Meeting future demand for drinking water supply in Dar es Salaam

Hydrological modelling of the Ruvu River and assessment of flows

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The city of Dar es Salaam in Tanzania requires significant new surface water resources if it is to meet Sustainable Development Goal 6. This study reports on the development of a hydrological model, using existing data, which assesses the impacts of upstream irrigation abstraction on downstream water security for the city. Results indicate that water deficits will likely still occur in dry years even after the construction of an additional storage dam. Water managers will need to finely balance upstream and downstream demands within the catchment, using improved knowledge of the state of the water resource.

Contents

Summary

Sustainable Development Goal 6 aims to promote the "availability and sustainable management of water and sanitation for all" by 2030. It has a range of complementary and potentially competing targets including improving access to water and sanitation with a view to universalising access; encouraging the participation of communities in water and sanitation services; promoting the sustainable use and management of water resources and ecosystems; and protecting low-income groups from the impacts of water-related disasters. IIED has explored, with partners at the Wami-Ruvu Basin Water Board (WRBWB), Ardhi University, DAWASA and local communities, the inter-connected elements of these targets across three different scales – low-income and informal urban settlements, the city of Dar es Salaam as a unit, and the Ruvu river basin as a whole.

Dar es Salaam lies in the coastal zone of the catchment of the WRBWB. Only around half of the city's population has access to piped water and plans are being drawn up to extend this city-wide. This report presents an updated hydrological assessment of surface water availability for supplying the city, as a contribution to meeting future water demand in the context of resource availability within the Ruvu Basin. The study assesses the Dar es Salaam current and future water offtake under different scenarios, which include construction of the Kidunda dam, environmental flow recommendations and increasing irrigation abstractions in the upstream sub-catchments.

The Ruvu basin experiences a typical bimodal rainfall pattern with the mountainous Upper Ruvu catchment receiving over twice as much annual rainfall as the coastal zone. While total mean annual flows are considerable, minimal flows during the dry season (August to October) constrain downstream day to day water availability for productive uses. This period is a critical bottleneck for both irrigation and drinking water supply throughout the basin.

A Mike Hydro model has been developed using the Mike Hydro building blocks connected by traced river reaches and channels as well as delineated catchments. The building blocks are used to represent the natural systems of the basin i.e. wetlands, swamps and natural lakes, and the development interventions introduced in the basin like irrigation use, abstractions for water supply, hydropower and reservoirs. The model includes water permits authorised by the WRBWB (quantity, permit holder and the months of the year that abstraction is authorised, i.e. dry or wet season). There is also an (unknown) level of unauthorized abstraction. The existing reservoirs in the basin are Mindu, Lugologolo, Wavane Group and Mindutulieni. The proposed Kidunda dam was also included in the model, using the feasibility study operating rules.

No new data were collected for this study. The model uses the best available datasets provided by the WRBWB, often incomplete time series, and existing rating curves for major gauging stations.

Running the model showed that authorized upstream abstractions exceed the available water supply during the dry season. However, the authorized permits do not indicate whether or not the water is actually used. For water offtakes for Dar es Salaam, water availability fails, on average, to meet demand 18 days (Lower Ruvu Offtake, 3.125 m3/s) and 7 days per year (Upper Ruvu Offtake, 2.27 m3/sec) respectively during the dry season. The highest water deficit is 9.4% of demand and scenarios are run with and without Kidunda dam. These 30 year averages hide significant differential impacts in wet and dry years.

The study concludes that:

1. The quality of water flow data in many of the catchments in the basin is questionable. Better data is required on the observed flows to ensure more accurate water resource modelling in future. Of particular concern are the level of dry season losses from the river bed to the aquifer in the reach downstream of Kidunda dam. The model suggests that most of the water released from Kidunda does not reach the Ruvu offtakes during the dry season but the reliability of low water gauging data (and the resultant Flow Duration Curves) will need to be checked to verify this conclusion.

2. Environmental flows at Ruvu/Kongo cannot be met during the dry years, this would likely affect the water quality at the estuary.

3. Increased Dar es Salaam demand for water offtake from Ruvu comes with an increased frequency of water deficits. On average, demand is not met for 18 days per year even with Kidunda dam and alternative sources will need to be mobilized. The situation is expected to worsen with the issuance of more water abstraction permits in the upstream catchments.
4. The total abstraction upstream of the Dar es Salaam water offtakes, currently stands at about 13 m^3/s, WRBWB should consider limiting new upstream permits, or making them time bound, or limited to certain times of year, to ensure improved long term water security for DSM in the dry season.
5. The current study has assumed similar trends of flows in the future. The impact of climate change on flows should be considered in future studies.

1

Background

Sustainable Development Goal 6 (SDG 6) aims to promote the "availability and sustainable management of water and sanitation for all". It has a range of complementary and potentially competing targets including improving access to water and sanitation with a view to universalising access; encouraging the participation of communities in water and sanitation services; promoting the sustainable use and management of water resources and ecosystems; and protecting low-income groups from the impacts of water-related disasters. The International Institute for Environment and Development (IIED) intends to explore, with partners, the inter-connected elements of these targets across three different scales – low-income and informal urban settlements, the city as a unit, and the river basin as whole. It will provide a new evidence base to identify and understand the potentially competing water demands of key water users, such as low-income urban residents, industry, rural households and commercial agriculture. The research will offer insights into the ways that water is allocated, and the ways that different actors secure access to water and sanitation, at the community, city and catchment scale. Dar es Salaam and the surrounding river basin has been selected as the initial field site and will serve as an opportunity to seriously consider and reconcile river basin and urban water access policy research agendas.

The population of Dar es Salaam is around 4.5 million people. Some 51% are supplied with piped water while only 10% have access to piped sewerage. The remainder source their water from groundwater, the quality of which is affected by pollution from badly lined pit latrines, saline water intrusion of marine origin, and in some areas saline rock formations. Cholera is endemic in some city areas supplied by boreholes. Six new 600m deep boreholes have recently been drilled to feed the piped network and seek to alleviate these issues. Surface water is available from the Ruvu River (some 65 km away) but potentially competes with upstream irrigation uses. A new dam is being constructed at Kidunda that may allow storage of seasonal flows and release downstream during the dry season. Riverine transit is dependent on high groundwater levels in the river bed as geological formations are porous.

IIED and partners have selected the following communities to work with in identifying their trajectories towards achieving universal access (SDG 6):

1. Kombo/Mji Mpya subwards at Vingunguti ward (Ilala district)
2. Tungi subward at Tungi ward (Temeke)
3. Mtoni sub ward at Mtoni ward (Temeke)

This will provide an opportunity to consider how water and sanitation rights and entitlements could be realised, and the implications that realising the demands of the urban poor would realistically have for water resources at different scales (local, city wide, basin wide).

Dar es Salaam lies within the area of the Wami-Ruvu Basin Water Board (WRBWB) and in 2012, the Japan International Cooperation Agency (JICA) completed a hydrological model of the basin using MIKE-Hydro software that is operated by the river basin office under licence from DHI. Since 2012, a number of changes have been made to water use and planning within the basin and the model now requires updating to serve as a planning tool to inform future water consumption scenarios in Dar es Salaam.

This work is linked to three other pieces of work under the same project:

1. A review of community defined trajectories for improved water supply and sanitation with their concomitant water demand. This work is led by the Center for Community Initiatives (CCI)
2. A review of the institutional framework for decision making around water supply in Dar (Ardhi University)
3. An analysis of the sustainability of borehole supply (shallow and deep) to meet growing city needs

The results of this process will place scenarios for future water demand in Dar in the context of basin wide resource availability, taking into consideration the issuing of permits for water abstraction upstream in the basin. The analyses and results were presented and discussed in a workshop in Dar es Salaam in November 2016.

The study aims at assessing the Dar es Salaam water offtake under different scenarios, which include construction of the Kidunda dam, environmental flow recommendations and increasing abstractions in the upstream sub-catchments.

The following main assumptions were made in the analysis:

i) Issuance of water permits remains at the current level (no agricultural expansion) in the future

ii) Rainfall patterns and flow follow trends observed since 1980.

2

Understanding basin dynamics

Ruvu originates in the Uluguru mountains, where small streams combine to form three main tributaries, namely Mgeta, Ruvu and Ngerengere (Figure 1). The Mgeta and Ruvu drain the south side and the Ngerengere drains the north. The gradient of the river reduces as it descends to the lowland areas and the river is characterized by large meanders at lowland areas. During the rains, the main river channel floods its banks and four extensive floodplains are formed between the estuary and the village of Ruvu, around the Dar es Salaam-Morogoro road bridge (IUCN, 2010).

The geology of the catchment is mainly dominated by Precambrian in the western part of the Ngerengere sub-basin. Jurassic rocks occur in the eastern margin of the Uluguru Mountains and elevated rolling hills between the Ruvu and Wami rivers. Tertiary and Quaternary (youngest strata in the basin) occur in the catchment area of the Ngerengere River near Morogoro Municipality, and in the elevated rolling hills and floodplains along the Ruvu River, Kibaha, Bagamoyo and extend up to Dar es Salaam.

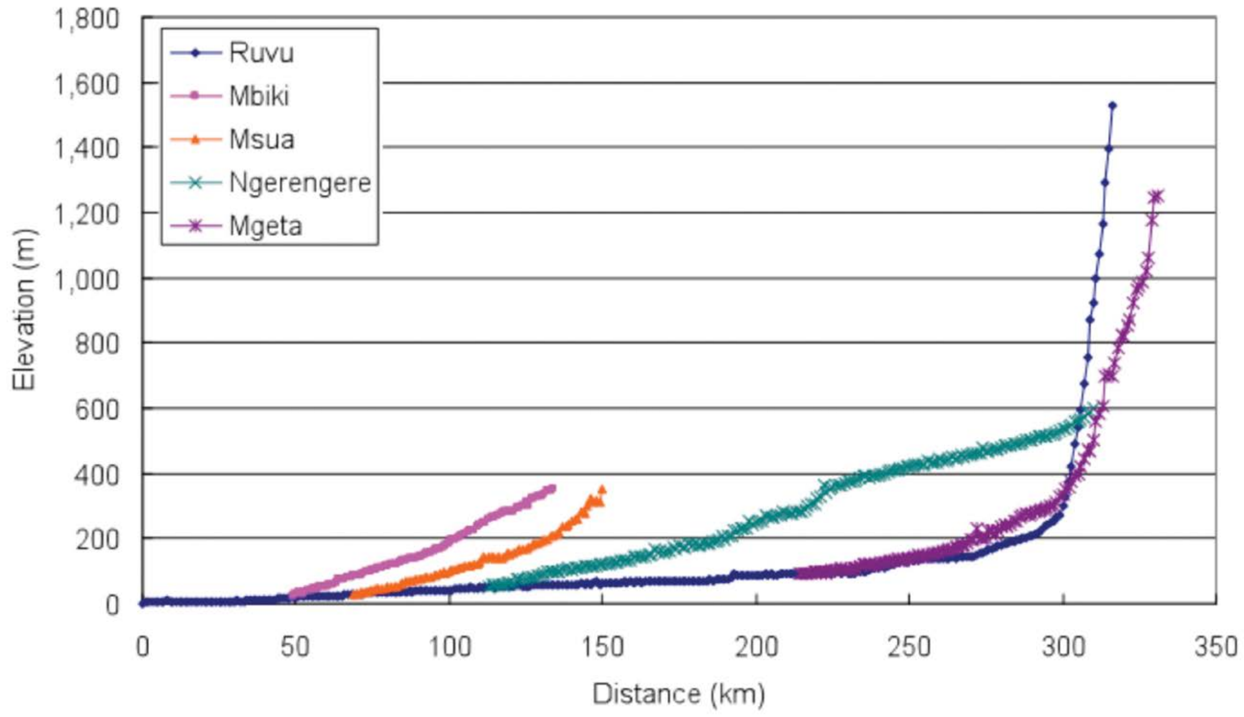
2.1 Rainfall characteristics

Ruvu basin experiences a typical bimodal rainfall pattern with Upper Ruvu catchment receiving more rainfall on average than other catchments in the basin (Figure 2). The two stations, Mondo and Morning side in Ngerengere catchments are located in the mountainous region and have higher rainfall than the rest of the stations within the catchment.

2.2 Flow characteristics

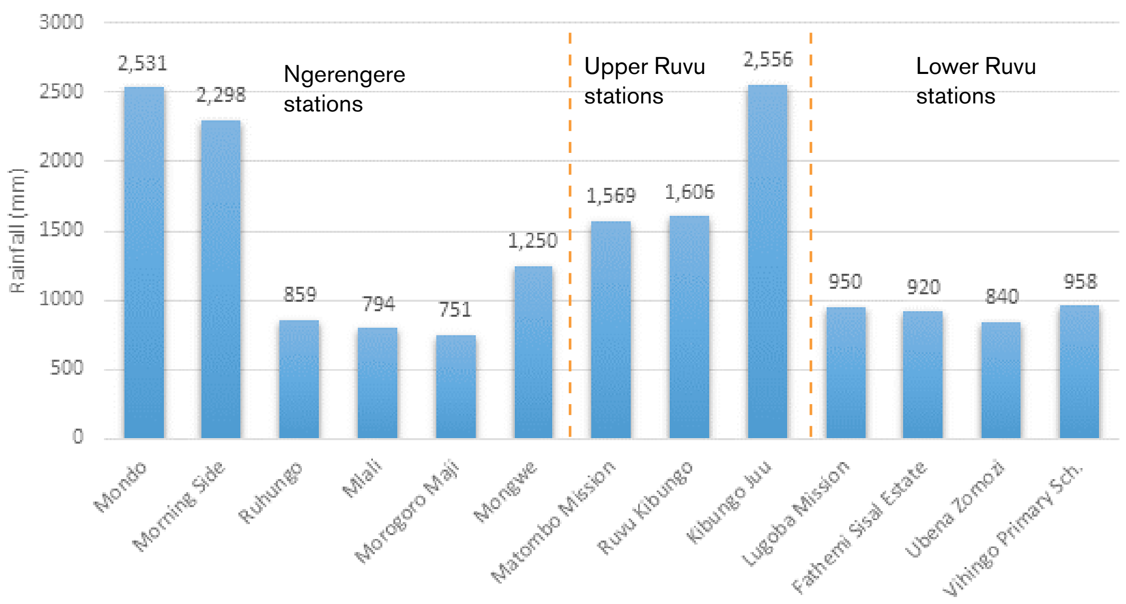
The flow regime follows the bimodal nature of the rainfall variability with distinct peaks in November and April/May following the short and long rains, respectively (Figure 3). The early rains in mid to late October contribute to flow increase first peaking in November/December and recession follows the end of the short rains.

Figure 1. Longitudinal Profile of Ruvu River and its tributaries



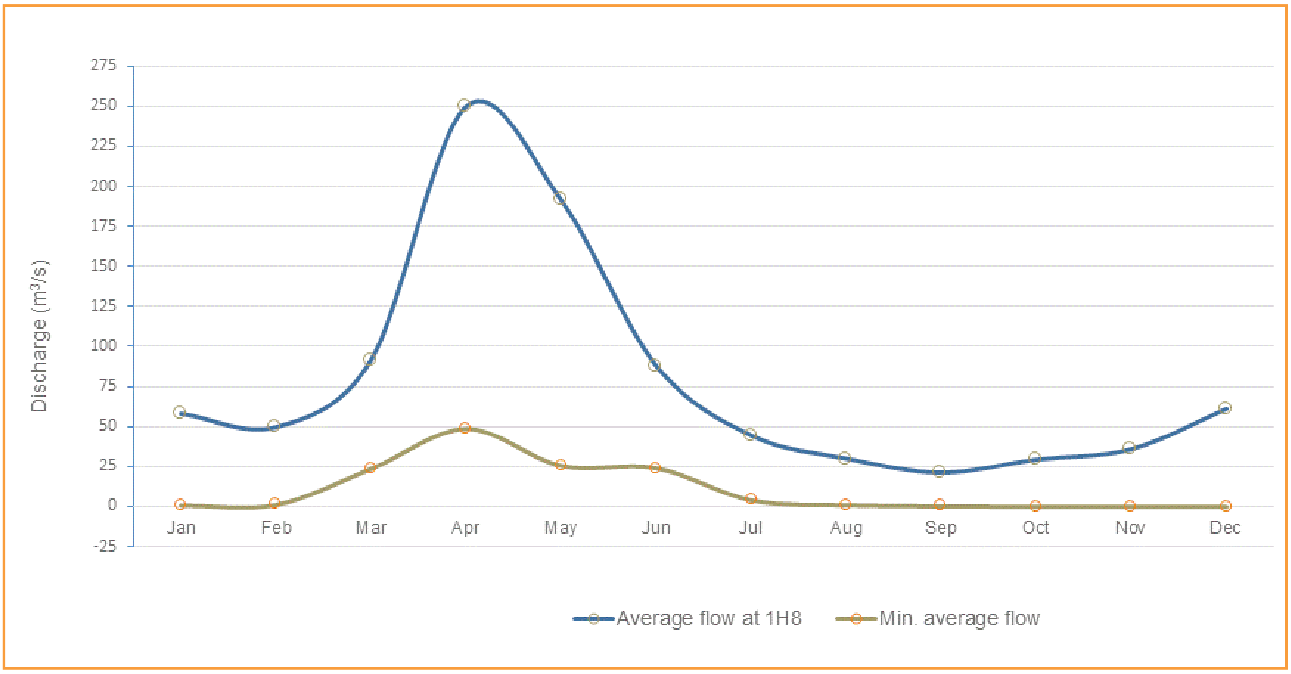
Source: JICA Study Team, 2012

Figure 2. Mean Annual Precipitation (MAP) for the selected stations in the Ruvu basin (1960–2010)



Source: Data provided by WRBWB

Figure 3. Mean monthly flow at 1H8 station



2.3 Inventory of the flow gauging stations

Ruvu sub-basin has about 25 flow gauging stations, spatially distributed as shown in Figure 4. However, only 9 or so of these are operational at the moment. The status of the rating curves for the selected stations are shown in Table 1. From the table, it can be noted that the rating curves for some of the key stations have some errors and require updating. The errors in the rating curves introduce uncertainties in the status of the water availability in the sub-basin.

Figure 4. Ruvu basin flow gauging stations

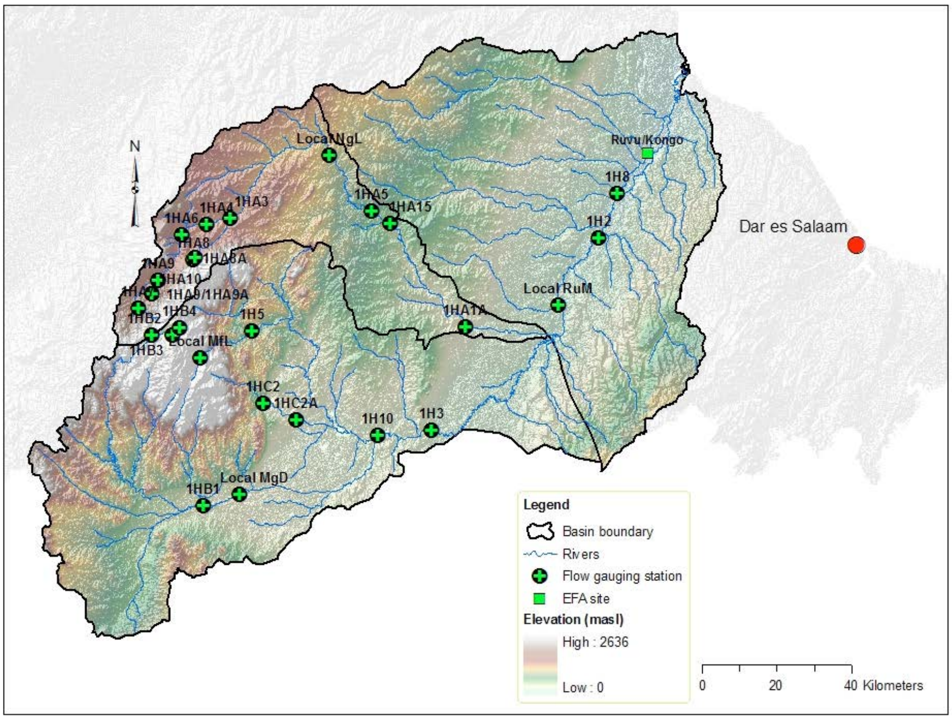


Table 1. Status of the selected gauging stations as per assessment done from November 2012 to May 2013

STATION CODE	DESCRIPTION
1H5	Ruvu River at Kibungo gauges numbers: 3.00–4.00m, 4.00–5.00m and 5.00–6.00m needed big adjustments which entailed dismantling and rebuilding. Observed a developed island at the channel hydraulic section and recommended to be removed in order to allow the flow hydro-dynamic processes to take place. This was dug-out and section cleared to reduce its effects on the uniform flow at the measuring site.
1H8	Found to be in good order, no adjustment
1HB2	An error was found between gauge plate number 0.0–1.00m and 1.00–2.00m, for which the 1.00–2.00m gauge was re-erected to comply with the appropriate levels of the range of the existing gauges.
1HA9A	A misleading error for the gauge plate that used to be considered 0.0–1.00m, but for which in reality it was 0.0–0.50m, but on top it used to read 1.00m. This error was noted and rectified and the gauge ranges now read 0.0–0.50m as the first gauge, second gauge reads 0.50–1.00m, third 1.00–2.00m, fourth 2.00–3.00m, fifth 3.00–4.00m and the last 4.00–5.00m. The total gauge range is up to 5.50m instead of 6.00m. Such errors might have had implications on the previously recorded water levels at the sections and subsequently on the computed discharges. Reviewing of historical water levels since last check survey was recommended.
1HA15	The gauges 1.00–2.00m, 2.00–3.00m and 3.00–4.00m were adjusted. Gauge no. 0.0–1.00m was found to be submerged in sand by 0.38m that is while the water level was 0.88m. Actual depth was 0.50m. The banks at this station were found to be actively degraded by livestock movement across the measuring section. Recommend installing a signpost to bar the trespassing at section. Furthermore, the authorities, especially the village government should be informed. This station is important because its location may be taken to represent a larger part catchment of the Ngerengere River Catchment before its confluence with Ruvu river.

Source: Global Water for Sustainability Program – Florida International University (GLOWS-FIU), 2014b

3

Model development

A Mike Hydro model has been developed using the Mike Hydro building blocks connected by traced river reaches and channels as well as delineated catchments. The building blocks are basically used to represent the natural systems of the basin i.e. wetlands, swamps and natural lakes, and the development interventions introduced in the basin like irrigation use, abstractions for water supply, hydropower and reservoirs.

3.1 Input data

The consultant met with the modelling Wami-Ruvu basin staff and accessed the existing baseline model in MIKEBASIN and the associated database. The existing baseline model in MIKEBASIN was developed by the JICA study team in 2012. The model basically covered most of the existing features. However, it was necessary to rebuild the model in MIKEHYDRO (the new version of the MIKEBASIN) to cover the recent development in the basin including new offtakes for Dar es Salaam water supply, proposed Kidunda dam and environmental flow recommendations. MIKEHYDRO is a multipurpose, map-based decision support tool for integrated water resources analysis, planning and management of river basins. Setting up the model in MIKEHYDRO basin, involved the following steps:

1 Reviewing the existing model and associated database.

2 Collecting data for the new features and development which included Kidunda dam (Level –Area-Volume, Characteristics levels (bottom, dead and flood levels), reservoir operation, spillway characteristics, etc), environmental flow data from USAID supported study, and water abstraction for Dar water supply.

The data used in the setup of the model and their corresponding sources are as shown in Tables 2 and 3. The discharge data used ended in the year 2009 and it is based on JICA's study. The Wami-Ruvu basin hydrologists should be able to update the discharge data once the rating curves are updated and validated.

The water permits provided by the WRBWB show the quantity, permit holder and months of the year that abstraction is authorised, i.e. dry or wet season. Once the permit is issued, it is not known whether or not the water is actually used and the permits do not indicate a time limit. It is worth noting that there will also be unuathorised abstraction.

The MIKEHYDRO basin modelling involved delineation (digitizing) catchments in the basin, allocating flows to each catchment, inserting water demand nodes and the water requirements, defining reservoir/dam characteristics and hydropower characteristics. The existing reservoirs in the basin are Mindu, Lugologolo, Wavane Group and Mindutulieni. The proposed Kidunda dam which is intended to augment the water supply for Dar es Salaam city was also included in the analysis. The following operation rules for the Kidunda dam were used: (i) minimum release of 24 m^3/s downstream of the dam, (ii) minimum operation level of 79.5 metres above sea level (masl)., and (iii) flood control level of 84 masl. The simulation using the MIKEHYDRO model can be done on a daily or monthly time step, but in this case daily was used since the discharge data was available at daily time step.

Table 2. Data used for the model set up

S/N	DATA	SOURCE
1	Discharge	WRBWB, JICA study team baseline model
2	Dam and reservoir characteristics	Dar es Salaam Water & Sewerage Authority (DAWASA) (2010) – Kidunda dam feasibility report
3	Environmental flow requirement	GLOWS-FIU (2014a) – Environmental flow recommendations for the Ruvu River basin
4	Water permits	WRBWB

Table 3. Level-Area-Storage characteristics for Kidunda dam

LEVEL (MASL)	SURFACE AREA (KM^2)	STORAGE (X 10^6 M^3)	LEVEL (MASL)	SURFACE AREA (KM^2)	STORAGE (X 10^6 M^3)
69	0	0	78	10.5	30
70	0.5	0	79	15	43
71	1	0.8	80	19	59
72	1.5	1	81	25	80
73	2	2.5	82	32.5	110
74	2.5	5	83	40	145
75	4.5	8	84	52	190
76	6	12	85	65	250
77	8	20	86	77.5	321

Source: DAWASA, 2010

3.2 Model calibration

Model calibration and validation are based on a generic approach to the calibration and validation of hydrological/water resources models. The baseline model was set up and calibrated for the Ruvu basin in order to simulate existing conditions. The purpose of the baseline model is to describe the existing situation and provide a platform upon which future development intervention scenarios can be built and their impacts compared. After the model set up a simulation was run and the results were compared to records from Ngerengere catchment (1HA1A), Upper Ruvu catchment (1H10) and Upper Ruvu offtake (1H8). The plots of simulated and observed flows for the stations are presented in Figures 5–19. From the plots, it can be seen that the simulated and observed mean monthly flows are in good agreement at 1H8 (Upper Ruvu offtake) during the dry season. This is the most downstream station in the sub-basin and used as the monitoring point for both Upper and Lower Ruvu offtakes. The simulated flows at 1H1A, Ngerengere catchment (1HA1A) indicate relatively low fit with the observed data. This may be due to data gaps at this particular station and the quality of the rating curve.

Figure 5. Simulated and observed flows at 1H8 (1980–1992), Upper Ruvu intake

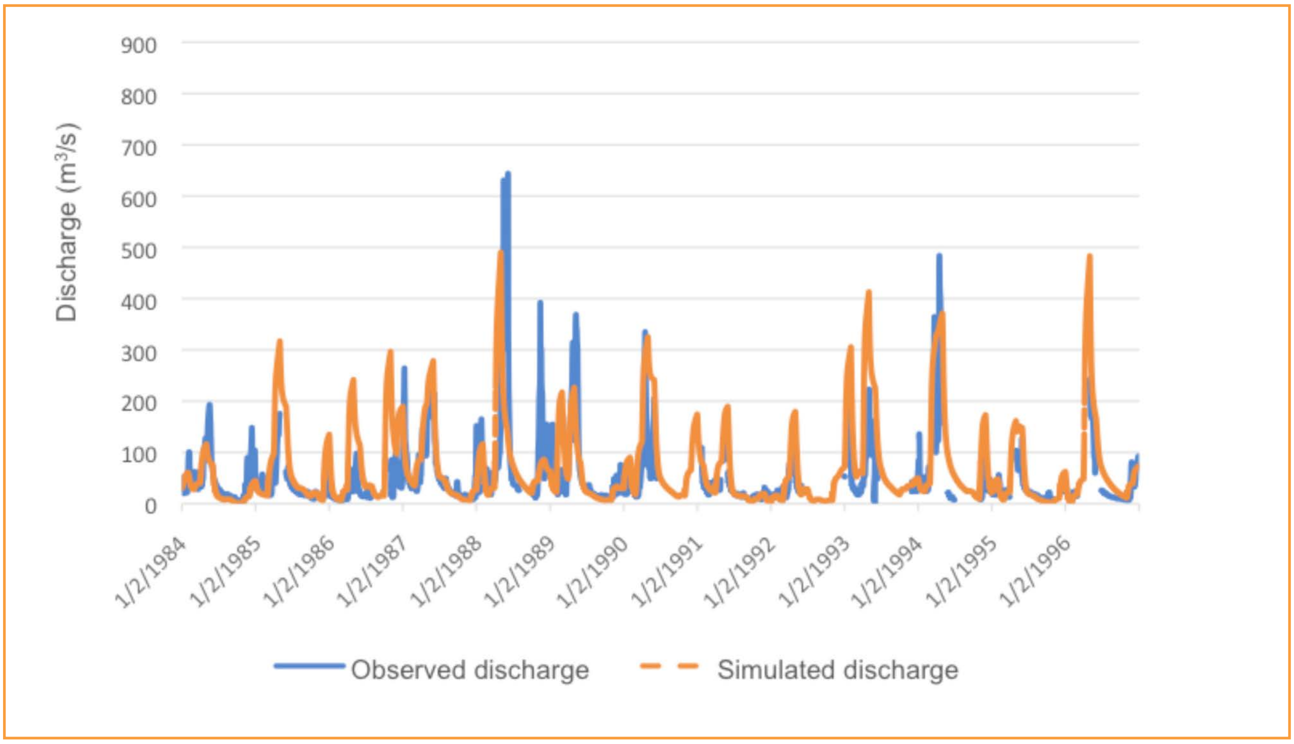


Figure 6. Simulated and observed flows at 1H8 (1980–1981), Upper Ruvu intake

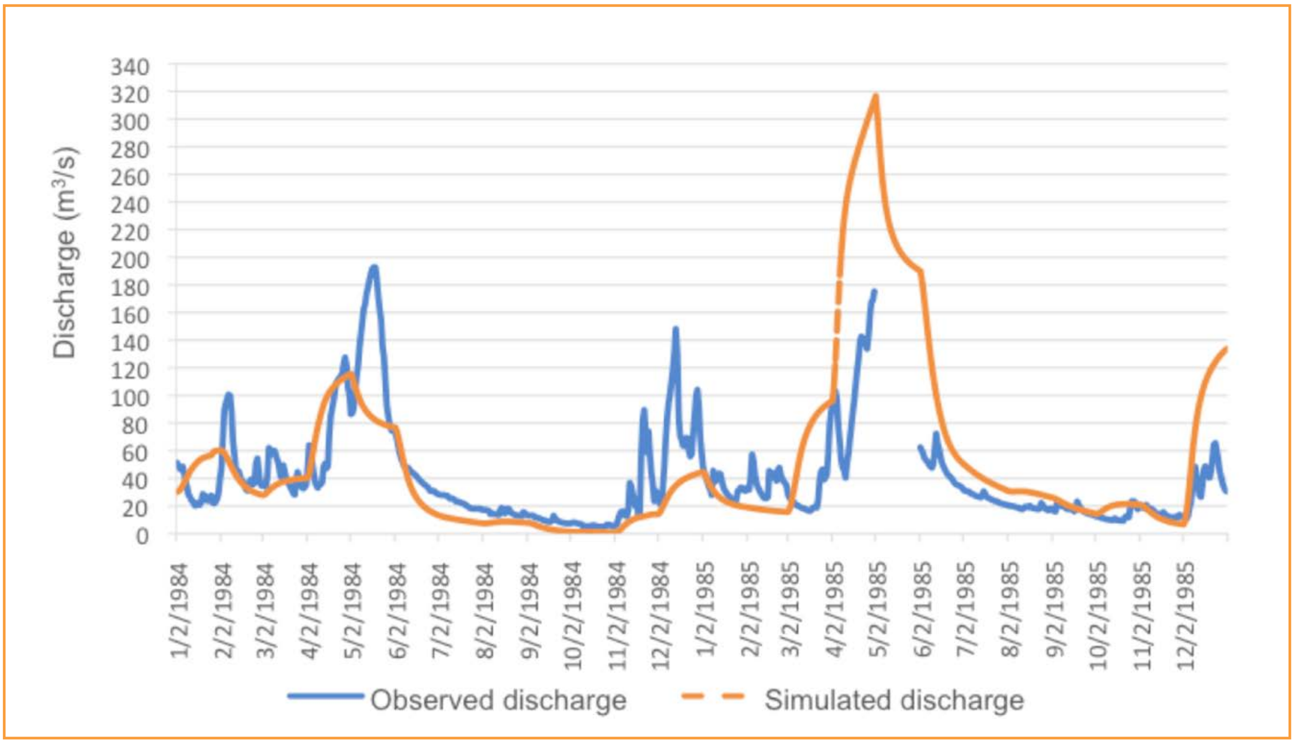


Figure 7. Observed and simulated mean monthly discharge (1980–1992) at 1H8

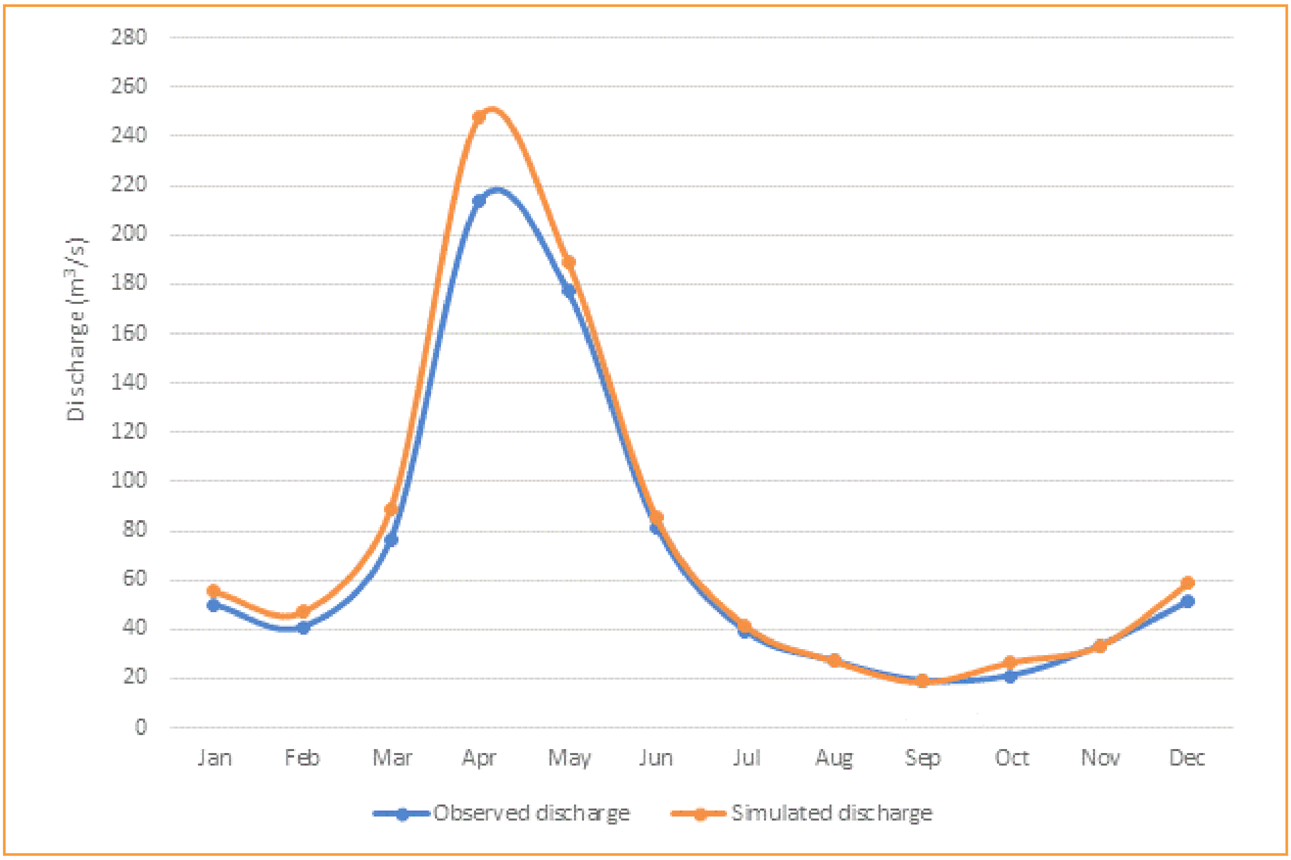


Figure 8. Observed and simulated mean monthly discharge (1980–1992) at 1H8, dry season

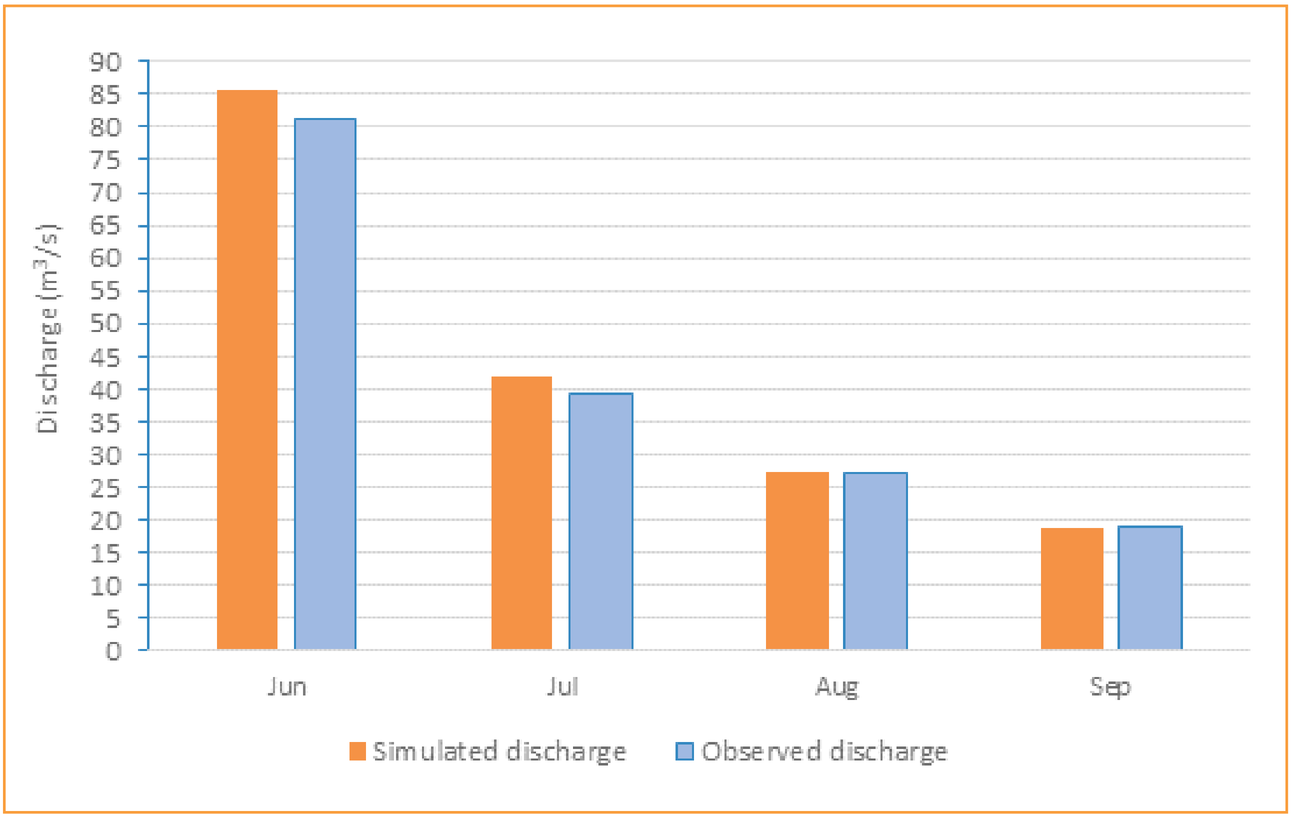


Figure 9. Scatter plot – simulated and observed mean monthly discharge (1980–1992) for 1H8

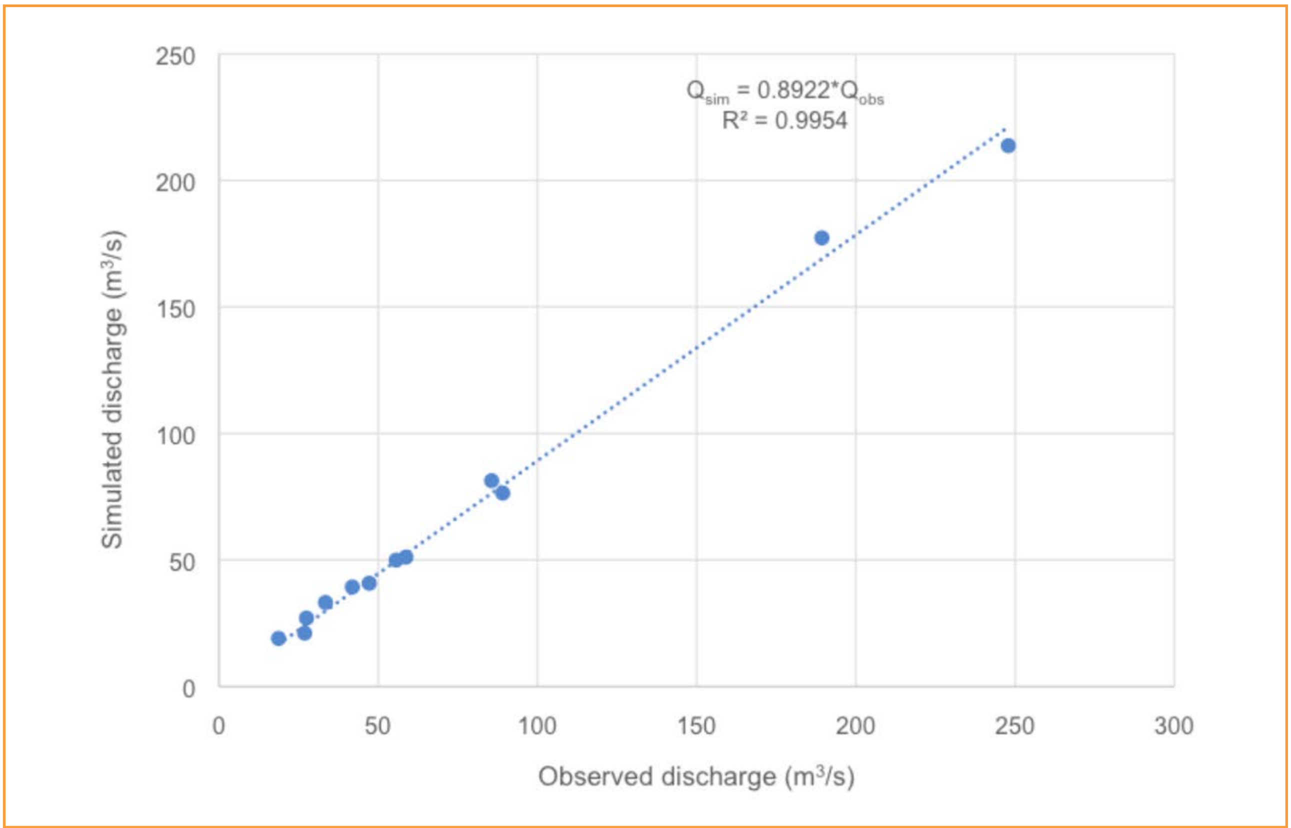


Figure 10. Simulated and observed discharge (1980–1992) at 1HA1A, Ngerengere catchment

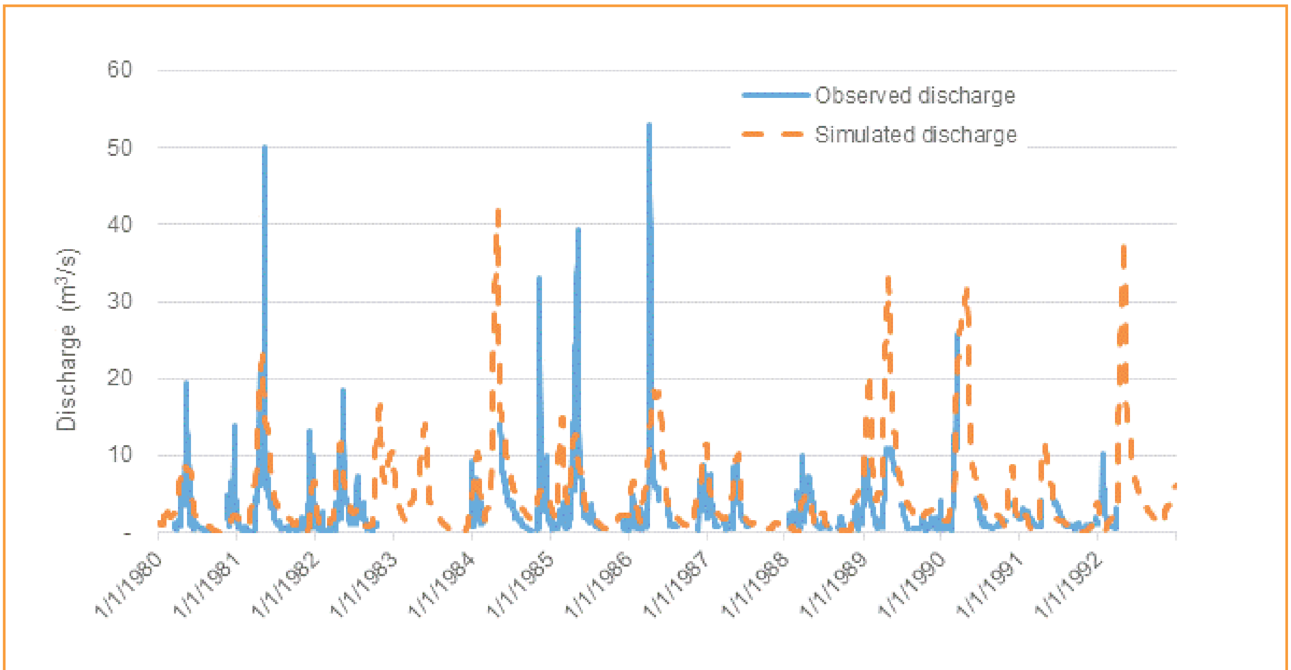


Figure 11. Simulated and observed discharge for 1HA1A (1980–1981) – Ngerengere catchment

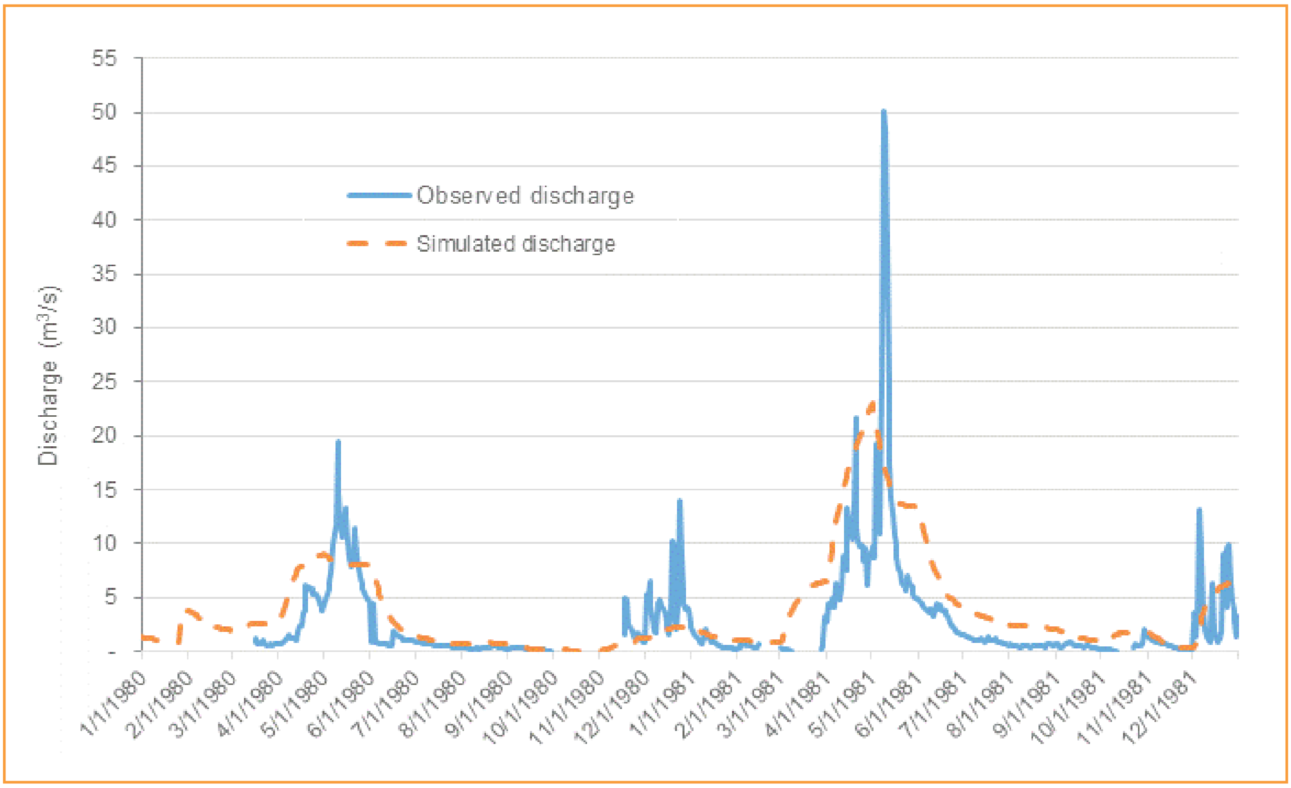


Figure 12. Observed and simulated mean monthly discharge (1980–1992) for 1HA1A

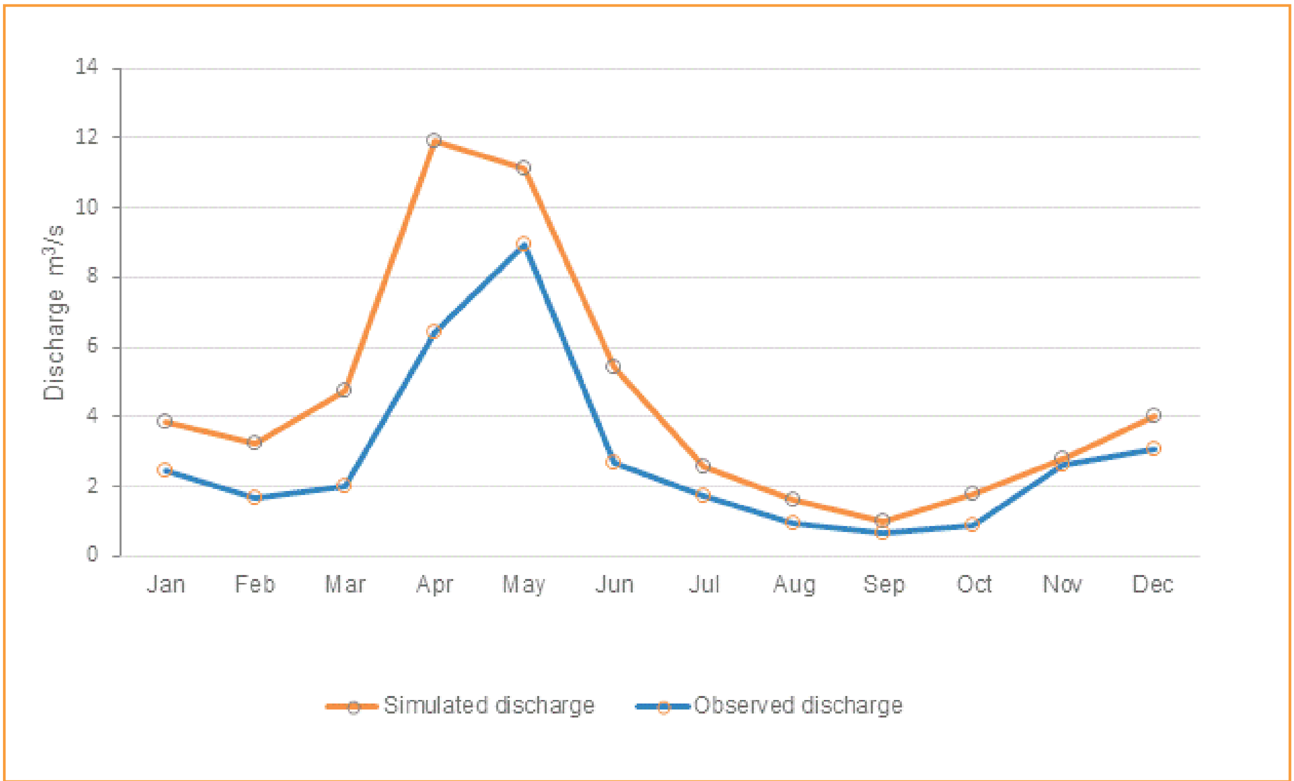


Figure 13. Observed and simulated mean monthly discharge (1980–1992) at 1HA1A– dry season

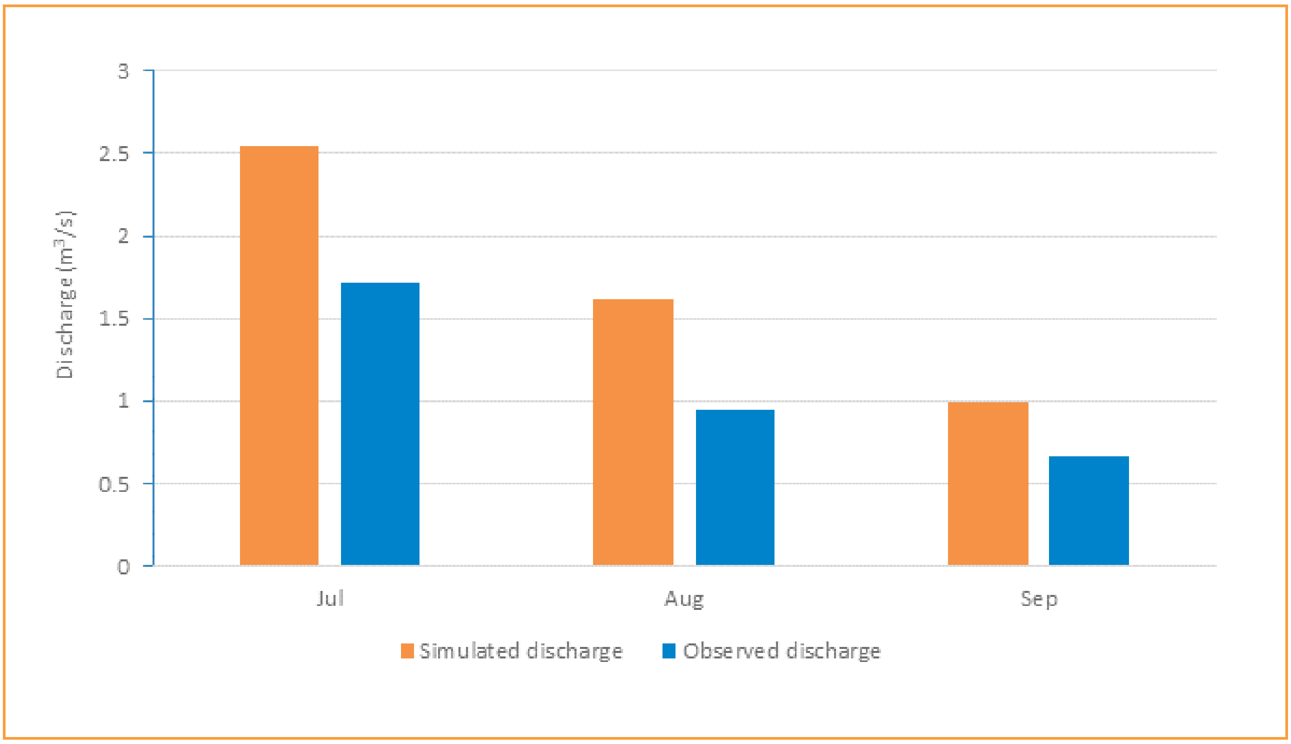


Figure 14. Scatter plot – simulated and observed mean monthly discharge (1980–1992) for 1HA1A

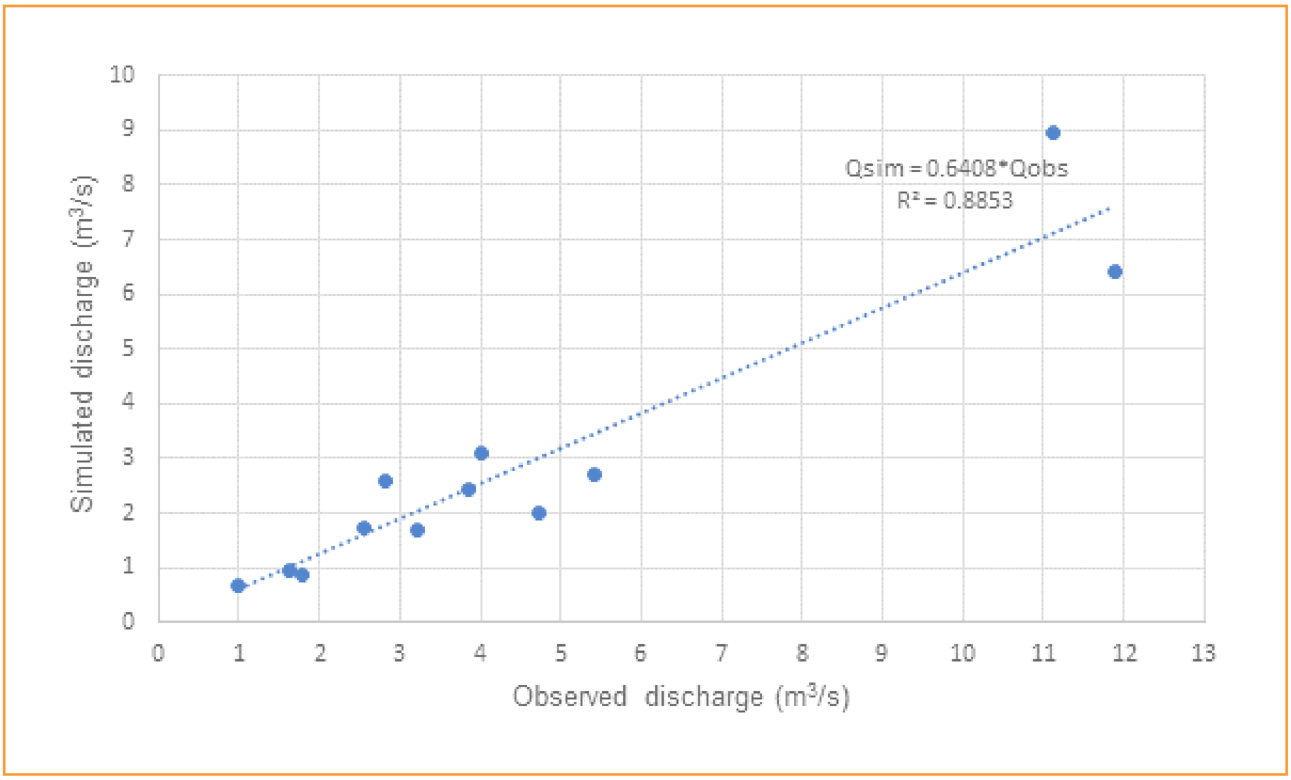


Figure 15. Observed and simulated discharge (1980–1988) at 1H10, Upper Ruvu catchment

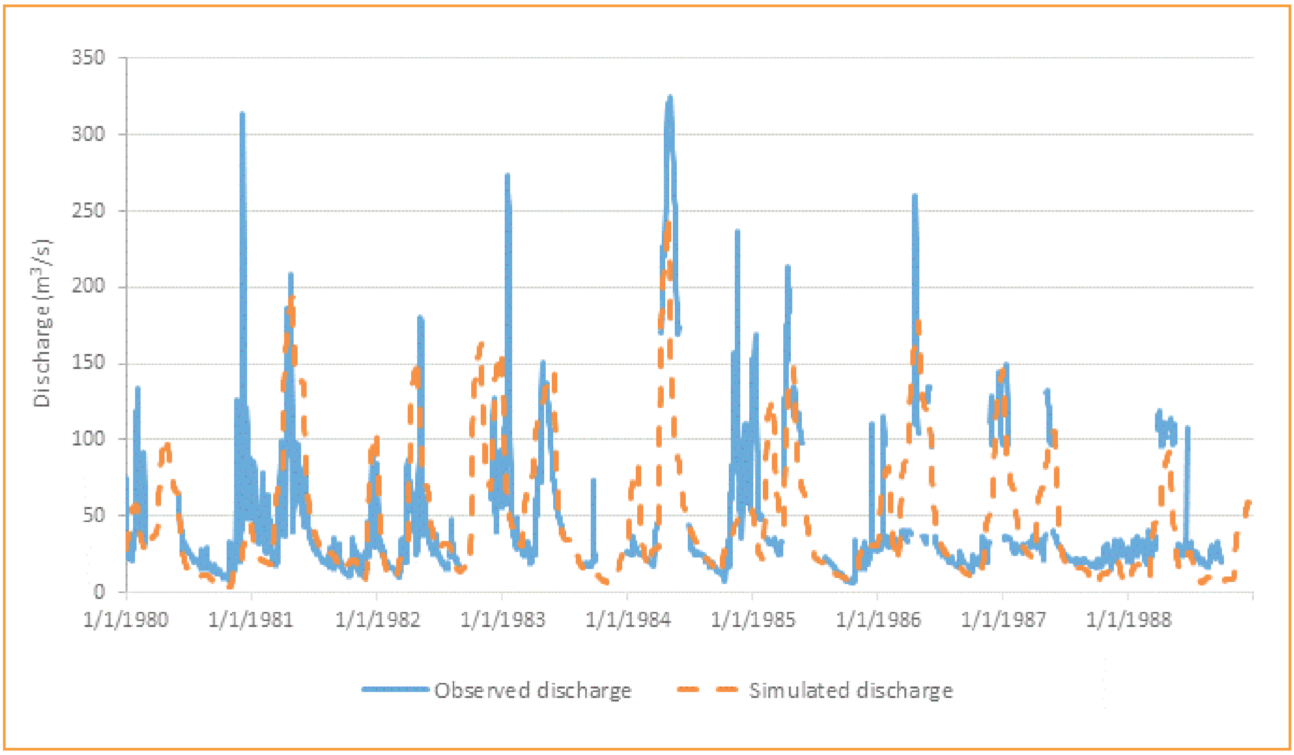


Figure 16. Simulated and observed discharge at 1H10 (1981–1982) at 1H10

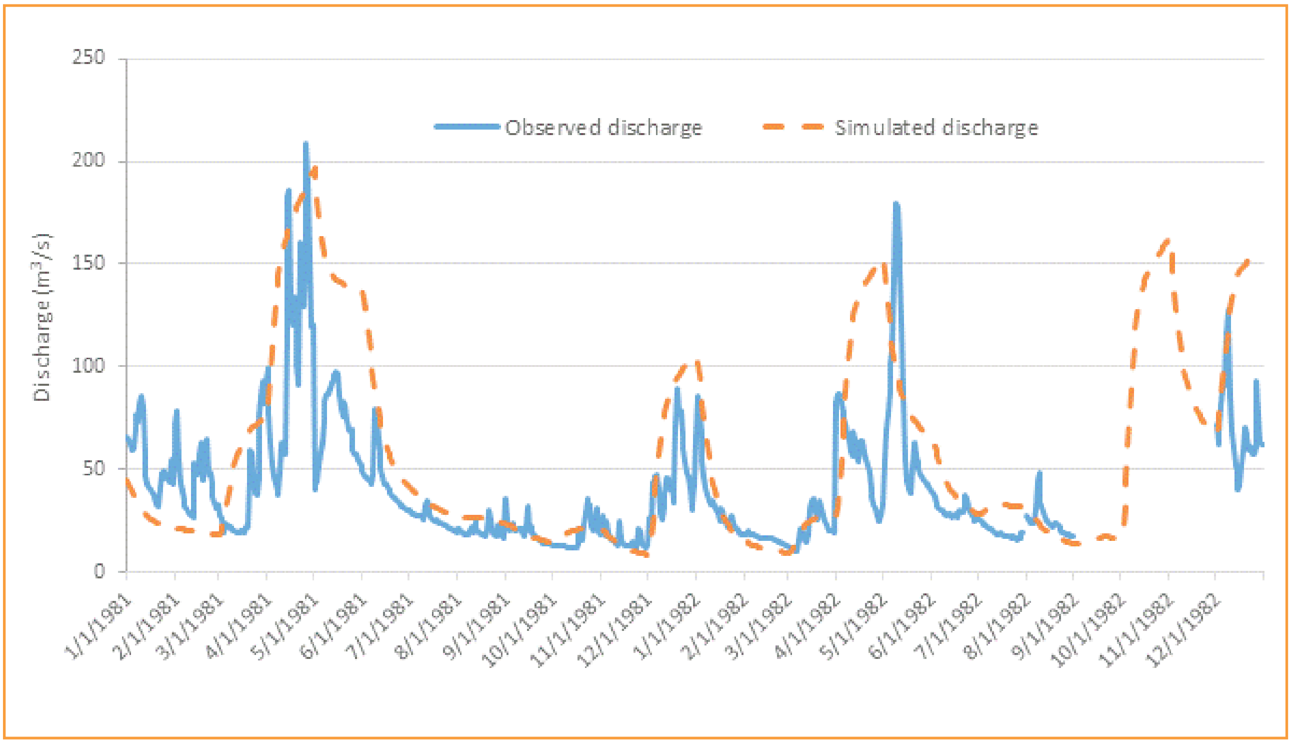


Figure 17. Observed and simulated mean monthly discharge (1980–1989) for 1H10, Upper Ruvu catchment

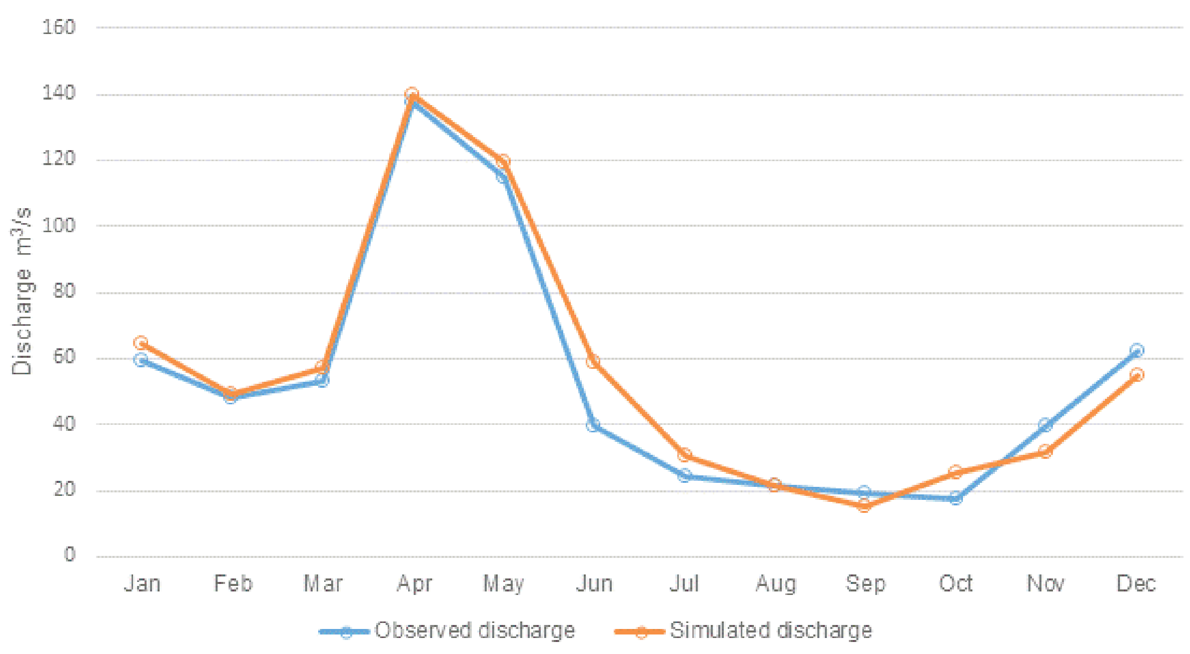


Figure 18. Scatter plot – simulated and observed mean monthly discharge (1980–1989) for 1H10

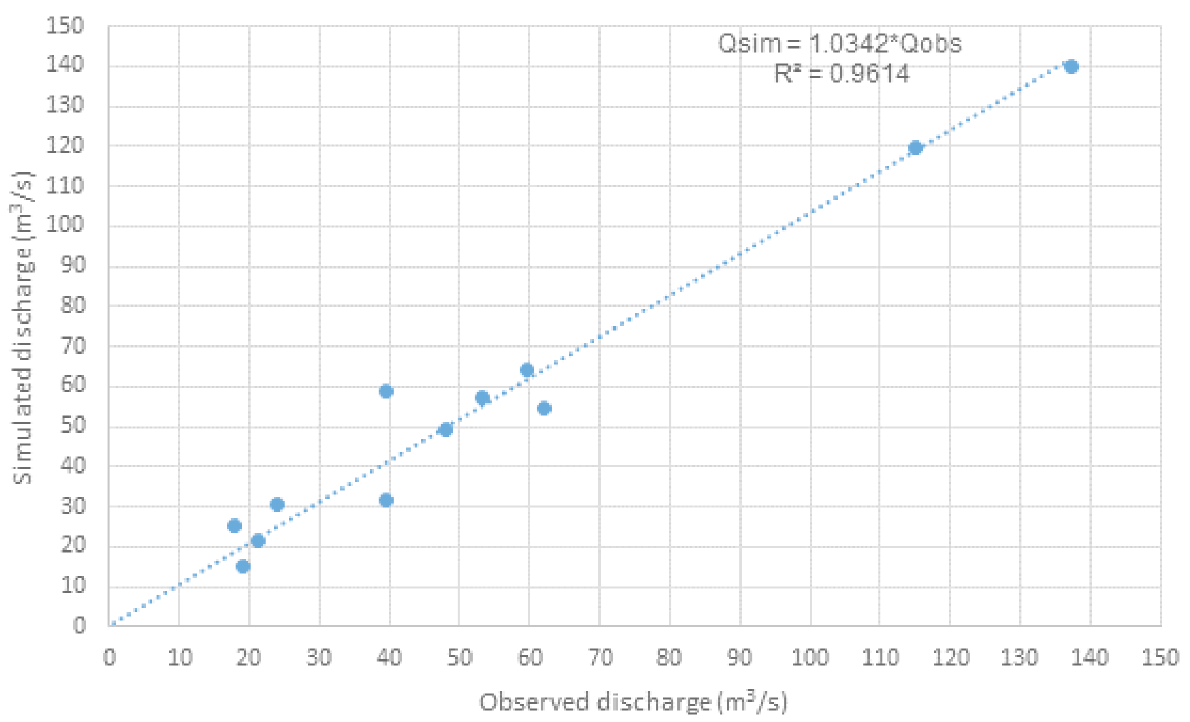
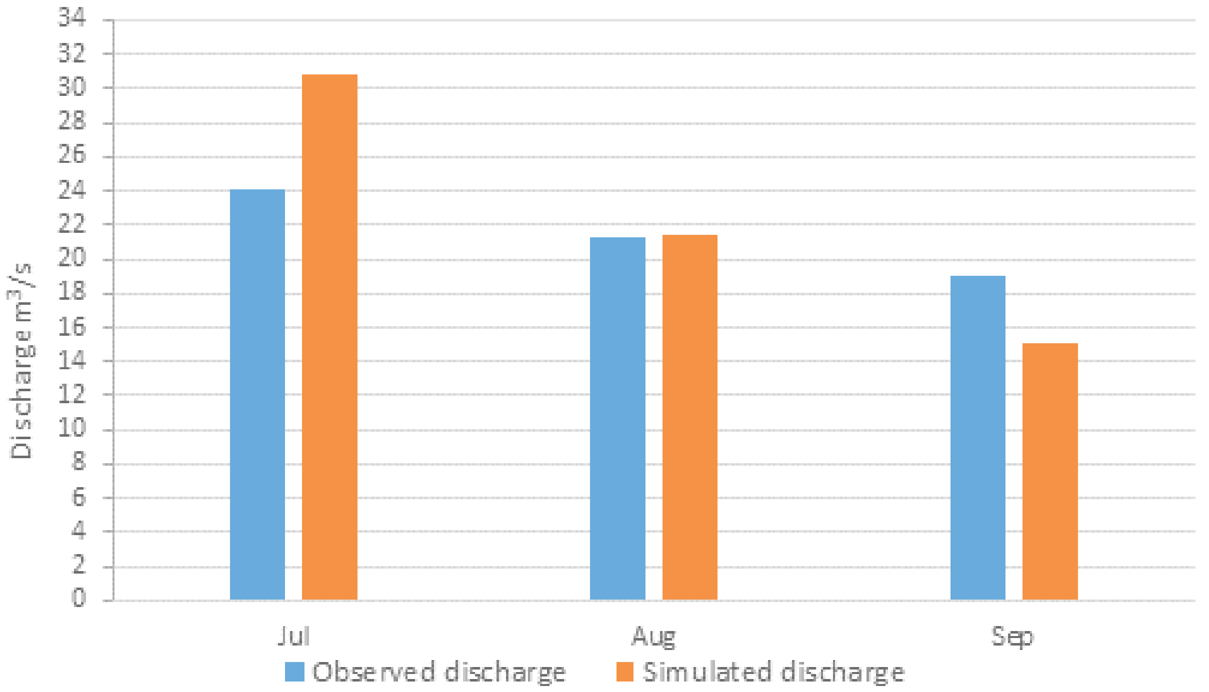


Figure 19. Simulated and observed mean monthly discharge at 1H10, dry season



4

Water resources and uses in the basin

4.1 Environmental flow requirement

The Tanzania National Water Policy (2002) recognizes the importance of environmental flows and prioritizes water use such that “Water for basic human needs in adequate quantity and acceptable quality will receive highest priority. Water for the environment to protect the eco-systems that underpin our water resources, now and in the future will attain second priority and will be reserved.” The Tanzania Water Resources Management Act (2009) defines the reserve as “the quantity and quality of water required for (a) satisfying basic human needs and (b) protecting aquatic ecosystems”. According to GLOWS-FIU (2014a), the Environmental Flow Assessment (EFA) for the Ruvu river basin has been conducted for the following five sites:

1) Ruvu River at Kibungo
2) Mgeta River at Duthumi
3) Ngerengere River at Mgude
4) Ruvu River at Kidunda
5) Ruvu River at Kongo

This study assessed whether the proposed environmental flow requirement at the identified sites can be met or not in light of the new offtakes for Dar es Salaam water supply, proposed Kidunda dam and increasing water permits in the basin. The Ruvu River at Kongo site was selected for the analysis based on the fact that it is below both Upper Ruvu and Lower Ruvu offtakes. However, it should be noted that upstream environmental flow requirement does not have an impact on the Dar offtakes as this is the reserve which is finally available downstream. The downstream environmental flow requirement at Ruvu Kongo also has no impact for the Dar water offtakes as domestic water requirement is given priority when there is competition between the two uses.

Figures 20 and 21 show the seasonal flows and environment flows for Ruvu/Kongo station. From the plot, it can be noted that environmental flow requirements can be met if measured as the average monthly flows but for dry years (based on minimum flows for the month), the environmental flow requirement cannot be systematically met during the dry season (July to September).

Figure 20 Seasonal flow and environmental flow requirement for Ruvu/Kongo

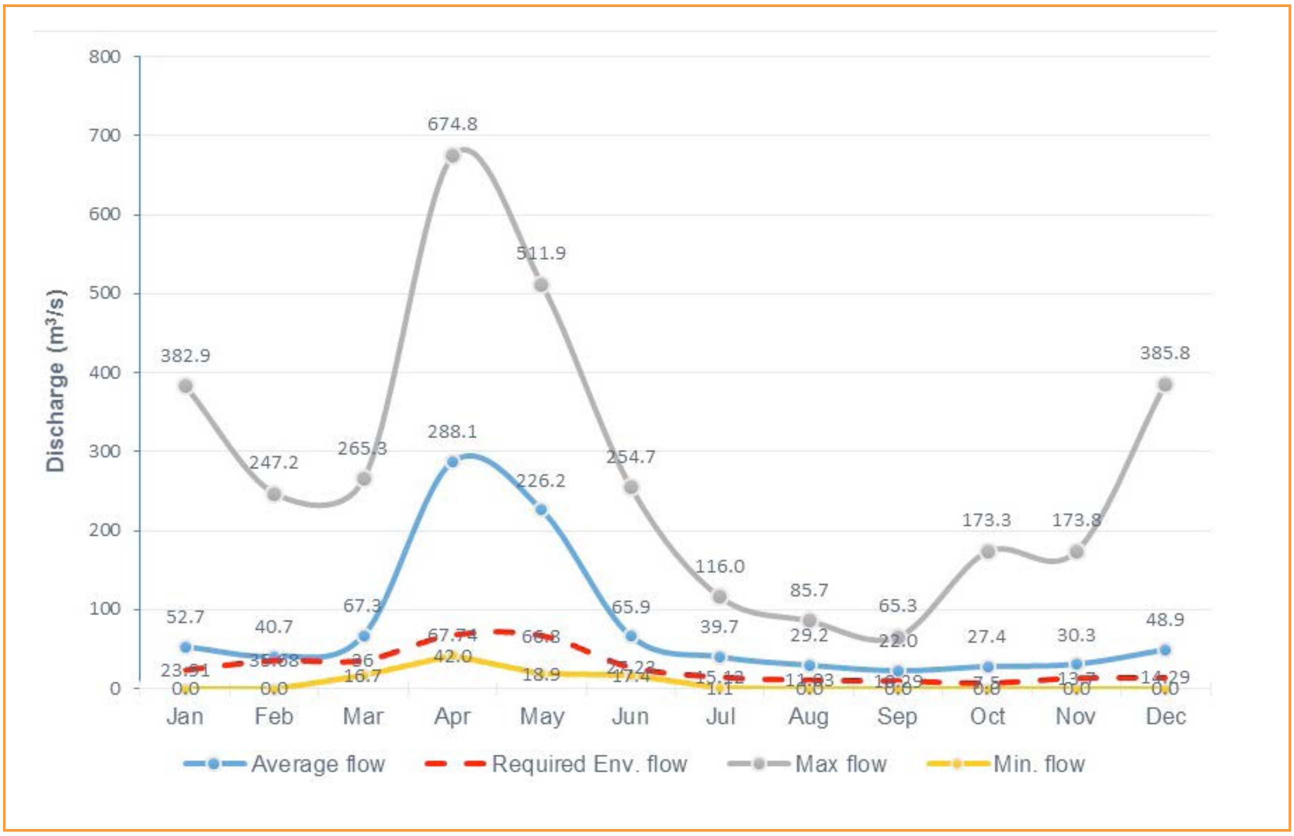
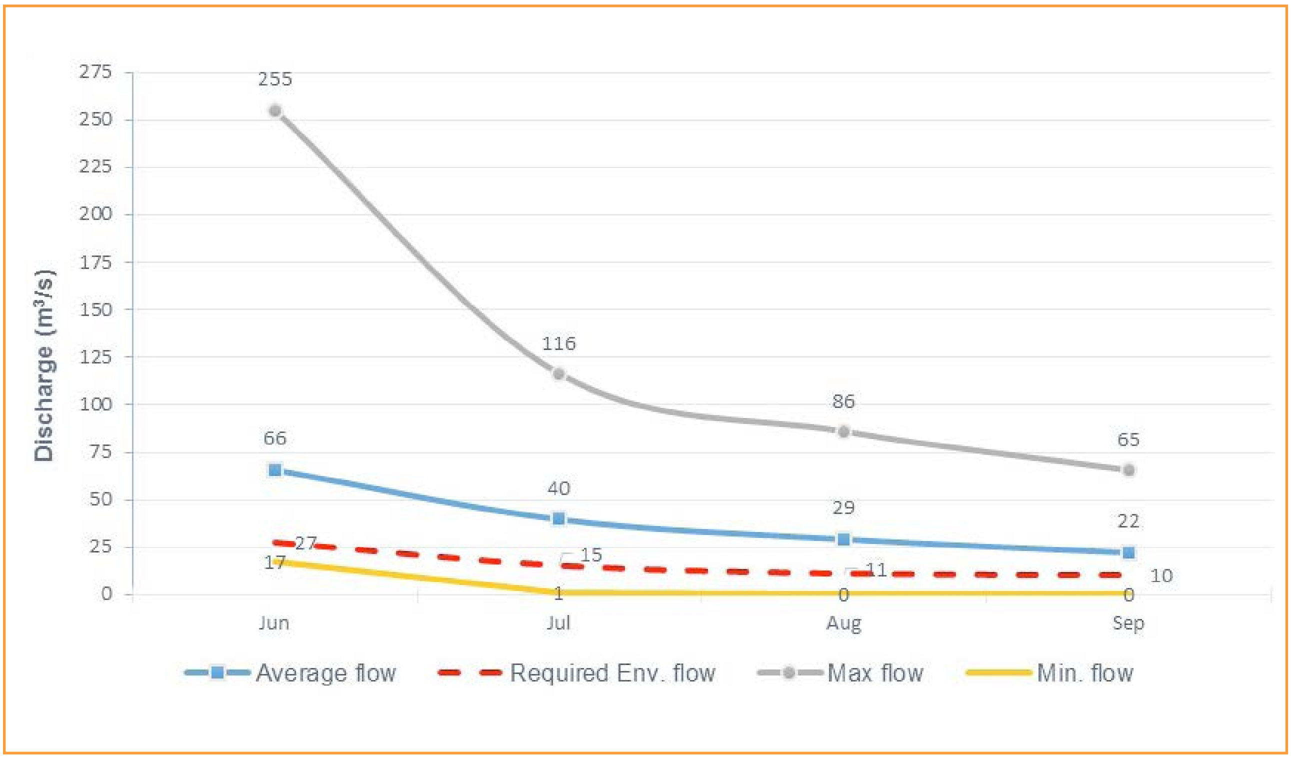


Figure 21. Seasonal flow and environmental flow requirement for Ruvu/Kongo- dry season



4.2 Water availability for other uses (domestic, irrigation, industry)

The Ruvu River is the source of surface water supply for domestic, industrial uses and irrigation for residents of Morogoro, Dar es Salaam City, Kibaha and Bagamoyo towns and also for the people residing along the pipeline. The population growth coupled with increasing water demand for domestic, industrial and irrigation uses is posing challenges in the allocation of the scarce resource in the basin. Figure 22 shows the spatial distribution of the water abstraction points in the basin.

4.2.1 Assessment of seasonal flows and water permits

The spatial distribution of the permits in the basin (Figure 22) shows that the distribution is skewed towards the Ngerengere catchment. Based on the allocation of water permits, assessment of water availability for the Ngerengere catchment is shown in Figures 23 and 24. From the figures, it can be noted that the water permits allocated exceed the minimum flows throughout the year. Furthermore, the water permits exceed the long term average flows during the dry season which is the main period for irrigation. Despite the fact that Ngerengere is the catchment with the highest water permits, the only significant permit issued recently is the Mkulazi paddy and sugarcane irrigation issued to Tanzania Investment Centre (TIC) in 2014. The permit amounts to 5 m^3/s but is not yet operational and is issued for the abstraction during the dry season as per the WRBWB database. From the analysis, it is evident that water security cannot be ensured for the permit during the dry season.

Figures 25 and 26 show the comparison of mean monthly flows and minimum average flows with the cumulated abstractions in the Upper Ruvu catchment. From the figures, it can be noted that the total abstraction in the catchment is 5.46 m^3/s and exceeds the average minimum flow during the dry season. The permit with the significant abstraction (5 m^3/s) was issued in the year 2008 and for irrigation purposes.

Figures 27 and 28 show the comparison between the mean monthly and average minimum flows for the lower Ruvu catchment at 1H8 gauging station. The gauging station is located at the Upper Ruvu intake (Ruvu bridge). It is the last station in the lower reach of the basin and is used for both intakes (lower and upper Ruvu intakes). The total abstraction upstream of the station as estimated from the water permits is 12.9 m^3/s. The abstraction exceeds the average minimum flows during the dry season, which means Dar es Salaam city water permits cannot be guaranteed during the dry years.

Figure 22. Water abstraction points in the Ruvu basin

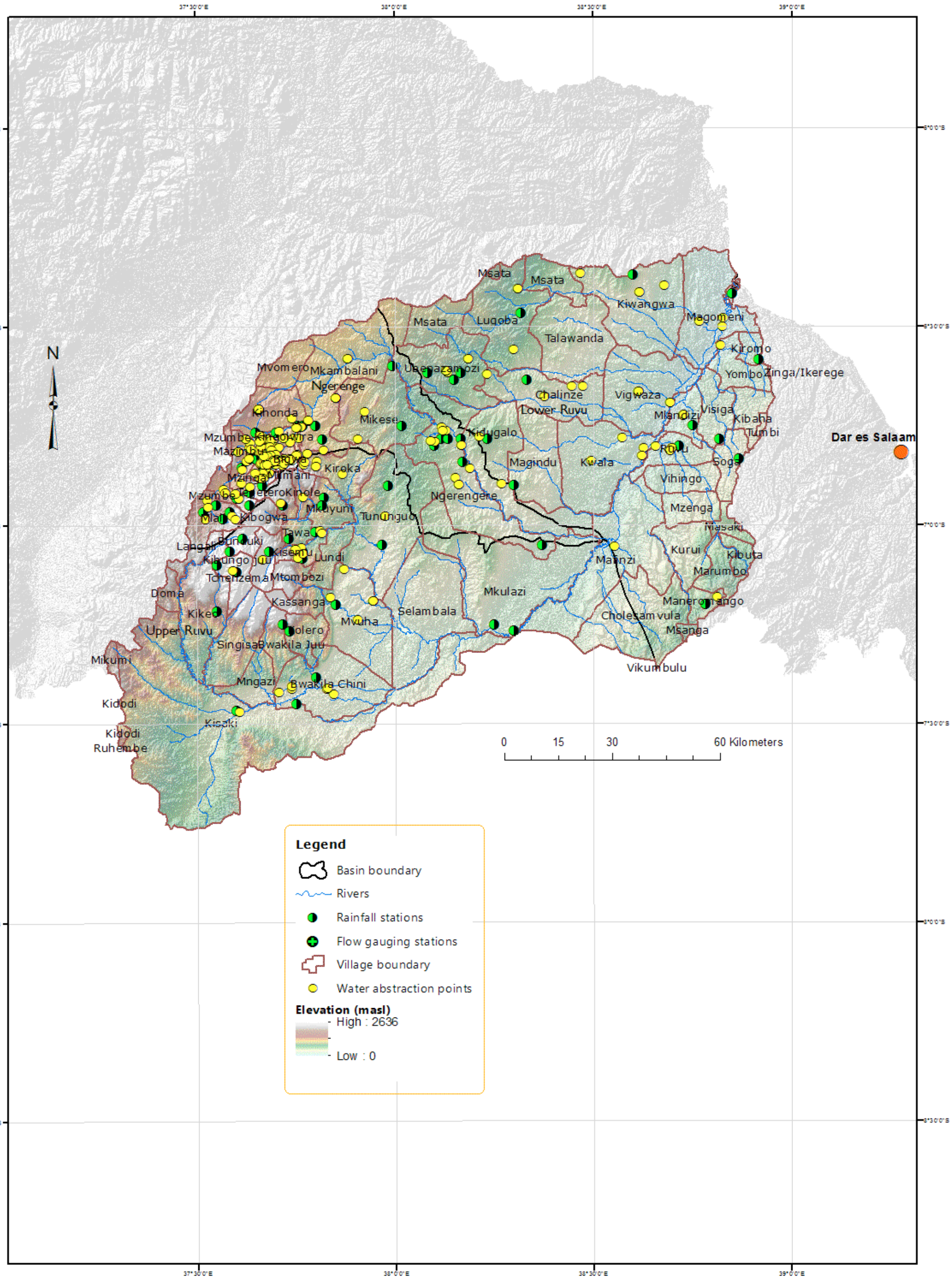


Figure 23. Seasonal flow at 1HA1A gauging station and total abstraction upstream (Ngerengere catchment)

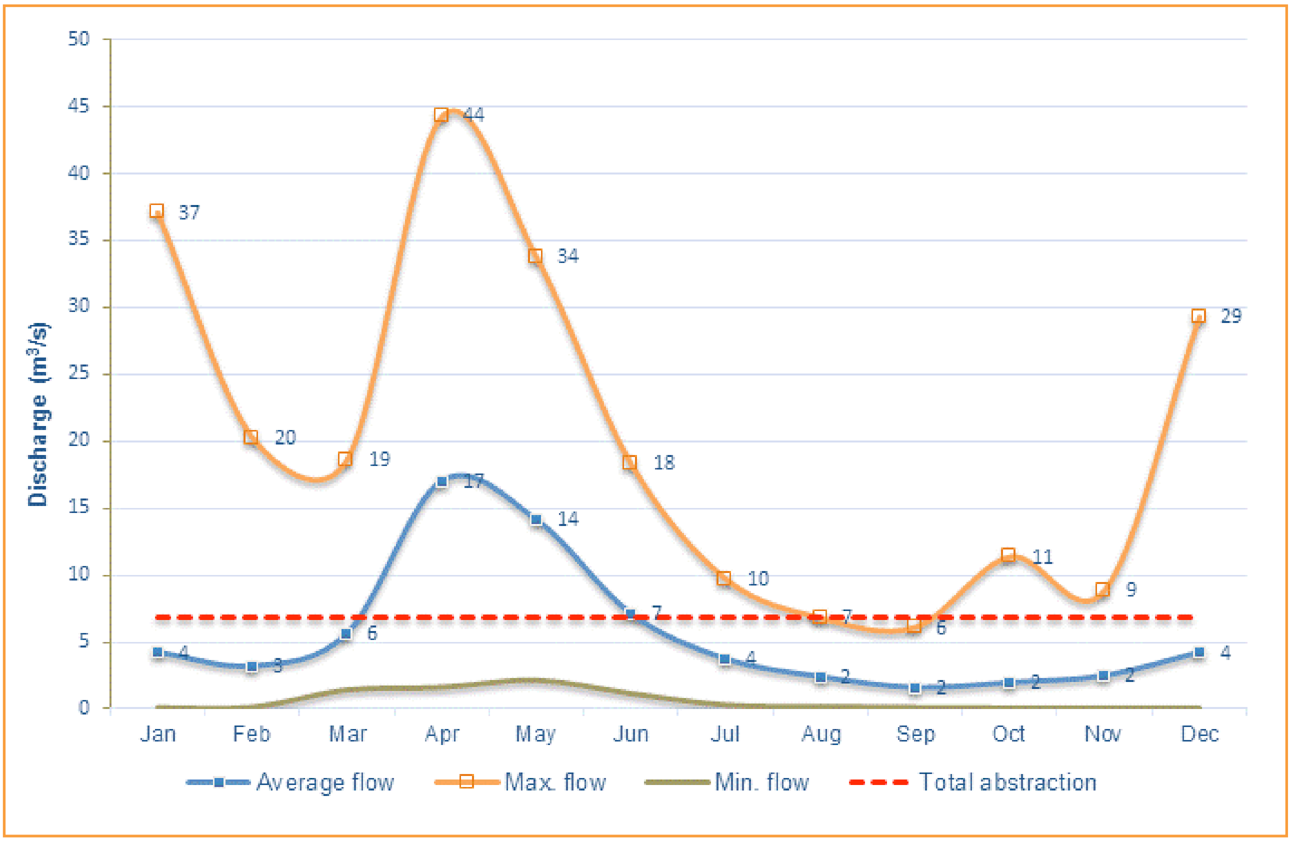


Figure 24. Seasonal flow at 1HA1A gauging station and total abstraction upstream (Ngerengere catchment) – dry season

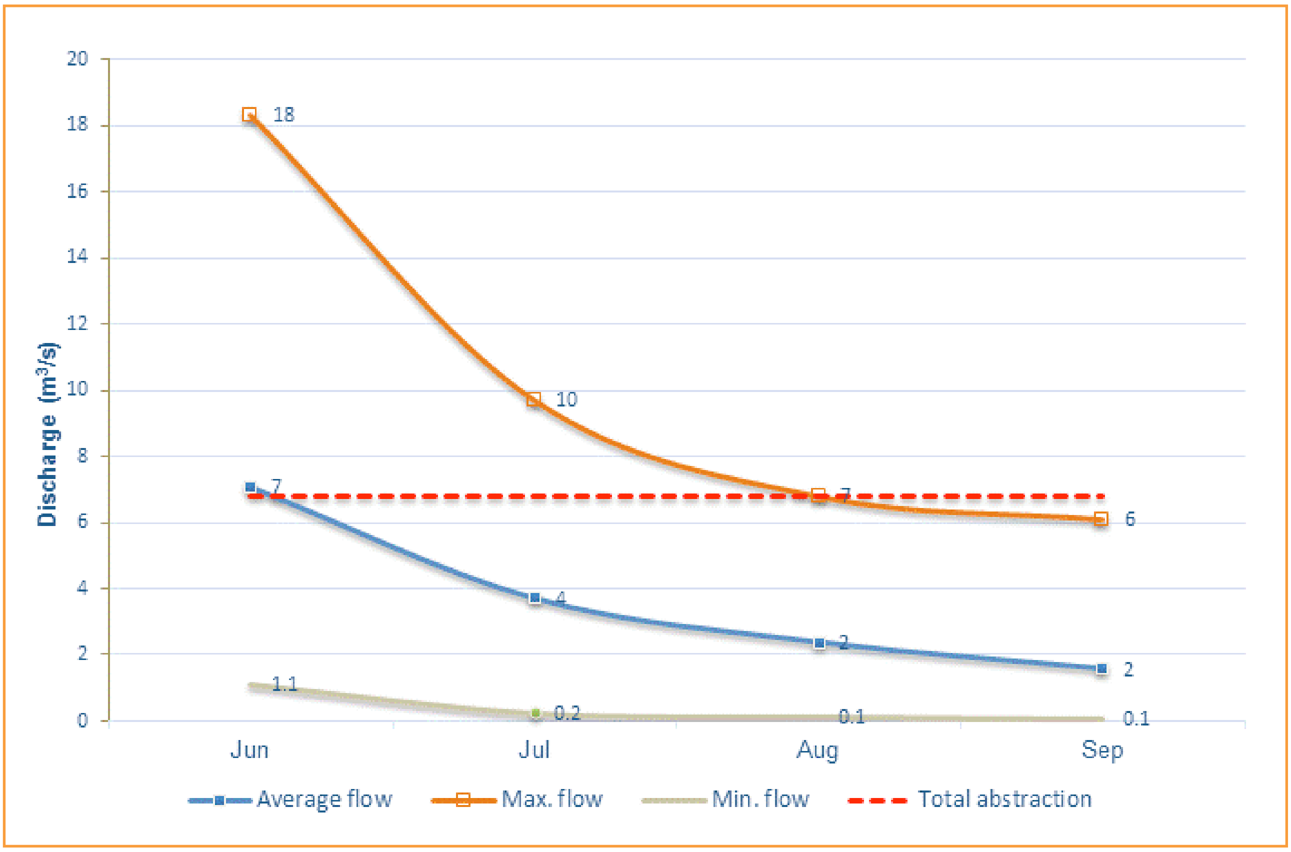


Figure 25. Seasonal flow at 1H10 gauging station and total abstraction upstream (Upper Ruvu catchment)

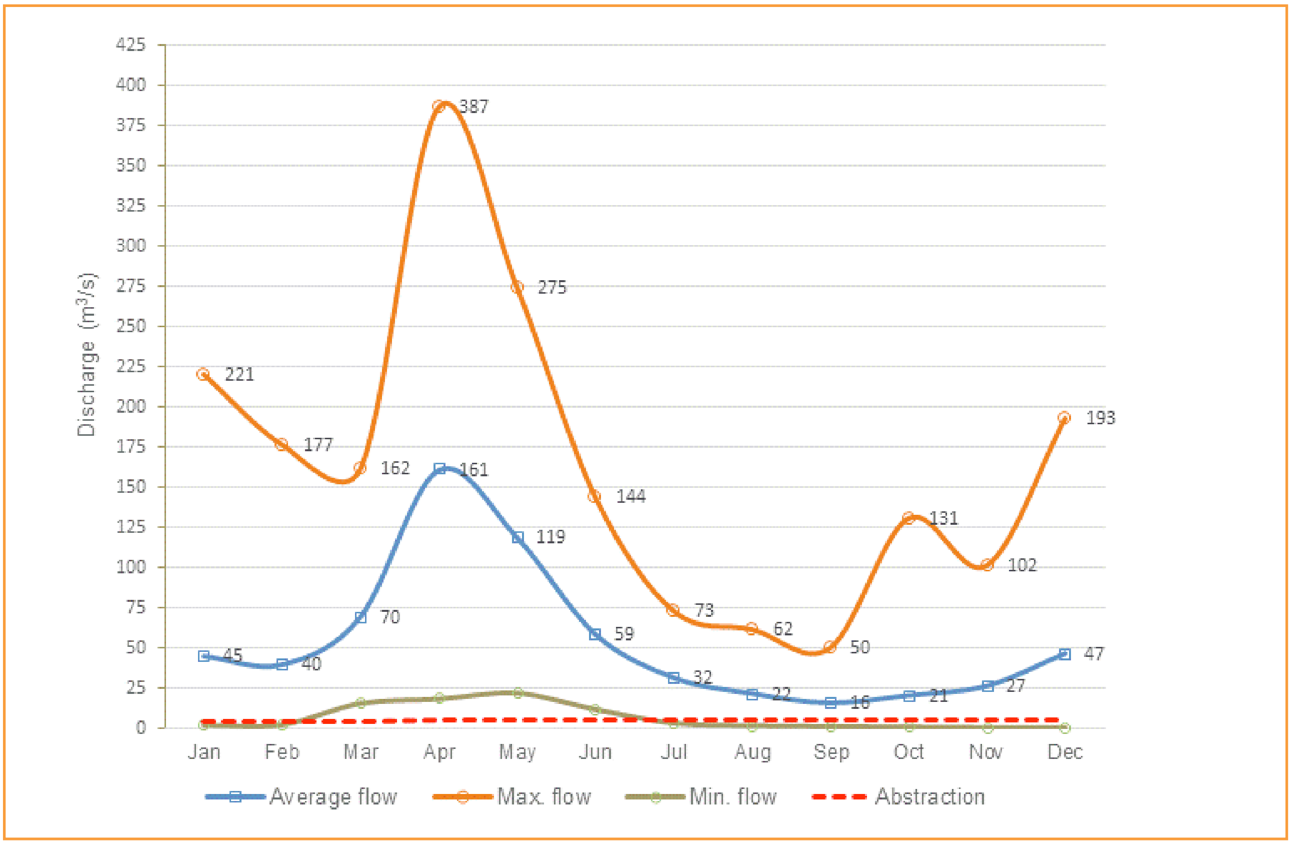


Figure 26. Seasonal flow at 1H10 gauging station and total abstraction upstream (Upper Ruvu catchment), dry season

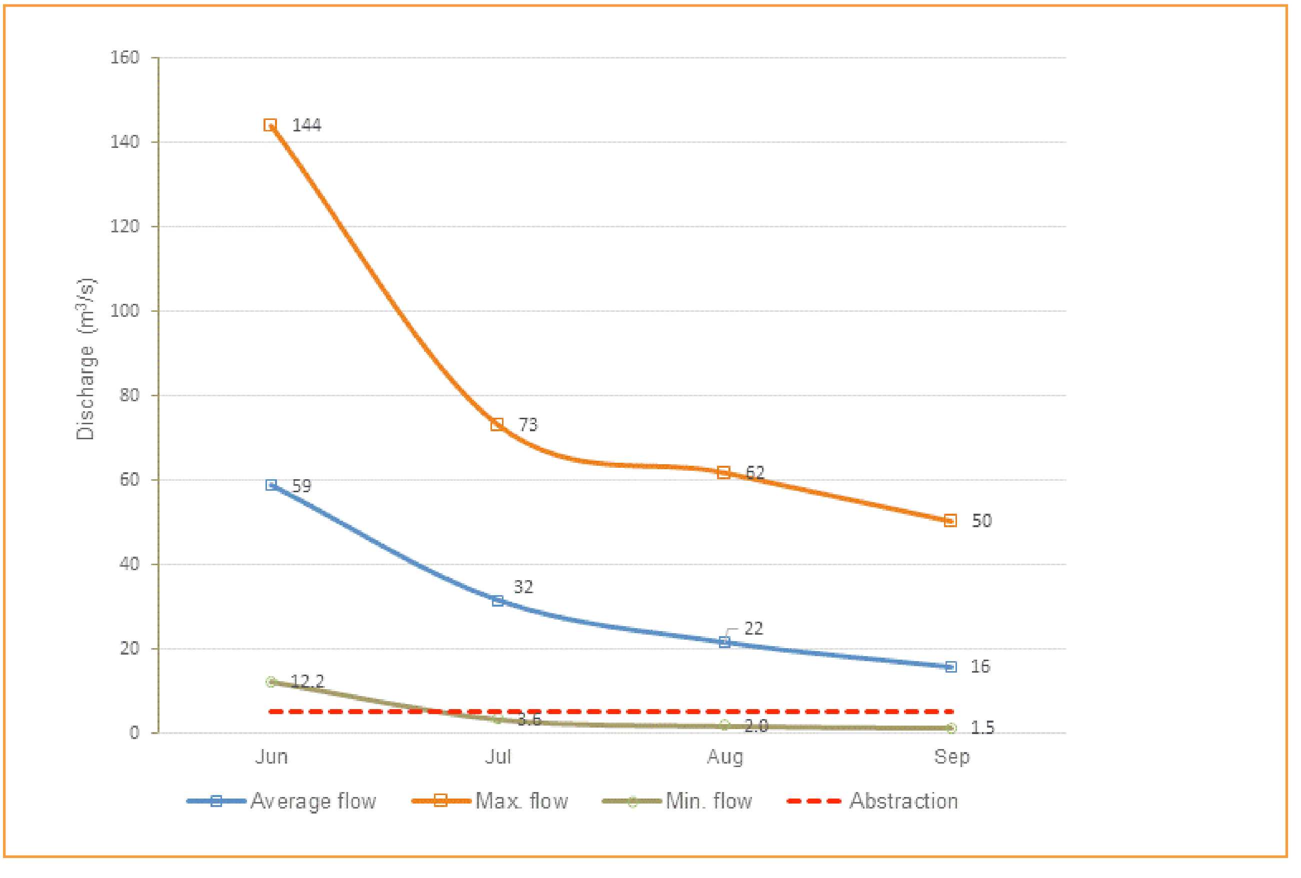


Figure 27. Seasonal flow at 1H8 gauging station and total abstraction upstream (Lower Ruvu catchment)

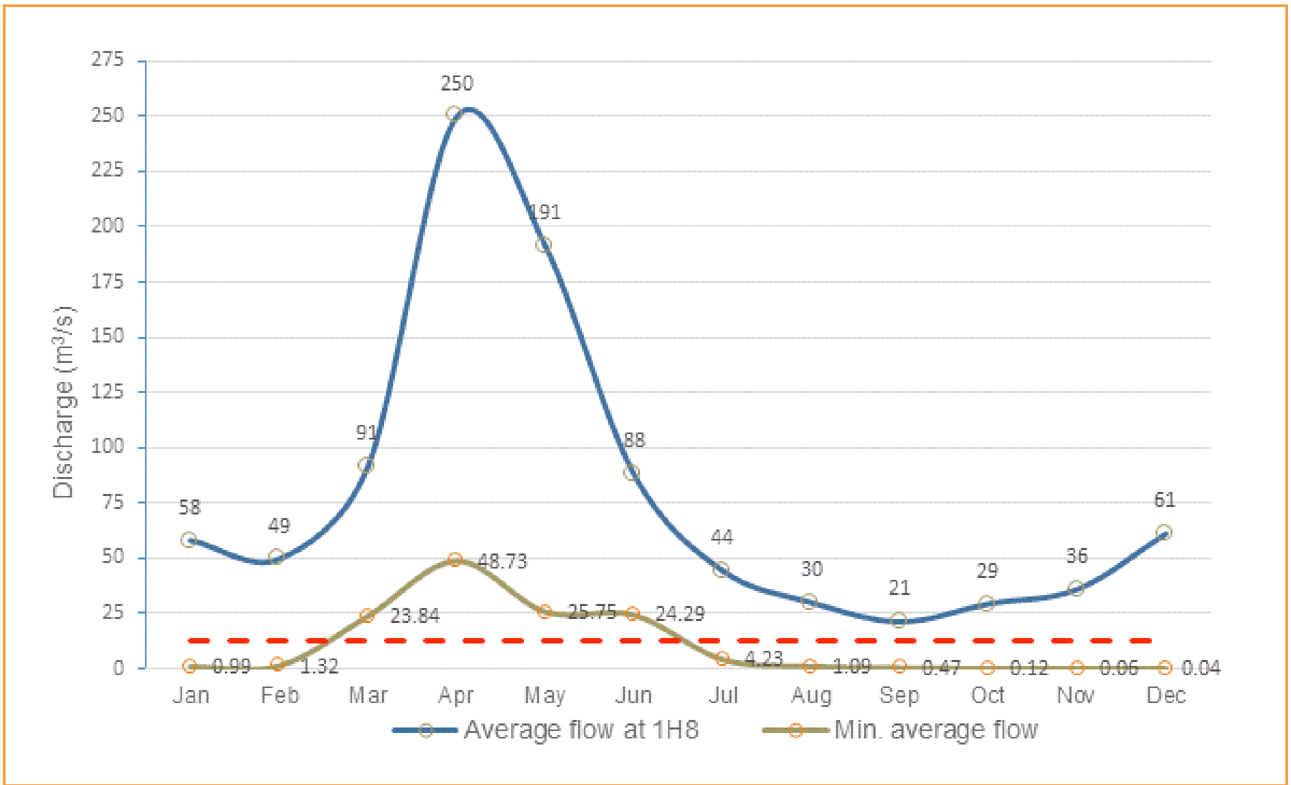
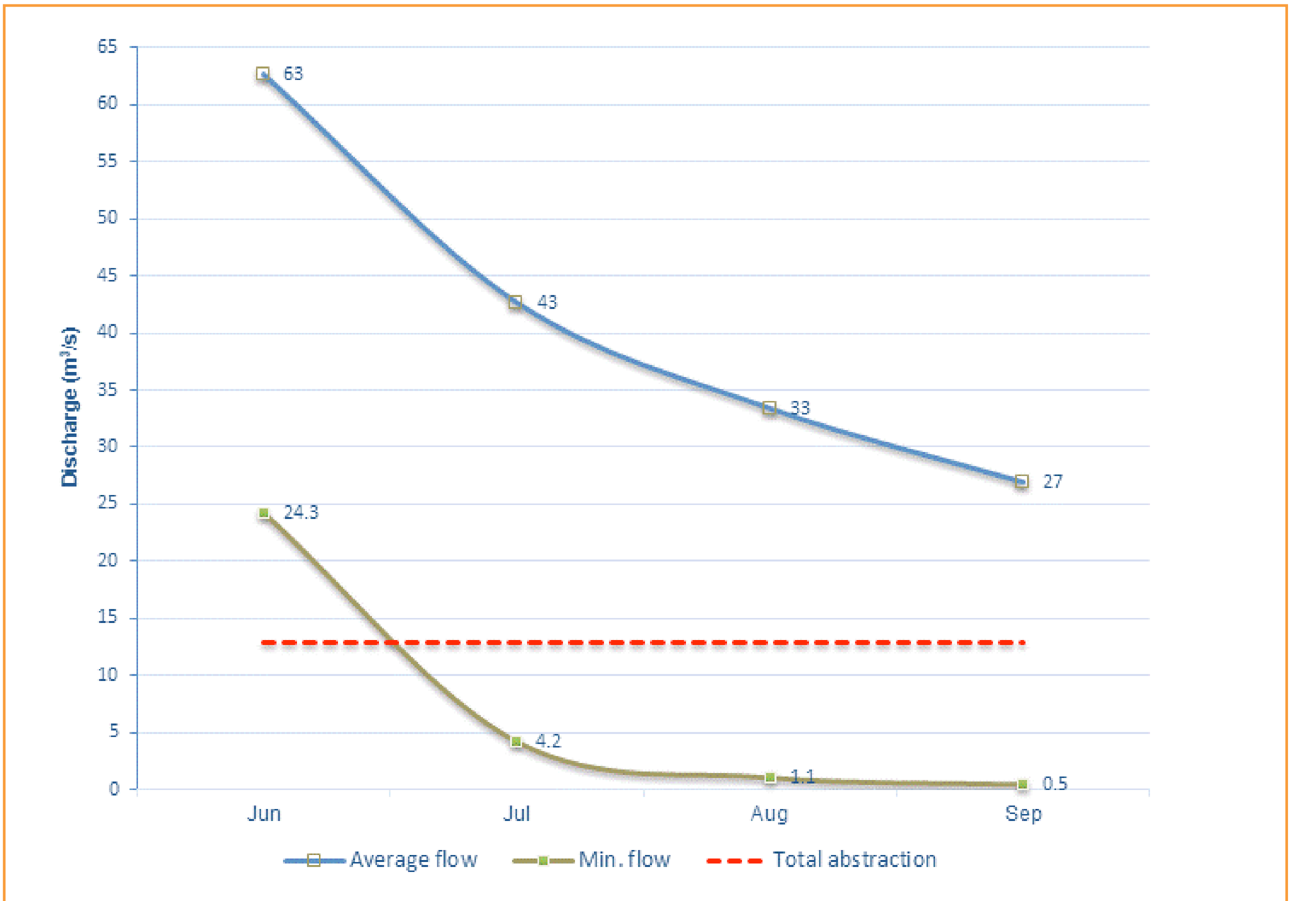


Figure 28. Seasonal flow at 1H8 gauging station and total abstraction upstream (Lower Ruvu catchment)



4.2.2 Water deficit linked to supply to Dar es Salaam at upper and lower Ruvu offtakes

Water deficit is defined as the difference between water demand and water supply. In order to assess the impact of Kidunda dam on Dar es Salaam water availability, two scenarios were simulated, i.e. baseline scenario with and without Kidunda dam.

The simulated average water deficit for Upper and Lower Ruvu intakes are presented in Figures 29–32. From the plots, it can be noted that the highest water demand deficit is 0.08 m³/s (3.5% of demand) for the Upper Ruvu intake for the both scenarios. For the Lower Ruvu intake the highest water deficit is 0.29 m³/s (9.4% of demand) for the baseline scenario without Kidunda dam and 0.16 m³/s (5.2% of demand) for the scenario with Kidunda dam. It is worth noting that in this case the operation of the reservoir was set such that the full capacity of the hydropower production of 20.8 MW was only set to the month of April. It was also noted that if power production was extended to the end of May, the highest water deficit would be the same as the baseline scenario as the reservoir would dry by the end of December due to the significant releases during the wet season to meet the installed capacity of the hydropower plant.

Figure 29. Simulated average water deficit for the Upper Ruvu Intake (at 1H8), with and without Kidunda dam

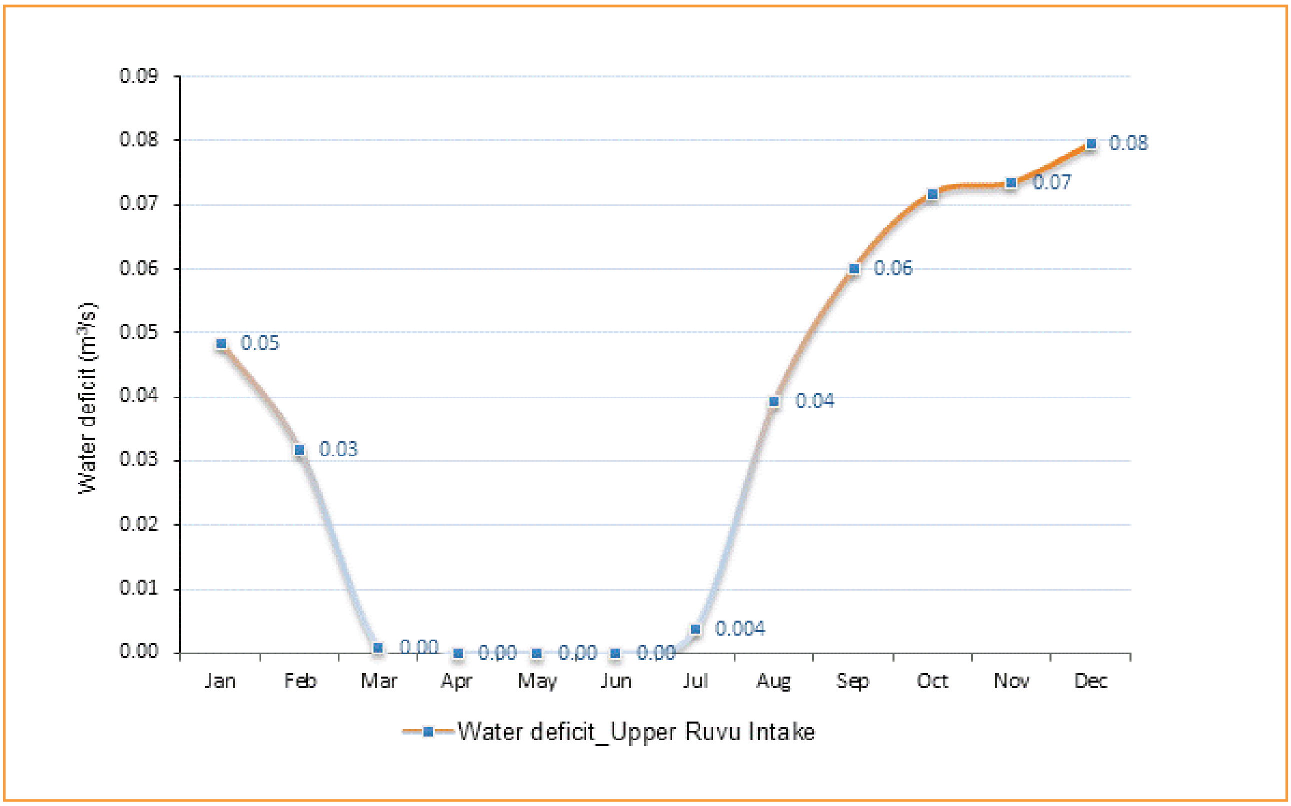


Figure 30. Percentage of water deficit for the Upper Ruvu intake (1H8), with and without Kidunda dam

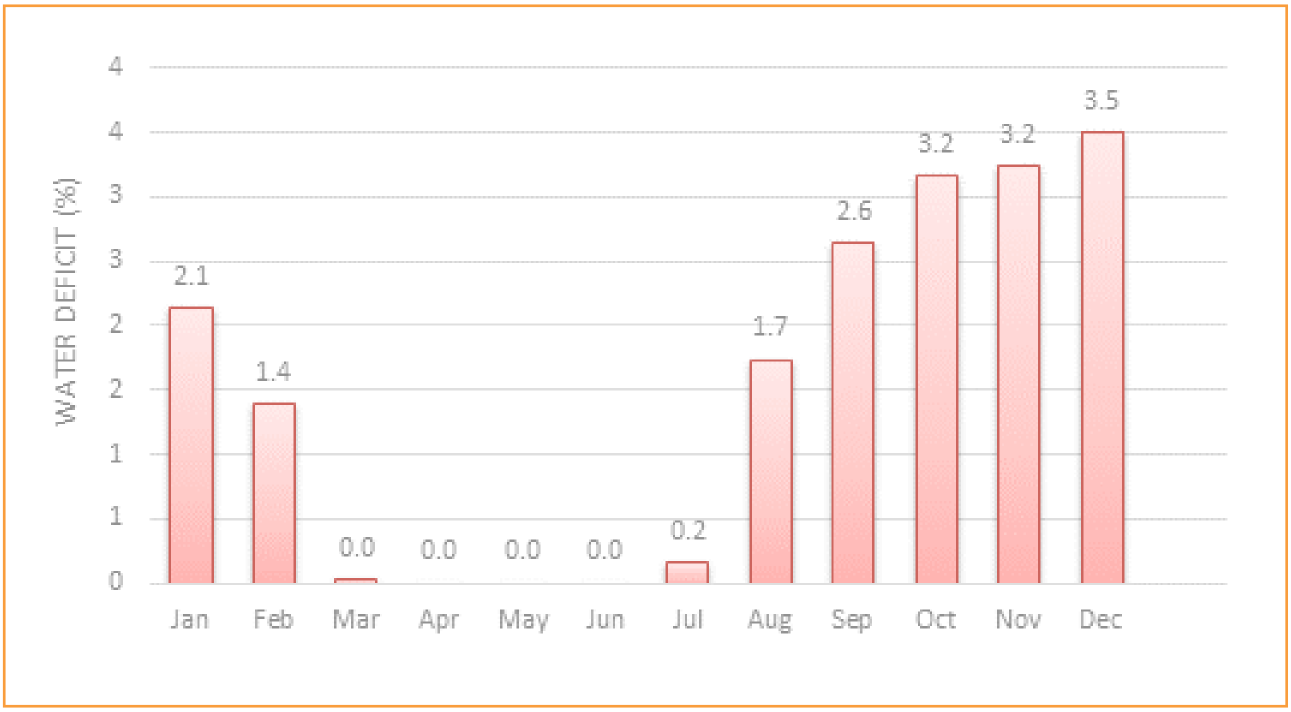


Figure 31. Simulated water deficit for the Lower Ruvu Intake

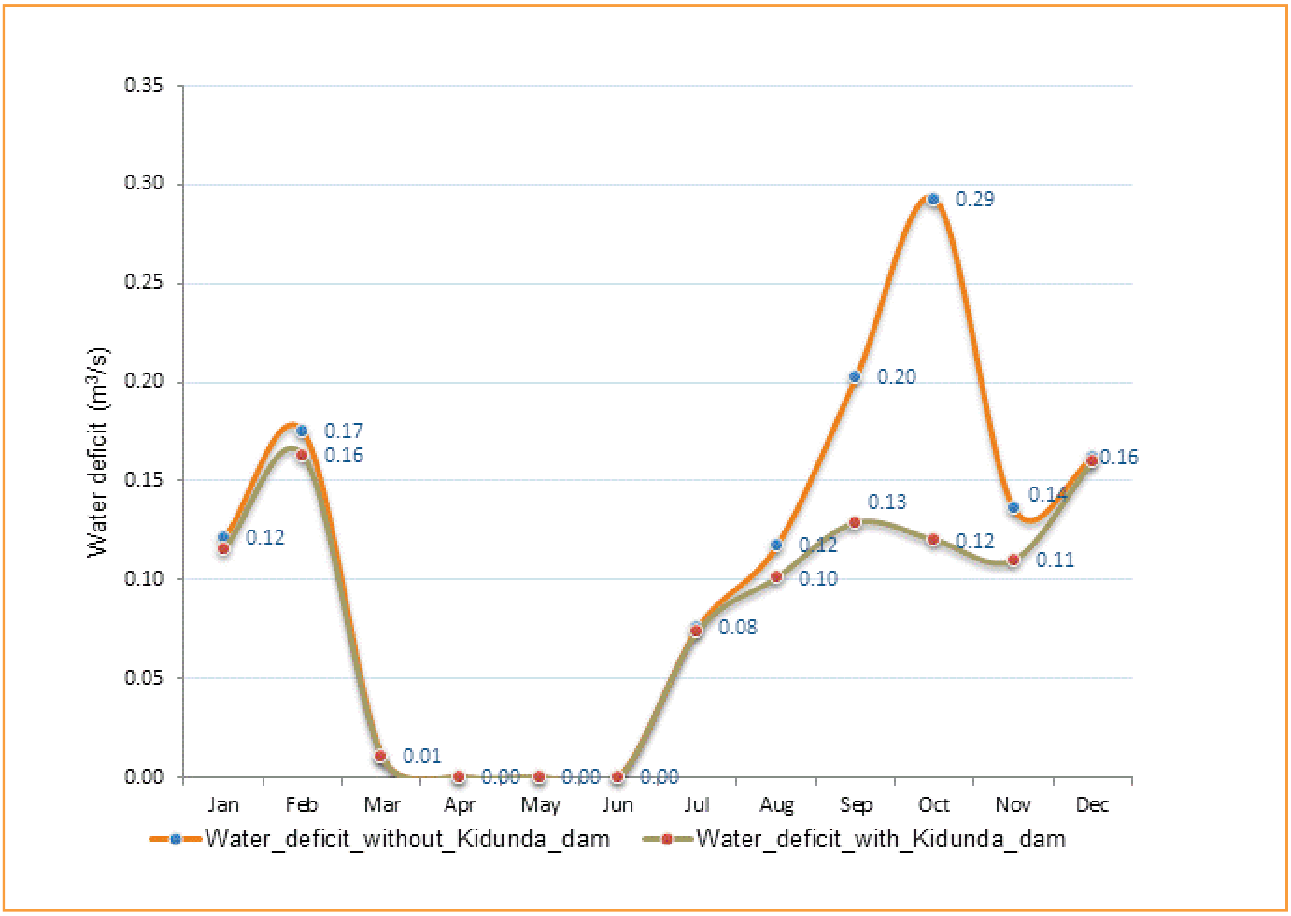
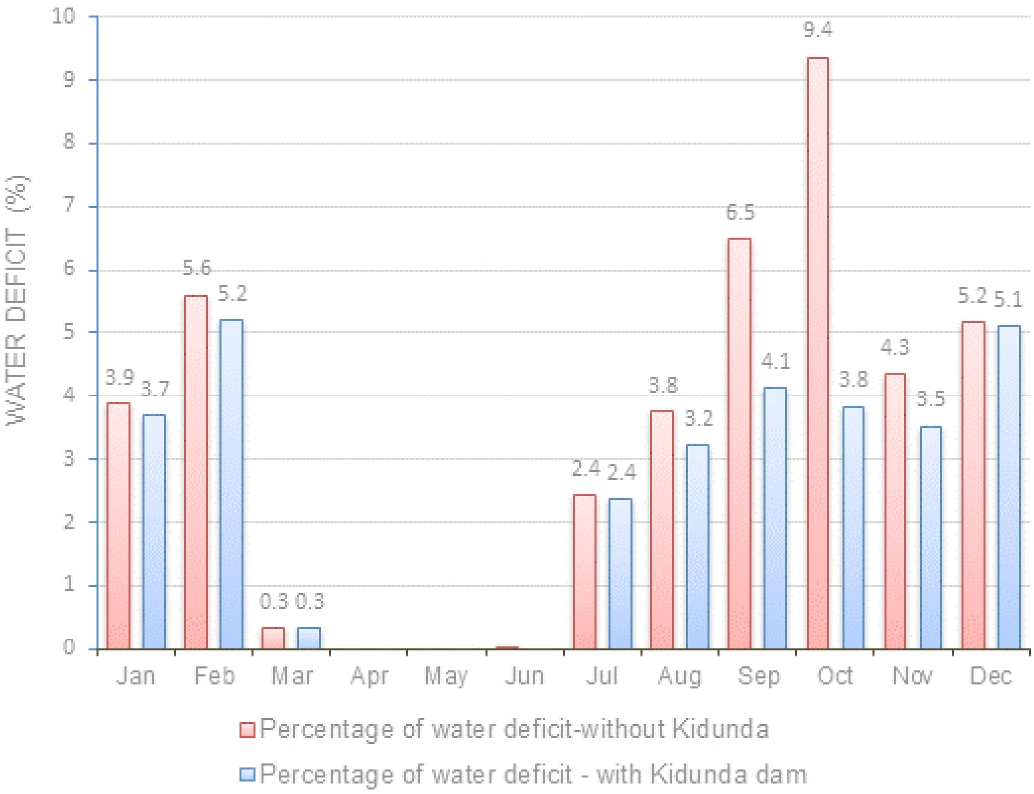


Figure 32. Percentage of water deficit for the Lower Ruvu intake



4.2.3 Frequency of water deficit linked to Dar es Salaam water supply

The flow duration curves (FDCs) for the Upper and Lower Ruvu intakes are shown in Figures 33 and 34. The flow-duration curve is a cumulative frequency curve that shows the percentage of time specified discharges were equalled or exceeded during a given period, in this case 30 years. It combines in one curve the flow characteristics of a stream throughout the range of discharge, without regard to the sequence of occurrence. The curve, drawn to average the plotted points of specified discharges versus the percentage of time during which they were equalled or exceeded, thus represents an average for the period considered rather than the distribution of flow within a single year. From the FDCs, it can be noted that the water abstraction at Upper Ruvu intake (2.27 m^3/s) and Lower Ruvu intake (3.125 m^3/s) with Kidunda dam can be satisfied 98% and 95% of the time, respectively. It should be noted that the shape of the flow duration curve is determined by the hydrological and geological characteristics of the drainage area. The slope of the lower end of the curve, i.e. low flow characteristics, shows the behavior of the perennial storage in the drainage basin; a flat slope at the end indicates a large amount of storage (baseflow contribution); and a steep slope indicates negligible amount. The steep slopes of the curves (Figures 33 and 34), can therefore be attributed to negligible contribution of the baseflow, and possibly the streamflow might be recharging the aquifer in the low-lying areas below the Kidunda dam, this argument is also supported by JICA's 2012 study, which indicated a significant loss of water between the proposed Kidunda dam site and Dar offtakes. The second possible reason could be the errors in the data. However, the rating curve at the Upper Ruvu offtake (1H8) is one of the relatively reliable gauging stations and the simulated and observed discharge at this site are in good agreement

Figure 33. Flow duration curve at the Upper Ruvu intake

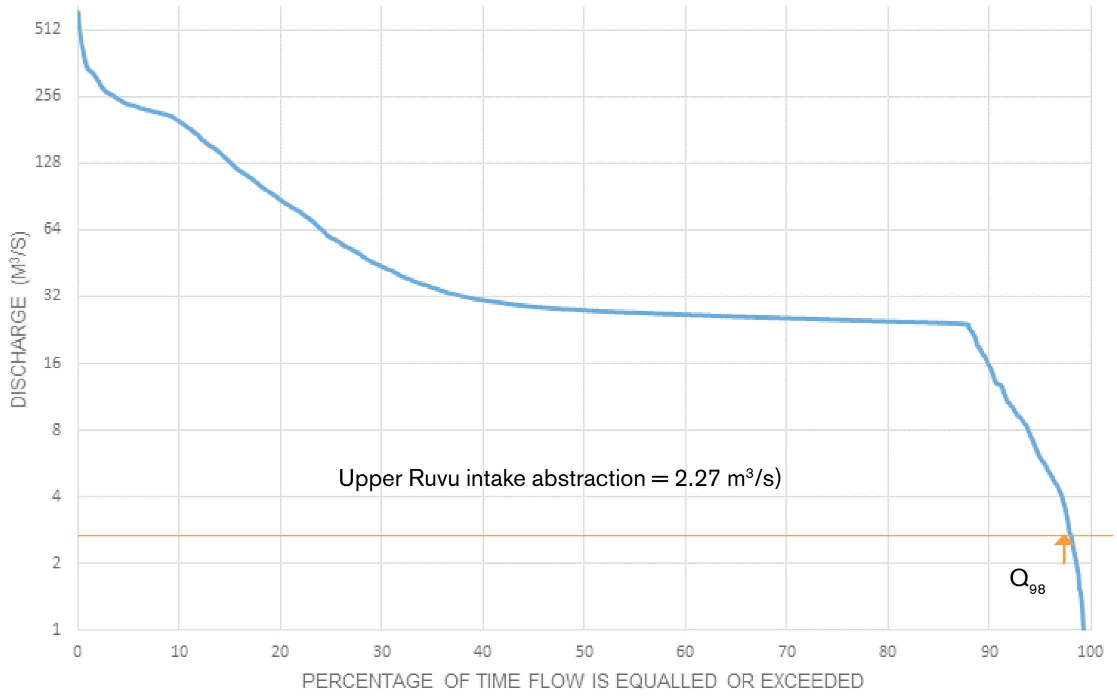
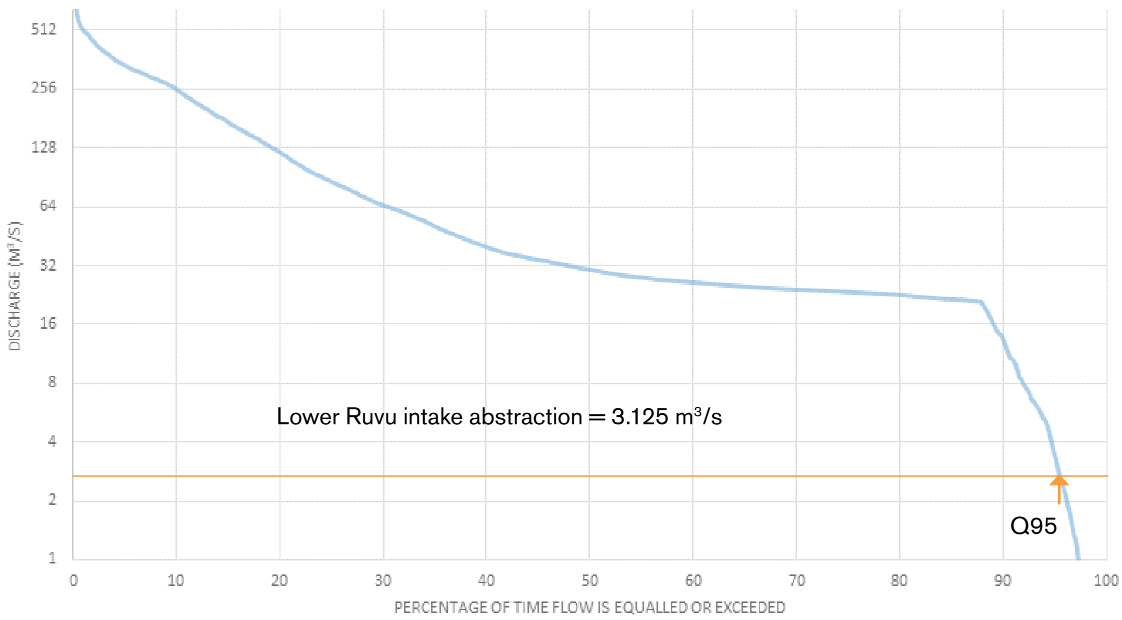


Figure 34. Flow duration curve at the Lower Ruvu intake



during the low flow seasons, which increases the confidence of the modelling results.

The frequency of water deficits for the upper and lower Ruvu offtakes are shown in Figures 35 and 36, respectively. The estimated frequency of water deficits is based on the following assumptions:

i) The same flow trends as observed between 1980–2009, will be repeated the future

ii) The water abstraction permits in the future will remain at the current level

Following these assumptions and with the Kidunda dam in place, Dar es Salaam water supply targets cannot be met during the dry years for a considerable number of days.

Increasing Dar es Salaam Water and Sewerage Corporation (DAWASCO) permits by up to 2m3/s (assuming upstream abstractions remain at the current level) would result in increasing water deficits from 5.2% to 6.1% of demand for the lower Ruvu intake (Figure 37). Consequently, from the FDC, this will result in the decrease of water security for Dar es Salaam from 95% to 94%.

Figure 35. Frequency of deficits for the upper Ruvu intake (1H8)

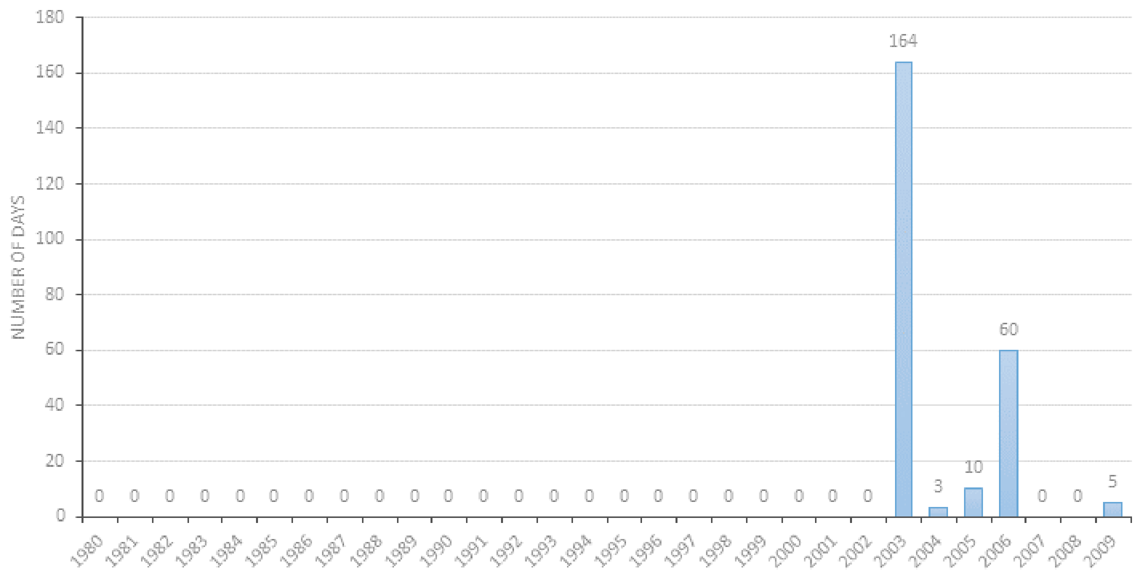


Figure 36. Frequency of deficits for the Lower Ruvu intake

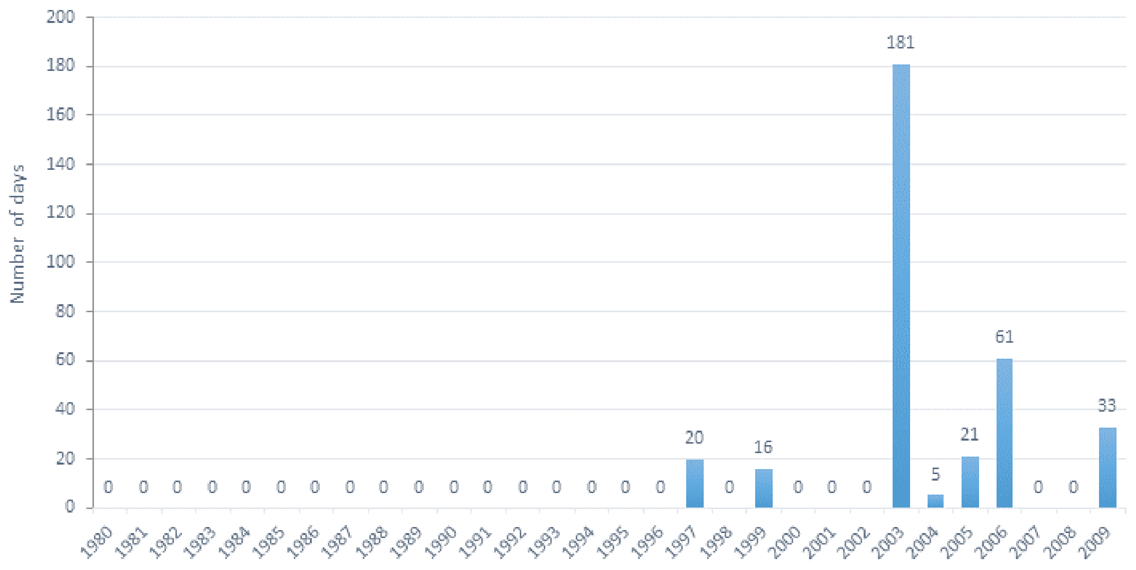
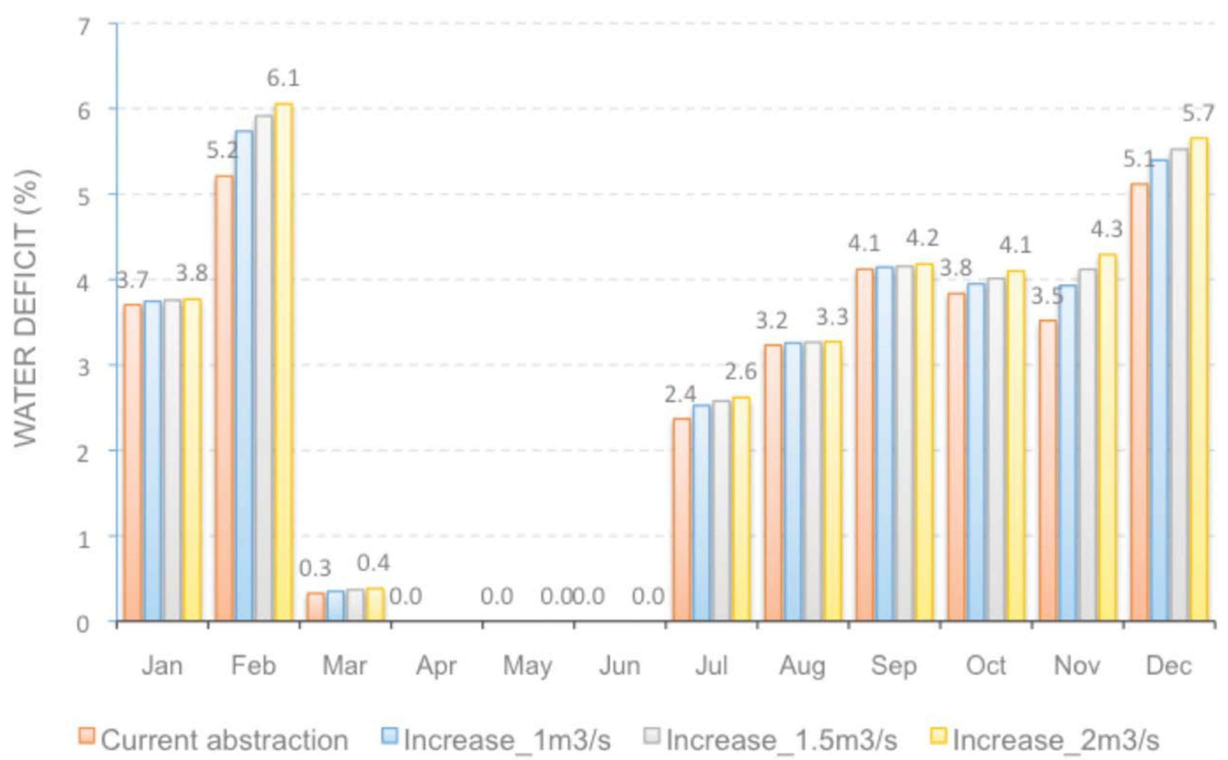


Figure 37. Water deficits at lower Ruvu intake for different scenarios of permits for Dar es Salaam



4.3 Cumulative annual allocation of water permits and water availability

Figures 38 to 40 show the plot of cumulated abstraction as per permits issued by the WRBWB, the long-term average annual flow and the average minimum flow. From the plots, it can be noted that the long term average annual in Ngerengere catchment is exceeded by the total abstraction permits issued from the year 2014 and the average minimum flows are less than the total abstractions authorized for the whole period considered (i.e. 30 years). In the case of the Upper Ruvu catchment, both average and minimum average flows are higher than the total abstraction in the catchment. The total abstraction authorized above 1H8 gauging station (offtake for the upper Ruvu) exceeds the minimum average flow from the year 2014.

Total abstraction for the permits upstream of Lower Ruvu intake is about 13 m^3/s and is rising with time, sometimes by 5 m^3/s per year (e.g. 2007–2008, 2013–2014) and these permits are mainly during the dry season. The FDC (Figure 34) shows that 19–20 m^3/s is about the point when flow security really drops off. If a water security level of 88% (321 days per year on average) is sufficient for the Dar es Salaam water supply, then WRBWB should consider only giving upstream permits up to this level to ensure water security for Dar es Salaam.

Figure 38. Cumulated abstraction permits and long term average and minimum annual flows for the Ngerengere catchment (1HA1A gauging station)

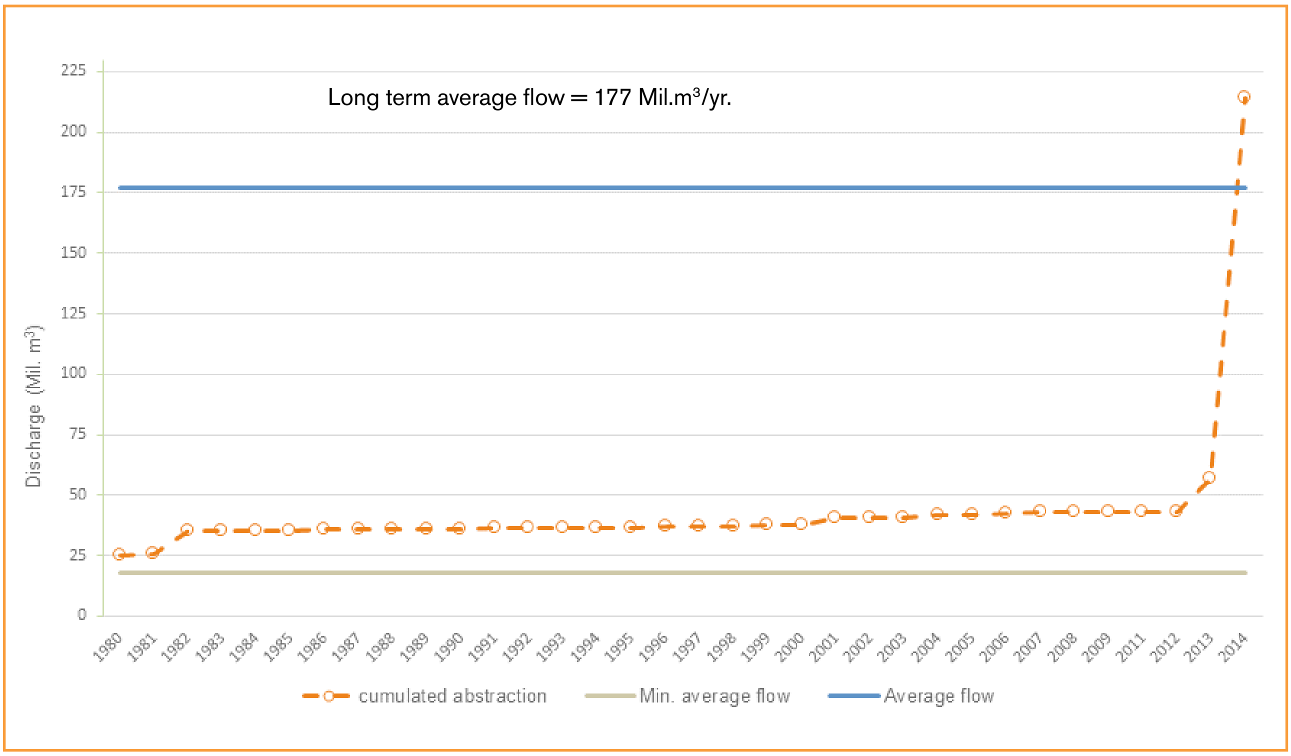


Figure 39. Cumulated abstraction permits and long term average and minimum annual flows for the Upper Ruvu catchment (1H10 gauging station)

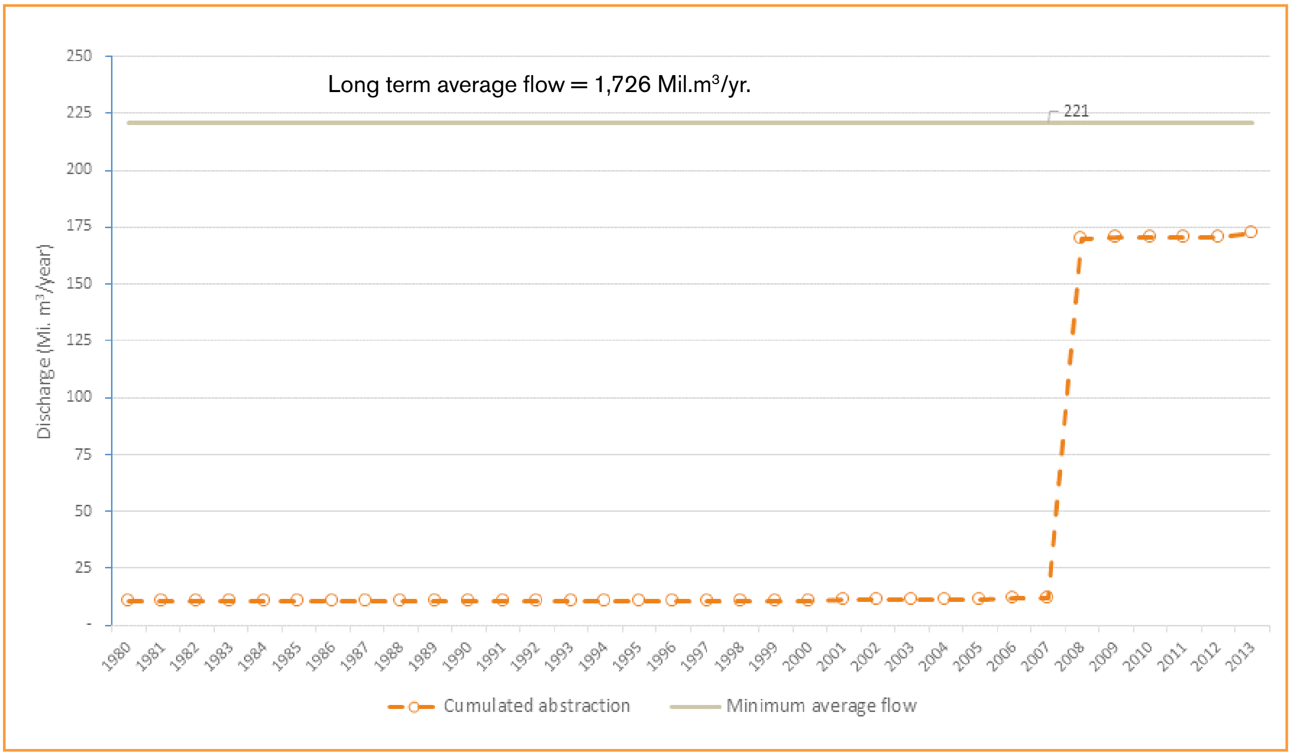
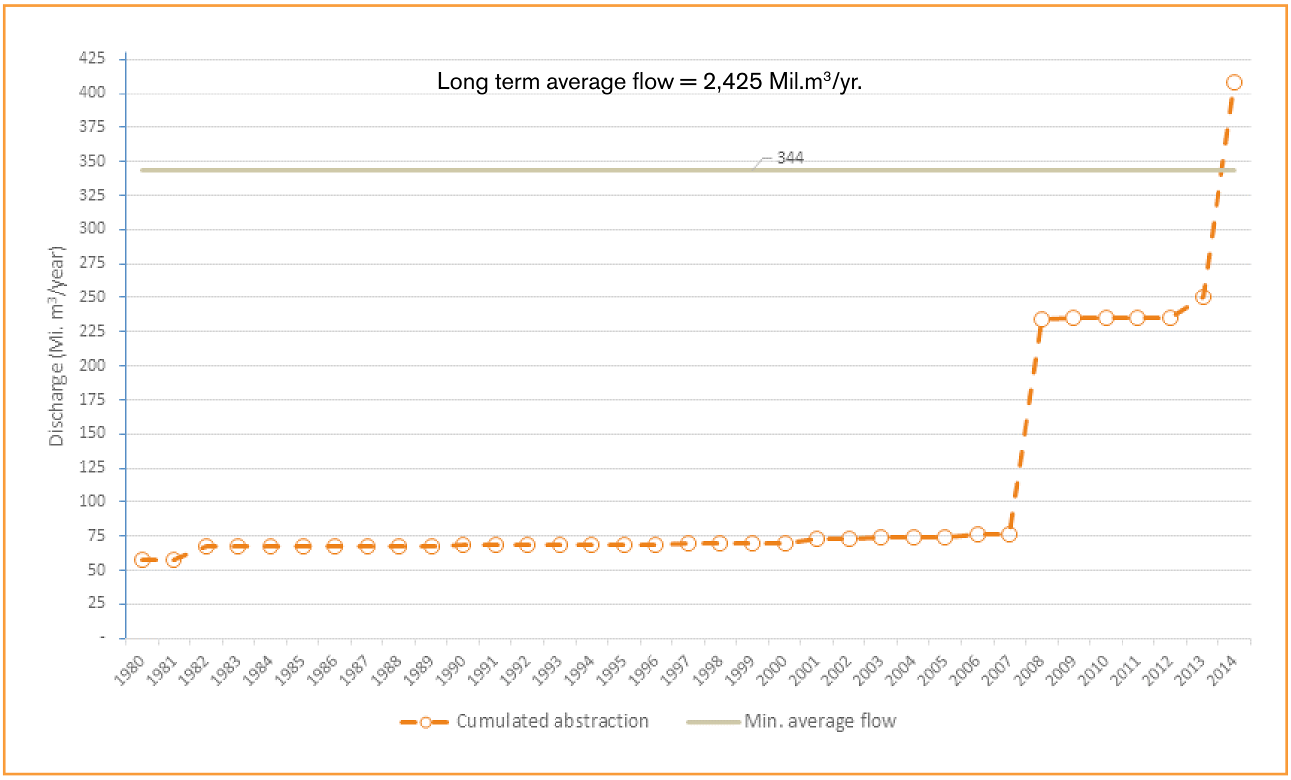


Figure 40. Cumulated abstraction permits and long-term average and minimum annual flows for the Lower Ruvu intake



5

Conclusions

1. The quality of water flow data in many of the catchments in the basin is questionable. Better data is required on the observed flows to ensure more accurate water resource modelling in future. Of particular concern are the level of dry season losses from the river bed to the aquifer in the reach downstream of Kidunda dam. The model suggests that most of the water released from Kidunda does not reach the Ruvu offtakes during the dry season but the reliability of low water gauging data (and the resultant FDCs) will need to be checked to verify this conclusion.
2. Environmental flows at Ruvu/Kongo cannot be met during the dry years, this would likely affect the water quality at the estuary.
3. Increased Dar es Salaam demand for water offtake from Ruvu comes with an increased frequency of water deficits. On average, demand is not met for 18 days per year even with Kidunda dam and alternative sources will need to be mobilized. The situation is expected to worsen with the issuance of more water abstraction permits in the upstream catchments. DAWASA could look for other options such as Kimbiji and Mpera aquifer systems during dry years or the shallow Quaternary aquifer.
4. The total abstraction upstream of the Dar es Salaam water offtakes, currently stands at about 13 m^3/s, WRBWB should consider limiting new upstream permits, or making them time bound, or limited to certain times of year, to ensure improved long term water security for Dar es Salaam in the dry season.
5. The current study has assumed similar trends of flows in the future. The impact of climate change on flows should be considered in future studies.

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McGranahan, G, Walnycki, A, Dominick, F W, Kombe, A, Kyessi A, Limbumba, T M, Magambo, H, Mkanga, M and Ndezi, T (2016) Universalising water and sanitation coverage in urban areas: From global targets to local realities in Dar es Salaam, and back. IIED Working Paper. IIED, London. http://pubs.iied.org/10812IIED

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Acronyms

DAWASA	Dar es Salaam Water and Sewerage Authority
FDC	Flow duration curve
GLOWS-FIU	Global Water for Sustainability Program – Florida International University
IIED	International Institute for Environment and Development
JICA	Japan International Cooperation Agency
SDG	Sustainable Development Goal
WRBWB	Wami-Ruvu Basin Water Board

The city of Dar es Salaam in Tanzania requires significant new surface water resources if it is to meet Sustainable Development Goal 6. This study reports on the development of a hydrological model, using existing data, which assesses the impacts of upstream irrigation abstraction on downstream water security for the city. Results indicate that water deficits will likely still occur in dry years even after the construction of an additional storage dam. Water managers will need to finely balance upstream and downstream demands within the catchment, using improved knowledge of the state of the water resource.

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