WATERMARQ

WATER INSIGHTS: SAMPLE REPORT

UNIT(S) OF ANALYSIS: (Country/ Company/ Sector/ Basin)

Country, Basin, Sector

AREA(S) OF FOCUS:

Zambia, Zambezi Basin, Critical Minerals

ANALYSIS FRAMEWORK(S):

Water demand and supply dynamics

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Contents

Summary

This spatial hydrological assessment details key water risk drivers in the Zambezi river basin from 2000 to 2020. Drivers analysed on the supply and storage side include surface water reservoirs, groundwater storage, and precipitation trends. Our analysis of key competitors for available water resources covers agriculture, domestic and industrial water use. A literature review of water quality drivers is also provided for the Kafue sub-basin.

The Zambezi basin is selected for this Watershed Assessment due to its relevance for mining activities and its vulnerabilities to droughts. The Kafue sub-basin, meanwhile, occupies an upstream portion of the basin and contains some of the most valuable mineral reserves, the largest reservoirs, and the largest city (Lusaka) in the basin, making it strategically important to the entire region.

This assessment covers multiple data sources with a variety of methods. Data on groundwater mostly comes from local government organisations measuring water levels in situ in the Kafue sub-basin, as well as gravity-based remote sensing for the wider Zambezi basin. Agricultural data meanwhile comes from national statistics on yield and water consumption, as well as remote sensing of crop-type maps. Reservoir and precipitation data is acquired through remote sensing, while population data is based on census records combined with satellite data.

Water resources in the Zambezi basin, particularly in the Kafue sub-basin, are perhaps best characterised in terms of both converging and diverging trends. For example, while some of the smaller reservoirs evidence significant reductions in surface water area, the majority actually show an increase, which can be primarily attributed to the construction of new reservoirs, especially in the lower Kafue basin. Surface water supplies show an overall decreasing trend with significant fluctuations, as do groundwater levels. Precipitation is observed to decrease overall, with an associated increase in drought periods.

On the demand side, population growth is contributing to an increase in water consumption, while agricultural water use has remained relatively stable overall.

However, an analysis of water consumption by crop type highlights that crops such as cassava and maize have (until 2017) evidenced an increase in green and blue water use driven by higher yields; whilst other crops such as soybeans and sugarcane show a downward trend in consumption.

In terms of water demand from industrial users, analysis is constrained by limited activity and low levels of disclosed information. However, the mining sector is the most significant industrial actor in the upper Kafue sub-basin. Mine 'dewatering' (i.e. pumping water out of the aquifer to access the ore body) is a prevalent activity in relation to copper mining, although volumetric data is not readily accessible. Separately there are documented issues relating to the impact of mining on water quality throughout the Kafue sub-basin, including pollution from heavy metals. Again a quantitative analysis of impacts on water quality from the mining sector is not readily accessible, and would be a valuable area for further research.

Overall trends with regard to water availability and water quality in the Zambezi basin in general (and the Kafue sub-basin in particular), are indicative of deteriorating resilience, exacerbated by the likely increasing prevalence in drought conditions in the future. Adaptive responses to the situation will require additional investments for water security and basin resilience. It is not readily apparent as to which stakeholders are able and/or willing to fund these investments, which embeds a high risk that conditions will continue to deteriorate. This will have self-evidently negative implications for economic, environmental and societal welfare outcomes.

As an urgent next step, it is recommended that resources are made available to support the generation and collection of various data in situ, including on river discharge, groundwater levels, agricultural and industrial water use, water quality, and biodiversity. This information is needed to provide a robust baseline to assess the short-, medium-, and long-term impacts of increased mining and other industrial activity on water resources within the basin.

Introduction

The Zambezi River is a vital source of freshwater for the entire region, crossing six countries (Angola, Zambia, Namibia, Botswana, Zimbabwe, and Mozambique), while its river basin area further covers parts of Tanzania and Malawi.

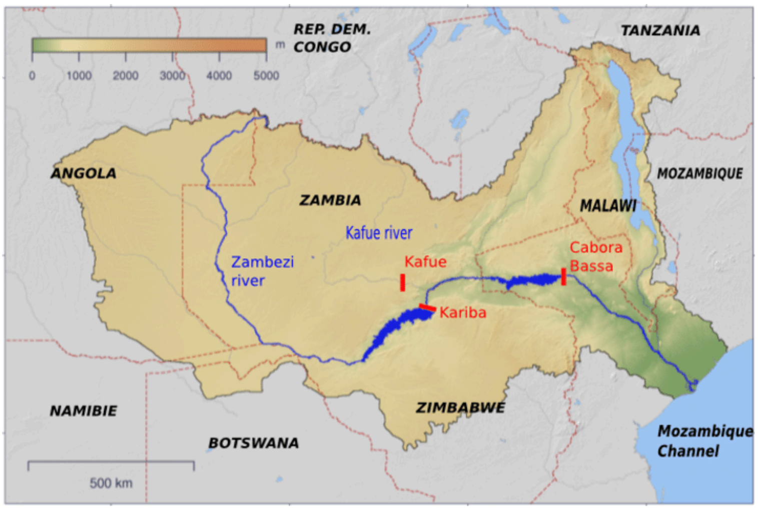


Figure 1 - The Zambezi river basin (source: Tilmant et al., 2010)

The basin's water resources are heavily utilised to support large-scale mining activities, especially involving copper, cobalt, and other minerals (The World Bank, 2010). The extraction and processing of these minerals have significant impacts on water quality and availability, raising concerns about sustainable water management within the entire basin. Beyond mining, the biggest freshwater users of the Zambezi basin are domestic, hydropower (non-consumptive), industrial, and agricultural users.

Within the Zambezi river basin, the Kafue sub-basin is one of Zambia's most important regions, playing a crucial role in the country's economy. It drains an area of 156,566 km^2 and is the only sub-basin within the Zambezi basin where both the basin and the 1,599 km long Kafue river are completely within Zambia. Around 50% of Zambia's population live in the Kafue basin (WARMA et al., 2019) with more than 60% living in urban areas including Lusaka, the Zambezi's largest city. The Kafue provides water resources that support key economic activities, including mining, tourism, agriculture, and hydropower generation and the basin is home to a wide range of biodiverse ecosystems consisting of lagoons, marshes and floodplains (Kalumba & Nyirenda, 2017). These ecologically sensitive areas are crucial for biodiversity - the Kafue Flats, for example, are designated as an Important Bird Area, as they support a large variety of migratory and resident birds, and this area is considered one of the world's most important wetlands for avian biodiversity, featuring many species of conservation concern (BirdLife International, 2024). The Kafue National Park is also Zambia's oldest national park, and supports over 500 bird species, 158 mammal species, of which 21 are antelopes - making this the region with the largest diversity of antelopes in Africa (African Parks, 2024).

Figure 2 - Location of Kafue sub-basin

The main water users in the Kafue river basin are hydropower generation (non-consumptive use), agriculture, industry, tourism, and domestic consumption (WWF, 2018). Domestic water demand is expected to grow significantly, especially as the population shifts from rural to urban areas, increasing pressure on water resources. The Kafue river is exposed to the highest water demand in Zambia, both in terms of water rights and withdrawals. The lower Kafue river basin generates over 50% of the country's electricity (WWF, 2016), with hydropower accounting for 83% of Zambia's total energy supply (Ministry of Energy Zambia, 2024). As a result, the water flowing through the Kafue basin is of critical importance to all economic sectors relying on domestic electricity generation. Additionally, the Kafue basin hosts over 90% of Zambia's copper mines, which are the major consumers of energy, accounting for 68% of the country's electricity use (Mwelwa, 2008).

Methodology and Approach

Data on three variables of water availability—reservoirs, groundwater, and precipitation—, and three variables of water demand—agricultural, domestic and industrial—were collected. Data sources for each element are shown below:

Table 1 - Data sources for water availability drivers

Variable	**Data source**	**Timeframe**	**Description**	**Citation**
Reservoirs	Global Water Watch	2000 - 2020	Remotely-sensed data processed by Global Water Watch on worldwide small and medium-sized reservoirs	Donchyts et al. 2022
Ground-water	Water Resources Management Authority (WARMA)	2015 -2023	In-situ measurements for urban areas e.g Lusaka Water use and demand	WARMA 2024
	Global Gravity-based Groundwater	2002 - 2020	Gridded anomalies of groundwater, 0.5° resolution	Güntner et al., 2024

Variable	Data source	Timeframe	Description	Citation
	Product (G3P)			
Precipitation	CHIRPS	1994 - 2023	Gridded rainfall time series from satellite imagery combined with in-situ observations	Funk et al. 2015
Agriculture	WorldCereal	2021	Active & irrigated cropland, by crop	Van Tricht et al. 2023
	MapSPAM	2000 - 2020	Yield per 5'' gridcell	IFPRI, 2024
	Water Footprint Network	Static	Water use by yield, per country & crop	Mekonnen & Hoekstra, 2011
Domestic	WorldPOP	2000 - 2020	1km resolution country population counts	Lloyd et al., 2019
Industrial	Camargo, Salazar & Morgan	Static	Compilation of open asset-level data, including site locations	Camargo et al., 2022

Statistical analyses were then conducted on each of the six variables separately, to understand temporal changes and spatial variations in water supply and demand across the study region. These methods are explained in greater detail in each of the respective sections.

Challenge of Data Availability

While many global datasets are available to conduct high level hydrological assessments of water risk in various regions of the world, there are significant limitations in relation to the availability of high-quality local in situ data. Our analysis suggests that some of the most up-to-date and high resolution data that exists is currently ‘siloed’ within departments of public sector agencies, or held in proprietary repositories that are owned by private sector companies. Even where this data is notionally accessible to third parties for research and other purposes, the process to gain access is procedurally challenging and can be very time consuming. Moreover, access is frequently a function of the quality of personal relationships that requesters have with key individuals within public agencies and other organisations. In any event, data is typically being collected using sporadic, disconnected and unconsolidated processes. There is a strong case to be made for resourcing the systematic generation and collection of high resolution data; and for disseminating this information at minimised transaction cost. This would unlock capacity for analysis and insight that is vital to developing a comprehensive and complete overview of the state of water resources in the basin.

Our analysis has highlighted several key datasets that are currently largely missing or incomplete. We suggest that these should be prioritised under any initiatives to improve availability and access to relevant information.

- **River discharge data:** In-situ observations of streamflow data are able to provide direct measurements of water volume, capturing real-time changes in flow rates. However, in situ measurement may not always be practicable due to cost and other considerations, leading to significant temporal gaps and/or uneven spatial distribution. As an alternative, we have used the remotely sensed surface water area of reservoirs as a proxy for water storage dynamics in areas where local hydrological data is unavailable. Existing and emerging initiatives such as *Digital Innovations for Water Secure Africa* (DIWASA) and *WorldWater* offer the prospect of applying remote sensing to measuring river discharge rates, which would also help to close the data gap.

- **Land cover data:** There are marked variations in the green and blue water footprints associated with different crop types. This is in addition to differences associated with whether the crop(s) are irrigated or rain-fed. Remote sensing can provide a broad approximation of water use by crop type, but the spatial and temporal resolution available from publicly-available datasets is often quite poor in many regions. Ground truth data would significantly improve the analysis that we have performed; by identifying more explicitly which crops are being grown in what quantity in specific locations. This would in turn inform a more accurate assessment of associated water consumption.

- **Soil type & moisture:** High quality, healthy soils can store large amounts of rainwater and make them accessible over time to support crop growth. Hardened, overworked soil on the other hand mostly leads to run-off, which makes the water inaccessible to crops and increases the need for irrigation. While there are global soil moisture datasets that can be acquired via remote sensing (e.g. using synthetic aperture radar, such as this project by the European Space Agency), they are at relatively low resolution, with estimates that frequently rely on modelled augmentation to close data gaps. Locally acquired data using soil moisture sensors would significantly improve the quality of outputs in terms of accuracy and reliability.

- **Groundwater data:** For this analysis, we used non-publicly available datasets on groundwater levels around Lusaka. However, this data is difficult to routinely obtain for the region as a whole because of limited monitoring piezometers, and it can also be time-consuming to collect. A more accurate understanding of current groundwater levels and how they have changed over time could significantly improve management and allocation decisions especially in regions where changes in surface water levels may not be reflective of the underlying trends in groundwater levels. Encouragingly, there are groundwater datasets available which can materially close the information gap (such as those curated by SADC-GMI). We are beginning to work with this data, having gained access via official channels. We would recommend a more detailed analysis using these datasets as part of any future hydrological analysis within the region.

- **Borehole attribution data:** For this study, WARMA was able to provide us with data on which borehole was used for commercial, industrial, irrigation, and domestic water supply. However, accessing this data is difficult and requires navigating various procedural complexities (in this case, including the establishment of a Memorandum of Understanding with WARMA). Accurate and accessible borehole attribution data could improve sustainable water management practices, and could usefully inform allocation prioritisation decisions, based on an improved understanding of competing water use.

- **Water quality data:** Measuring water quality via remote sensing is still very difficult and largely limited to algal blooms and turbidity. Getting a sense of the impact of mining and industrial activity on water quality is difficult without in situ measurements, which can be costly to obtain in remote areas. There are several hybrid satellite and sensor-based solutions emerging in the marketplace (an example is Gybe)to measure and track changes in water quality. These are increasingly being used for watercourses in many developed countries, but are much less frequently deployed in countries such as Zambia, due to cost and other considerations. We consider that a programme to support sensor-based monitoring of water quality, particularly in locations where point-source pollution can be identified, could transform a wider understanding of the impact of e.g. mining and processing critical minerals on water quality. The cost of establishing and maintaining water quality monitoring, whether using in situ sensors or sample collection with lab analysis, vary greatly. Considerations include the type of sensor used, the remoteness of the area , and expenditures related to data collection, processing and management (Harmel et al., 2023).

- **Biodiversity impact data:** River basins support a large number of sub-ecosystems that depend on healthy water sources and habitats from rivers, lakes, and wetlands. Deteriorating water quality, along with reduced environmental return flows, have been scientifically proven to contribute to biodiversity loss. The interdependencies are often complex and context-specific. The relationship between water use, water quality, climate impacts and other anthropogenic factors on biodiversity remains relatively unexplored across much of the Zambezi basin (and elsewhere). There are a number of providers (such as 3Bee) developing solutions to assess anthropogenic impacts on natural capital endowments, but most of these initiatives are still at an incipient or pilot stage. A programme to support the systematic assessment of how these factors are influencing biodiversity impact could similarly transform wider understanding of the water stewardship responsibilities of the critical minerals sector, and beyond.

For this analysis, some of the data challenges identified above were addressed by integrating available datasets and making 'reasonable' inferences. The process necessarily results in some tradeoffs between insight and rigour, and this should be front of mind when reaching conclusions based on the analysis provided. In subsequent sections, we provide further detail on the approach used in our methodology, but the overarching challenges of data availability and access identified here remain broadly applicable in each case.

Known Unknowns & Assumptions

To meet the objective of providing decision-useful insight, various methodological assumptions have been made in this report. We summarise some of the key issues here, and caution that these may negatively impact on the rigour of our findings. ,

When analysing surface water area changes in reservoirs, key unknowns include reservoir use, management, and construction or expansion dates. In the Kafue sub-basin, we identified reservoirs constructed in the 2000s by visually comparing optical satellite imagery. However, this approach is challenging due to cloud cover and gaps in temporal data, making it difficult to determine exactly when new reservoirs were built or expanded. Given the large number of reservoirs in our dataset and the limitations of satellite imagery, trends in surface storage often need to be generalised. This generalisation may not accurately reflect real changes when factors such as reservoir use and construction dates are not readily available. To better understand surface water changes, it would be necessary to deepen the analysis, for example by focusing on specific water bodies and gathering detailed, validated information on their use and construction timelines. Automated detection methods could also help identify when reservoirs were built or expanded, improving our analysis of temporal changes in water storage.

In terms of domestic water use, a major limitation is our classification of urban and rural populations, which may lead to an over (or under) estimation of actual water consumption, for example in rural areas where access to water is limited. To address this gap, additional datasets such as national census records could be incorporated to the analysis, to provide a potentially more accurate representation of water use and access.

For agricultural water demand, the biggest ‘known unknown’ in this analysis is the variation in water consumption by crop yield for different crops over time. The current methodology fills this gap by assuming a constant value per crop per country, albeit by using a somewhat dated, global dataset from 2011. In reality, there is anecdotal evidence that, for example, advances in yield efficiency have taken place through using different crop varieties, improving soil health to store additional moisture, and increasing the efficiency of the irrigation system. There is some updated data available on total evapotranspiration and interception, for example, however, this does not break out green (rainfed) and blue (surface water) consumption. Irrigation data by FAO Aquastat would also be available, but only under a non-commercial licence and therefore not usable for this project.

Novelty of our approach

Conventional approaches to assessing watershed dynamics typically rely on hydrological models (such as PCR-GLOBWB 2, used in the latest version of the Aqueduct Risk Atlas). These models have the benefit of scale and enable some degree of comparability, albeit at fairly low resolution. Traditional assessments also typically rely more heavily on static, historic data as proxies of water supply and demand.

Our approach iterates on what has come before in several ways. We use high resolution data from remote sensing and in situ measurements to measure changes in surface and groundwater. This resolution enables us to capture important intra-basin dynamics that conventional models are less well suited to. For example, we show, in our analysis, that the surface water area in the Kafue sub-basin is actually *increasing* due to the recent construction of new reservoirs, which is contrary to the dynamics of the overall Zambezi basin. We also work with datasets that are updated on a higher temporal frequency (often weekly) than the inputs (often updated annually, or even less frequently) in conventional models. This enables us to better capture current dynamics of water supply, and to project future changes with higher confidence, given the lower latency of the data.

We take a similar approach to measure changes in water demand. Our framework categorises sources of demand between agricultural, industrial and domestic users - which at a global level account for approximately 70%, 20% and 10% of water demand, respectively (Gleick et al. 2018). We recognise that natural ecosystems are also a source of water 'demand' - for example through the environmental return flows necessary to preserve basin health and biodiversity - although our current approach does not currently account for this explicitly.

To better understand agricultural demand, we use remote sensing and global footprint datasets to identify crop location, type, yield and consumption profiles. Future iterations will include further distinctions between irrigated and rain-fed crops, for example. Our analysis of industrial demand also emphasises the location of assets, and profiles associated with different industrial sectors and processes. For this study, we have used available global datasets (Camargo et al., 2022) to generate a high-level overview of industrial demand in the basin. The approach faces the limitations commonly associated with datasets of this type in terms of resolution, comprehensiveness, accuracy etc., and further iterations will focus on improving on the state of the art, depending on user-specified requirements. As an example, for this project (which has critical minerals in Zambia as an area of focus) we reviewed the data available on the Cadastre portal, which includes information on mining licences, and is a potentially useful proxy for future water demand.

Finally, our analysis of domestic demand differentiates between consumption profiles of rural and urban populations, and uses geospatial data and official statistics to capture the dynamics of demographics and migration. Future iterations will refine this methodology - for example, by incorporating census data - to capture both location and context-specific information, including socioeconomic and other variables that are associated with domestic demand. We consider there to be promising applications of machine learning approaches when working with this data, such that insights can be derived at scale without compromising heavily on rigour.

In summary, the novelty of our approach derives from synthesising the drivers of demand and supply within sub–basins at higher resolution, using more recently updated data, and with lower latency than many conventional approaches. In addition, we augment remotely sensed data with locally verified and in situ information wherever possible, for example in our analysis of groundwater dynamics. To curate and validate our assessments, we employ local 'basin specialists' with specific domain expertise of the context, hydrological regime, sources of available data and other relevant factors, to improve the quality of our methods, and the veracity of our analysis. We also actively search for the most up-to-date national and global sets that are available to inform our analysis, noting the regular release of new and potentially relevant sources of information.

Our approach prioritises transparency and methodological rigour: we use open-source data wherever appropriate, providing full attribution to the source, and documenting our methods of analysis. Where data is not open-source, we provide as much attribution as possible, to minimise the risk of generating a 'black box' analysis to deliver insights.

Underlying our approach is a theory of change which emphasises the dynamics of current and future supply and demand as a basis of understanding the value of water in specific contexts and locales. We consider this approach to be more relevant to informing decisions by the specific stakeholders that we focus on, compared to conventional basin-scale hydrological modelling, which emphasises flux and flow dynamics, informed by detailed analysis of basin regimes and hydrogeology. We consider our approach to be additional and complementary to the well-established frameworks for hydrological modelling, rather than a replacement or alternative.

Finally, a key consideration in our approach is its extensibility. Our framework is generally agnostic to the configuration of source data, provided we have the capability to re-configure as required for our analysis (we currently work with multiple APIs, for example). This means that we can ingest new and/or updated data with minimal delay; and can customise our insights to reflect the salience of different inputs for the questions being asked. It also means that end users can overlay internal (or proprietary) data, either facilitated through us; or directly by themselves. This extensibility was a key design consideration in our framework in order to maximise the utility and application of insights derived.

Key Findings

We set out the core findings from our analysis; highlighting the spatial and temporal trends of water availability and demand at the basin and Kafue sub-basin level. The discussion that follows interprets these findings in the context of regional water management, offering insights into potential risks and opportunities for sustainable water resource management in the Zambezi Basin.

Zambezi basin overview

Reservoirs

Reservoirs are vital to the terrestrial water cycle, regulating surface water storage and supporting water management for hydropower, irrigation, domestic use, and flood control. Analysing temporal changes in surface water area of reservoirs provides insights into resource availability and acts as key indicators of water-related risks. Small to medium-sized reservoirs are more sensitive to climate variability than large ones (Donchtys et al., 2022), highlighting the importance of monitoring smaller water bodies, especially in transboundary river basins.

To analyse reservoir water dynamics, we used monthly surface water area data from **842 reservoirs** in the Zambezi Basin for the 2000 - 2020 period detected by Global Water Watch(GWW). GWW uses Landsat and Sentinel imagery to reconstruct surface water area in time, applying a Normalised Difference Water Index to detect changes in water surface. Monthly anomalies were computed for each reservoir to identify intra-annual variability in water storage and the Mann Kendall test was used to calculate the trend of the time series. Additionally, total anomalies were aggregated for all reservoirs in the Zambezi sub-basins to assess the overall regional dynamics.

Figure 3 shows a concentration of reservoirs in central Zambezi, particularly around the major cities of Harare and Lusaka. Surface water area trends, shown in figure 4, reveal that monthly variabilities are unevenly distributed, possibly due to reservoirs being filled, climate variability between locations, geographic differences in streamflow contribution, and storage management for hydropower, agriculture and flood control. Overall, the analysis reveals a significant aggregated negative trend in the Kafue, Kariba, and Luangwa basins. Although most reservoirs in the Kafue Basin show a positive trend, the significantly larger area of Lake Itezhi-Tezhi contributes to the overall negative trend. A more comprehensive approach, including the identification of newly constructed reservoirs, periods of drought, decommissioned reservoirs, and distinguishing between man-made and natural lakes, would provide a more accurate understanding of storage dynamics and their contribution to changes in water availability.

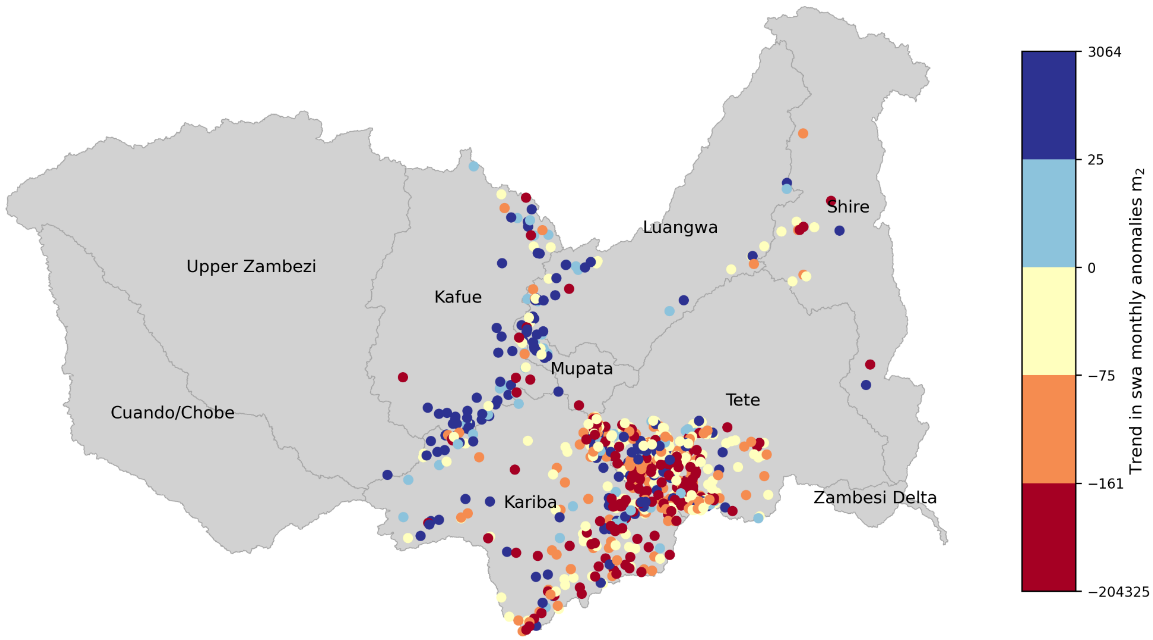


Figure 3 - Basin reservoir location and monthly surface water area trend, 2000-2020

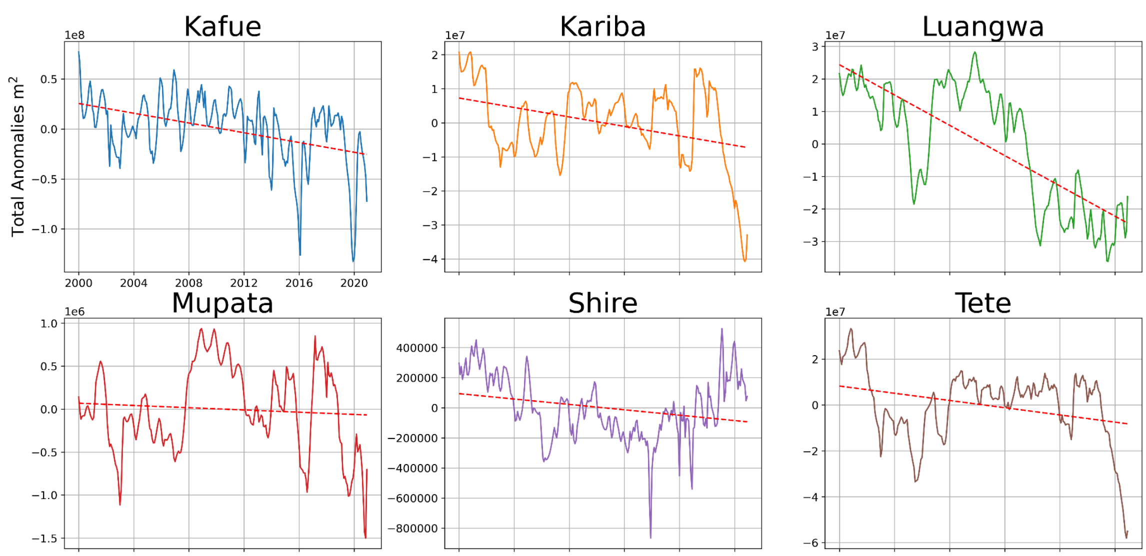
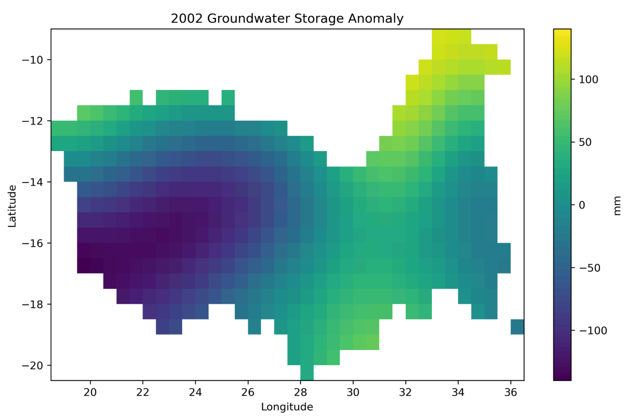


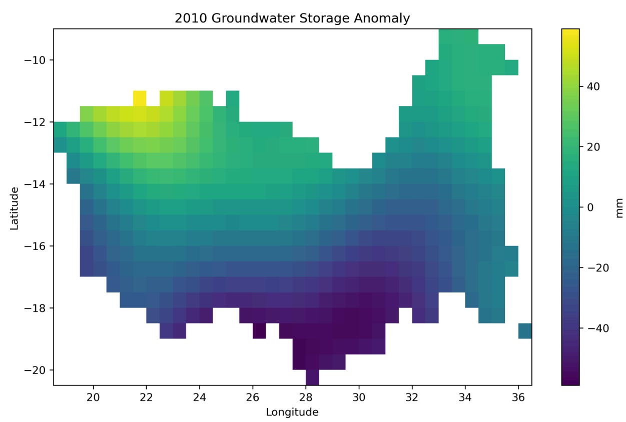
Figure 4 - Reservoir surface area change disaggregated by Zambezi sub-basins, 2000-2020

Groundwater

Groundwater is the primary source of drinking water for rural populations across the Zambezi and plays a significant role in water supply in urban and peri-urban areas, including some major cities. The mining industry plays a critical role in groundwater resources, as deep mining operations often involve pumping out water from the aquifers and fluctuations in mining activities, driven by global metal prices, influence water abstractions and mine dewatering (World Bank, 2010).

In the wider Zambezi basin, there seems to be a stark decrease in groundwater, leading to more severe and frequent negative groundwater anomalies. This trend is visible over the entire basin as seen in the graphs below. While groundwater anomalies were more positive in the North between 2002 and 2010, the entire basin shows negative anomalies by 2020.





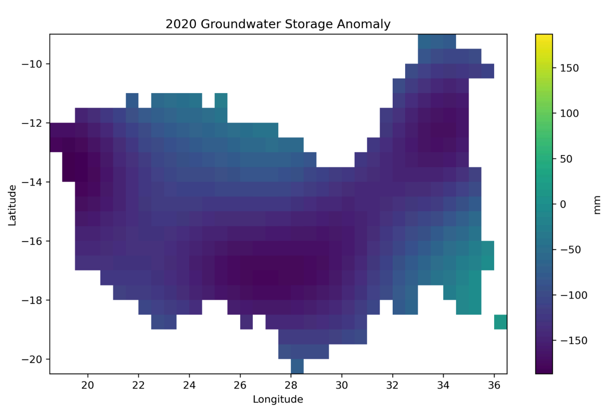


Figure 5 - Groundwater storage anomalies in the Zambezi basin, 2002 to 2020

Precipitation

Changes in rainfall are crucial for understanding spatial and temporal climate variability, allowing for improved readiness for extreme events like droughts and heavy rainfall. This understanding helps adapt to shifts in water resource availability and ensures more effective management of water risks. To analyse changes in rainfall patterns, we used CHIRPS, a quasi-global gridded dataset at 5km^2 resolution that combines satellite imagery and in-situ station data to derive gridded rainfall time series from 1981 to present.

Total annual anomalies for 2023 were calculated based on the 1994–2022 climate normal. Figure 6 shows negative anomalies in the western part of the Zambezi, particularly in the southwest, whereas most of the eastern basin shows normal to positive changes and an increase in rainfall in central eastern Zambezi. However, it is also important to further analyse seasonal rainfall variations, identify areas of the Zambezi that are experiencing significant and continuous precipitation deficits, determine whether the return periods of drought are increasing, and assess the impacts of climate change on cyclical extreme events.

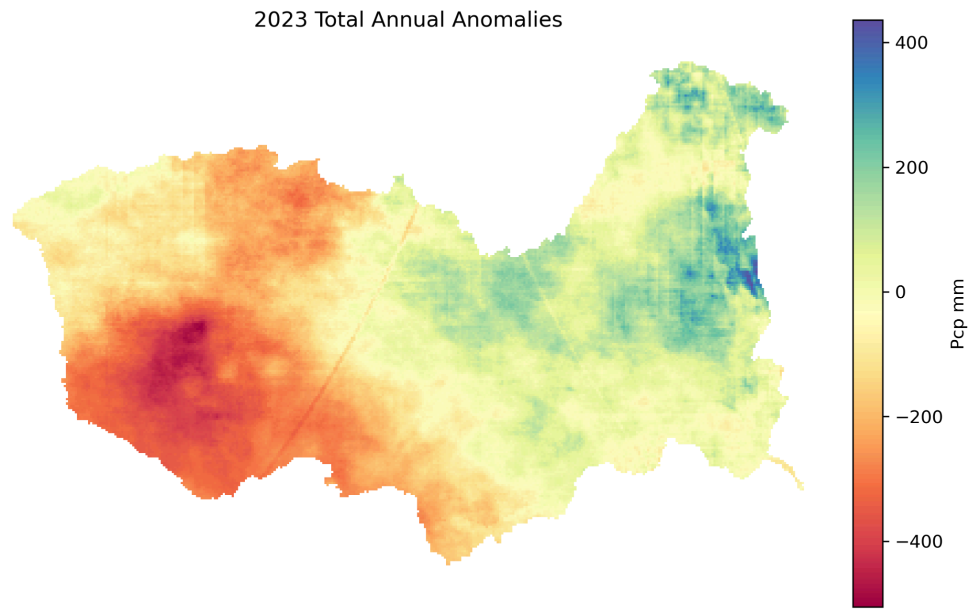


Figure 6 - Zambezi basin 2023 precipitation deviation from the long term mean (1994-2022)

Agriculture

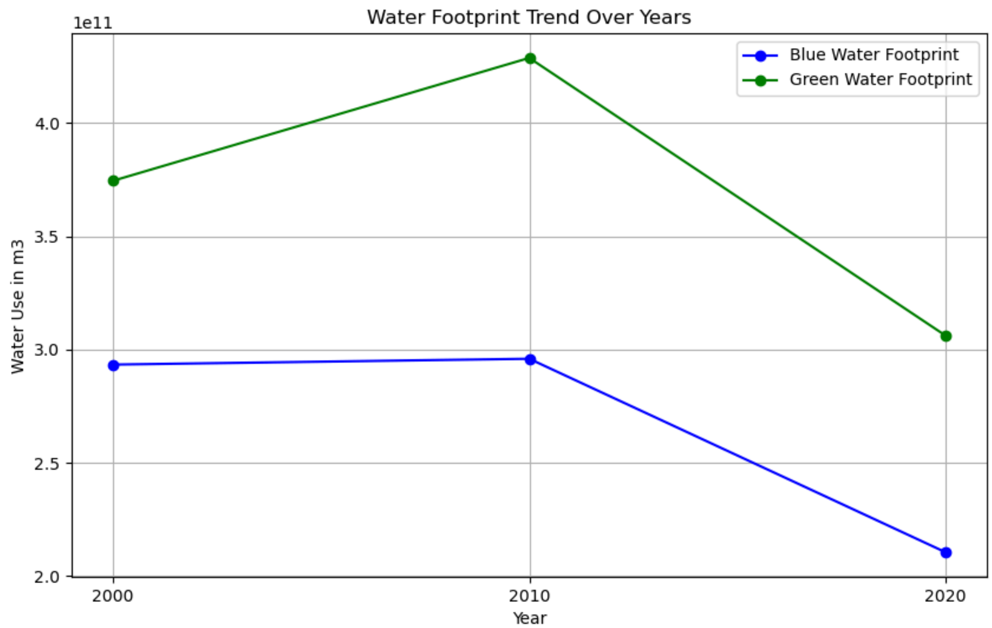


Figure 7 - Agricultural blue and green water use across the Zambezi basin, 2000-2020

Agriculture is the biggest water user globally, and will remain as such for the foreseeable future, despite domestic and industrial use increasing more rapidly (UN Water, 2018). The agricultural water demand analysis for this report covers how much water is used for which crops, and where. Agricultural water use can be split into green and blue water - blue water being the use of freshwater for irrigation from lakes, rivers, and groundwater, while green water is stored as soil moisture and in the plants themselves.

To start this analysis, the Water Footprint Network (WFN) dataset on water usage per yield per country and crop was used, to determine the water usage in each of the eight countries covered by the Zambezi river basin (Mekonnen & Hoekstra, 2011). This dataset includes 126 different crops, including the most important food and commodity crops which are maize, groundnut, sugarcane, cassava, and soybeans.

This was then combined with mapSPAM data to determine the yield per five arcminute gridcell per crop (IFPRI, 2024). By multiplying the yield with water demand for each specific crop, a water demand per gridcell was calculated. For the Zambezi basin overview, all of the crops included in the dataset were added up to calculate a total water demand of agricultural activity.

Figure 7 shows that the overall amount of water use has decreased since 2000 with a temporary green water increase from 2000 to 2010. This decrease is due to an overall reduction in yield of the most water-intensive crops, or even possibly agriculture moving outside the basin. The maps in figure 8 below show spatially how this trend has shifted. The primary locations of this water use have migrated, with significantly more agricultural water use in the East and North, particularly in Malawi in 2020. This is most likely due to an increase in yield in Malawi which increases water use.

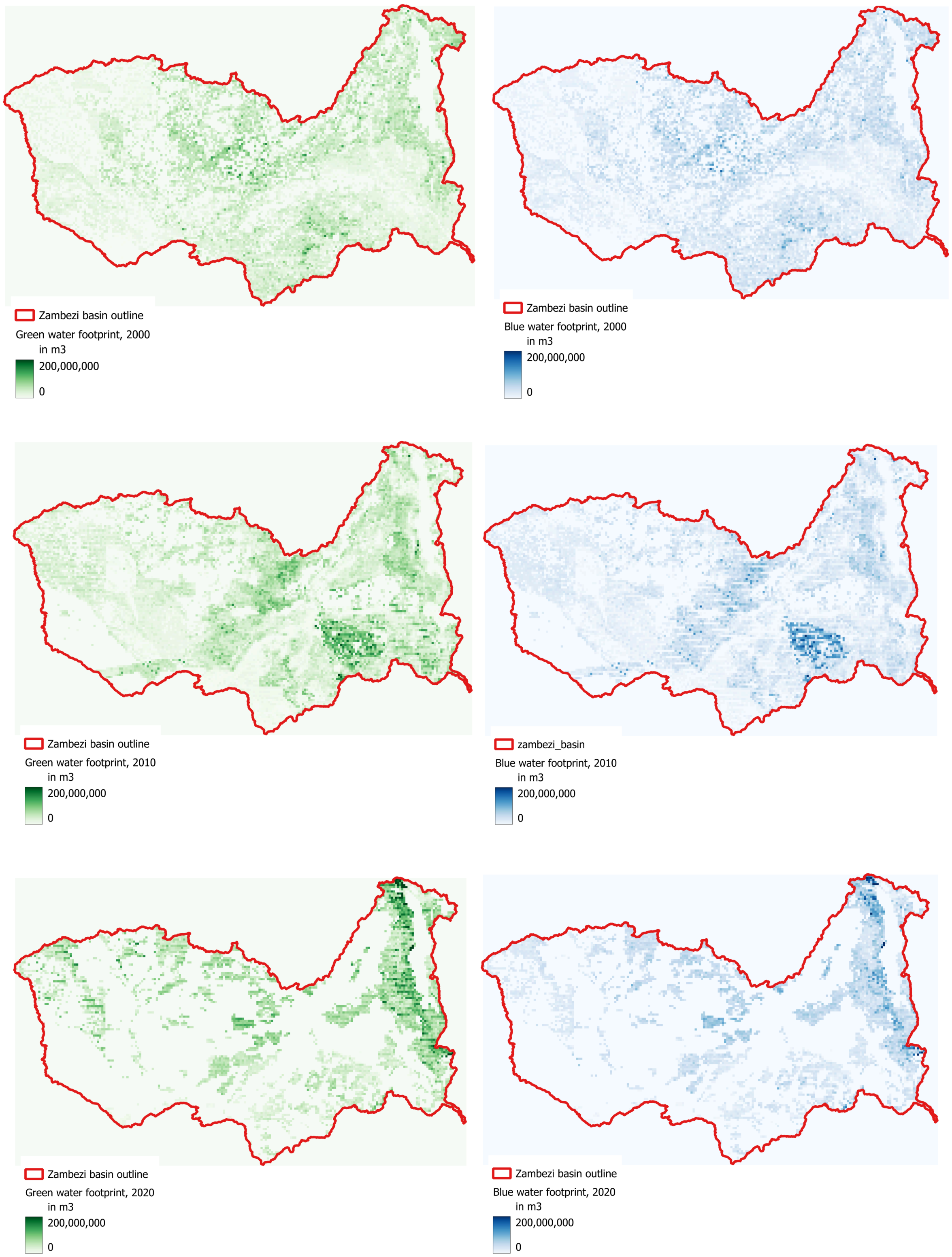


Figure 8- Agricultural blue and green water consumption distribution, 2000-2020

Domestic

The population of the Zambezi is approximately 49 million, with the majority concentrated in the capital cities of Lilongwe, Harare, and Lusaka. Over 58% of the population resides in rural areas, while the remainder lives in major towns and cities.

To analyse population dynamics in the Zambezi River Basin, we used WorldPop population counts data with a resolution of 1 km^2. We categorised the population into rural and urban areas to observe the shifts between these two groups. To identify population hotspots, we selected pixels with a population density exceeding 300 counts per pixel. Hotspots with an aggregated population of over 5,000 were classified as urban, and the rest as rural. This classification is based on the Zambian Statistics Agency's definition of an urban area, which specifies a *"minimum population size of 5,000 people, with the primary economic activities being non-agricultural, such as wage employment"* (ZSA, 2022). Although we did not investigate the economic activities in these areas, we adhered to the urban threshold of populated areas with more than 5,000 inhabitants as urban. The domestic water demand for the Zambezi is based on the figures provided by the National Water Policy published by the Ministry of Energy and Water Development in 2010, where it is estimated that domestic water use per capita is taken as 180 litres/capita/day and 45 litres/capita/day for rural areas.

Figure 9 shows the population distribution in Zambezi in 2020, indicating a concentration in Malawi, Zimbabwe, and Zambia, particularly on the eastern side of the basin and around Lake Malawi. Over the 20-year period from 2000 to 2020, the total population in the Zambezi grew by approximately 66%. Urban areas experienced a slightly higher average annual growth rate of 2.8%, compared to 2.4% in rural areas, reflecting a gradual shift towards urbanisation, as displayed in figure 10. As urban areas expand and more people migrate to cities, domestic water demand is expected to rise, putting greater pressure on water resources in the Zambezi.

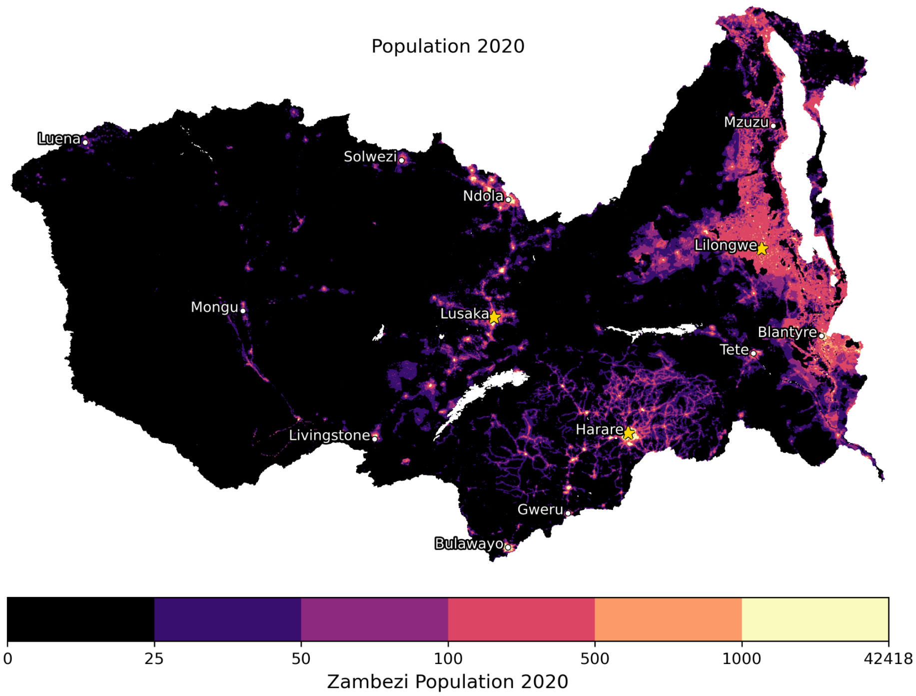


Figure 9 - Population density distribution in the Zambezi basin, 2020

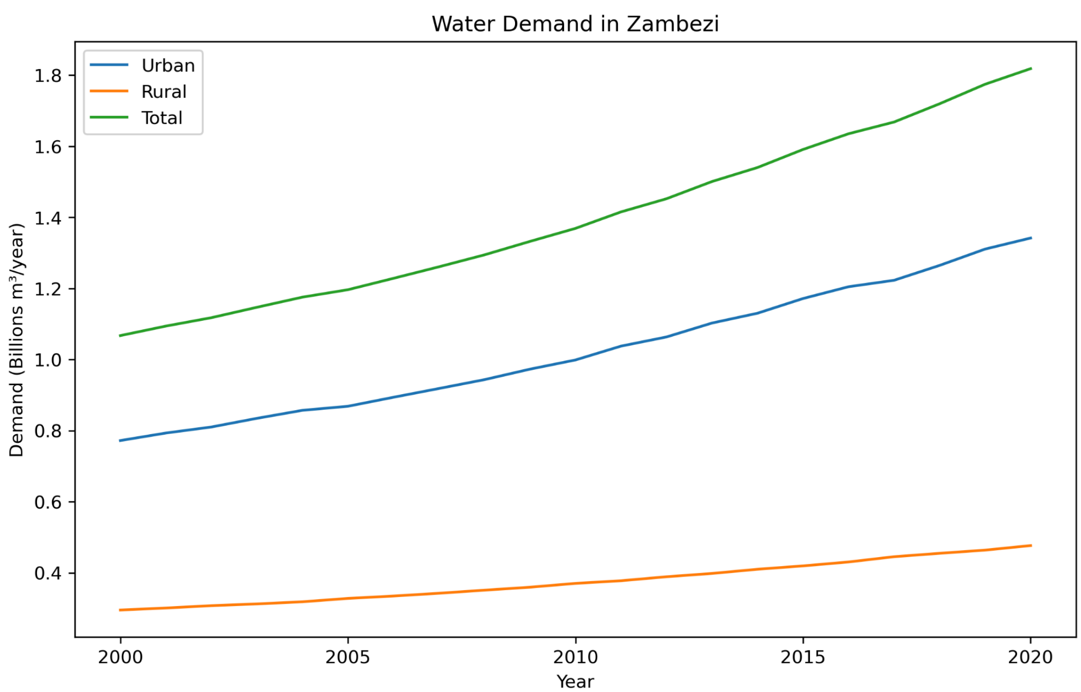


Figure 10 - Domestic per capita water consumption in the Zambezi basin, 2000-2020

Industry

The Zambezi river basin incorporates a wide range of industrial and water-consuming activities due to its rich natural resources and the population it supports. Hydropower generation is one of the key resources in the Zambezi River Basin, especially along the main tributaries of the Kafue and Shire Rivers (World Bank, 2010). To identify the different industries across the Zambezi, we used data from Camargo et al., 2023, who derived a global dataset of publicly available multi sectoral asset-level data and their site locations. Sources of this dataset include Global Dam Watch, the Global Power Plant Database, Global Tailings Portal, Fine Print Mining Database and others. We filtered the global dataset to match the Zambezi boundaries and classified the data by industry. Figure 11 shows the boundaries of the Kafue's sub-basins and the locations of industrial assets.

Different industries are concentrated in the central and southern areas of the Zambezi, particularly in the Kariba and Mupata basins, with agriculture and electric energy production being especially prominent. The Metals and Mining Industry dominates the basin, primarily in the northern Kafue Basin/Copperbelt Province, followed by Agriculture, which is predominant in the southeast, particularly in the Kariba and Tete basins.

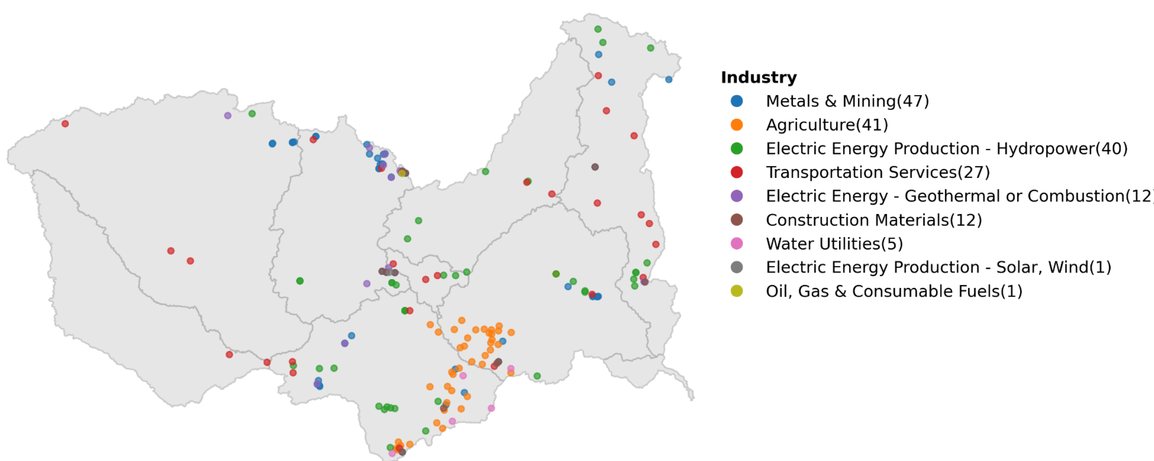


Figure 11 - Water-consuming assets in the Zambezi Basin by industry, 2022

Competitors to water demand

At its peak, agricultural water demand of the Zambezi river basin amounted to over 700 billion cubic metres of water, and is thereby the largest water consuming sector in the river basin. According to the data used in this report, domestic water use amounts to around 1.8 billion cubic metres in 2020 in comparison.

According to a report by the Food and Agriculture Organisation (Salman et al., 2022), agriculture makes up 73% of total water consumption in Zambia, compared to 19% municipal (domestic) use, and 8% industrial use.

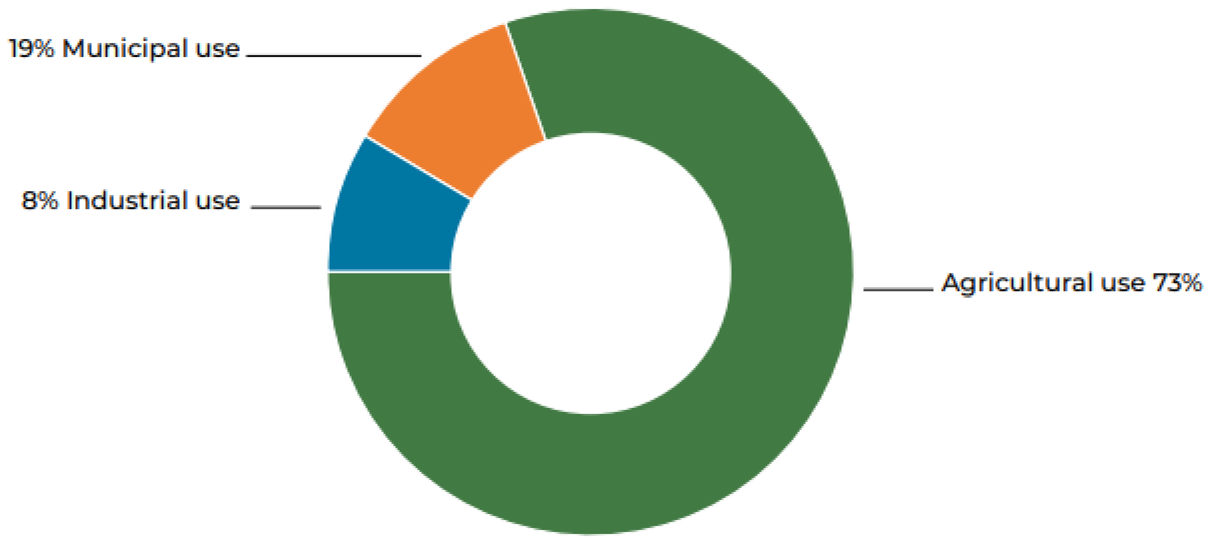


Figure 12 - Estimate of water withdrawal by sectors in Zambia (source: FAO, 2022, AQUASTAT)

Detailed analysis of Kafue sub-basin

In this section, we focus specifically on the state of water resources in the Kafue sub-basin. While many of the same datasets have been used as in the Zambezi river basin, this analysis is done at a higher resolution, and better differentiation between areas, crops, and groundwater boreholes, where appropriate.

Reservoirs

For the Kafue reservoir analysis we used the same Global Water Watch dataset as for the previous Zambezi basin analysis. Trends in surface water area of 63 reservoirs in the Kafue basin were analysed as an indicator of surface water availability risk. Reservoirs of different sizes often behave differently in response to climatic and human factors, significantly affecting their storage dynamics. Therefore, we classified reservoirs into three categories based on their area: small (0–3.8 km²), medium (3.8–15 km²), and large (>15 km²), with Lake Itezhi-Tezhi being a significantly larger water body in the Kafue Basin (see figure 12a).

To observe trends and changes through time in surface water, we aggregated the monthly time series data for each category to obtain the total surface area for small, medium and large (Lake Itezhi-Tezhi) reservoirs. The aggregated time series in figure 12b indicates a relatively stable trend with high and low peaks mostly due to climate variability. In contrast, Lake Itezhi Tezhi (figure 12c) shows a significant downward trend in surface water area, especially during the 2015-2016 and 2019-2020 periods, coinciding with periods of severe drought across Southern Africa.

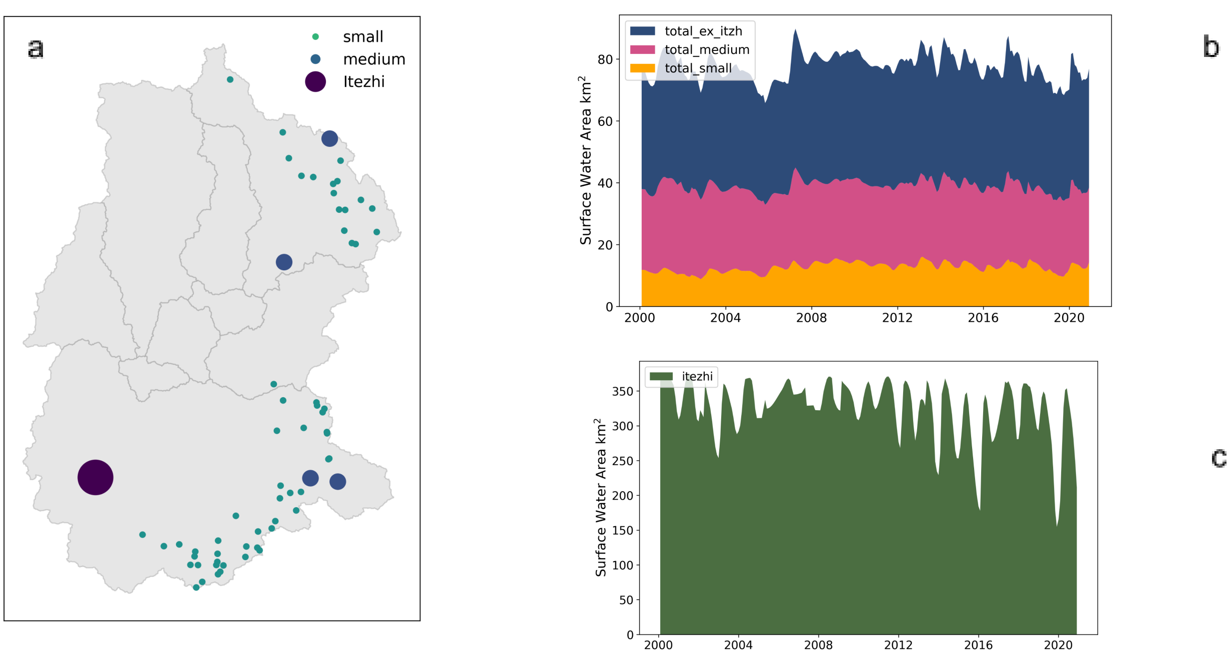


Figure 12 - (a) reservoir locations; (b) total surface water extents for small and medium reservoirs; and (c) total surface water extents for the Itezhi-Tezhi reservoir in the Kafue sub-basin, 2000-2021

In addition to the aggregated total storage for reservoirs in Kafue, we computed monthly anomalies of surface water for small and medium-sized reservoirs, shown in figure 13. We found a clear upward trend in small-sized reservoirs. By examining temporal imagery in Google Earth and the Aqua Monitor Tool, we detected new reservoir construction and filling of new impoundments, particularly in the Lower Kafue sub-basin during the 2000-2010 decade (see figure 14). This increase in newly developed reservoirs can be attributed to the expansion of agricultural land and the need for new irrigation schemes, contributing to an increase in overall surface water storage in small-sized reservoirs. Moreover, medium-sized reservoirs show a decrease in surface water area, which can be attributed to changes in the contribution of streamflow to the water body. This may be due to climatological factors or changes in the dynamics of their use. However, since we do not have detailed information on their specific uses or an analysis of climate change impacts in the areas where these reservoirs are located, it is difficult to determine the precise causes of this decrease.

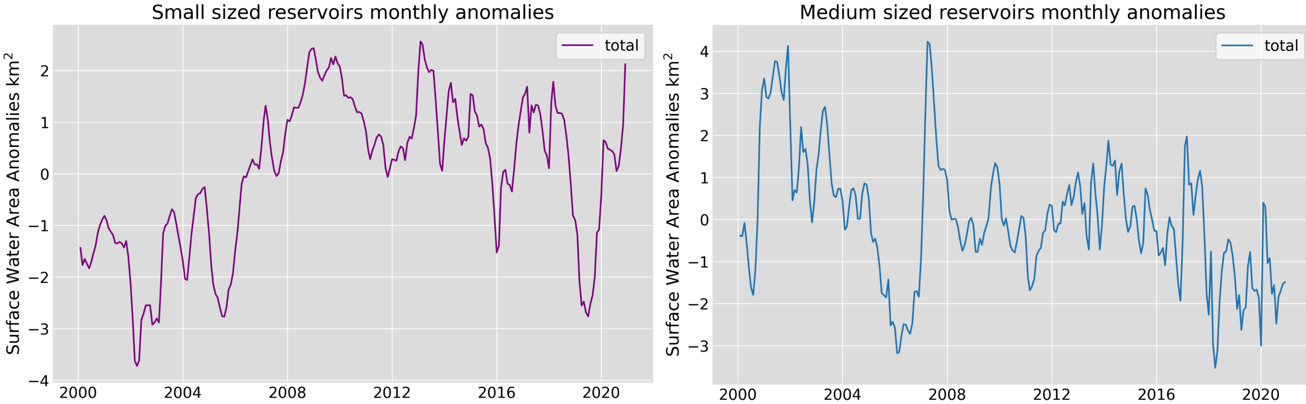


Figure 13 - Variability in surface water extents for small and medium reservoirs in the Kafue sub-basin, 2000-2021

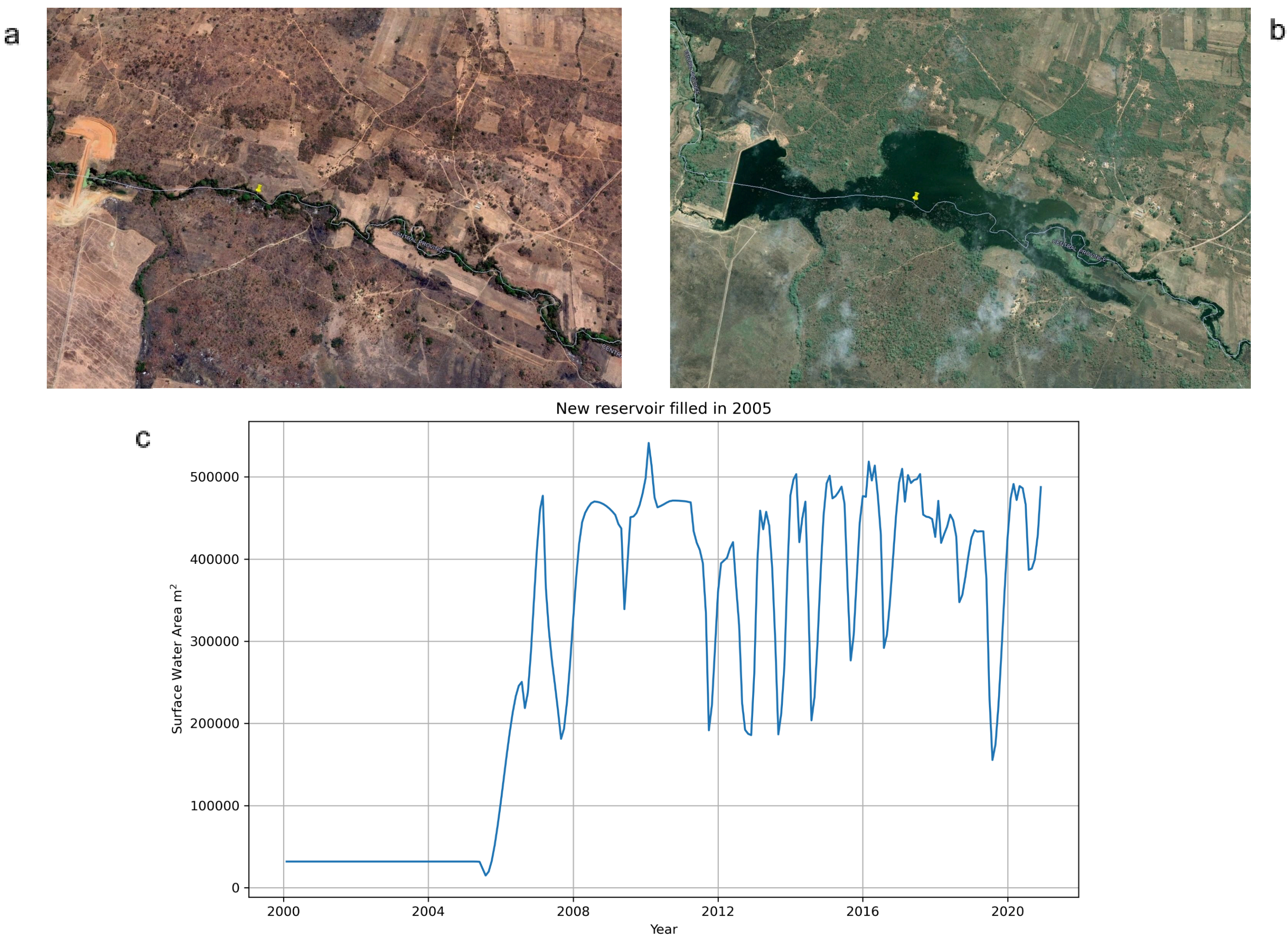


Figure 14 - Example of a new reservoir in west Lusaka, with visual images of 2000 (a) and 2010 (b) and surface water extent changes, 2020-2021 (c). (Image source: Google Earth)

Groundwater

The northern parts of the Kafue sub-basin contain highly productive aquifers, producing around 70 litres per second. These are limestone/dolomite aquifers that have karstified and formed fissures that hold huge volumes of water. These aquifers account for over 50% of the domestic water supply of the towns Lusaka, Kabwe, and Chingola (SADC-GMI, 2019).

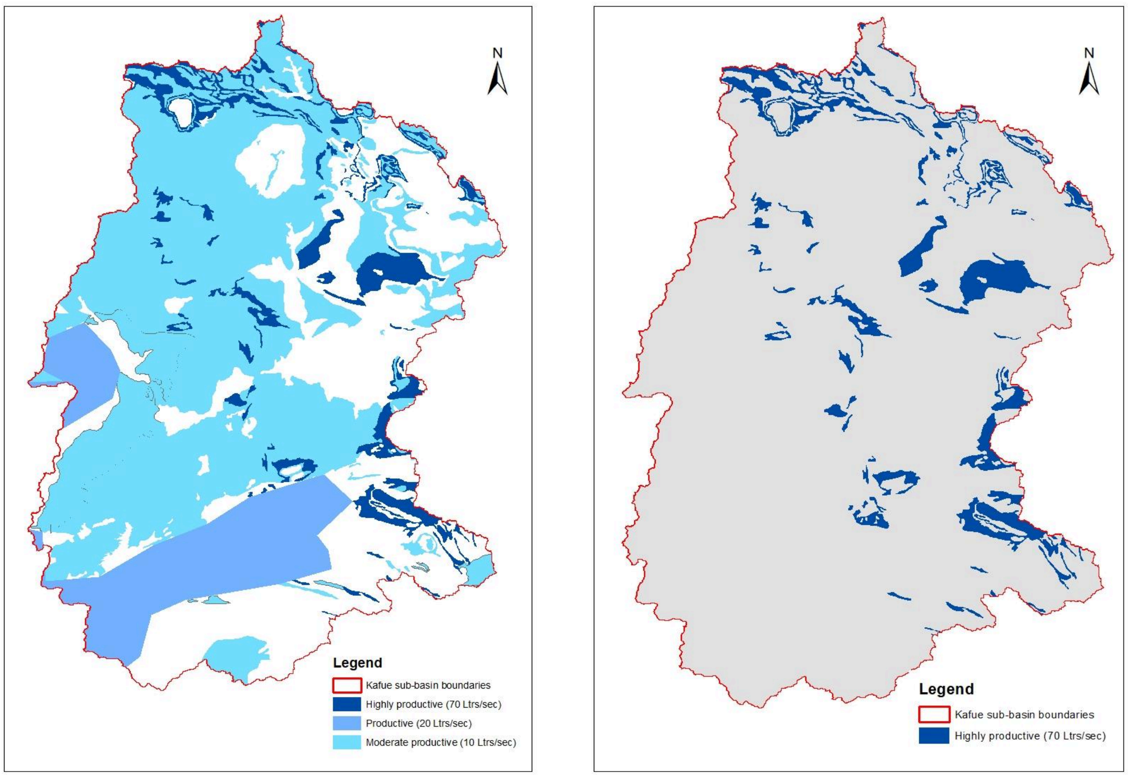


Figure 15 - Location and productivity of Kafue sub-basin aquifers, 2019

Insights on groundwater use data from WARMA, and as can be seen from the mapped groundwater use in figure 16, smallholder farms and self-supply (commercial use) to households is the largest user of groundwater in the sub-basin. In the Copperbelt and around Lusaka's industrial areas, factories and manufacturing industries also use significant quantities of groundwater. Agricultural groundwater use is more pronounced in the outskirts of the urban centres, such as the southern parts of the sub-basin in Chibombo, Chisamba and Mkushi (WARMA, 2024).

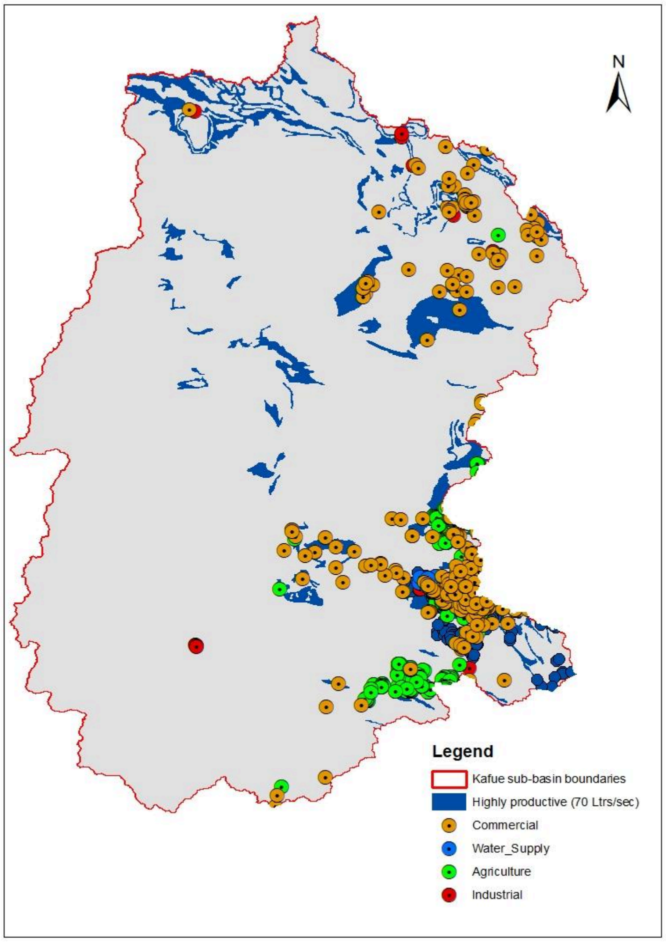


Figure 16 - Borehole location and use type in the Kafue sub-basin

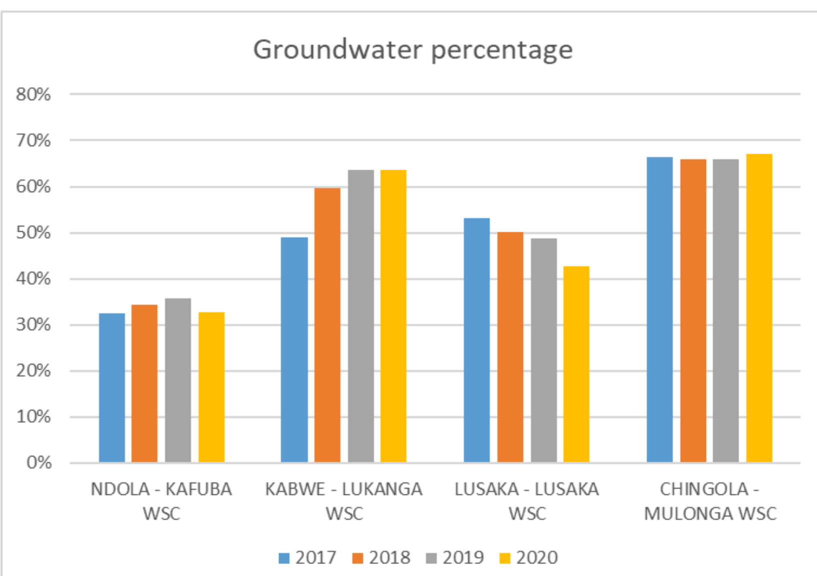


Figure 17 - Proportion of water sources from groundwater by water supply companies in the Kafue sub-basin, 2017-2020

The four major water supply utility companies in the Kafue sub-basin have two major sources for their raw water abstraction: surface water and groundwater. In the four major towns of the Kafue sub-basin i.e Lusaka, Kabwe, Ndola and Chingola the karstified dolomite aquifers serve as a major source of water (SADC-GMI, 2019). Using data from relevant institutions NWASCO, WARMA and Ministry of water development and Sanitation, the groundwater abstracted for water supply by the water utilities range from 33% - Ndola, 50% - Lusaka and above 60% - Kabwe & Chingola (Government of the Republic of Zambia (GRZ), Ministry of Water Development and Sanitation, Ministry of Finance and National Planning, Zambia Statistical Agency, 2022), as shown in figure 17.

Between 2017 and 2020, Kabwe through Lukanga WSC shows an increase in the proportion of groundwater used for water supply from 49% in 2017 to 64% in 2020, Chingola and Ndola proportions remained constant at 65% and 33% respectively. However, the groundwater proportion for Lusaka in this period has seen a decline trend from 53% to 43% indicating a possible decline in the groundwater quantity of the city.

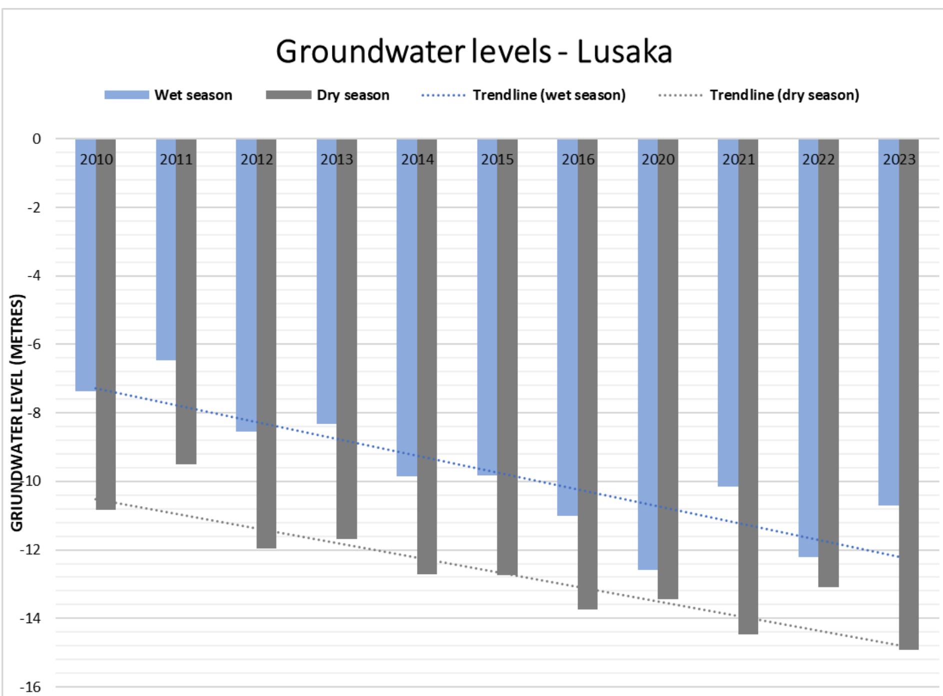


Figure 18 - Trend in groundwater supply in Lusaka (Kafue sub-basin), 2010-2023

Zambia has about 100 groundwater monitoring piezometers and 44 of these are in Lusaka (IGRAC, 2017). This makes it possible to monitor the changes in groundwater in Lusaka. Data from WARMA was used to analyse the changes in groundwater levels in Lusaka, and is shown in figure 18. Due to the gaps in data, only data from 2010 was available for this analysis. Despite the groundwater showing some signs of recovering every year, the trends in both the dry season and wet season continue to decline from 11m in 2010 to 15m in 2023. Some of the identified factors influencing this decline includes rapid population growth, urbanisation, increased water demand and climate variability among others.

Precipitation

The same CHIRPS dataset as for the Zambezi basin rainfall analysis was used for the Kafue basin. We calculated anomalies in annual totals for the period from 1994 to 2023, serving as the climate normal. The average total yearly rainfall in the Kafue basin is around 984 mm, and the spatial distribution shows a clear north-to-south gradient in precipitation levels, with most of the rainfall falling in the northern part of the basin (see figure 19a). Rainfall in Kafue is concentrated in the wet season from October to April, with little to no rain falling between May and September. We looked at changes in annual total rain for the 30-year climate normal period.

Figure 18b shows the yearly rainfall totals, with colours representing each year's deviations from the 30-year mean. Very dry years are observed in 2019, 1994, 1995, and 2002, and very wet years in 2017, 2001, and 2007, in order of magnitude. Throughout the 30-year period, the trendline remains stable, but there is significant variability in terms of dry and wet years. The driest year is 2019, with 710 mm, which is 28% less rainfall than the average. This significant variability between dry and wet years highlights the importance of improved resilience and adaptation measures during extended periods of drought to ensure that water resource demands are met.

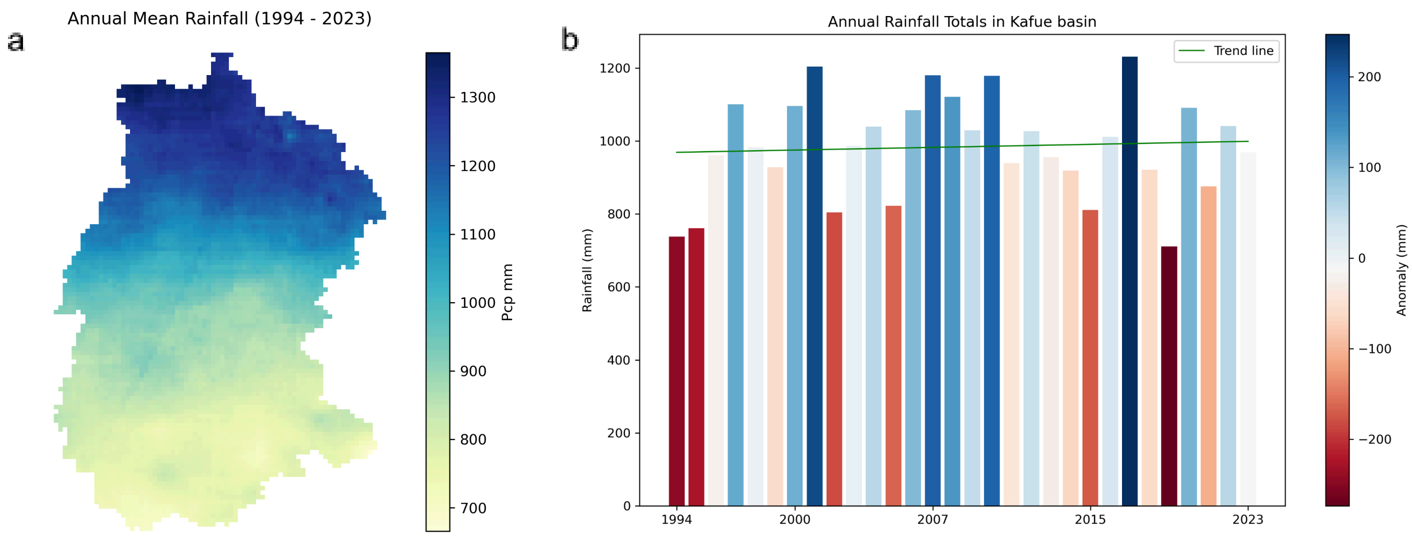


Figure 19 - (a) mean 30-year rainfall distribution across the Kafue sub-basin; and (b) annual rainfall totals and deviation from the 30-year mean, 1994-2023

Agriculture

The initial methodology for this analysis is as above for the Zambezi river basin, however, drilling down into the main water use crops. To make the maps more detailed and precise, it was masked and redistributed only to the areas where the relevant crops are actually grown according to WorldCereal's temporary crops and maize-specific and temporary crop maps. The WorldCereal's original 10-metre resolution was resampled to a 1km-resolution due to processing constraints and to avoid false precision.

The only dataset available with change over time is the mapSPAM data, with datasets for 2000, 2010, 2017, and 2020. Therefore, the water use per kilogramme yield was considered static, as was the active temporary crop and maize land distribution. The change in water use purely stems from the change in overall yield, as well as yield per gridcell.

The three maps of figure 20 below show the blue (surface freshwater) footprint of maize in the Kafue sub-basin. This shows the areas where maize increased from 2000 to 2010, and then also where it subsequently decreased until 2020.

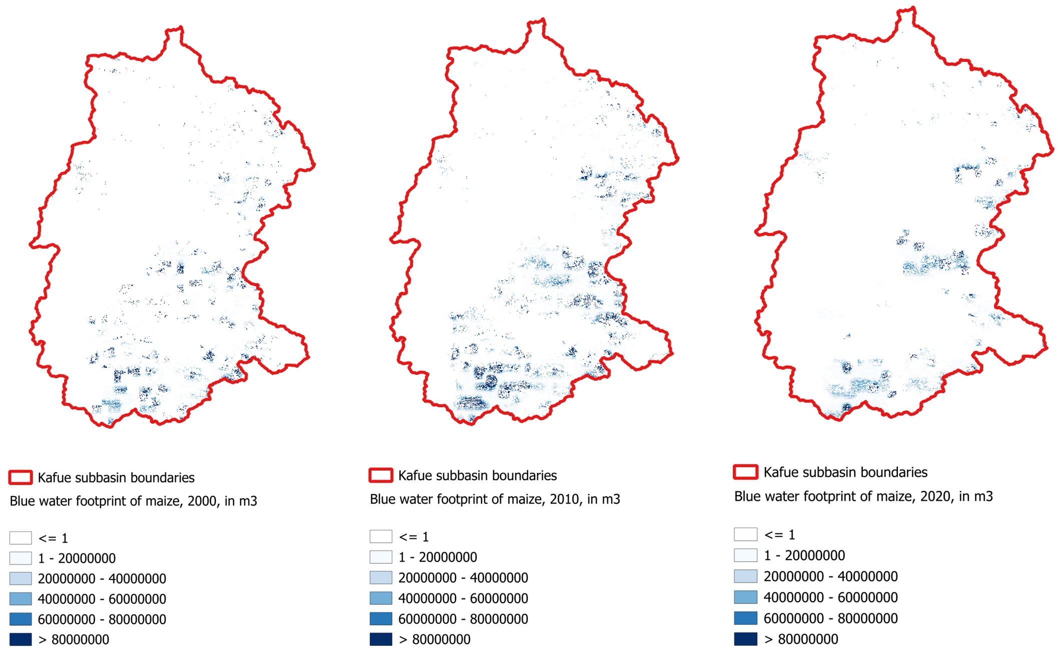


Figure 20 - Maize blue water consumption distribution in Kafue sub-basin, 2000-2020

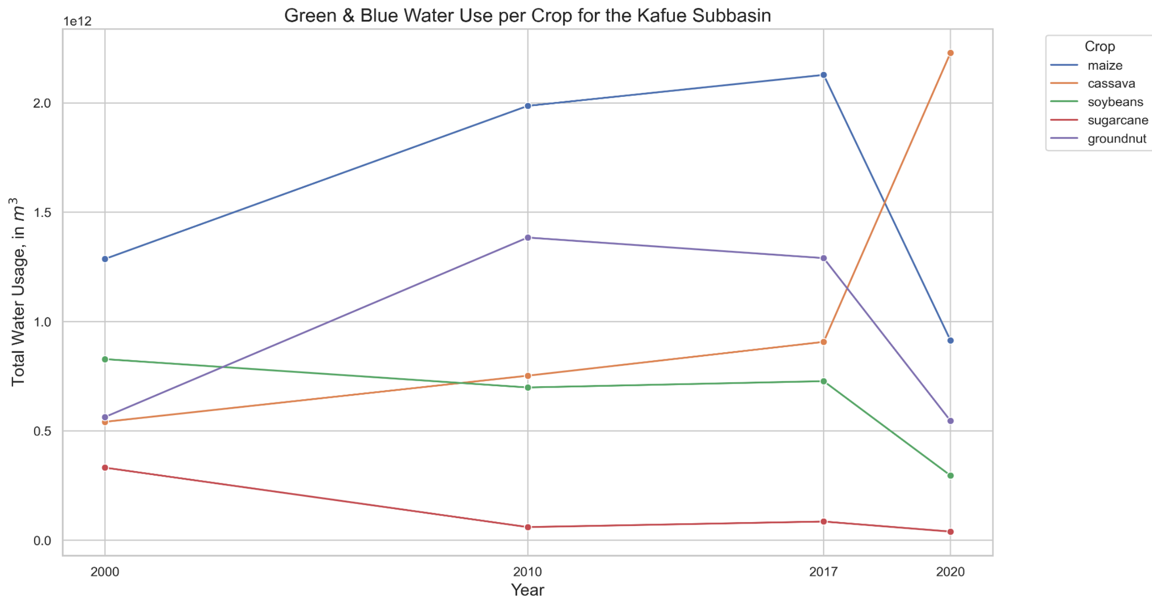


Figure 21 - Total agricultural water consumption per crop in the Kafue sub-basin, 2020-2022

Figure 21 shows the combined change over time in blue (surface and groundwater) and green (precipitation and soil moisture) water use for the most important crops in the region from 2000 to 2020. Maize was the highest water user until 2017, with cassava overtaking in 2020. Sugarcane, soybeans and groundnuts also use a significant amount of water, with an overall decreasing trend.

The blue water footprint in cubic metres per gridcell of the four main crops in Kafue basin from 2000 to 2020 is displayed in figure 22, and shows how the region's agricultural production and water footprint has changed. Sugarcane especially has dropped off significantly since the early 2000s, despite multiple reservoirs being built for it to supply water for irrigation at the time. There is also a general decline visible in the copperbelt area, particularly from 2010 to 2020, as agricultural activity reduced to make space for mining activity and population growth.

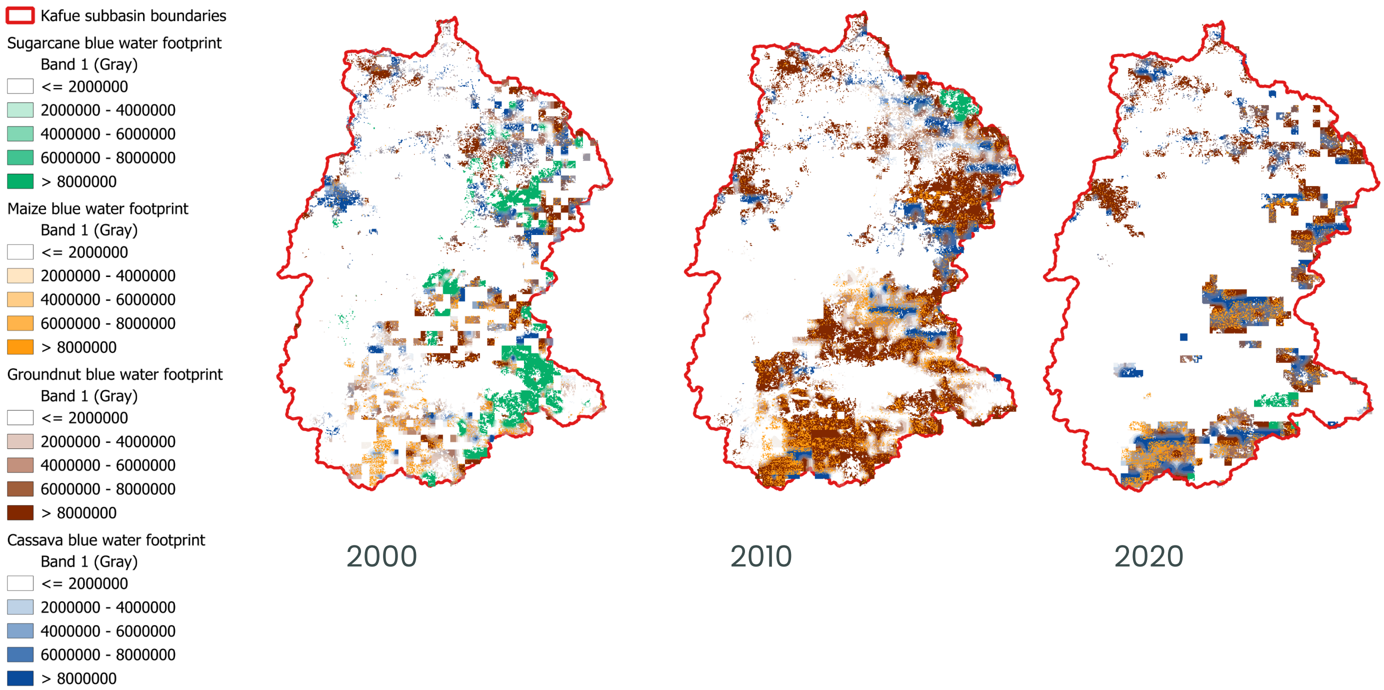


Figure 22 - Crop blue water consumption (m3) distribution in Kafue sub-basin, 2000-2020

Domestic

The population in the Kafue subbasin is rapidly growing and is expected to continue increasing in the coming decades, putting significant pressure on water resources. Despite the rising demand from industrial and agricultural sectors, the needs of the growing population will remain a dominant concern for water resource management.

Population dynamics were analysed for the Kafue river basin using the same WorldPop dataset and methodology as for the Zambezi basin. Over the past two decades (2000 - 2020) the population in the Kafue river basin has experienced significant population growth, with a clear shift towards urbanisation. From 2000 to 2020, the urban population increased by approximately 103%, rising from 1.9 million to nearly 3.9 million. In contrast, the rural population grew by only 50%, increasing from 1.7 million to 2.6 million during the same period. This means that the urban population growth rate was more than double that of the rural areas.

Overall, the combined population of urban and rural areas in the basin grew by approximately 78%, from 2000 to 2020. These trends reflect a significant move to urban areas especially in Lusaka and northern cities such as Ndola and Mufulira.

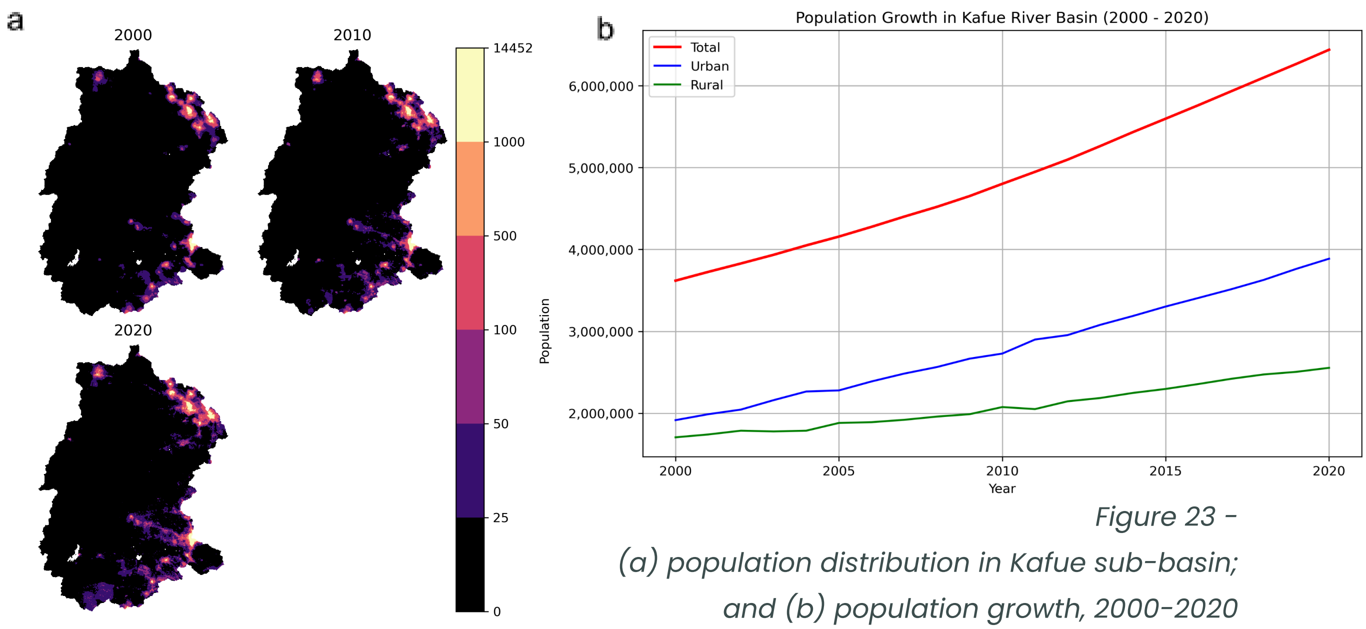


Figure 23 –
(a) population distribution in Kafue sub-basin; and (b) population growth, 2000-2020

Industry

Multisector Asset Level Data

The Kafue basin is rich in a range of natural resources, driving numerous economic activities that compete for the use of water. With more than half of Zambia's population living in the Kafue Basin, the region is highly dependent on water resources and it is a focal area for the establishment of various industrial sites. The Kafue basin asset analysis uses the same dataset compiled by Camargo et al., 2023, used for the wider Zambezi analysis. We extracted the global dataset to the Kafue Basin boundaries and classified the data by industry. Figure 24 displays the boundaries of the Kafue's sub-basins and the locations of industrial assets.

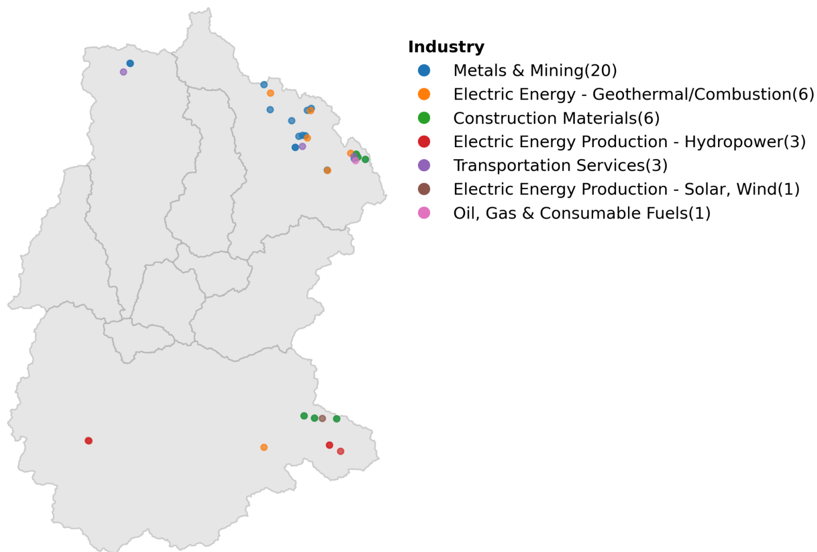


Figure 24 - Water-consuming assets in the Kafue sub-basin by industry, 2022

The Metals & Mining industry dominates the basin activities, with a total of 20 sites identified. These are concentrated in the upper Kafue sub-basin/Copperbelt province, and most of these sites involve copper and cobalt mining as well as emerald mining. Other industrial sites include energy production with coal power plants serving the mining operations. Hydropower is generated in the lower Kafue River basin, with key sites at Lake Itezhi-Tezhi Dam, Kafue Gorge Upper Dam, and Kafue Gorge Lower Dam. Additional assets in the Kafue include solar farms, oil plants, and cement plants.

Zambia Mining Cadastre Data

The Zambia Mining Cadastre Map Portal is a resource for data on mining licences in the copperbelt province of the upper Kafue basin. Figure 25, taken directly from the portal, shows all active licences as well as restricted areas in the region.

There has been a large extension of active large scale exploration licences, as well as large and small mining licences, which includes emeralds and copper mining. Further mineral processing and petroleum licences are scattered throughout in smaller areas.

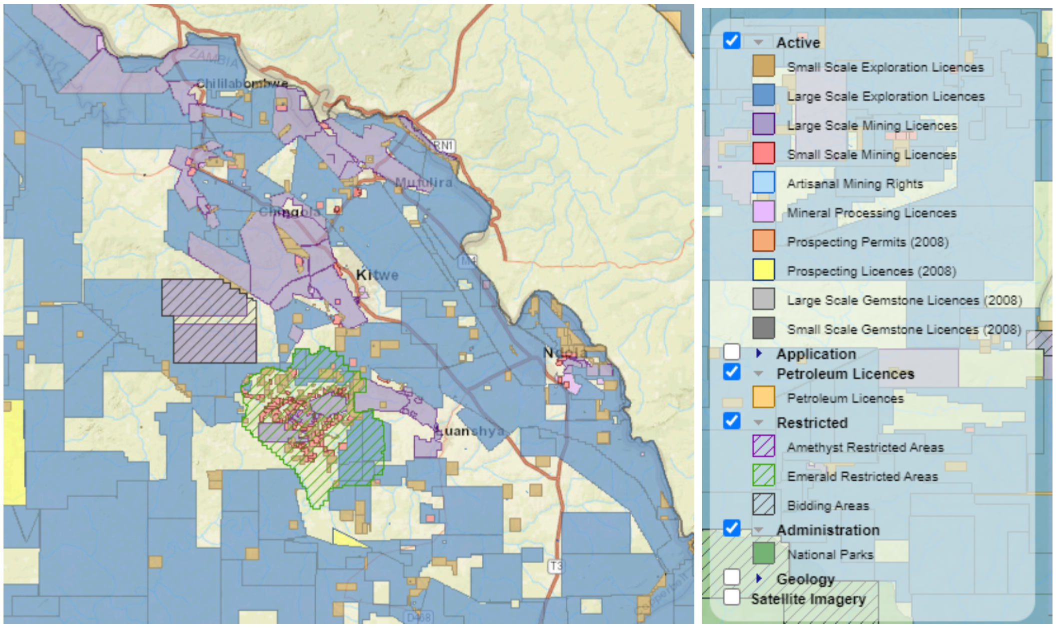


Figure 25 - Mining licences in the Copperbelt (Source: Ministry of Mines)

Water Quality

The Kafue basin supports most of the mining, industrial, and agricultural activities in Zambia. The Copperbelt in north Kafue is among the world's largest metallogenic regions (Kambole, 2003), hosting a dense concentration of extraction and processing sites. The Kafue river flows south-east through the Copperbelt, receiving effluent waters from various contamination sources such as discharge water from mines and other industries.

Surface mining and extreme rainfall events cause runoff to carry pollutants into rivers, and deep mining impacts groundwater quality through dewatering (World Bank, 2010). Several studies have assessed the extent of heavy metal contamination in the Kafue River, revealing the extent and effects of industrial contamination on the environment.

High concentrations of copper and nickel, reaching toxic levels, have been recorded at the Blue Lagoon in Kafue lechwe, a semi-aquatic antelope native to the Kafue river basin (M'kandawire et al., 2012). In another study, trace elements of caesium, cobalt, copper, and chromium were found in river-caged fish located downstream of industrial sites (Norrgren, 1999), while nickel, zinc, iron, and lead were also detected in tilapia fish from the Kafue River (Kaile, 2016). M'kandawire (2017) reported elevated levels of copper, cobalt, manganese, and arsenic in sediments within the Copperbelt mining area, while Mwaba Kapungwe (2013) observed heavy metal contamination in water, soil, and crops from farms in Mufulira and Chilumba Gardens in Kafue, with runoff from these agricultural areas further contributing to nutrient loading and degrading water quality.

Findings of heavy metals in animals, sediments, and streams in the Kafue Basin indicate significant levels of environmental contamination and present risks to the biodiversity of the region. The Kafue River hosts a rich diversity of wildlife and ecosystems that play a crucial role in the food chain, so pollution control is critical to maintain ecological balance, and safeguard the economic benefits of fishing for local communities.

Continuous water quality monitoring is essential to understanding changes in water quality, seasonal pollution level variations, and capturing the impact of pollutants on the river ecosystem. It also supports the decision-making process of the development of new strategies and resource allocation. The World Wide Fund for Nature (WWF) highlights the insufficiency of data on water quality across all regions of the Kafue Flats in their Lower Kafue Basin report (WWF, 2018). Water quality data collection can be improved by the private sector through platforms such as the Kafue Flats Joint Action Group, complementing government efforts and contributing to basin security, ecosystem health, and local livelihoods.

Discussion

Drought, electricity and the mining sector in Zambia

Abnormally low levels of precipitation during the 2023-4 rainy season due to the El Niño effect has resulted in one of the worst droughts on record in the Zambezi region. The year began with a significant drop in monthly rainfall totals compared to the 30-year historical average. February saw less than half the usual rainfall, and March followed a similar trend. Hydropower provides more than 80% of the country's installed capacity, and given the deficit in rainfall low water levels were reported at key dams such as Itezhi-Tezhi, Kafue Gorge, and Kariba, resulting in a decrease in power generation. Zambia's copper industry relies heavily on energy for its operations, with mining accounting for more than 50% of the country's total energy consumption (Department of Water Resources Development -Zambia 2024).

This is not the first instance of drought-induced power shortages in Zambia, with a comparable event occurring in 2015. Poor rainfall in the 2014/2015 rainy season led to low water levels in reservoirs used for hydroelectric power generation. Most households and businesses experienced 8 or more hours of power cuts per day, with some areas facing up to 15-16 hours of outages. Previous studies examined the impact of power outages on Zambia's manufacturing firms, noting that the sector's share of GDP decreased from 4.6% in 2015 to 4.1% in 2017 (Ahmed et al., 2019)

In response to the current situation, ZESCO, Zambia's national energy provider, has implemented rolling power cuts that can last up to 22 hours per day. Businesses, particularly in the manufacturing sector, are struggling to maintain operations. Power shortages have a direct negative impact on economic activity, with unreliable electricity significantly disrupting operations, reducing output, and increasing operational costs.

During the 2015 crisis, the mining sector was largely exempt from power cuts and even saw an increase in power consumption of 6.4% from 2014 to 2015 (Kesselring, 2017). Access to electricity was observed to be a divisive factor within communities and across stakeholder groups. The situation for the mining sector appears to be different during this drought period, however. In July 2024, Zambia's energy regulator requested that the mining sector curtail normal power use by forty percent. Anecdotal evidence suggests that First Quantum Minerals, which accounts for more than half of Zambia's copper output, has managed to cover over half of its normal power demand through importing electricity, mainly from Namibia and Mozambique. Additionally, the company plans to conclude a power-purchase agreement (PPA) with a consortium including TotalEnergies SE for wind and solar projects that will produce a combined 430 megawatts by late 2027 (Bloomberg News, 2024).

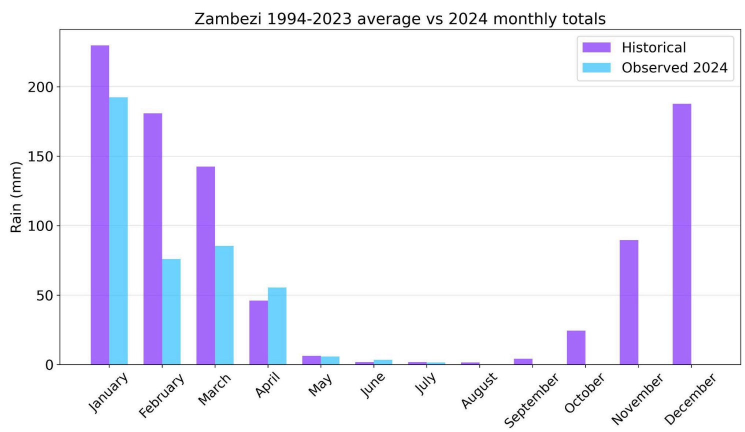


Figure 26 - Monthly Rainfall Totals in 2024 and Historical Average (1994 - 2023)

We make the self-evident observation that drought-induced variability in the availability of electricity will have economic and societal consequences for Zambia. Policy decisions on sourcing, pricing and allocating electricity to meet the country's industrial, commercial and societal needs are likely to be closely scrutinised, and that mining companies face risks to their social licence to operate. Beyond the current drought situation, it is likely that the economy will remain highly vulnerable to climate variability in terms of its electricity generation, unless adaptive responses are rapidly developed and implemented.

Conclusions

- The Zambezi is one of Africa's major river basin systems, and is the location of a significant share of the continent's mineral resource endowment. Our assessment focused on hydrological dynamics in relation to surface water, groundwater, precipitation, agricultural consumption, industrial consumption and domestic consumption of water resources.

- The analysis covers dynamics over the 20 year period from 2000 to 2020. This period was selected to optimise against the best available data, and to account for the significant changes in anthropogenic activity over these two decades. We used a combination of remote sensing and in situ data to inform our analysis. Data was sourced both from publicly available datasets, as well as proprietary datasets which we accessed via government agencies.

- Hydrological dynamics within the basin vary significantly by location. For example, the creation of man-made reservoirs to meet consumption needs has resulted in an increase in surface water availability in several economically important locations. Equally, there has been a significant increase in the overall demand for water for domestic and industrial use. Key drivers include demographics (population growth) and increased industrial activity, particularly mining. Agricultural demand for water presents a more nuanced picture, reflecting changes in yield and land use.

- However, in overall terms, markers of water availability and water quality across the Zambezi basin in general (and the Kafue sub-basin in particular) indicate deteriorating resilience, which is likely to be exacerbated by the increasing prevalence of drought conditions in the future. In this context, many parts of the basin are particularly vulnerable to increased abstraction of water resources, particularly from mining, which also has attendant implications on water quality, environmental return flows, and water availability for competing uses, notably domestic consumption.

- A key challenge that surfaced in our analysis is the paucity of highly resolved spatial and temporal data, particularly in situ measurements of water availability, water quality, water demand, and the impact of changing hydrological dynamics on biodiversity.

- We consider that many of the risks to basin resilience that we identify are addressable, and can be addressed. However, this requires a significant and coordinated investment to support improved water security. What remains unclear is which stakeholders are able and/ or willing to fund these investments. Under the status quo, there is a high risk that conditions will continue to deteriorate. This has negative implications for economic, environmental and societal welfare outcomes.

- To address the current impasse, we consider the logical next step is to identify and secure resources to support the generation and collection of various data in situ, including on river discharge, groundwater levels, agricultural and industrial water use, water quality and biodiversity. This information is needed to provide a robust baseline to assess the short-, medium-, and long-term impacts of increased mining and other industrial activity on water resources within the basin.

- Our analysis identifies several pathways to sourcing the information required, along with insights on what is currently available, to help ensure that future efforts are not duplicative; and evidence an acceptable return on the time and financial investment that is required. In our methodology, we set out the various source data that we use for our analysis, to provide a marker of the best available information that is currently available.

- We highlight that much of this data is currently ‘siloed’ within departments of public sector agencies, or held in proprietary repositories that are owned by private sector companies. The processes involved to gain access are often procedurally challenging and can be very time consuming. Access is often intermediated through personal relationships, which creates additional information asymmetries.

- Finally, we note that much of the available data is typically being collected using sporadic, disconnected and unconsolidated processes. There is a strong case to be made for resourcing the systematic generation and collection of high resolution data; and for disseminating this information at minimised transaction cost. This would unlock capacity for analysis and insight that is vital to developing a comprehensive and complete overview of the state of water resources in the basin.

Recommended stakeholder actions

This section draws directly from a blog post on this topic, produced by the World Resources Institute in January 2024 (WRI, 2024).

Global data from the U.S. Geological Survey (USGS) and WRI's Aqueduct tool, suggests at least 16% of the world's land-based critical mineral mines, deposits and districts are located in areas already facing high or extremely high levels of water stress. In these locations, at least 40% of the available water supply is required each year to meet existing demand. A further 8% of global critical mineral locations are in arid and low-water-use areas, where available water supplies and total water demand are very low. Rapid increases in mining activity in these regions could easily increase demand for water and push these locations with already-scarce freshwater supplies into high or extremely high levels of water stress.

The situation necessitates improvements to current practices in water management. WRI highlights the following interventions for stakeholder consideration.

1. New technologies to reduce mining's impacts on water

Several mining companies are exploring new methods, such as direct lithium extraction (DLE), to reduce the water-related risks of mining. Unlike the evaporation process, DLE captures usable forms of the mineral directly from brine water, reducing water usage and decreasing the potential for toxic waste to leak from evaporation pools into water supplies. It may also increase the recovery rate of lithium from brine, reducing environmental impacts while boosting production. Some start-ups are also developing new microbial technologies to remove harmful toxins from mining waste and enable wastewater to be reused at mining sites. This can reduce overall water use in critical mineral mining and limit potential contamination of clean water. However, many of these technologies are still nascent and have not yet been implemented on a commercial scale. Further studies by researchers, engineers and the scientific community are needed to better understand their impacts, in addition to more investment in research and development.

2. Assess water risks across companies' value chains

Growing media attention as well as complaints from local communities have prompted some companies to begin addressing water-related risks in the critical minerals industry. Setting contextual water targets is one way companies can respond to water challenges along their value chains. Several mining companies have already set water targets for their operations. These are mainly focused on reducing water use, such as by repairing leaks and reusing treated wastewater

However, companies need to look beyond water usage within their own facilities and also consider the surrounding watershed. Efforts should address not only water quantity issues, but also water quality and other challenges. Actions could include implementing nature-based solutions, such as restoring wetlands and forests to recharge groundwater, mitigate flood risk and improve water quality. Companies further downstream in the value chain, such as technology companies and EV manufacturers, should also consider the water impacts of critical minerals in their supply chains when setting contextual water targets and stewardship strategies.

3. Improve governance and environmental regulation

Voluntary corporate initiatives are not enough to combat water challenges; governments also need to take action. Poor oversight and regulation can exacerbate water-related issues and other environmental and social risks related to mining. Yet high volumes of critical minerals such as copper, lithium, nickel and cobalt are produced in regions with low governance scores.

Better governance is especially important for artisanal and small-scale mining operations, which tend to be rife with environmental and safety hazards. Although this type of mining is often illegal, it's not uncommon: It accounts for 15%-30% of cobalt produced in the Democratic Republic of Congo, which provides 70% of the world's supply.

While many countries enforce environmental standards in the private sector, few have developed mining-specific regulations. Existing guidance from multi-stakeholder efforts and industry organisations such as IRMA and ICMM can serve as a starting point for local and national governments to develop robust regulations around water use, discharge and waste management. Decision-making must also include local communities and Indigenous Peoples, with mechanisms for these groups to voice concerns throughout the permitting and planning stages and beyond.

At the international level, countries including the U.S., Australia and Canada have partnered to strengthen responsible mining, processing and recycling of critical minerals through the Minerals Security Partnership and the Energy Resource Governance Initiative. By sharing best practices, improving transparency and attracting investment, these partnerships have the potential to bolster environmental governance worldwide — especially in countries where local and national regulatory capacity is low and where artisanal and small-scale mining is prevalent.

4. Expand access to data about mining's impacts

Few mining companies publish data on water use and water quality at critical mineral sites. Public data on mining and processing locations is also lacking. In addition, most companies source critical minerals from third-party smelters and refiners and may not know where the minerals in their products were mined. These data gaps limit governments' ability to set effective water policies and companies' capacity to set robust water targets along their value chains. One major effort to improve transparency in critical minerals sourcing — the Global Battery Alliance (GBA) Battery Passport — aims to collect and report data on the make-up, manufacturing history and sustainability of a battery across its lifecycle. Including information on water risks or impacts in this and other supply chain data initiatives could help.

Governments can also set clear and consistent reporting requirements for the mining sector. Mining companies should be required to report on site-level water sources, use and discharge, as well as any certifications in place. In the meantime, downstream companies can use available data and guidance to begin assessing upstream risks from critical mineral mining and processing. For example, the Organization for Economic Co-operation and Development recently published a Handbook on Environmental Due Diligence in Mineral Supply Chains, which encourages companies to collaborate with known suppliers to provide more visibility into minerals' origins.

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