locations of the large dams, which have a combined capacity of around 1,556 Mm^3: Swakoppoort, Von Bach, Omatako, Friedenau, Omatjenne, Kalkfeld and Goreangab in the central part of the country; Olushandja in the north; Omaruru Delta (Omdel) in the west; Otjivero (Silt and Main dams), Tilda Viljoen and Daan Viljoen in the east; Hardap, Naute, Oanob, Dreihuk, Bondels and Neckartal Dam in the south (NAMWATER, 2023). It should be noted that the word 'dam' is used in southern Africa to describe both the containment wall and the lake of impounded water.

The town of Mariental and Hardap Irrigation Scheme were flooded in 1972, 1989, 2000 and 2006 when the sluice gates of Hardap Dam had to be opened wide to accommodate excessive inflows. Prolonged, heavy rains in the upper catchment of the Fish River caused flash floods that would exceed the dam's capacity and could potentially damage the dam wall, which would have been catastrophic for Mariental and the Hardap Irrigation Scheme. Some other factors compounded the flooding, such as infrastructure development in the floodplain, thick reed beds that slowed the outflow, and another flooding tributary joining the Fish River below the dam wall. After the last flood, MAWLR, the bulk water supplier (NamWater) and representatives of the town and irrigation scheme came to an agreement that the normal water level would be capped at 70% of the dam's capacity through low-volume releases. This should provide sufficient capacity to accommodate large inflows, but also keep enough water in reserve to supply the town and irrigation scheme in years of hydrological drought, which is a frequent occurrence.

Wetlands

Article 1.1 of the Ramsar Convention defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres", and it includes "riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands" in Article 2.1 (UNESCO, 1994).

Namibia has three coastal and two inland Ramsar sites, namely the Walvis Bay Wetlands, Sandwich Harbour, the Orange River Mouth, Etosha Pan and the Bwabwata-Lower Okavango area. The Walvis Bay site (Ramsar site no. 742) encompasses a tidal lagoon, adjacent intertidal areas, Pelican Point sand spit, mudflats exposed at low tide, and sandbars serving as roosting sites for waterbirds. Sandwich Harbour (Ramsar site no. 743) has shingle bars, mudflats, and two distinct wetlands – one of them fed by a freshwater aquifer and the other under tidal influences. The Orange River Mouth (Ramsar site no. 526) is a transboundary area shared with South Africa, with salt marshes, freshwater lagoons and marshes, sand banks, and reed beds. Etosha Pan and Lake Oponono (Ramsar site no. 745) is part of the Cuvelai drainage system of ephemeral rivers, feeding pans and the associated lake and delta. The Bwabwata-Okavango site (Ramsar site no. 2193) includes the lower Okavango River, part of the Okavango Delta Panhandle and permanently or temporarily flooded marshes and floodplains bordered by riparian forest and open woodland (RAMSAR, 2023).

Namibian wetlands can be grouped into five classes: marine, estuarine, riverine, lacustrine and palustrine. Marine wetlands include mudflats, sandbanks, lagoons and rocky shores of coastal waters. Examples are the highly biodiverse lagoons at Walvis Bay, Sandwich Harbour and Lüderitz which provide feeding and breeding grounds for large numbers (up to 300,000 individuals) of 40 to 50 bird species, as well as several fish species. Estuarine wetlands are partially enclosed water bodies at the interface of perennial rivers and seawater and are subject to tidal influences, such as the Kunene River Mouth and Orange River Mouth. These highly productive and dynamic systems are inhabited by species that are adaptable to changing salinity. Riverine wetlands can be perennial or ephemeral and refer to the flowing (lotic) river water as well as associated floodplains, river mouths and freshwater lagoons. The seasonally inundated floodplains of the Okavango, Zambezi and Kwando-LinyantiChobe Rivers as well as the entire eastern Zambezi Region provide grazing for wildlife and livestock, and breeding and feeding grounds for fish, aquatic invertebrates and birds in the wet season. Lacustrine wetlands, such as dams, lakes, sinkholes, pans and pools in granitic rocks, have standing (lentic) open water and very little or no vegetation. Pans are shallow depressions with clayey bottoms that are filled irregularly for short periods in the rainy season by local rainfall or ephemeral rivers, such as Etosha Pan, Nyae-Nyae Pan, Sossusvlei and the Kalahari pannetjiesveld. They play host to aquatic invertebrates that can complete their life cycles in a few weeks. Deep, permanently water-filled caverns occur in the Karstveld dolomites, namely cave lakes (such as Aigamas and Dragon’s Breath) and sinkhole lakes (such as Otjikoto and Guinas) that support rare endemic fishes and invertebrates. The artificial water bodies created by impounding the flow of ephemeral rivers have many negative environmental implications for downstream hydrology and geohydrology and for the inundated land, but this is offset to some extent by the creation of new wetland habitats. In a country as arid as Namibia, even water transfer canals and wastewater treatment ponds can become important wetland habitats, such as the sewage-cleaning reed beds in Walvis Bay that provide sanctuary to birds. Palustrine wetlands are also lentic systems, but they are vegetated and include swamps, marches, vleis (or vleys), springs (artesian groundwater) and seeps (aquifers intersecting the surface). Freshwater swamps, springs and vleis often boast water lilies and sedges. Geothermal springs (such as Ai-Ais and Gross Barmen) support only heat-adapted algae and bacterial mats where they emerge, but lush vegetation can usually be found at some distance where the water is cool enough. Seeps in the Namib Desert tend to be saline to hypersaline (BETHUNE et al., 2007).

Groundwater

Away from the permanent rivers, the entire rural interior of the country depends on groundwater for households, livestock, small crop fields and gardens. Groundwater varies greatly in depth, accessibility, availability and quality (Figure 12). Towns, villages and settlements receive groundwater through state schemes, while farmers on private land have to drill, equip and manage boreholes themselves (NAMWATER, 2023).

The high-yielding fractured Windhoek Aquifer is of vital importance for the city’s survival. Four coastal towns depend entirely on groundwater abstracted from porous alluvial aquifers below ephemeral rivers. Lüderitz uses water piped from the fossil Koichab Aquifer, Walvis Bay is supplied from the Kuiseb Aquifer, and Swakopmund and Henties Bay get their water from the Omdel Aquifer. The highly productive Karstveld Aquifer in the dolomite and limestones of the Otavi Mountains supplies water to nearby towns and even to Windhoek in times of severe water shortages (VAN VUUREN, 2011).

The Karstveld Aquifer is the source of two spectacular sinkholes (cenotes), Lake Otjikoto (Figure 10) and Lake Guinas (Figure 11), and the world’s largest non-subglacial underground lake, Dragon’s Breath (HEYNS et al., 1998; CHRISTELIS & STRUCKMEIER, 2002).

Figure 10. Lake Otjikoto.
Source: TRAVEL NEWS NAMIBIA, 2023.

Figure 11. Lake Guinas.
Source: LAKE GUINAS, 2023.

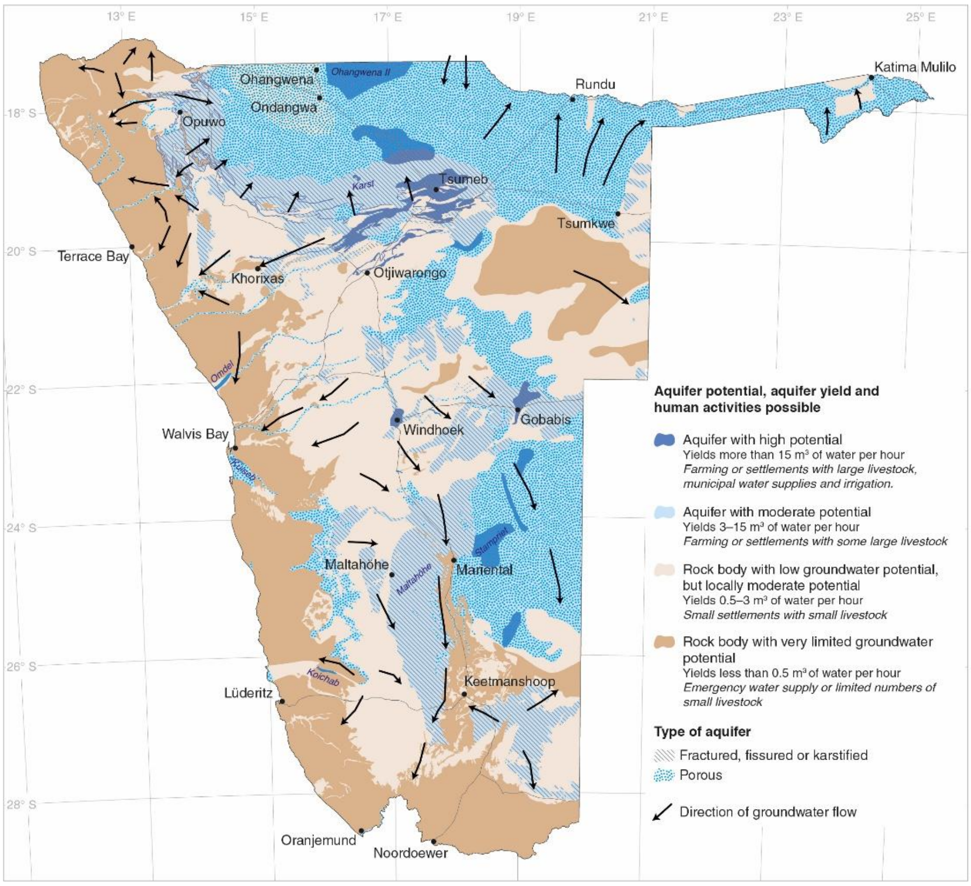

Figure 12. Groundwater potential and aquifer yield.
Source: ATLAS OF NAMIBIA TEAM, 2022.

A vast artesian aquifer, Ohangwena II, was discovered in northern Namibia in 2012. It is estimated to contain about 5 Gm^3 of mainly fossil groundwater that may be up to 10,000 years old. It could supply water to the 45% of the Namibian population living in the north-central regions for the next 400 years, though it is recommended that abstraction is limited to the annual recharge rate. The aquifer is about 300 metres deep. It poses some technical challenges to prevent saline intrusion, as the freshwater aquifer lies beneath a smaller saline aquifer (SORENSEN, 2013).

More than 100,000 boreholes had been drilled over the years throughout the country, with about half of them still in use to supply drinking water for humans, livestock and wildlife, irrigate vegetable gardens and crop fields, and provide water for industries and mines (NAMWATER, 2023).

Local groundwater abstraction is the most economic water source for more than 80% of the country, despite the cost of drilling, equipping and maintaining boreholes. As surface water is restricted to the permanent rivers along the northern and southern borders and a few, widely scattered dams in ephemeral rivers, the size of the country and low population density in most of rural Namibia do not justify large investments in a more extensive water distribution network. Pipeline distribution systems are only used in those areas where groundwater is either absent, scarce, too deep or too saline for human consumption, like the northwestern parts of the Cuvelai-Etosha Basin (NAMWATER, 2023).

Making every Drop Counts

The estimated dependable annual volume of water available to the country is about 6 126 Mm^3, namely 361 Mm^3 from groundwater and 5,765 Mm^3 from surface water (IWRMP JOINT VENTURE NAMIBIA, 2010). The major water potential lies in the 4,000 Mm^3 a^{-1} that could, in theory, be abstracted from the Zambezi River – a tenth of its mean annual runoff at that point – should Namibia reach such an agreement with the other basin-states. However, the Zambezi River is far from the capital city and other centers of industry, which would make such a long water transfer very costly. Namibia has reached the limits of easily accessible water sources. Careful, responsible stewardship is the only way forward, with integrated water resource management on both the supply side and demand side. In a country as water restricted as Namibia, the inhabitants have learned to make optimal use of every drop of water. Namibia has become a world leader in managed aquifer recharge, direct potable reuse, and conjunctive use of water.

References

ATLAS OF NAMIBIA TEAM (2022). Atlas of Namibia: its land, water and life. Namibia Nature Foundation. Windhoek. Available online: 04.08.2023. Source: https://atlasofnamibia.online/.

BETHUNE S., SHAW, D., ROBERTS, K. S., THE WETLAND WORKING GROUP OF NAMIBIA (2007). Wetlands of Namibia. John Meinert Printing. Windhoek, Namibia.

CHRISTELIS, G., STRUCKMEIER, W. (2001). Groundwater in Namibia – an explanation to the hydrogeological map. Department of Water Affairs, Division Geohydrology, Geological Survey of Namibia, Namibia Water Corporation, Federal Institute for Geosciences and Mineral Resources. Windhoek, Namibia and Hannover, Germany. pp. 130. Available online: 04.08.2023. Source: https://www.bgr.bund.de/EN/Themen/Wasser/Projekte/abgeschlossen/TZ/Namibia/groundwater_namibia.pdf%3F__blob%3DpublicationFile.

GOUDIE, A., VILES, H. (2015). Landscapes and landforms of Namibia. World Geomorphological Landscapes. Springer Science & Business Media. Dordrecht, Netherlands. pp. 173. https://doi.org/10.1007/978-94-017-8020-9.

HEYNS, P., S. MONTGOMERY, J. PALLETT, M. SEELY (1998). Namibia's Water, A Decision Makers' Guide. Desert Research Foundation of Namibia and Department of Water Affairs, Ministry of Agriculture, Water and Rural Development Windhoek, Namibia. pp. 173.

IWRMP JOINT VENTURE NAMIBIA (2010). Integrated water resources management plan for Namibia. Ministry of Agriculture, Water and Forestry. Windhoek, Namibia.

JACOBSON, P. J., JACOBSON, K. M., SEELY, M. K. (1995). Ephemeral rivers and their catchments: Sustaining people and development in western Namibia. Desert Research Foundation of Namibia, Windhoek. pp. 160.

LAKE GUINAS (2023). Lake Guinas website. Available online: 04.08.2023. Source: www.lakeguinas.com.

NAMWATER (2023). NamWater website. Available online: 04.08.2023. Source: www.namwater.com.na.

OGWANG, B. A., ONGOMA, V., SHILENJE, Z. W., RAMOTUBEI, T. S., LETUMA, M., NGAINA, J. N. (2020). Influence of Indian Ocean Dipole on rainfall variability and extremes over southern Africa. Mausam 71(4): 637–648. https://doi.org/10.54302/mausam.v71i4.50.

RAMSAR (2023) Ramsar Sites Information Service. Available online: 04.08.2023. Source: https://rsis.ramsar.org.

ROBERTSON, T., JARVIS, A., MENDELSOHN, J., SWART, R. (2012). Namibia's coast. Ocean riches and desert treasures. Ministry of Environment and Tourism. Windhoek, Namibia. pp. 192.

SORENSEN, P. (2013). The massive Ohangwena II aquifer in northern Namibia. International Journal of Environmental Studies 70:2, 173–174. https://doi.org/10.1080/00207233.2013.779149.

SWART, R., MARAIS, C. (2009). Landshapes. The geomorphology of Namibia. Windhoek: Macmillan Education Namibia Publishers (Pty) Ltd. pp. 134.

TRAVEL NEWS NAMIBIA (2023). Travel News Namibia website. Available online: 04.08.2023. Source: https://www.travelnewsnamibia.com/news/stories/featured-stories/namibias-bottomless-lakes-otjikoto-guinas/.

UNESCO (19949. Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar, Iran, 2.2.1971, as amended by the Protocol of 3.12.1982 and the Amendments of 28.5.1987. Office of International Standards and Legal Affairs, United Nations Educational, Scientific and Cultural Organization (UNESCO). Available online: 04.08.2023. Source: https://www.ramsar.org/sites/default/files/documents/library/scan_certified_e.pdf.

VAN VUUREN, O. (2011). Groundwater – A Namibian perspective. O. V. Vuuren, Windhoek, Namibia. pp. 119.

WARD, J. D., SWART, R. (1997). Flash-flood fluvial systems of the Central Namib Desert. Field Guide, 6th International Conference Fluvial Sedimentology. Cape Town, South Africa.

Author

Marina E. Coetzee
PhD student
Department of Soil Science, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, Páter Károly u. 1. H-2100 Gödöllő, Hungary.
Faculty of Engineering and the Built Environment, Namibia University of Science and Technology, Private Bag 13388, Windhoek, Namibia.
mcoetzee@nust.na