Technical Annex

Water Availability Assessment

Lower Mara River Basin, Tanzania

March 2020

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EXECUTIVE SUMMARY

"Water resource assessment is the determination of the sources, extent, dependability and quality of water resources, which is the basis for evaluating the possibilities of their utilization and control" (UNESCO/WMO, 1997 in WMO 2008).

Based on the limited availability of long-term hydro-meteorological data as well as the lack of hydrogeological information within the Mara River Basin (MRB), the focus of the current Water Availability Assessment (WAA) lies within the scope of an assessment of the available surface water resources in the catchment. The assessment builds on earlier work carried out under the MaMaSe project in the Kenyan part of the MRB, extended with new data and information collected during the SWP Programme. Groundwater is omitted in this assessment due to the absence of observation wells in the catchment and the nonexistence of reliable groundwater level data.

This technical annex describes the analytical procedures and results of a water availability assessment for the entire Mara River Basin using long term historical data sets of precipitation and discharge. Objectives of this assessment were (i) to regionalize average monthly and average annual discharge data, (ii) estimate flow duration curves, (iii) to setup long term water balances for the sub-catchments within the Mara River Basin, and (iv) to assess changes in the hydro-meteorological time series data sets.

The first part of the assessment includes a brief overview of the available geospatial and long-term hydrological data sets used for the water availability assessment. In the following sections the data analysis steps, data corrections, regionalization, and trend analysis procedures are explained.

Results of the water availability assessment are presented as overview maps and figures in the respective sections. Comprehensive data tables are also included in the appendices.

Average annual water availability in the full Tanzanian Mara River Basin is 2,909,701 m^3/day. Of this total, 76% flows to Tanzania from Kenya. The available water generated in Tanzania amounts to 700,397 m^3/day, of which 329,178 m^3/day is generated in the Serengeti hydrological unit, 90,739 m^3/day is generated in the Somoche hydrological unit, and 280,479 m^3/day is generated in the Mara hydrological unit (encompassing Mara Wetland). Seasonally, total availability varies from a low of 1,759,968 m^3/day in February to a high of 6,068,736 m^3/day in May.

Abbreviations

A	catchment area
Alpha	Predefined significance level
AWS	Automatic Weather Station
BB	Bomet Bridge
Const	Regression constant
CV	Coefficient of variation
DEM	Digital Elevation Model
DRWS	Department of Rural Water Supply
EM	Emarti
FDC	Flow duration curve
FAO	Food and Agriculture Organization of the United Nations
FF	fully functioning
HU	Hydrological Units
HQ_{month}	Maximum monthly discharge
HYS	Hydrometric Station
IDW	Inverse Distance Weighting
IHA	Indicators of Hydrologic Alteration
IHE-Delft	IHE Institute for Water Education, Delft
JICA	Japan International Cooperation Agency
KA	Kapkimolwa
KT	Kichwa Tembo
LB	Left Bank
LCL	Lower confidence limit
LVBWB	Lake Victoria Basin Water Board
MaMaSe	Mau Mara Serengeti Sustainable Water Initiative
Max	Maximum value
Mean	Arithmetic mean of the data
Median	Median or second quartile
Min	Minimum value
MM	Mara Mines
MoW	Ministry of Water
MQ_{month}	average monthly discharge
MQ_{year}	mean annual discharge
MRB	Mara River Basin
NF	not functioning
NQ_{month}	Minimum monthly discharge
$\overline{P}$	Areal catchment precipitation
PF	partially functioning
P_{year}	Total annual precipitation
p	p-value of statistical hypothesis test
PC_{month}	Pardé coefficient
Q1	First quartile
Q3	Third quartile
r(1)	Lag-1 autocorrelation coefficient
RB	Right Bank
RS	Rainfall Station
SD	Standard deviation
SE	Standard error
SFDC	Standardized flow duration curve
Skew	Skewness
Slope	Regression slope
SWP	Sustainable Water Partnership Programme
UCL	Upper confidence limit
UNESCO	United Nations Educational, Scientific and Cultural Organization, Paris
WaPOR	Water Productivity through Open access of remotely sensed derived data
WMO	World Meteorological Organization, Geneva
WRMA	Water Resources Management Authority
WRA	Water Resources Authority

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0. OBJECTIVES

Main Objective

The main objective of this report is to quantify the current water availability across the lower part of the Mara River Basin in space (sub-catchments) and time (monthly and inter-annually). This effort was conducted in cooperation with the Tanzanian Ministry of Water and Irrigation and the Lake Victoria Basin Water Board (LVBWB), and consisted of an in-country data compilation on water resources and a data analysis.

Specific objectives

The specific objectives of this report are:

- Organize the available hydro-meteorological data and information
- Conduct a primary data quality assessment
- Aggregate and conduct a statistical analysis
- Divide the Mara River Basin into sub-catchments
- Quantify the water balance components
- Assess the water resources per sub-catchment on an annual and monthly time scale
- Report water resources availability for the Tanzanian part of the Mara River Basin
- Integrate the results of this assessment with the water resources assessment outcomes for the Kenyan part of the MRB, which were compiled under the MaMaSe Initiative

Deliverables

The deliverables of this report are to (i) quantify the natural water balance of each sub-catchment, to (ii) produce maps of the mean annual values of components of the natural water balance, to (iii) generate data and graphics for each sub-catchment showing the variability in natural yield, and to (iv) create data and graphics showing trends in the climatic driven changes in the catchment.

1. DATA SITUATION

Available hydro-meteorological data and information is limited in the lower part of the Mara River Basin due to the capacity of the observation network. In June 2018, within the framework of the SWP – Sustainable Water Partnership project, a 3-day field visit took place by two IHE Delft staff members together with several staff members from LVBWB and the Ministry of Water and Irrigation. During this mission 12 out of 13 stations of the LVBWB hydrological monitoring network for the Mara River basin were inspected. The stations were assessed with respect to their condition and functioning. The missing station was visited in September 2018, and the findings are reported in the document: Assessment of the hydrological monitoring network in the Mara river basin – Tanzania SWP (2018).

The hydrological monitoring network for the Mara River basin in Tanzania consists of 13 stations, whereof 4 are automatic weather stations, 5 are rainfall stations, and 4 are hydrometric stations. In June 2018 100% of the automatic weather stations, 80% of the rainfall stations, and 25% of the hydrometric stations were not functional (SWP, 2018).

Even though some historical hydro-meteorological data are available, most of the time series show substantial data gaps with missing data of 29% to 81%. An overview of the network setup, and status and data availability is given in **Figure 1** and **Table 1**.

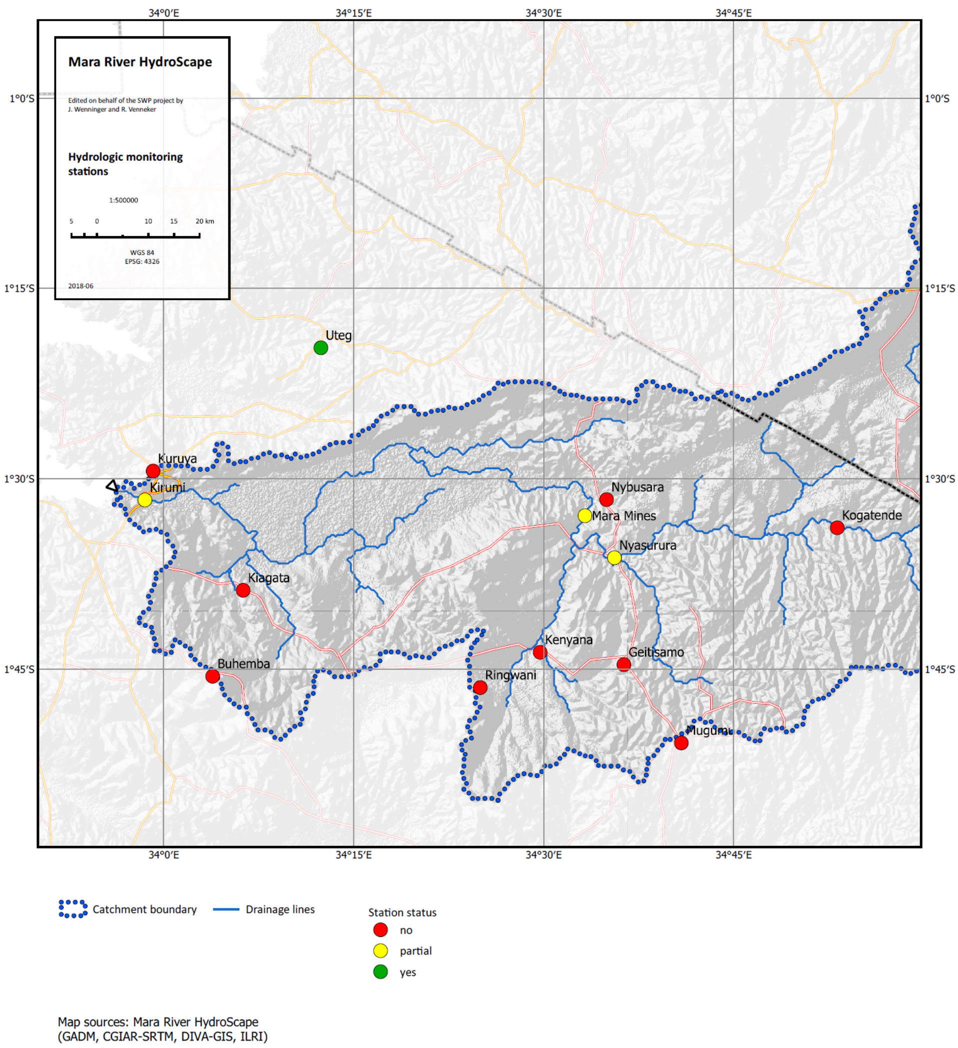


Figure 1: Network station overview; status: 2018-06 (SWP, 2018)

Table 1: Overview of the network status and data availability (SWP, 2018)

Station	ID	Type*	Parameter	Start Date yyyy-mm-dd	End Date yyyy-mm-dd	Years	Data points	Valid points	Missing [%]	Status**
Buhemba	9NNNN09	AWS	-	-	-	-	-	-	-	NF
Mugumu	9134033	AWS	Rainfall	1970-01-01	2018-05-31	48	17683	12371	30	NF
Nyabusara	9NNNN08	AWS	-	-	-	-	-	-	-	NF
Kuruya	9NNNN10	AWS	Rainfall	2005-01-01	2018-06-01	13	4596	2771	40	NF
Kiagata	9NNNN05	RS	-	-	-	-	-	-	-	NF
Ringwani	9134032	RS	-	-	-	-	-	-	-	NF
Kenyana	9NNNN06	RS	-	-	-	-	-	-	-	NF
Geitisamo	9NNNN07	RS	-	-	-	-	-	-	-	NF
Utegi	913434	RS	Rainfall	1970-01-01	2018-06-01	48	17684	8553	52	FF
Nyasurura	5H4	HYS	Stage	2009-06-01	2016-02-03	7	2439	1731	29	PF
Mara Mine	0107072	HYS	Stage	1969-08-01	2018-06-04	49	17977	12629	30	PF
Mara Mine	0107072	HYS	Discharge	1969-08-01	2018-06-04	49	17977	12618	30	PF
Kirumi	0107281	HYS	Stage	1978-02-01	2018-04-30	40	14364	2729	81	PF
Kogatende	5H(NEW)	HYS	-	-	-	-	-	-	-	NF

*: *AWS = Automatic Weather Station; RS = Rainfall Station; HYS = Hydrometric Station*
**: *NF = not functioning; PF = partially functioning; FF = fully functioning*

Due to the limited capacity of the current observation network, the lack of reliable historical time series, the uneven distribution of the stations within the catchment, missing or not updated rating curves, most of the data could not be directly used for a detailed hydrological analysis to fulfil the objectives of this study, and the analysis had to draw back on long-term data and information generated in earlier studies carried out in the basin.

Data used for this assessment include topographic data and derived information (like e.g. flow direction, flow accumulation, catchment boundaries, catchment areas, and river networks) as well as location information of precipitation and hydrometric stations. Time series used for the analyses consist of long term annual and monthly precipitation and discharge values, aggregated from daily records. Geospatial data sets were taken from the Mara River HydroScape dataset, developed within Result area 1 of the MaMaSe project. Precipitation and discharge time series were a combination of outputs from the WRMA/WRA and LVBWB databases and from data collected during the MaMaSe project. A detailed description of the available stations and the data sets for the Mara River Basin can be found in Hulsman (2016), MaMaSe-SWP (2018), and SWP (2018).

1.1. CATCHMENT DELINEATION

The basis of a catchment delineation process is the information about elevation values within the area of interest. Catchments and drainage networks were derived from the SRTM 90m Digital Elevation Database v4.1 (CGIAR, 2016). In Figure 1, an orohydrographic overview map of the MRB is presented.

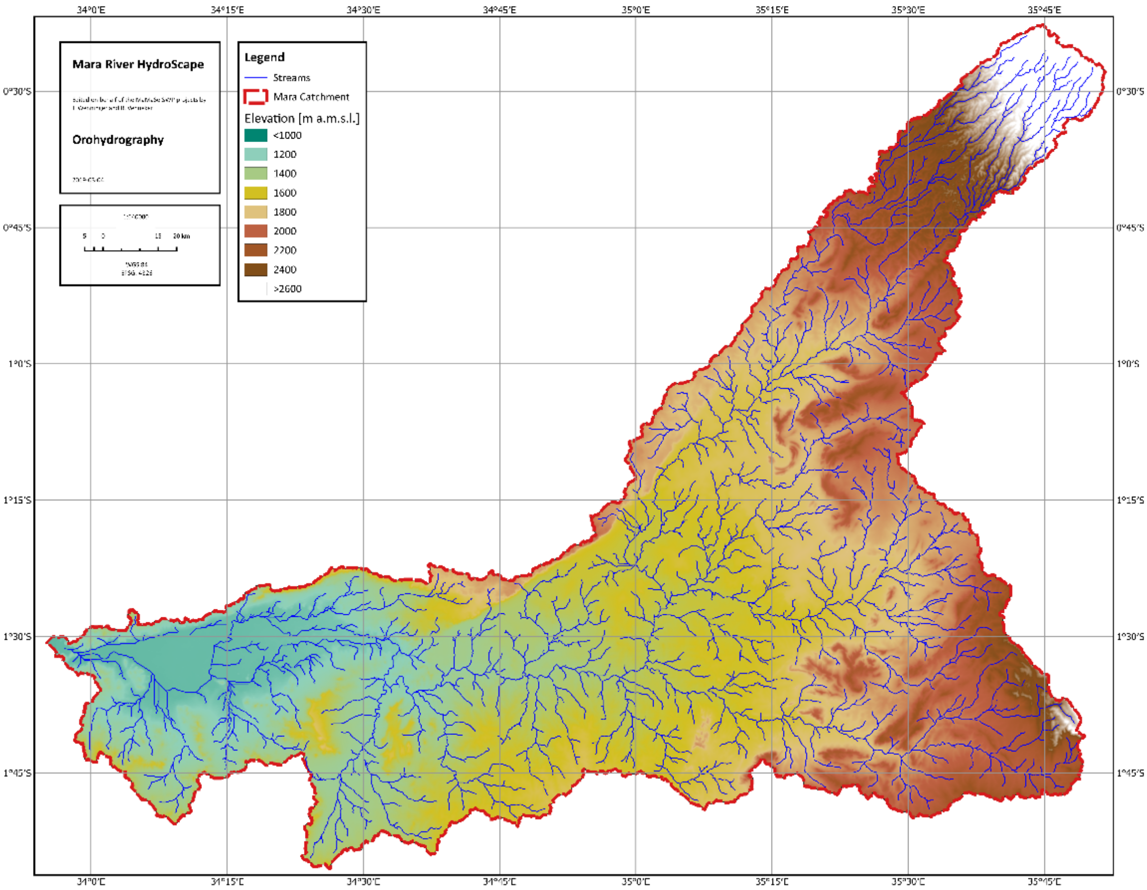


Figure 2: Orohydrographic overview map of the Mara River Basin

Delineation of sub-catchments within the MRB, the so-called hydrological units, was carried out in two levels (HU1 and HU2) using the widely adopted Pfafstetter coding system (Verdin and Verdin, 1999). This is a recursive hierarchical subdivision of larger basins into smaller ones until the desired level of detail is reached. Details of delineated catchments for the hydrological units level 1 (HU1) and level 2 (HU2) can be found in Figure 2 and Figure 3, as well as in Appendix A.

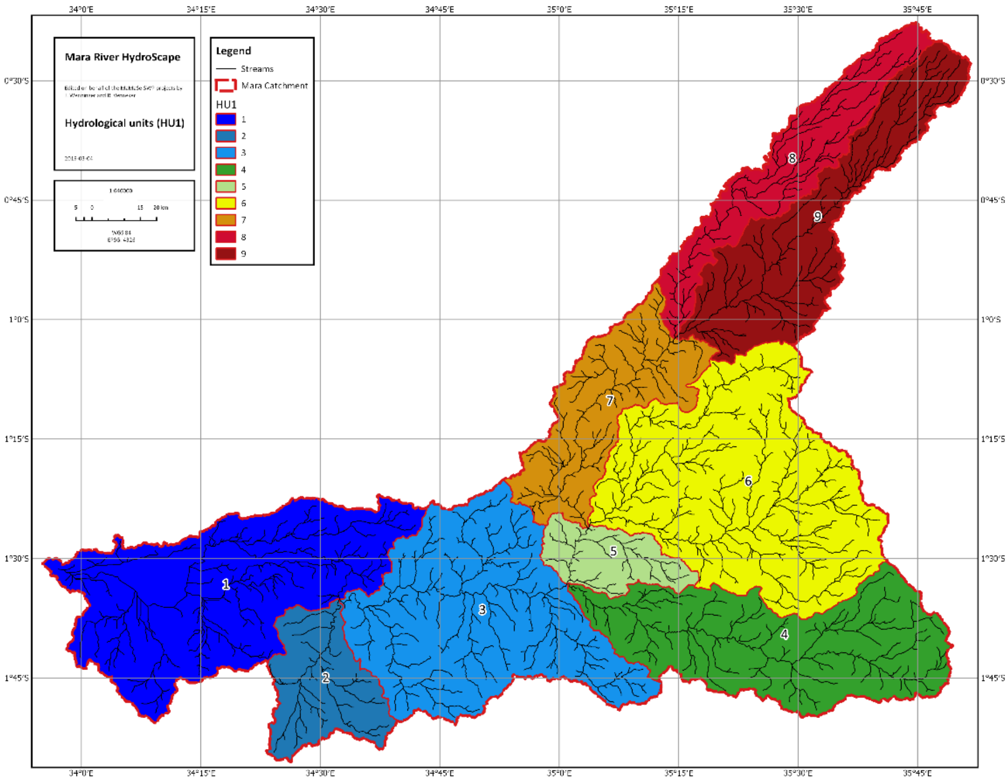


Figure 3: Hydrological units level 1 (HU1) delineated using the Pfafstetter system

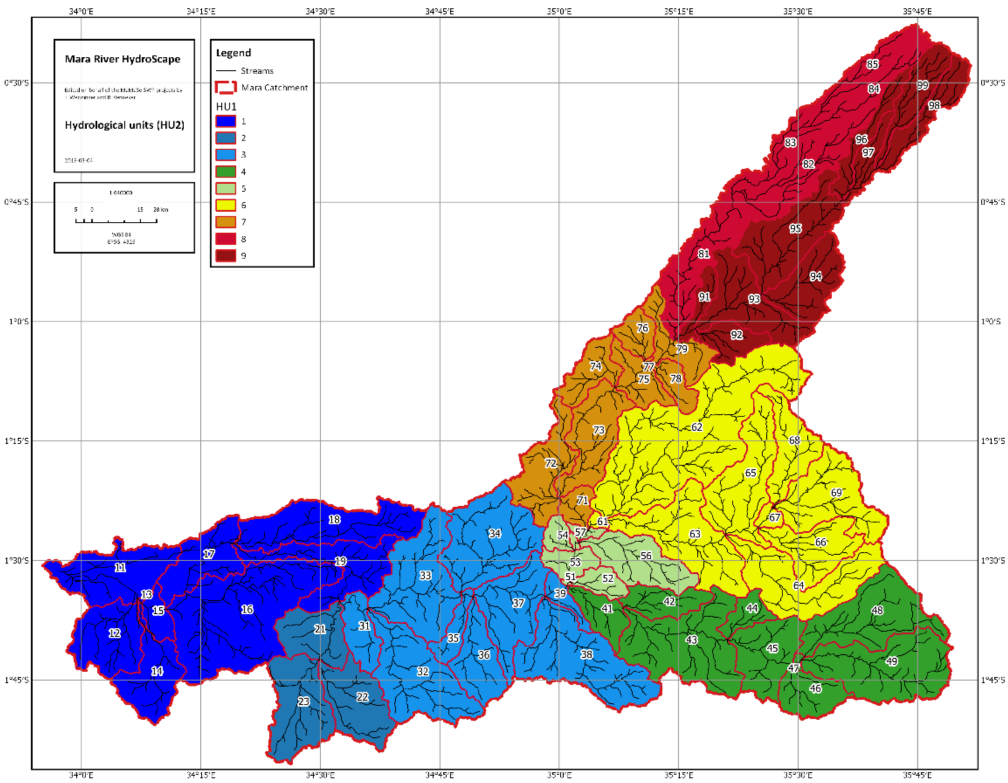


Figure 4: Hydrological units level 2 (HU2) delineated using the Pfafstetter system

1.2. PRECIPITATION DATA

For the precipitation input, in total 25 stations in and around the MRB were selected (see Figure 4 and Table 1). Of these stations, 16 are located inside and nine are located outside the catchment. Time series of daily precipitation were available ranging from 15 to 49.5 years, with 0 to 40% of missing data (Figure 5). After a visual inspection and first correction of outliers, the daily time series were aggregated to monthly and annual time series. The consistency of the dataset was checked by double mass curve analyses. Monthly totals were only calculated if at least 25 daily observations for the month were available in the database. For the annual calculations only years with a complete set of 12 months were used. Details of the precipitation stations can be found in Appendix B.

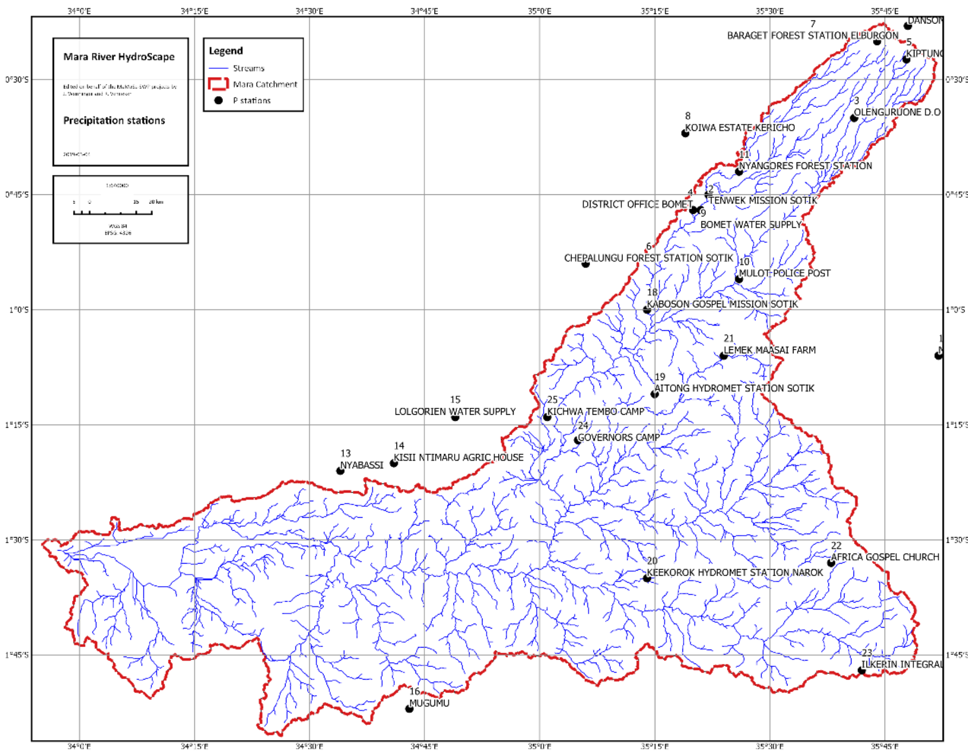


Figure 5: Precipitation stations used for the water resources assessment

Table 2: List of stations with long term precipitation data

NO	Station_I	Station_Name
1	9035031	DANSON K NGUGI SAW MILL
2	9035079	TENWEK MISSION SOTIK
3	9035085	OLENGURUONE D.O OFFICE
4	9035227	DISTRICT OFFICE BOMET
5	9035228	KIPTUNGA FOREST STATION
6	9035236	CHEPALUNGU FOREST STATION
7	9035241	BARAGET FOREST STATION
8	9035260	KOIWA ESTATE KERICHO
9	9035265	BOMET WATER SUPPLY
10	9035284	MULOT POLICE POST
11	9035302	NYANGORES FOREST STATION
12	9133000	MUSOMA METEOROLOGICAL
13	9134008	NYABASSI
14	9134019	KISII NTIMARU AGRIC HOUSE
15	9134027	LOLGORIEN WATER SUPPLY
16	9134033	MUGUMU
17	9135001	NAROK METEOROLOGICAL STATION
18	9135008	KABOSON GOSPEL MISSION SOTIK
19	9135010	AITONG HYDROMET STATION SOTIK
20	9135013	KEEKOROK HYDROMET STATION
21	9135019	LEMEK MAASAI FARM
22	9135022	AFRICA GOSPEL CHURCH NAIKARA
23	9135025	ILKERIN INTEGRAL DEVELOPMENT
24	9135026	GOVERNORS CAMP
25	9135035	KICHWA TEMBO CAMP

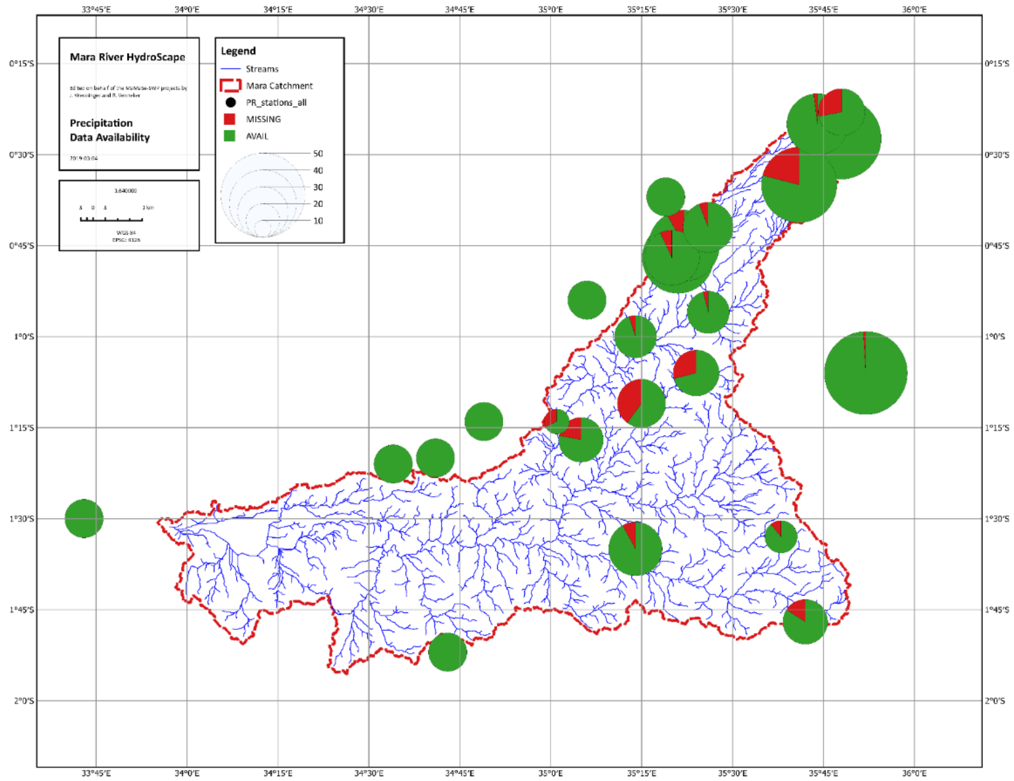


Figure 6: Precipitation data availability

The uneven distribution of precipitation stations, with available long-term data series, in the lower part of the Mara River Basin and the low station density in this part of the catchment, may lead to uncertainties of the areal rainfall estimations.

1.3. DISCHARGE DATA

In total 11 hydrometric stations are available in the MRB, of which seven are situated in the Kenyan part and four in the Tanzanian part of the catchment (Figure 6). Daily discharges were available for only five stations with long time series (Table 2). Time series of daily discharge were available ranging from 2.7 to 59.5 years, with 15.5 to 75.1% of missing data (Figure 6). After a visual inspection and first correction of outliers, the daily time series were aggregated to monthly and annual time series. Monthly averages were only calculated if at least 25 daily observations for the month were available in the database. For the annual calculations only years with a set of minimal ten available months were used. Details of discharge stations can be found in Appendix B.

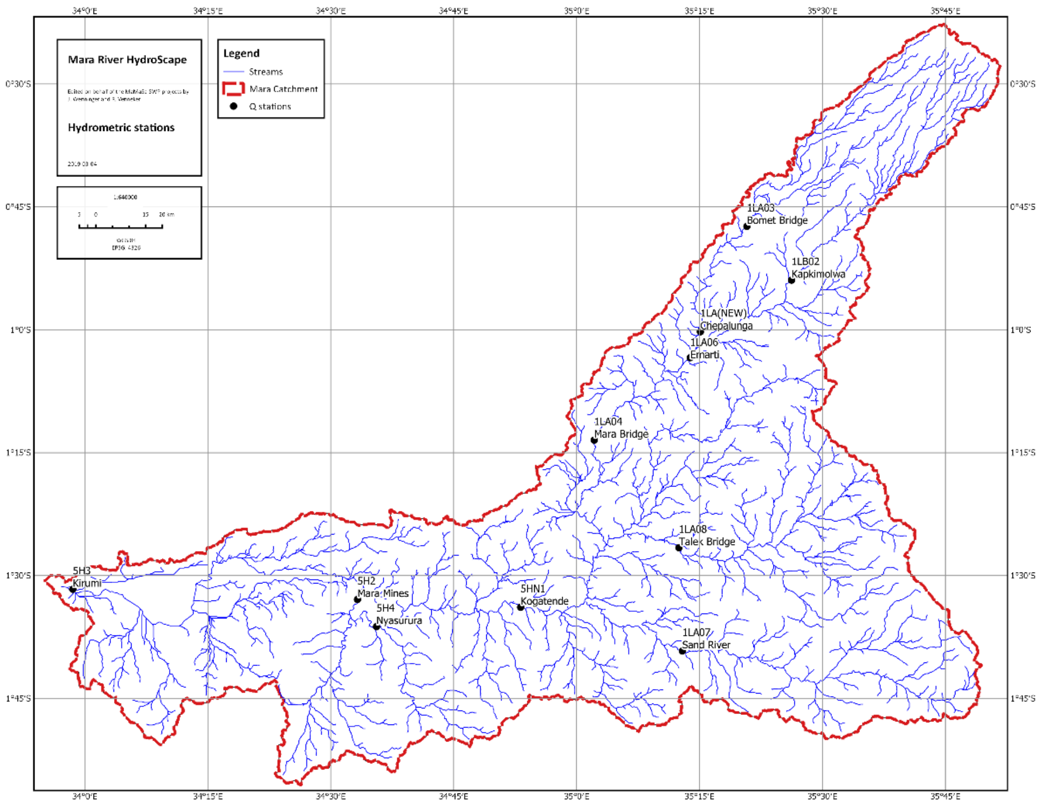


Figure 7: Hydrometric stations used for the water resources assessment

Table 3: List of stations with long term discharge data

	1LA03 Bomet Bridge	1LA04 Kichwa Tembo	1LA06 Emarti	1LB02 Kapkimolwa	5H2 Mara Mines
VALID [-]	15866	4085	828	15538	12503
MISSING [-]	2908	12351	172	6190	5337
MIN [m³/s]	0.229	0	0.0015	0	0
MEAN [m³/s]	7.92	7.56	20.15	7.22	30.78
MAX [m³/s]	52.47	36.56	116.85	108.54	942.54
STDEV [m³/s]	8.27	4.52	19.49	10.45	55.98
SKEW [-]	2.35	0.79	1.90	3.49	4.93
END [yyyy-mm-dd]	2015-03-17	2014-12-31	2015-06-29	2015-03-17	2018-06-04
YEARS [-]	51.4	45	2.7	59.5	48.9
% MISSING	15.5	75.1	17.2	28.5	29.9

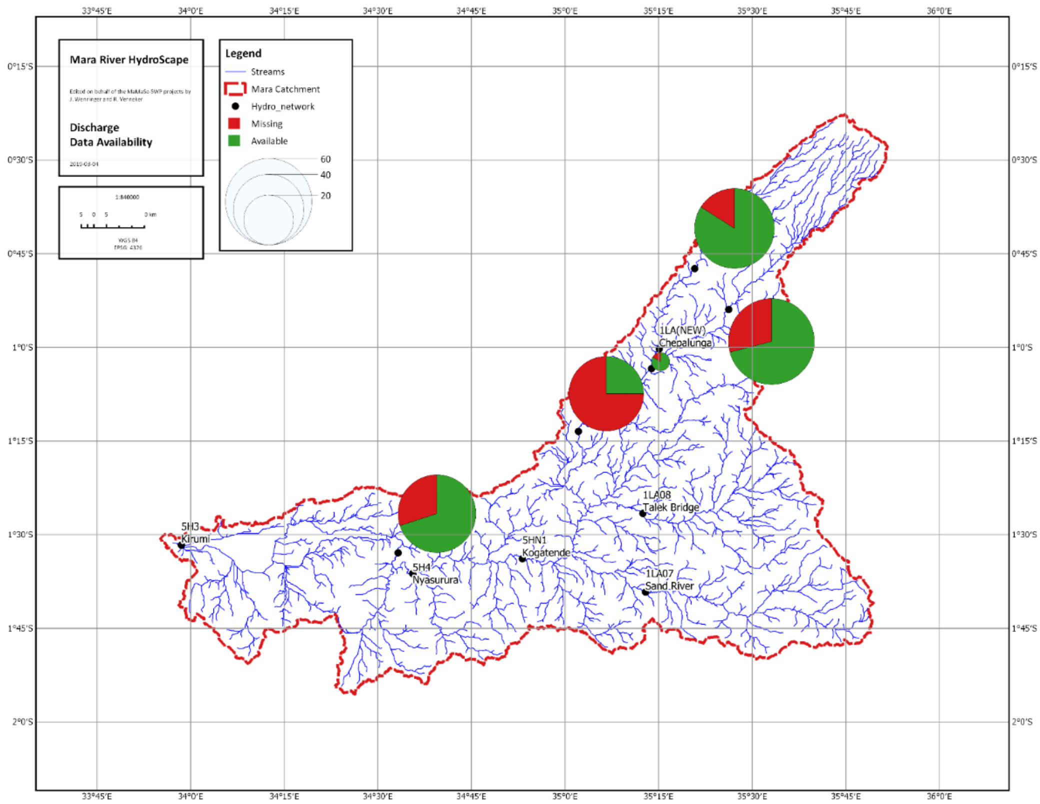


Figure 8: Discharge data availability

1.4. GROUNDWATER DATA

Groundwater observation wells and therefore groundwater level data are not available for the Tanzanian part of the Mara River Basin. Consequently the assessment of groundwater as a resource was omitted in this assessment, justified also by the scope of this report. For the future there is a need to have observation boreholes for groundwater monitoring purposes in the catchment.

However a detailed study was carried out between 2005 and 2006 by the Japan International Cooperation Agency (JICA) in collaboration with the Department of Rural Water Supply (DRWS) and the Ministry of Water (MoW). The study is entitled “The Study on Rural Water Supply in Mwanza and Mara Regions in the United Republic of Tanzania; (JICA, 2006)”, and contains an assessment of the groundwater potential and a groundwater development plan.

1.5. EVAPORATION DATA

Measured potential or actual evaporation data are not available within the Tanzanian part of the Mara River Basin. In order to validate the results of the regionalized water balance components data sets from e.g. the FAO WaPOR portal (https://wapor.apps.fao.org/home/1) could be used in the future. The portal contains remotely sensed data like annual actual evapotranspiration and interception values for the years 2009 to 2017 with a spatial resolution of 100m and 250 m.

2. DATA ANALYSIS

Data analysis was carried out using the HEC-DSSVue software package for data storage and manipulation, and the geographical information system QGIS version 3.4.1 Madeira for spatial analysis steps. A flowchart of the methodology can be found in Appendix F. Data validation and quality control was carried out following the general guidelines as described in WMO (2018), and the methods used to carry out this Water Availability Assessments can be found in WMO (2012).

2.1. AREAL PRECIPITATION

Calculation of the areal precipitation was done for the mean annual as well as for the mean monthly values based on the 25 used precipitation stations (see section 1). For the calculation of long term mean monthly and annual values, station data were filled based on a regression analysis between neighbouring stations. Details of this analysis can be found in Appendix B. Finally, the Thiessen polygon method was used (Equation 1 and Figure 8) to calculate areal precipitation values for the sub-catchments.

$$\overline{P} = \frac{P_1 \cdot A_1 + P_2 \cdot A_2 + \dots + P_n \cdot A_n}{A_1 + A_2 + \dots + A_n} = \sum_{n=1}^{n} P_i \cdot \frac{A_i}{A} \; [mm] \quad (1)$$

with: $\overline{P}$ = *areal catchment precipitation; [mm]*
$P_1, P_2, \dots, P_n$ = *precipitation of station 1, 2, … ,n; [mm]*
$A_1, A_2, \dots, A_n$ = *respective Thiessen polygon area 1, 2, … ,n; [km²]*
A = *catchment area; [km²]*

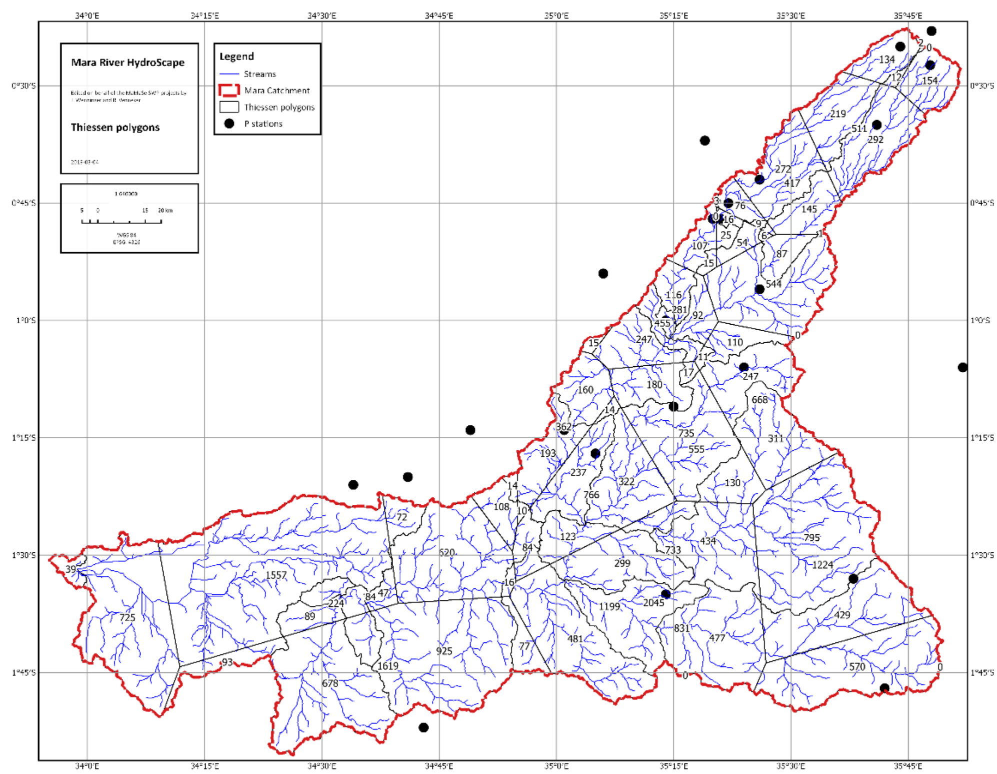


Figure 9: Thiessen polygons for areal precipitation calculations

Highest annual precipitation inputs, with values higher than 1400 mm/a, are observed in the upstream and middle parts of the MRB, namely in the headwaters of the Nyangores and the Amala rivers as well as the western parts of the lower MRB. The eastern and south-eastern parts of the MRB, the Talek and the Sand sub-catchments, receive considerablly less precipitation (Figure 8 and Figure 9). Annual precipitation in the headwaters of these catchments shows values below 700 mm/a.

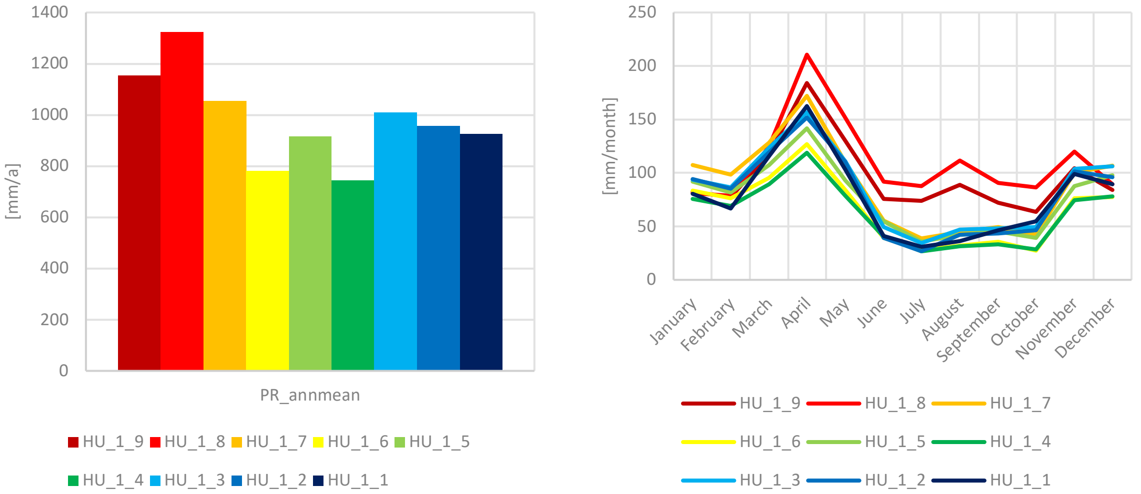


Figure 10: Mean annual (left) and mean monthly (right) precipitation amounts of HU1 catchments

Monthly precipitation values of the first level hydrological units are shown in Figure 9. Intra-annual variations show a bimodal precipitation pattern with two rainy seasons in March-May and November-December. One exception is the pattern in the two headwater catchments of the Nyangores and Amala rivers, showing also higher average precipitation values in August.

2.2. DISCHARGE

2.2.1. MEAN DISCHARGE

Calculation of mean monthly and mean annual discharge values were carried out for the five stations with available daily discharge data (Table 3). Time series can be found in Appendix C. Based on the mean monthly values, runoff regimes were classified and Pardé coefficients (PC) were calculated by dividing the mean monthly values by the annual average (Equation 2). Runoff regimes describe the seasonality, which is influenced by meteorological and catchment characteristics. This enables a better comparison of the intra-annual variability of the station data (Figure 10).

$$PC_{month} = \frac{MQ_{month}}{MQ_{year}} \; [-] \qquad (2)$$

with: PC_{month} = *Pardé coefficient; relation between mean monthly and mean annual discharge; [-]*
MQ_{month} = *mean monthly discharge; [m³/s]*
MQ_{year} = *mean annual discharge; [m³/s]*

Table 4: Monthly and annual average discharge values [m^3/s] of hydrometric stations

		1LA03 BOMET BRIDGE	1LA04 KICHWA TEMBO	1LA06 EMARTI	1LB02 KAPKIMOLWA	5H2 MARA MINES
	Start	Nov 1963	Jan 1970	Oct 2012	Sep 1955	Aug 1969
	End	Feb 2015	Dec 2014	May 2015	Feb 2015	Apr 2018
	Missing	16%	80%	3%	28%	30%
Average Monthly	**1**	3.52	5.00	5.24	5.46	19.67
	2	3.04	6.82	10.34	2.69	19.49
	3	2.78	6.39	19.42	3.81	36.38
	4	7.76	7.65	37.69	8.58	70.93
	5	12.34	10.28	42.97	14.47	62.96
	6	9.35	8.91	22.82	7.49	32.79
	7	9.29	10.01	20.16	6.98	19.32
	8	10.93	9.22	28.59	11.62	19.12
	9	12.80	8.67	17.77	11.37	23.40
	10	8.23	6.48	11.74	6.75	15.57
	11	6.63	6.97	10.10	3.77	18.58
	12	4.99	5.86	11.84	4.56	28.23
Average Annual		**7.60**	**7.55**	**20.05**	**7.19**	**30.47**

During a first data quality control step unrealistic low discharge values for the station 1LA04 Kichwa Tembo were observed. Monthly and annual flow values of this station are much lower than those of the upstream situated station 1LA06 Emarti. Also, an earlier hydrological analysis of the data quality within the Mara River Basin indicated the poor quality of the rating curve for the station 1LA04 Kichwa Tembo (Hulsman, 2016). Therefore, this station was excluded from further analyses.

The largest discharge values are observed at the most downstream station 5H2 Mara Mines in Tanzania, followed by the station 1LA06 Emarti on the Mara, and 1LB02 Kapkimolwa and 1LA03 Bomet Bridge on the Amala and Nyangores sub-catchments (Figure 10). The intra-annual pattern given by the precipitation input is also visible in the discharge time series and the runoff regimes. For the three upstream stations a bimodal pattern is visible with a main peak in April/May and a second one in August/September. This second peak is caused by the high precipitation amounts in the upstream catchments H1_8 and H1_9 during these months (Figure 9).

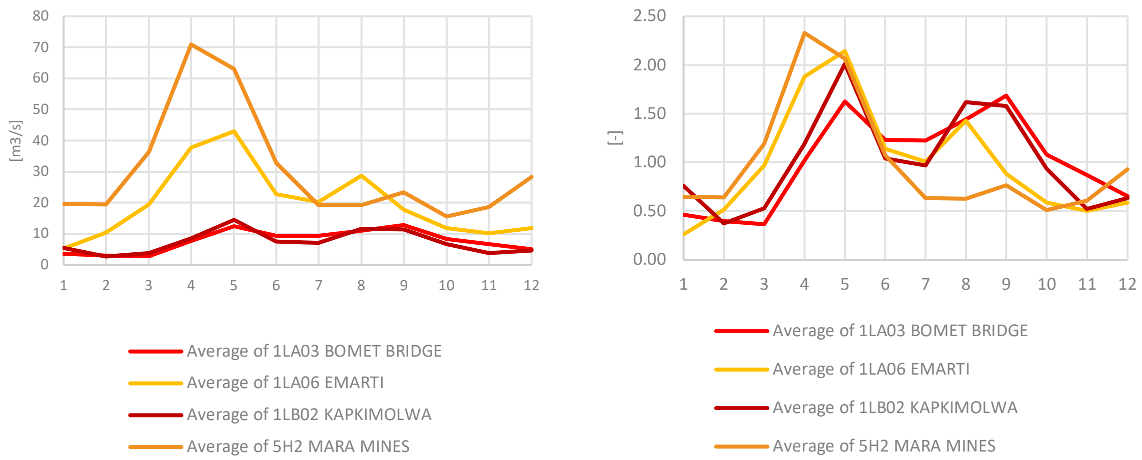


Figure 11: Long term mean monthly discharge (left) and runoff regimes (right)

During a second data quality step it was observed that for four months the mean monthly discharges at 1LA06 Emarti are lower than the sum of the discharge values of the upstream located stations 1LA03 Bomet Bridge and 1LB02 Kapkimolwa. Also, for the station 5H2 Mara Mines it was observed that for five months the values are lower than the upstream station 1LA06 Emarti. In order to be able to proceed with the regionalization analysis of flow values (see Chapter 3), also on a monthly time basis, corrections of monthly values were made. Therefore, the missing monthly discharge values were filled based on a monthly regression analysis between stations. Details of this analysis can be found in Appendix C. In Table 4 as well as in Figure 11 the corrected average monthly flow values are reported, and in Figure 12 an overview of the corrected monthly discharges and runoff regimes is given.

Table 5: Corrected monthly and annual average discharge values [m³/s]; filled data

		1LA03 BOMET BRIDGE	1LA06 EMARTI	1LB02 KAPKIMOLWA	5H2 MARA MINES
	Start	1955	1955	1955	1955
	End	2018	2018	2018	2018
Average Monthly	**1**	4.10	12.43	4.75	23.01
	2	3.60	9.25	2.60	18.75
	3	3.29	10.05	3.43	25.95
	4	8.12	25.18	9.52	53.90
	5	13.20	36.14	14.31	63.44
	6	9.26	21.69	7.57	33.68
	7	8.88	19.74	7.19	24.44
	8	10.48	26.60	11.73	27.24
	9	12.45	30.03	11.98	33.93
	10	8.13	17.95	6.98	21.21
	11	6.31	13.63	4.31	21.59
	12	5.48	13.69	4.23	28.66
Average Annual		**7.76**	**19.68**	**7.37**	**31.24**

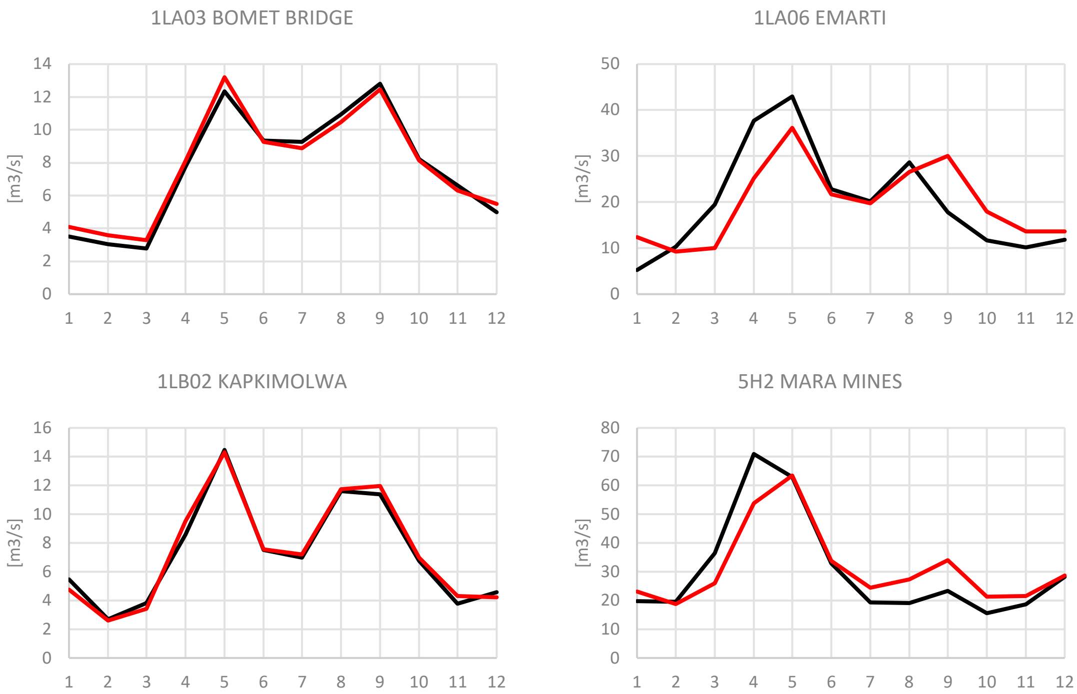


Figure 12: Comparison between original (black) and filled (red) monthly average discharge data

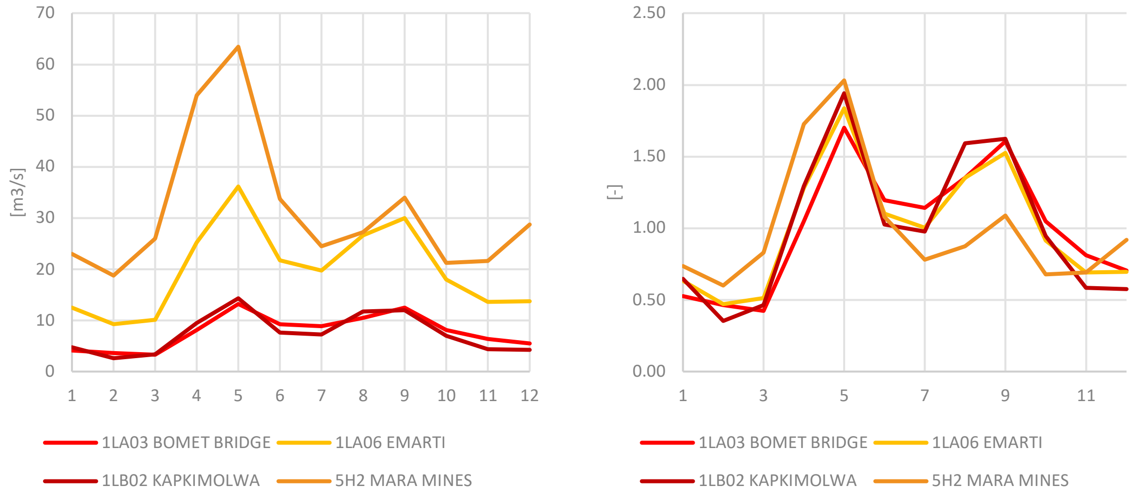


Figure 13: Corrected mean monthly discharges (left) and runoff regimes (right)

2.2.2. FLOW DURATION CURVES

Flow duration curves (FDC) based on monthly flow values have been calculated from the monthly times series for the stations 1LA03 Bomet Bridge (BB), 1LA06 Emarti (EM), 1LB02 Kapkimolwa (KA), and 5H2 Mara Mines (MM). Due to the limited amount of monthly data, not all percentiles could be determined for all stations on the original data set (Table 5 and Figure 13).

Table 6: Percentile values of the FDC for considered stations, original data in [m^3/s]

Percentile	1LA03 Bomet Bridge	1LA06 Emarti	1LB02 Kapkimolwa	5H2 Mara Mines	AVERAGE
0.100					
0.200	33.296				
0.500	28.980		80.257	247.41	**118.88**
1.000	26.766		50.906	221.16	**79.68**
2.000	25.012		39.506	178.30	**65.25**
5.000	21.844		34.471	128.43	**49.95**
10.000	17.162	64.729	24.348	75.71	**39.09**
15.000	14.806	49.755	17.704	58.67	**30.60**
20.000	12.275	42.246	14.839	40.78	**24.23**
30.000	9.312	29.074	11.374	30.17	**17.93**
40.000	7.310	21.069	8.280	20.82	**13.19**
50.000	5.709	19.138	5.874	15.31	**10.62**
60.000	4.500	16.430	3.874	11.60	**8.49**
70.000	3.226	13.037	2.594	7.83	**6.29**
80.000	2.070	9.674	1.674	5.25	**4.43**
85.000	1.686	5.053	0.972	3.90	**2.92**
90.000	1.230	3.108	0.714	2.77	**2.05**
95.000	0.913	2.463	0.502	1.72	**1.39**
98.000	0.568	1.113	0.307	1.07	**0.72**
99.000	0.471		0.194	0.87	**0.52**
99.500	0.386		0.132	0.87	**0.46**
99.800	0.343				
99.900					

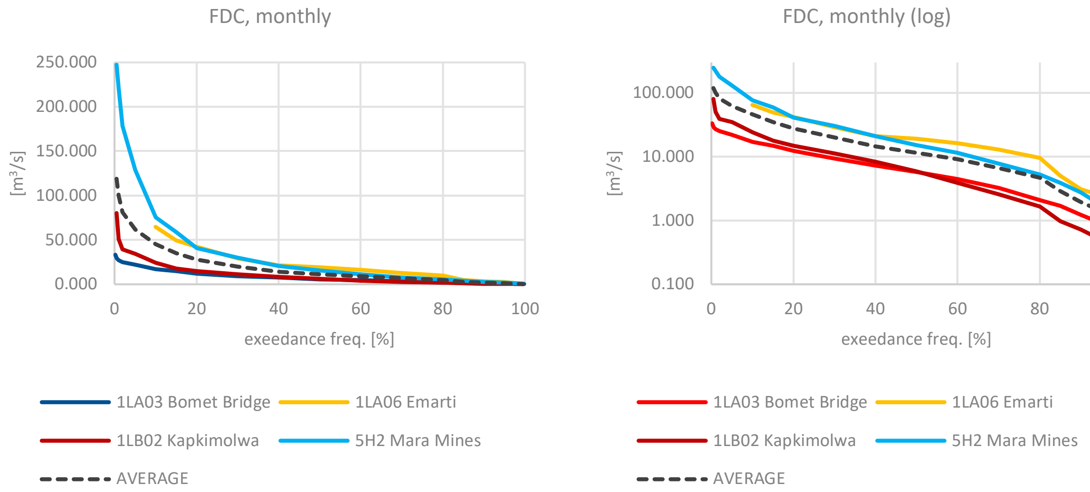


Figure 14: Flow duration curves based on monthly data set for considered stations

3. REGIONALIZATION

Regionalization of hydrological parameters within the MRB was carried out using distinct approaches and methodologies.

In a first analysis step the long term mean annual and mean monthly flows were regionalized using runoff coefficients (RC), being the ratio between runoff (R) and precipitation (P). Therefore estimated areal precipitation values of gauged catchments (Chapter 2.1) were compared to runoff values derived from discharge information at the gauging stations (Chapter 2.2.1). The resulting RC values for gauged catchments were then regionalized to the ungauged catchments based on area relationships and precipitation information. After regionalization of RC values for ungauged catchments the discharge values on an annual and monthly time scale could be calculated using the areal precipitation information (Chapter 3.1). As an additional product of this analytical step the water balance for ungauged catchments was set up, and the total actual evaporation was determined (Chapter 3.2) on an annual and monthly time scale.

In a second analysis step, the flow duration curves for monthly flows of the ungauged catchments were estimated by regionalizing standardized flow duration curves from gauged catchments to ungauged ones using mean values of discharge (Chapter 3.1) and the coefficient of variation (CV) of the monthly discharge values (Chapter 3.3).

3.1. DISCHARGE VALUES

The first step in the regionalization process uses catchments with plausible discharge data (see Chapter 2). In this analysis the stations Kapkimolwa (KA), Bomet Bridge (BB), Emarti (EM), and Mara Mines (MM) were used. Kapkimolwa and Bomet Bridge are considered as headwater catchments, and the catchments of the more downstream stations Emarti and Mara Mines were further split up into their nested sub-catchments Emarti_only (area of Emarti minus Kapkimolwa and Bomet Bridge; EM-BB-KA) and Mara Mines_only (area of Mara Mines minus Emarti; MM-EM). The catchments used for the analysis are shown in Figure 14.

For each catchment and sub-catchment, the catchment area [km^2] was determined as well as the long term mean annual and monthly precipitation [mm] and discharge [m^3/s]. For the catchments Emarti_only (EM_only) and Mara Mines_only (MM_only) the discharges were calculated as the differences between the station value and the flow value from the upstream catchment(s). From those discharges [m^3/s] the total and sub-catchment runoff values [mm] were calculated using the respective catchment area, and runoff coefficients were determined (Table 6).

In order to determine the runoff coefficients for the hydrological units level 1 (HU1), additional catchments have to be delineated to account for the differences between the extent of the HU1 catchments and the catchments defined by the gauging stations (Figure 15). Therefore the sub-catchment of H9 is defined by a combination of KA and KA_lower, H8 by the combination of BB and BB_lower, and H7 by an arrangement of EM_upper and MM. Runoff coefficients (RC) of the sub-catchments H6 to H1 are estimated by the RC of MM_only modified by multiplying by the ratio between the respective sub-catchment precipitation and the precipitation value of MM_only.
Results of the regionalization analysis of flow values for hydrological units level 1 (HU1) can be found in Table 7 and Table 8. The water availability per sub-catchment [m^3/d] is presented in Appendix D.

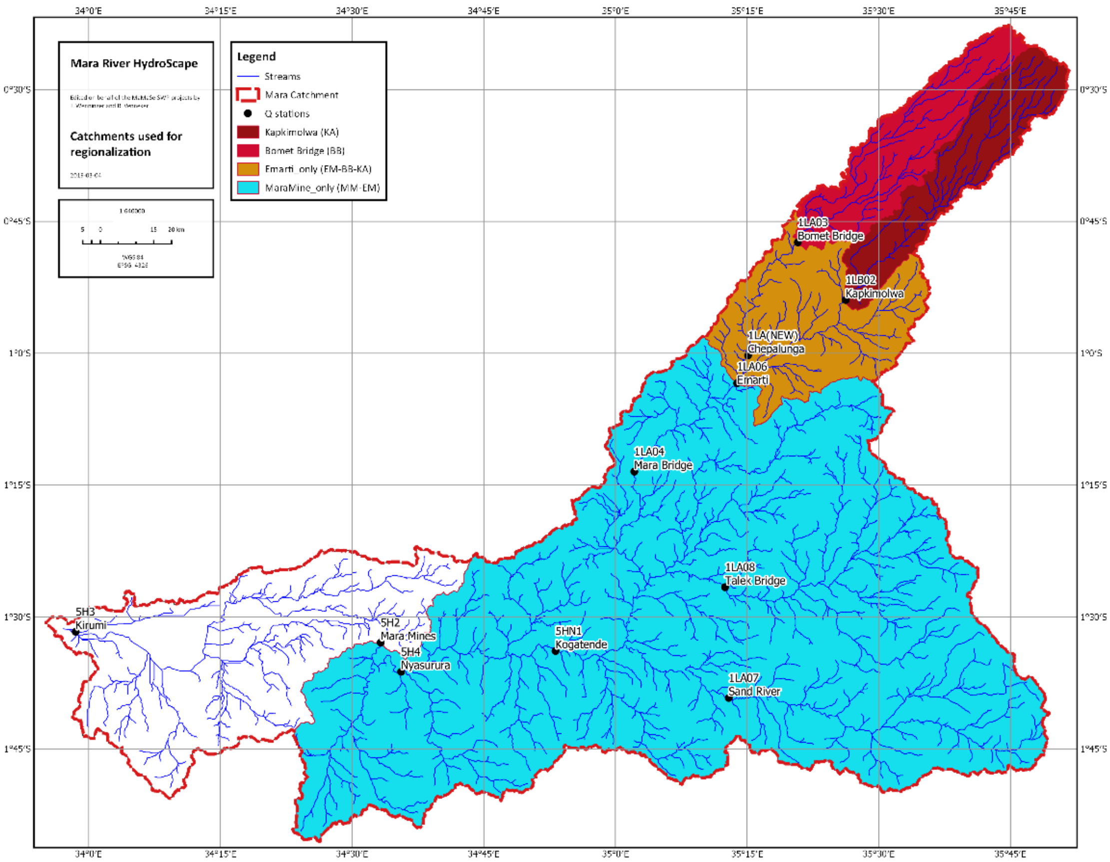


Figure 15: Catchments defined by gauging stations used for regionalization

Table 7: Example calculation for average annual discharge values of catchments H1-H9

Name	Area [km^2]	Area_sub [km^2]	P_total [mm]	P_sub [mm]	Q_total [m^3/s]	Q_sub [m^3/s]	R_total [mm]	R_sub [mm]	R/P_total [-]	R/P_sub [-]
Kapkimolwa (KA)	698	698	1363	1363	7.37	7.37	333	333	0.244	0.244

Bomet Bridge (BB)	695	695	1416	1416	7.76	7.76	352	352	0.249	0.249
Emarti (EM)	2447	1055	1206	963	19.68	4.55	254	136	0.210	0.141
Mara Mines (MM)	11284	8836	954	885	31.24	11.55	87	41	0.091	0.047
KA_lower	-	717	-	950	-	3.05	-	134	-	0.141
BB_lower	-	237	-	1056	-	1.12	-	149	-	0.141
EM_upper	-	101	-	834	-	0.38	-	118	-	0.141
H9	1415	1415	1154	1154	9.95	9.95	222	222	0.192	0.192
H8	932	932	1324	1324	8.67	8.67	293	293	0.222	0.222
H7	3403	1056	1169	1053	20.58	1.96	191	59	0.158	0.056
H6	2664	2664	781	781	2.72	2.72	32	32	0.041	0.041
H5	6489	422	994	917	23.89	0.59	116	44	0.103	0.048
H4	1830	1830	744	744	1.69	1.69	29	29	0.039	0.039
H3	10543	2225	954	1009	29.37	3.79	88	54	0.081	0.053
H2	690	690	957	957	1.06	1.06	48	48	0.050	0.050
H1	13508	2275	949	926	33.68	3.26	79	45	0.074	0.049

P=precipitation; Q=discharge; R=runoff; _sub=sub-catchment

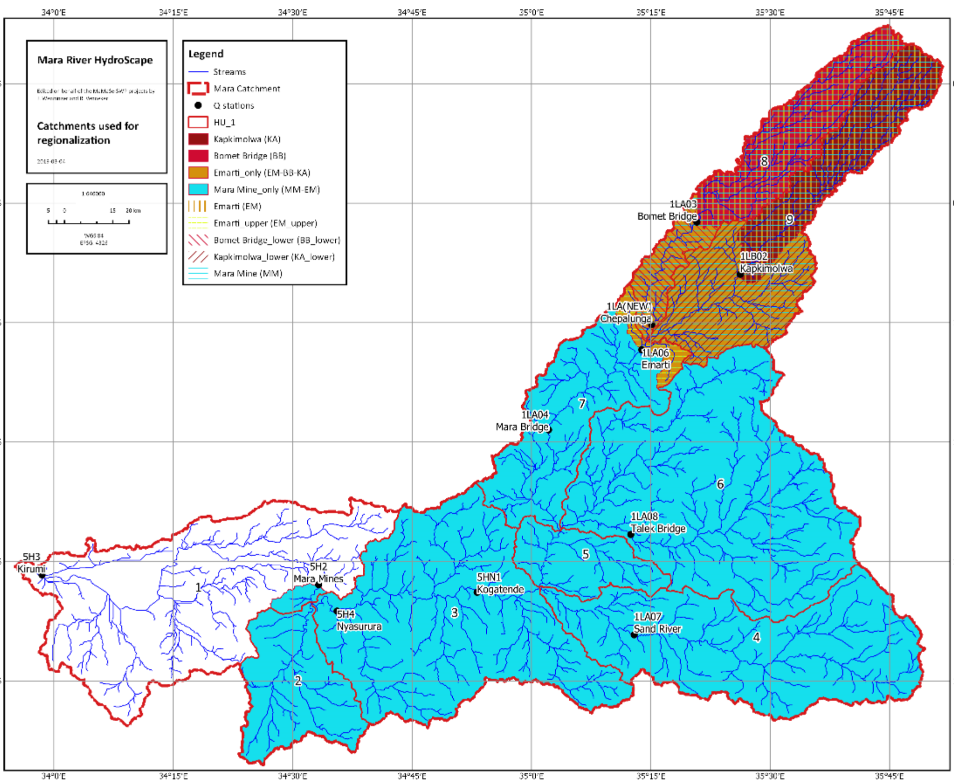


Figure 16: Catchments of gauging stations and HU1 used in the regionalization process

Table 8: Regionalized average flow [m³/s] values of level 1 hydrological units (HU1)

FLOW [m³/s]									
MONTH	H9	H8	H7	H6	H5	H4	H3	H2	H1
1	7.67	4.96	14.44	2.84	17.83	1.62	22.45	0.95	25.67
2	4.87	4.37	10.86	2.57	13.90	1.47	18.13	0.84	20.65
3	5.82	4.11	12.36	3.82	16.94	2.30	24.59	1.56	30.93
4	14.36	9.86	28.78	7.06	37.23	4.25	50.48	2.62	63.03
5	19.12	14.82	38.21	6.36	45.81	3.80	58.93	2.85	69.99
6	10.45	10.38	22.93	2.79	26.59	2.05	32.32	0.73	35.63
7	9.50	9.48	19.96	1.16	21.42	0.73	23.62	0.28	25.12
8	13.60	11.59	25.71	0.13	25.88	0.09	26.21	0.06	26.42
9	14.51	13.55	29.16	0.87	30.26	0.52	32.15	0.34	33.76
10	7.93	8.58	17.20	0.54	17.91	0.39	19.75	0.40	21.98
11	6.14	6.89	14.31	1.79	16.47	1.17	20.41	0.82	23.80
12	6.98	6.43	15.78	3.29	19.89	2.29	27.33	1.31	32.36
Total	10.08	8.75	20.81	2.77	24.18	1.72	29.70	1.06	34.11

H9…H1 = Number of catchments for hydrological units level 1

Table 9: Regionalized runoff regimes of level 1 hydrological units (HU1)

REGIME [-]									
MONTH	H9	H8	H7	H6	H5	H4	H3	H2	H1
1	0.76	0.57	0.69	1.03	0.74	0.94	0.76	0.89	0.75
2	0.48	0.50	0.52	0.93	0.57	0.85	0.61	0.79	0.61
3	0.58	0.47	0.59	1.38	0.70	1.34	0.83	1.47	0.91
4	1.42	1.13	1.38	2.55	1.54	2.47	1.70	2.47	1.85
5	1.90	1.69	1.84	2.30	1.89	2.21	1.98	2.69	2.05
6	1.04	1.19	1.10	1.01	1.10	1.19	1.09	0.69	1.04
7	0.94	1.08	0.96	0.42	0.89	0.42	0.80	0.26	0.74
8	1.35	1.32	1.24	0.05	1.07	0.05	0.88	0.06	0.77
9	1.44	1.55	1.40	0.31	1.25	0.30	1.08	0.32	0.99
10	0.79	0.98	0.83	0.19	0.74	0.23	0.66	0.38	0.64
11	0.61	0.79	0.69	0.65	0.68	0.68	0.69	0.77	0.70
12	0.69	0.73	0.76	1.19	0.82	1.33	0.92	1.23	0.95

H9…H1 = Number of catchments for hydrological units level 1

3.2. WATER BALANCE

As an additional product of this regionalization analysis, the water balance for ungauged catchments was assessed. Areal precipitation per sub-catchment was determined by calculating the catchment area average of the Thiessen polygon analysis (see Chapter 2.1). Runoff values were derived from the regionalized discharges described in Chapter 3.1, and the total actual evaporation was calculated as the remainder term in the water balance equation on an annual and monthly time scale.

$$\boldsymbol{P - E - R - \frac{dS}{dt} = 0\ [mm/a]} \qquad (3)$$

with: *P = Precipitation [mm/a]*
E = Evaporation [mm/a]
R = Runoff [mm/a]
$\frac{dS}{dt}$ *= Storage change over time [mm/a]; is equal to zero for long time periods*

3.2.1. WATER BALANCE HU 1

The analytical results for each of the water balance components for level 1 hydrological units (HU1) can be found in Figure 16, Figure 17, and Figure 18. The detailed numerical values are tabulated in Appendix A.

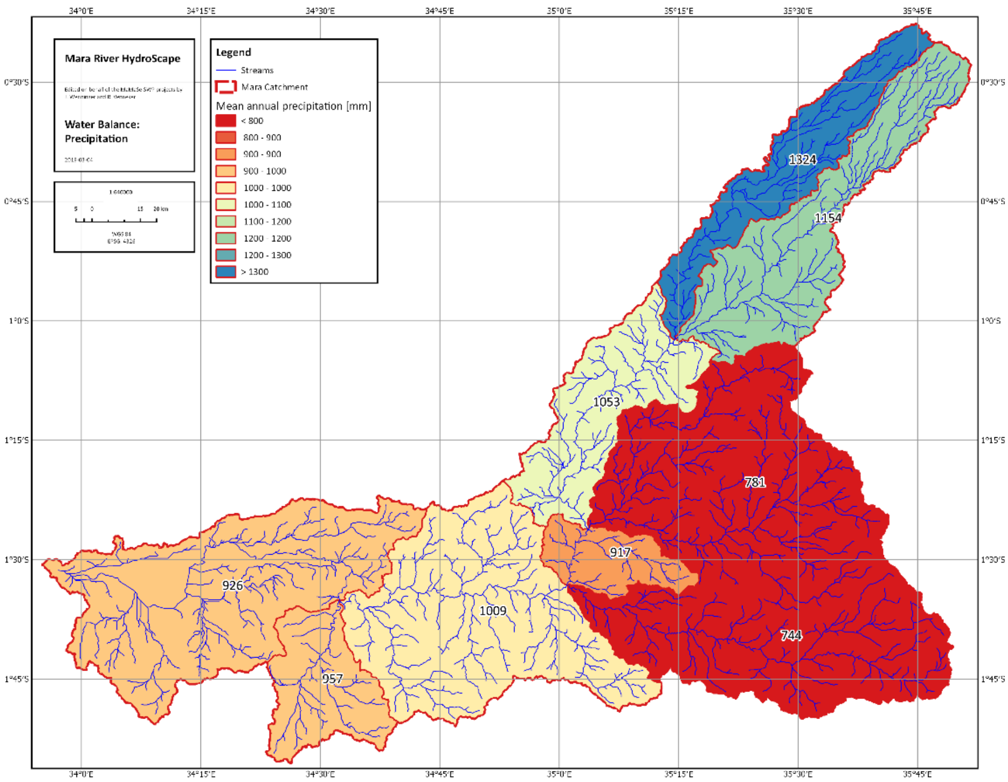


Figure 17: Water balance assessment: Mean annual precipitation P [mm] for HU1

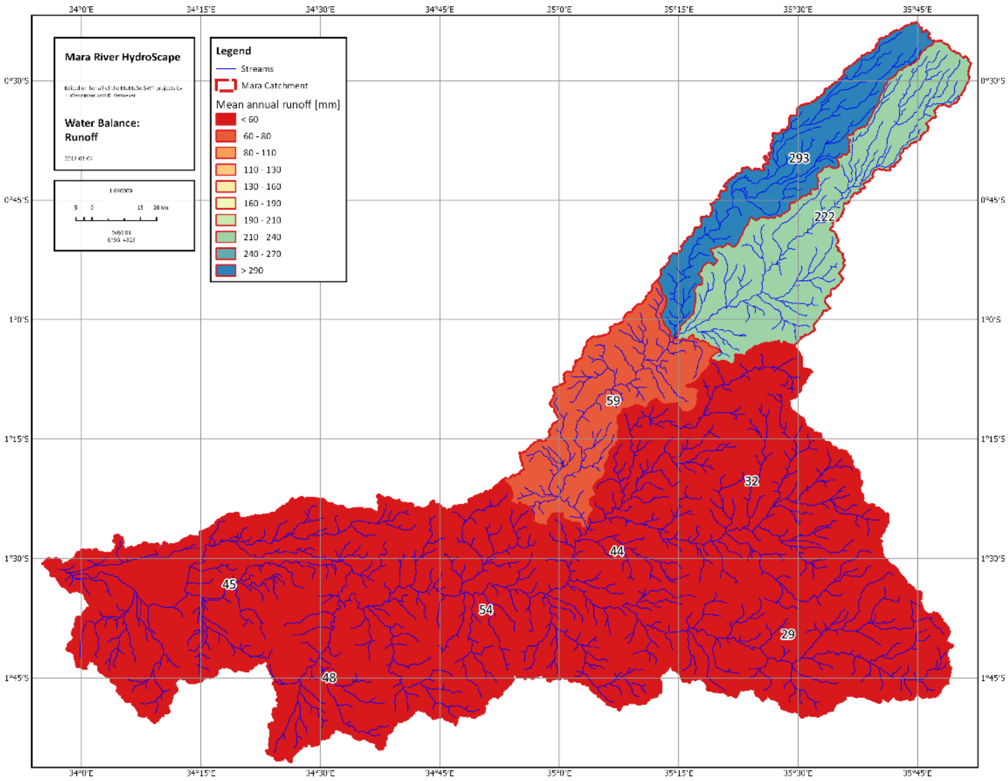


Figure 18: Water balance assessment: Mean annual runoff R [mm] for HU1

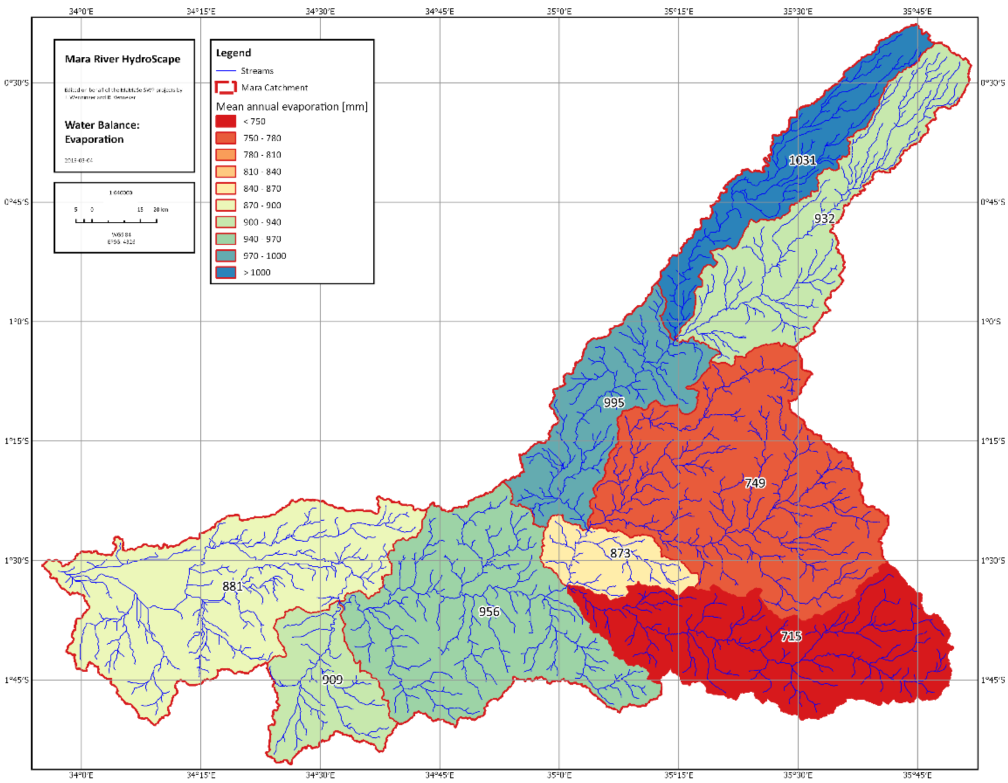


Figure 19: Water balance assessment: Mean annual evaporation E [mm] for HU1

3.2.2. WATER BALANCE HU 2

The analytical results for each of the water balance components for level 2 hydrological units (HU2) can be found in Figure 19, Figure 20, and Figure 21. The detailed numerical values are tabulated in Appendix A.

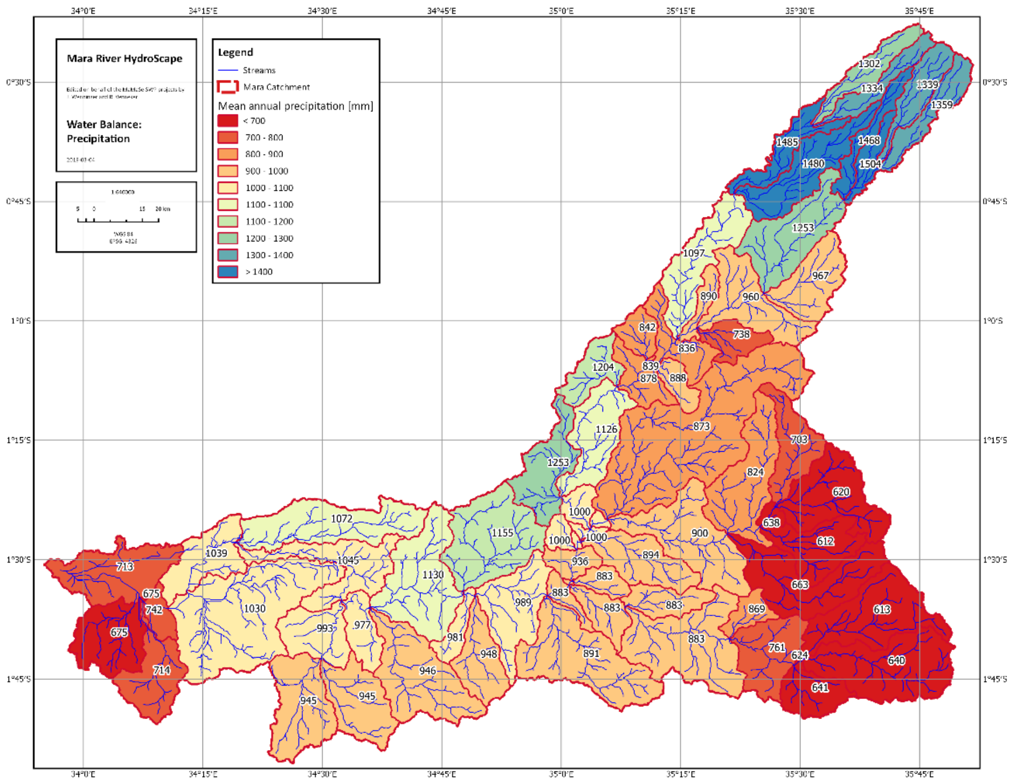


Figure 20: Water balance assessment: Mean annual precipitation P [mm/a] for HU2

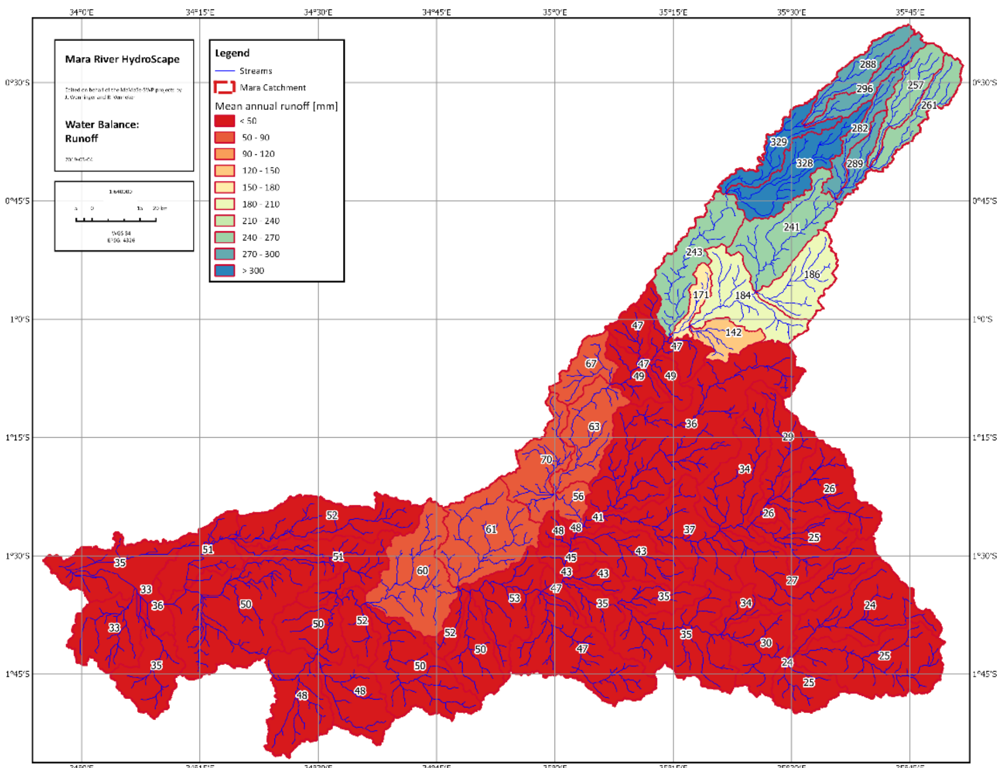


Figure 21: Water balance assessment: Mean annual runoff R [mm/a] for HU2

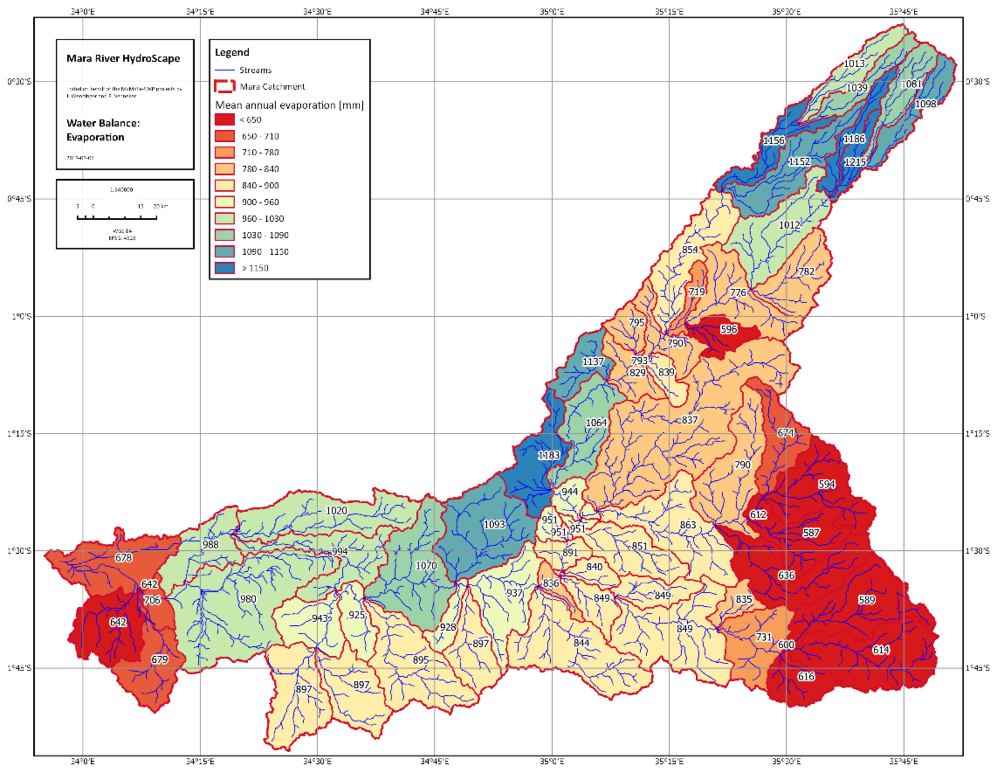


Figure 22: Water balance assessment: Mean annual evaporation E [mm/a] for HU2

3.3. FLOW DURATION CURVES

Estimation of flow duration curves (FDC) at catchment outlets was based on the results of the regionalized flows of the hydrological units HU1. Therefore, the filled discharge time series of the gauging stations were used and monthly flows were extrapolated using monthly areal precipitation values and corresponding runoff coefficients of the respective catchments. From these generated time series the FDCs were derived as shown in Table 9 and Figure 22. The numerical results of regionalized values for annual and monthly FDC of the Hydrological units HU1 are presented in Appendix D.

Table 10: Percentile values of FDC for BB, KA, and MM, filled data in [m³/s]

Percentile	1LA03 Bomet Bridge	1LB02 Kapkimolwa	5H2 Mara Mine
0.100	46.012	60.046	282.297
0.200	40.040	51.099	269.226
0.500	29.561	42.351	246.565
1.000	26.770	35.821	194.287
2.000	24.694	29.695	148.770
5.000	20.608	22.825	102.649
10.000	16.296	16.998	71.290
15.000	13.755	14.468	56.658
20.000	11.767	11.631	44.135
30.000	9.350	8.723	33.240
40.000	7.741	6.982	24.790
50.000	6.065	4.876	18.560
60.000	4.920	3.201	14.450
70.000	3.761	2.068	10.300
80.000	2.532	1.200	7.170
85.000	2.039	0.853	5.840
90.000	1.587	0.569	3.950
95.000	1.000	0.316	2.385
98.000	0.636	0.208	1.354
99.000	0.554	0.135	1.085
99.500	0.465	0.100	0.870
99.800	0.375	0.018	0.870

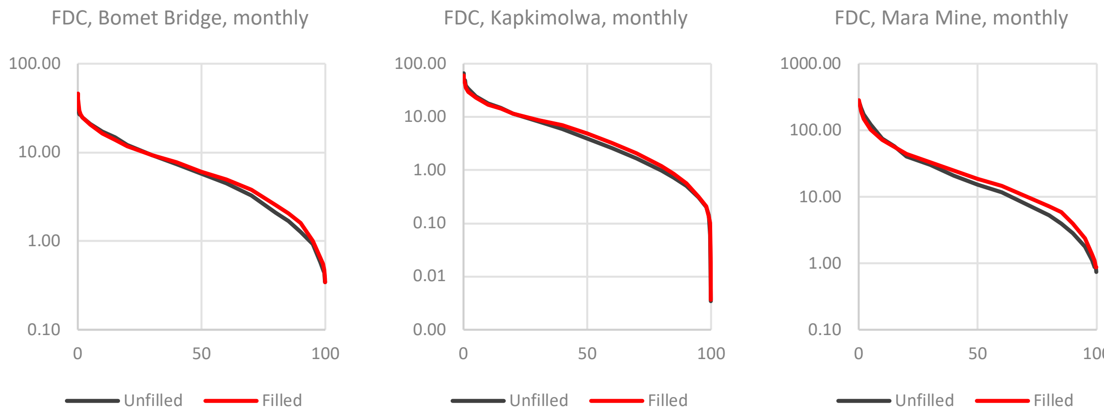


Figure 23: Comparison between FDC based on monthly data of original and filled data sets

4. TREND ANALYSIS

Trend analyses of hydro-meteorological parameters within the MRB were carried out using the DScreen software tool (Venneker, 2011) and the Indicators of Hydrologic Alteration (IHA) package (The Nature Conservancy, 2009; Richter et al., 1996).

In the first analysis step the total annual precipitation as well as the average annual and maximum and minimum average monthly discharge values were selected as variables. In a second analysis step, daily discharge values were used to further investigate the trends in the discharge time series.

To describe the data sets, their major relevant statistical descriptors were computed (**Table 11**). In addition to this, the normality was checked and time series were analyzed for potential change points and for long-term statistical consistency, homogeneity and stationarity. An overview of all computed values is given in Appendix E.

Trend test interpretations were based on results of the Mann-Kendall method, because this is considered to be more robust and is widely used for detecting trends in environmental data (Helsel et al., 2006). In case of autocorrelation present in the time series, the trend tests were applied after pre-whitening of the data.

Table 11: Items for statistical characterization of the time series data

Section	Description	Items
Statistics	Major statistical descriptors	Mean = The arithmetic mean of the data SD = The standard deviation Skew = The skewness SE = The standard error CV = The coefficient of variation
Summary	Tukey's five-number summary	Min = The minimum value Q1 = The first quartile Median = The median or second quartile Q3 = The third quartile Max = The maximum value
Apparent trend	Linear least-squares regression line fit	Const = regression constant Slope = regression slope
Normal(ity)	Shapiro-Wilk test for normality	p = The p-value
Persistence	correlation for a number of time lags in the series	r(1) = The lag-1 autocorrelation coefficient Alpha = predefined significance level UCL = The upper confidence limit LCL = The lower confidence limit
(Secular) trend	nonparametric tests for long-term, or secular, trend (Spearman and Mann-Kendall method)	p = The p-values for Spearman: Spearman p Mann-Kendall: Mann-Kendall p
Pre-white (secular) trend	nonparametric tests for long-term, or secular, trend after pre-whitening to reduce autocorrelation (Spearman and Mann-Kendall method)	p = The p-values for Spearman: Spearman p Mann-Kendall: Mann-Kendall p
Stability	analyse stability of variance and mean in sub-series	p = The p-values for variance = Variance p mean = Mean p

4.1. PRECIPITATION TRENDS

Total annual precipitation (P_{year}) values of 24 stations were considered for the trend analysis. The lengths of the time series rang between 4 and 45 years with 28-100% of available data. One station (9135035 Kichwa Tembo Camp) was excluded from the analysis because of its short time series of only 4 years. Almost all time series are normally distributed, except 9035236 Chepalungu and 9035260 Koiwa that show p values of the Shapiro-Wilk test below the significance level of 0.05. Autocorrelation was detected in two time series (9134027 Lolgorien and 9135008 Kaboson) and therefore pre-white trends were calculated for those.

Apparent tend results indicate positive slopes for 18 time series and negative slopes for 6 time series, however only two time series show a statistically significant trends in the total annual precipitation values. Those stations are:

- 9035236 Chepalungu; Mann-Kendall p = 0.016, negative trend -12.9/a; 23 years; P_{year}
- 9035260 Koiwa; Mann-Kendall p = 0.006; positive trend +25.5/a; 23 years; P_{year}

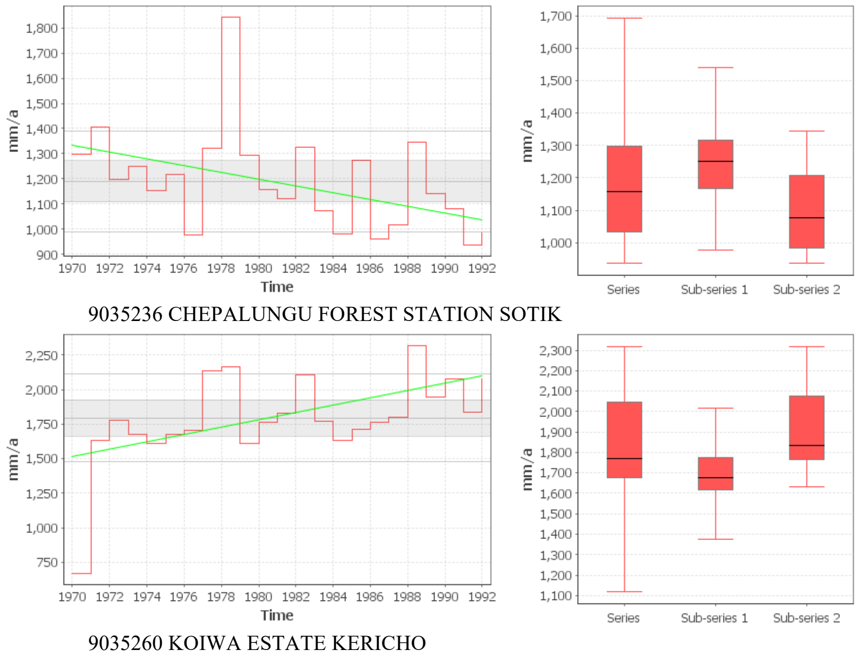


Figure 24: Apparent trends and box plots for total annual precipitation data sets

Taking the non-normal distribution of these time series into account, the results need to be interpreted with caution. All computed results of the analysis and graphical overviews of the apparent trends are presented in Appendix E.

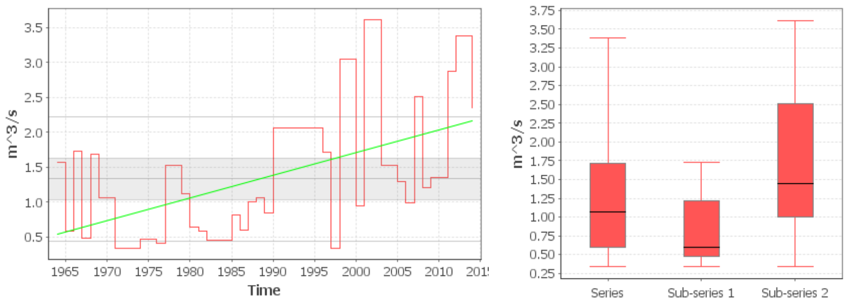
4.2. DISCHARGE TRENDS

In a first analysis step the average annual as well as the maximum and minimum average monthly discharge values were selected as variables.

Trend analyses were carried out for time series of the three stations 1LA03 Bomet Bridge, 1LB02 Kapkimolwa, and 5H2 Mara Mine. Data time series for 1LA04 Kichwa Tembo and 1LA06 Emarti were excluded from analysis because of short time series or data quality issues discussed in earlier sections of this document. The lengths of the time series range between 22 and 35 years, with 40-69% of available data. All time series show the expected non-normal distribution for discharge, confirmed by the results of the Shapiro-Wilk test. Autocorrelation was detected in one time series (5H2 Mara Mine; Minimum monthly discharge NQ_{month}) and therefore pre-white trends were calculated in this case.

Apparent tend results indicate positive slopes for the average annual discharge (MQ_{year}), maximum monthly discharge (HQ_{month}) and minimum monthly discharge (NQ_{month}) time series of the stations 1LA03 Bomet Bridge and 1LB02 Kapkimolwa, whereas time series of 5H2 Mara Mine show diverse trends. A positive slope is observed for HQ_{month}, and negative slopes are present in the MQ_{year} and HQ_{month} data sets. However only the NQ_{month} time series of the station 1LA03 Bomet Bridge shows a statistically significant trend:

- 1LA03 Bomet Bridge; Mann-Kendall p = 0.004, positive trend +0.05/a; 35 years; NQ_{month}



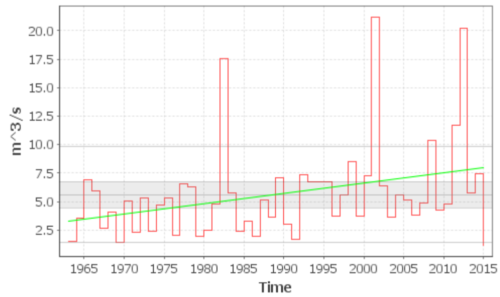
1LA03 Bomet Bridge

Figure 25: Apparent trend and box plot for minimum monthly discharge (NQ_{month}) data set

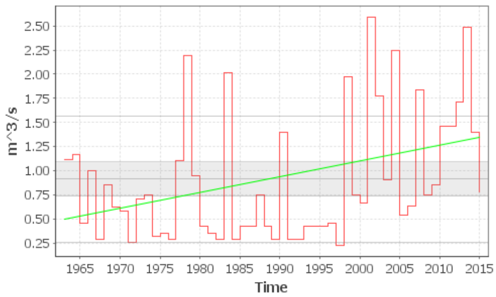
All computed results of the analysis and graphical overviews of the apparent trends are presented in Appendix E.

In a second analysis step daily discharge values of the three selected stations were used to further investigate trends and hydrological parameters in the discharge time series using the IHA software package. All computed results of the analysis can be found in Appendix E. Statistically significant trends were mainly found for the time series of 1LA03 Bomet Bridge, which confirmed the earlier analysis results:

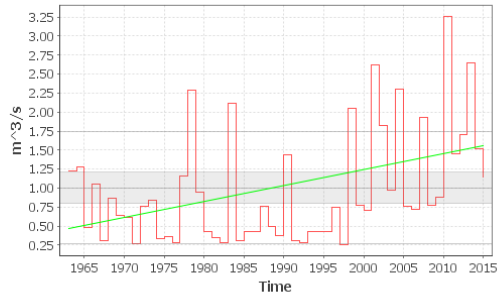
- $MQ_{November}$; $p = 0.025$; positive trend +0.087/a
- 1-day minimum; $p = 0.005$; positive trend +0.016/a
- 3-day minimum; $p = 0.005$; positive trend +0.02/a
- 7-day minimum; $p = 0.005$; positive trend +0.02/a
- 30-day minimum; $p = 0.005$; positive trend +0.03/a
- 90-day minimum; $p = 0.01$; positive trend +0.05/a



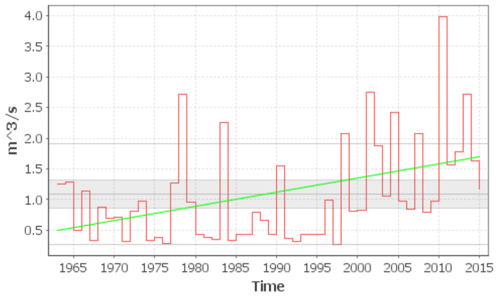
$MQ_{November}$



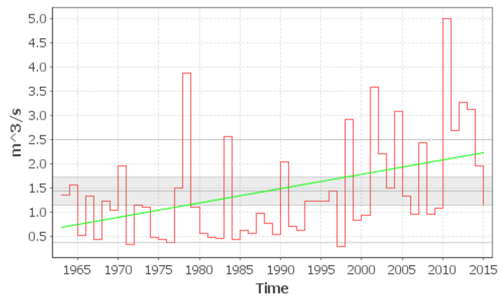
1-day minimum



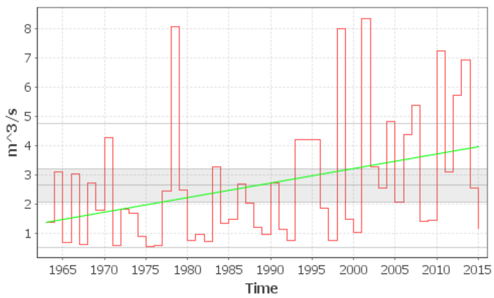
3-day minimum



7-day minimum



30-day minimum



90-day minimum

Figure 26: Apparent trends of $MQ_{November}$ and 1 to 90-day minimum data sets of 1LA03 Bomet Bridge

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APPENDIX A

A1: Catchment details HU0

CODE_1	CODE_2	NAME	NAME_1	AREA KM^2	TRIBUTARY	P_ANN	R_ANN	E_ANN
0	0	0	Mara	13508	0	949	79	871

P_ANN = average annual precipitation [mm/a], R_ANN = average annual runoff [mm/a], E_ANN = average annual evaporation [mm/a]

A2: Catchment details HU1

CODE_1	CODE_2	NAME	NAME_1	AREA KM^2	TRIBUTARY	P_ANN	R_ANN	E_ANN
1	0	IB_1	Mara	2275	0	926	45	881
2	0	LB_2	Somoche	690	1	957	48	909
3	0	IB_3	Mara	2225	0	1009	54	956
4	0	LB_4	Sand	1830	1	744	29	715
5	0	IB_5	Mara	422	0	917	44	873
6	0	LB_6	Talek	2664	1	781	32	749
7	0	IB_7	Mara	1056	0	1053	59	995
8	0	RB_8	Nyangores	932	1	1324	293	1031
9	0	IB_9	Amala	1415	0	1154	222	932

P_ANN = average annual precipitation [mm/a], R_ANN = average annual runoff [mm/a], E_ANN = average annual evaporation [mm/a]

A3: Catchment details HU2

CODE_1	CODE_2	NAME	NAME_1	AREA KM²	TRIBUTARY	P_ANN	R_ANN	E_ANN
1	**11**	IB_11	Mara	286	0	713	35	678
1	**12**	LB_12	Mara	235	1	675	33	642
1	**13**	IB_13	Mara	2	0	675	33	642
1	**14**	LB_14	Mara	205	1	714	35	679
1	**15**	IB_15	Mara	62	0	742	36	706
1	**16**	LB_16	Mara	665	1	1030	50	980
1	**17**	IB_17	Mara	204	0	1039	51	988
1	**18**	RB_18	Mara	349	1	1072	52	1020
1	**19**	IB_19	Mara	266	0	1045	51	994
2	**21**	IB_21	Somoche	179	0	993	50	943
2	**22**	RB_22	Somoche	231	1	945	48	897
2	**23**	IB_23	Somoche	280	0	945	48	897
3	**31**	IB_31	Mara	116	0	977	52	925
3	**32**	LB_32	Mara	363	1	946	50	895
3	**33**	IB_33	Mara	380	0	1130	60	1070
3	**34**	RB_34	Mara	382	1	1155	61	1093
3	**35**	IB_35	Mara	71	0	981	52	928
3	**36**	LB_36	Mara	178	1	948	50	897
3	**37**	IB_37	Mara	263	0	989	53	937
3	**38**	LB_38	Mara	421	1	891	47	844
3	**39**	IB_39	Mara	51	0	883	47	836

P_ANN = average annual precipitation [mm/a], R_ANN = average annual runoff [mm/a], E_ANN = average annual evaporation [mm/a]

CODE_1	CODE_2	NAME	NAME_1	AREA KM2	TRIBUTARY	P_ANN	R_ANN	E_ANN
4	**41**	IB_41	Sand	104	0	883	35	849
4	**42**	RB_42	Sand	117	1	883	35	849
4	**43**	IB_43	Sand	423	0	883	35	849
4	**44**	RB_44	Sand	70	1	869	34	835
4	**45**	IB_45	Sand	224	0	761	30	731
4	**46**	LB_46	Sand	135	1	641	25	616
4	**47**	IB_47	Sand	8	0	624	24	600
4	**48**	RB_48	Sand	349	1	613	24	589
4	**49**	IB_49	Sand	400	0	640	25	614
5	**51**	IB_51	Mara	3	0	883	43	840
5	**52**	LB_52	Mara	63	1	883	43	840
5	**53**	IB_53	Mara	73	0	936	45	891
5	**54**	RB_54	Mara	43	1	1000	48	951
5	**55**	IB_55	Mara	7	0	1000	48	951
5	**56**	LB_56	Mara	214	1	894	43	851
5	**57**	IB_57	Mara	20	0	1000	48	951
6	**61**	IB_61	Talek	14	0	1000	41	958
6	**62**	RB_62	Talek	900	1	873	36	837
6	**63**	IB_63	Talek	362	0	900	37	863
6	**64**	LB_64	Talek	339	1	663	27	636
6	**65**	IB_65	Talek	324	0	824	34	790
6	**66**	LB66	Talek	208	1	612	25	587
6	**67**	IB_67	Talek	28	0	638	26	612
6	**68**	RB_68	Talek	186	1	703	29	674
6	**69**	IB_69	Talek	303	0	620	26	594

P_ANN = average annual precipitation [mm/a], R_ANN = average annual runoff [mm/a], E_ANN = average annual evaporation [mm/a]

CODE_1	CODE_2	NAME	NAME_1	AREA KM2	TRIBUTARY	P_ANN	R_ANN	E_ANN
7	**71**	IB_71	Mara	60	0	1000	56	944
7	**72**	RB_72	Mara	225	1	1253	70	1183
7	**73**	IB_73	Mara	243	0	1126	63	1064
7	**74**	RB_74	Mara	127	1	1204	67	1137
7	**75**	IB_75	Mara	115	0	878	49	829
7	**76**	RB_76	Mara	78	1	842	47	795
7	**77**	IB_77	Mara	2	0	839	47	793
7	**78**	LB_78	Mara	70	1	888	49	839
7	**79**	IB_79	Mara	136	0	836	47	790
8	**81**	IB_81	Nyangores	273	0	1097	243	854
8	**82**	RB_82	Nyangores	267	1	1480	328	1152
8	**83**	IB_83	Nyangores	139	0	1485	329	1156
8	**84**	RB_84	Nyangores	115	1	1334	296	1039
8	**85**	IB_85	Nyangores	137	0	1302	288	1013
9	**91**	IB_91	Amala	61	0	890	171	719
9	**92**	RB_92	Amala	100	1	738	142	596
9	**93**	IB_93	Amala	265	0	960	184	776
9	**94**	RB_94	Amala	205	1	967	186	782
9	**95**	IB_95	Amala	313	0	1253	241	1012
9	**96**	LB_96	Amala	106	1	1468	282	1186
9	**97**	IB_97	Amala	76	0	1504	289	1215
9	**98**	RB_98	Amala	142	1	1359	261	1098
9	**99**	IB_99	Amala	146	0	1339	257	1081

P_ANN = average annual precipitation [mm/a], R_ANN = average annual runoff [mm/a], E_ANN = average annual evaporation [mm/a]

APPENDIX B

B1: Precipitation station details (original data)

NO.	Station_ID	Station_Name	LON	LAT	ANN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	FIRST	LAST	YEARS
1	9035031	DANSON K NGUGI SAW MILL	35.80	-0.38	1144	46	42	75	154	130	87	121	153	82	69	118	69	1960-01	1987-12	28.0
2	9035079	TENWEK MISSION SOTIK	35.37	-0.75	1470	107	98	151	254	158	95	72	94	90	96	135	120	1960-01	2002-02	42.2
3	9035085	OLENGURUONE D.O OFFICE MOLO	35.68	-0.58	1561	58	61	101	203	195	140	164	189	139	132	110	71	1960-01	2004-12	45.0
4	9035227	DISTRICT OFFICE BOMET	35.33	-0.78	1334	90	95	166	227	132	84	64	77	81	90	116	111	1960-02	1992-10	32.8
5	9035228	KIPTUNGA FOREST STATION ELBURGON	35.80	-0.46	1243	47	41	78	157	126	99	146	203	102	72	106	67	1961-01	2009-06	48.5
6	9035236	CHEPALUNGU FOREST STATION SOTIK	35.10	-0.90	1190	76	87	142	165	108	84	76	86	91	73	101	100	1970-01	1992-12	23.0
7	9035241	BARAGET FOREST STATION ELBURGON	35.73	-0.42	1164	39	46	69	142	125	94	149	187	92	70	96	54	1961-07	1997-12	36.5
8	9035260	KOIWA ESTATE KERICHO	35.32	-0.62	1796	70	101	146	253	254	144	129	162	134	143	160	100	1970-01	1992-12	23.0
9	9035265	BOMET WATER SUPPLY	35.35	-0.78	1402	99	93	165	232	145	92	70	86	82	85	137	114	1967-01	2009-06	42.5
10	9035284	MULOT POLICE POST	35.43	-0.93	1040	88	92	140	185	96	74	57	40	49	41	90	88	1973-10	1998-11	25.2
11	9035302	NYANGORES FOREST STATION	35.43	-0.70	1564	95	83	154	268	177	104	79	114	109	105	166	110	1979-08	2009-06	29.9
12	9133000	MUSOMA METEOROLOGICAL STATION	33.72	-1.50	866	52	70	111	192	105	30	19	15	29	67	91	85	1970-01	1992-12	23.0
13	9134008	NYABASSI	34.57	-1.35	1281	109	70	151	221	133	65	47	62	80	97	140	106	1970-01	1992-12	23.0
14	9134019	KISII NTIMARU AGRIC HOUSE	34.68	-1.33	1361	91	96	159	198	142	78	58	75	75	96	139	155	1970-01	1992-12	23.0
15	9134027	LOLGORIEN WATER SUPPLY	34.82	-1.23	1387	94	104	151	174	152	99	63	97	99	83	136	134	1970-01	1992-12	23.0
16	9134033	MUGUMU	34.72	-1.87	1086	98	98	134	153	114	51	35	60	58	67	102	115	1970-01	1992-12	23.0
17	9135001	NAROK METEOROLOGICAL STATION	35.87	-1.10	769	84	75	99	142	96	30	19	22	25	25	77	76	1960-01	2009-06	49.5
18	9135008	KABOSON GOSPEL MISSION SOTIK	35.23	-1.00	947	74	82	104	155	79	55	44	60	47	43	103	101	1960-06	1985-07	25.2
19	9135010	AITONG HYDROMET STATION SOTIK	35.25	-1.18	1075	111	102	125	166	74	55	49	62	66	31	125	110	1960-06	1989-03	28.8
20	9135013	KEEKOROK HYDROMET STATION NAROK	35.23	-1.58	1003	92	83	114	139	93	75	52	58	56	50	87	105	1965-01	1996-12	32.0
21	9135019	LEMEK MAASAI FARM	35.40	-1.10	798	99	83	92	117	83	53	50	33	37	27	50	76	1966-06	1993-09	27.4
22	9135022	AFRICA GOSPEL CHURCH NAIKARA	35.63	-1.55	641	77	66	72	81	61	43	30	29	47	15	67	52	1969-01	1988-05	19.4
23	9135025	ILKERIN INTEGRAL DEVELOPMENT PROJECT	35.70	-1.78	660	63	67	91	117	67	35	22	17	24	20	66	72	1973-04	1999-11	26.7
24	9135026	GOVERNORS CAMP	35.08	-1.28	1128	108	114	137	157	103	83	53	51	72	47	84	120	1973-02	1999-08	26.6
25	9135035	KICHWA TEMBO CAMP	35.02	-1.23	1637	154	116	189	219	164	94	80	99	77	88	161	195	1988-01	2002-12	15.0

LON/LAT = longitude/latitude [°], ANN = average annual precipitation [mm/a], JAN…DEC = average monthly precipitation [mm/month], FIRST/LAST = first/last data point, YEARS = data series length
[a]

B2: Precipitation station details (filled data)

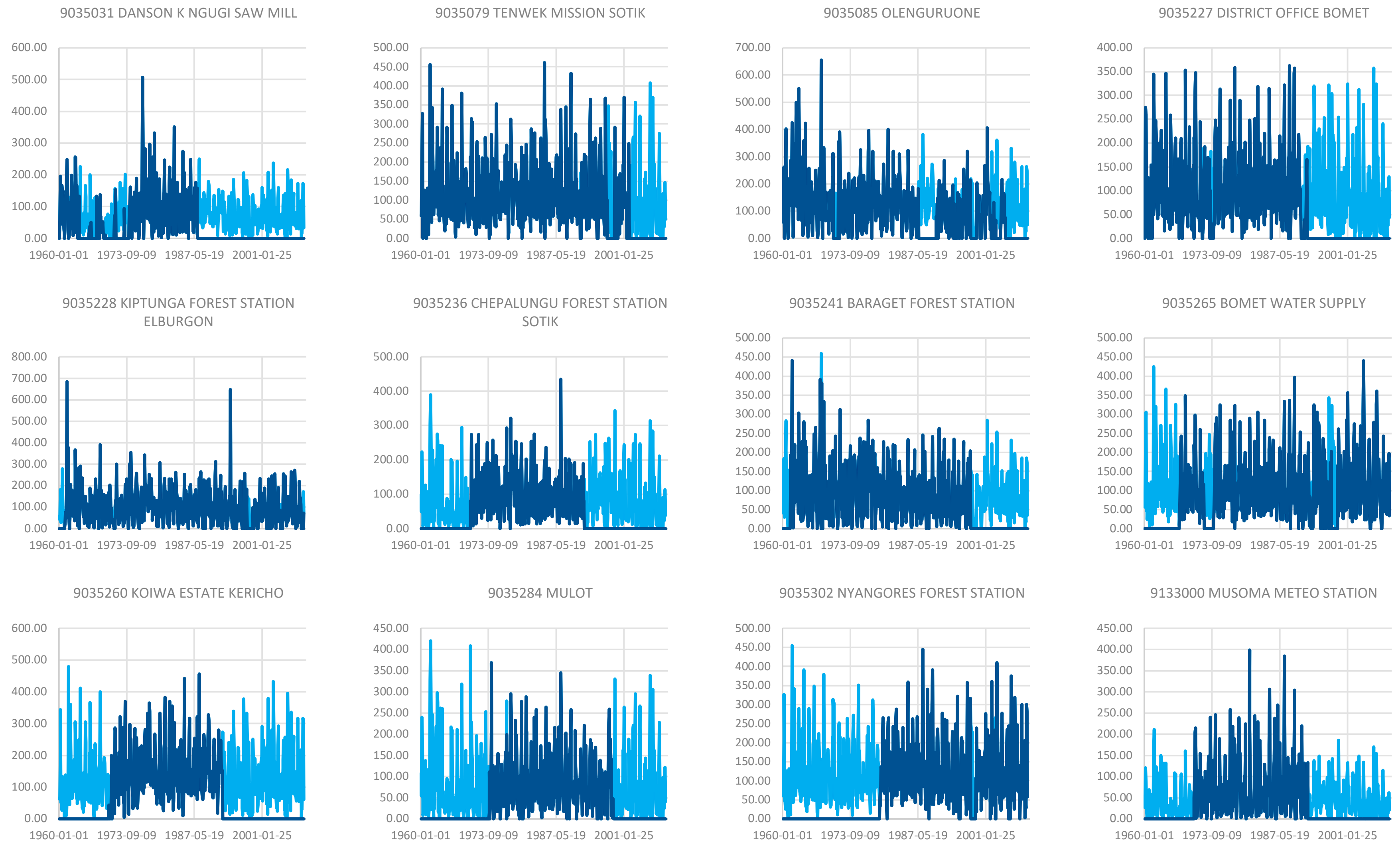
NO.	Station_ID	Station_Name	LON	LAT	ANN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	FIRST	LAST	YEARS
1	9035031	DANSON K NGUGI SAW MILL	35.80	-0.38	989	50	48	79	151	119	72	76	104	69	63	96	63	1960-01	2009-06	49.5
2	9035079	TENWEK MISSION SOTIK	35.37	-0.75	1360	103	97	144	238	151	79	61	79	78	79	134	115	1960-01	2009-06	49.5
3	9035085	OLENGURUONE D.O OFFICE MOLO	35.68	-0.58	1504	65	67	112	209	190	124	138	166	126	117	116	75	1960-01	2009-06	49.5
4	9035227	DISTRICT OFFICE BOMET	35.33	-0.78	1232	96	93	146	211	133	74	52	70	71	72	117	96	1960-01	2009-06	49.5
5	9035228	KIPTUNGA FOREST STATION ELBURGON	35.80	-0.46	1218	50	43	78	153	124	98	141	197	101	69	100	64	1960-01	2009-06	49.5
6	9035236	CHEPALUNGU FOREST STATION SOTIK	35.10	-0.90	1059	85	83	132	161	108	60	53	59	65	53	100	101	1960-01	2009-06	49.5
7	9035241	BARAGET FOREST STATION ELBURGON	35.73	-0.42	1123	43	46	76	146	124	88	125	161	90	78	95	52	1960-01	2009-06	49.5
8	9035260	KOIWA ESTATE KERICHO	35.32	-0.62	1656	89	100	146	265	214	119	95	132	111	116	161	108	1960-01	2009-06	49.5
9	9035265	BOMET WATER SUPPLY	35.35	-0.78	1376	101	96	150	236	149	88	64	82	83	82	139	107	1960-01	2009-06	49.5
10	9035284	MULOT POLICE POST	35.43	-0.93	965	97	89	127	173	103	49	36	33	40	34	95	88	1960-01	2009-06	49.5
11	9035302	NYANGORES FOREST STATION	35.43	-0.70	1493	100	94	150	260	172	96	75	100	96	94	145	110	1960-01	2009-06	49.5
12	9133000	MUSOMA METEOROLOGICAL STATION	33.72	-1.50	675	51	55	87	134	80	25	18	17	26	41	71	69	1960-01	2009-06	49.5
13	9134008	NYABASSI	34.57	-1.35	1041	94	70	128	177	113	48	37	45	57	62	112	97	1960-01	2009-06	49.5
14	9134019	KISII NTIMARU AGRIC HOUSE	34.68	-1.33	1206	98	93	149	187	132	59	46	56	60	66	125	134	1960-01	2009-06	49.5
15	9134027	LOLGORIEN WATER SUPPLY	34.82	-1.23	1096	92	93	127	155	122	65	40	62	63	51	118	108	1960-01	2009-06	49.5
16	9134033	MUGUMU	34.72	-1.87	945	95	88	118	148	110	38	25	42	41	44	100	96	1960-01	2009-06	49.5
17	9135001	NAROK METEOROLOGICAL STATION	35.87	-1.10	770	86	75	99	142	94	30	19	22	25	26	76	76	1960-01	2009-06	49.5
18	9135008	KABOSON GOSPEL MISSION SOTIK	35.23	-1.00	839	76	72	105	142	77	49	36	43	38	34	85	82	1960-01	2009-06	49.5
19	9135010	AITONG HYDROMET STATION SOTIK	35.25	-1.18	894	97	91	115	154	91	40	29	38	39	28	91	81	1960-01	2009-06	49.5
20	9135013	KEEKOROK HYDROMET STATION NAROK	35.23	-1.58	883	84	75	103	133	87	56	37	44	44	39	86	95	1960-01	2009-06	49.5
21	9135019	LEMEK MAASAI FARM	35.40	-1.10	707	78	69	87	115	83	33	29	25	29	24	64	69	1960-01	2009-06	49.5
22	9135022	AFRICA GOSPEL CHURCH NAIKARA	35.63	-1.55	611	67	62	74	98	68	29	19	24	27	18	63	61	1960-01	2009-06	49.5
23	9135025	ILKERIN INTEGRAL DEVELOPMENT PROJECT	35.70	-1.78	641	70	66	81	114	73	27	18	18	21	21	66	66	1960-01	2009-06	49.5
24	9135026	GOVERNORS CAMP	35.08	-1.28	1000	109	98	117	163	108	52	33	37	48	40	91	103	1960-01	2009-06	49.5
25	9135035	KICHWA TEMBO CAMP	35.02	-1.23	1330	136	121	160	211	143	70	49	53	64	58	122	141	1960-01	2009-06	49.5

LON/LAT = longitude/latitude [°], ANN = average annual precipitation [mm/a], JAN…DEC = average monthly precipitation [mm/month], FIRST/LAST = first/last data point, YEARS = data series length
[a]

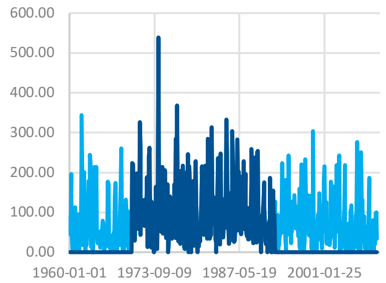
B3: Precipitation correlation matrix (monthly data)

r	9035031	9035079	9035085	9035227	9035228	9035236	9035241	9035260	9035265	9035284	9035302	9133000	9134008	9134019	9134027	9134033	9135001	9135008	9135010	9135013	9135019	9135022	9135025	9135026	9135035
9035031	1.00	0.14	0.28	0.18	0.31	0.10	0.25	0.31	0.15	0.14	0.24	0.17	0.13	0.16	0.19	0.07	0.07	0.09	0.04	0.14	0.07	0.07	0.14	0.04	-
9035079	0.14	1.00	0.40	0.84	0.38	0.64	0.37	0.57	0.84	0.65	0.80	0.59	0.53	0.45	0.44	0.53	0.72	0.67	0.56	0.59	0.59	0.59	0.59	0.58	0.63
9035085	0.28	0.40	1.00	0.38	0.63	0.41	0.73	0.57	0.34	0.27	0.48	0.21	0.24	0.13	0.29	0.15	0.34	0.41	0.34	0.24	0.28	0.33	0.23	0.24	0.24
9035227	0.18	0.84	0.38	1.00	0.45	0.62	0.38	0.50	0.92	0.70	0.76	0.62	0.57	0.54	0.46	0.58	0.71	0.66	0.65	0.61	0.60	0.61	0.68	0.60	0.70
9035228	0.31	0.38	0.63	0.45	1.00	0.45	0.79	0.55	0.39	0.32	0.44	0.25	0.23	0.26	0.27	0.17	0.34	0.44	0.37	0.29	0.40	0.35	0.24	0.23	0.20
9035236	0.10	0.64	0.41	0.62	0.45	1.00	0.40	0.48	0.64	0.63	0.66	0.50	0.48	0.41	0.45	0.44	0.61	0.59	0.63	0.62	0.58	0.54	0.56	0.58	0.74
9035241	0.25	0.37	0.73	0.38	0.79	0.40	1.00	0.53	0.29	0.26	0.45	0.21	0.17	0.18	0.20	0.10	0.31	0.39	0.42	0.18	0.32	0.31	0.14	0.20	0.15
9035260	0.31	0.57	0.57	0.50	0.55	0.48	0.53	1.00	0.56	0.58	0.77	0.50	0.39	0.39	0.40	0.36	0.45	0.36	0.41	0.41	0.38	0.34	0.43	0.45	0.55
9035265	0.15	0.84	0.34	0.92	0.39	0.64	0.29	0.56	1.00	0.65	0.73	0.64	0.58	0.52	0.47	0.54	0.70	0.68	0.63	0.62	0.64	0.61	0.63	0.59	0.58
9035284	0.14	0.65	0.27	0.70	0.32	0.63	0.26	0.58	0.65	1.00	0.69	0.66	0.54	0.49	0.49	0.61	0.77	0.80	0.73	0.67	0.71	0.71	0.63	0.66	0.58
9035302	0.24	0.80	0.48	0.76	0.44	0.66	0.45	0.77	0.73	0.69	1.00	0.65	0.59	0.46	0.41	0.50	0.70	0.60	0.57	0.59	0.61	0.61	0.56	0.63	0.61
9133000	0.17	0.59	0.21	0.62	0.25	0.50	0.21	0.50	0.64	0.66	0.65	1.00	0.57	0.55	0.46	0.59	0.60	0.60	0.54	0.56	0.47	0.47	0.56	0.61	0.64
9134008	0.13	0.53	0.24	0.57	0.23	0.48	0.17	0.39	0.58	0.54	0.59	0.57	1.00	0.56	0.41	0.49	0.58	0.58	0.48	0.50	0.42	0.41	0.53	0.50	0.35
9134019	0.16	0.45	0.13	0.54	0.26	0.41	0.18	0.39	0.52	0.49	0.46	0.55	0.56	1.00	0.47	0.46	0.50	0.48	0.49	0.49	0.44	0.27	0.45	0.53	0.63
9134027	0.19	0.44	0.29	0.46	0.27	0.45	0.20	0.40	0.47	0.49	0.41	0.46	0.41	0.47	1.00	0.46	0.45	0.54	0.65	0.50	0.38	0.49	0.48	0.41	0.27
9134033	0.07	0.53	0.15	0.58	0.17	0.44	0.10	0.36	0.54	0.61	0.50	0.59	0.49	0.46	0.46	1.00	0.61	0.62	0.53	0.51	0.49	0.53	0.58	0.57	0.62
9135001	0.07	0.72	0.34	0.71	0.34	0.61	0.31	0.45	0.70	0.77	0.70	0.60	0.58	0.50	0.45	0.61	1.00	0.77	0.74	0.69	0.74	0.71	0.76	0.75	0.62
9135008	0.09	0.67	0.41	0.66	0.44	0.59	0.39	0.36	0.68	0.80	0.60	0.60	0.58	0.48	0.54	0.62	0.77	1.00	0.70	0.67	0.71	0.72	0.70	0.69	-
9135010	0.04	0.56	0.34	0.65	0.37	0.63	0.42	0.41	0.63	0.73	0.57	0.54	0.48	0.49	0.65	0.53	0.74	0.70	1.00	0.71	0.70	0.71	0.74	0.59	0.74
9135013	0.14	0.59	0.24	0.61	0.29	0.62	0.18	0.41	0.62	0.67	0.59	0.56	0.50	0.49	0.50	0.51	0.69	0.67	0.71	1.00	0.63	0.70	0.69	0.64	0.66
9135019	0.07	0.59	0.28	0.60	0.40	0.58	0.32	0.38	0.64	0.71	0.61	0.47	0.42	0.44	0.38	0.49	0.74	0.71	0.70	0.63	1.00	0.64	0.63	0.68	0.62
9135022	0.07	0.59	0.33	0.61	0.35	0.54	0.31	0.34	0.61	0.71	0.61	0.47	0.41	0.27	0.49	0.53	0.71	0.72	0.71	0.70	0.64	1.00	0.77	0.62	-
9135025	0.14	0.59	0.23	0.68	0.24	0.56	0.14	0.43	0.63	0.63	0.56	0.56	0.53	0.45	0.48	0.58	0.76	0.70	0.74	0.69	0.63	0.77	1.00	0.67	0.61
9135026	0.04	0.58	0.24	0.60	0.23	0.58	0.20	0.45	0.59	0.66	0.63	0.61	0.50	0.53	0.41	0.57	0.75	0.69	0.59	0.64	0.68	0.62	0.67	1.00	0.74
9135035	-	0.63	0.24	0.70	0.20	0.74	0.15	0.55	0.58	0.58	0.61	0.64	0.35	0.63	0.27	0.62	0.62	-	0.74	0.66	0.62		0.61	0.74	1.00

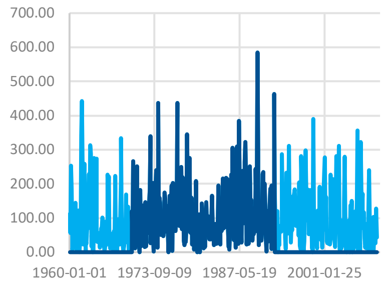
B4: Filled monthly precipitation time series



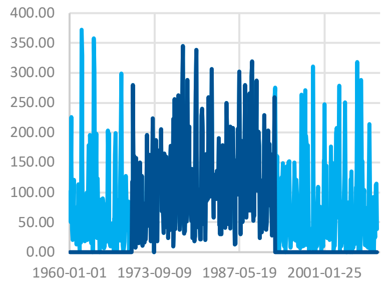
9134008 NYABASSI



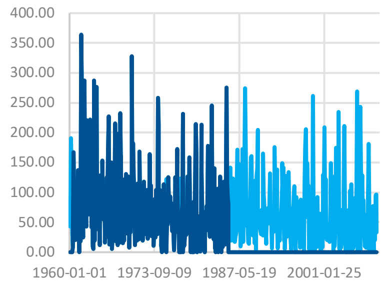
9134019 KISII NTIMARU AGRIC HOUSE



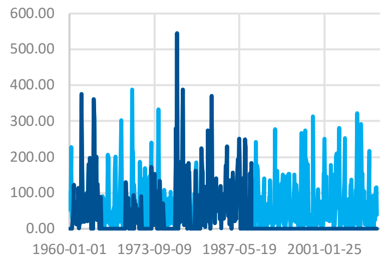
9134027 LOLGORIEN WS



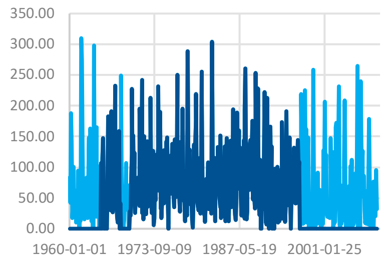
9135008 KABOSON GOSPEL MISSION SOTIK



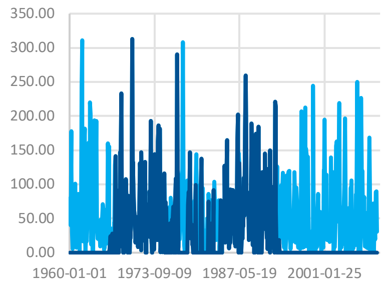
9135010 AITONG HYDROMET STATION SOTIK



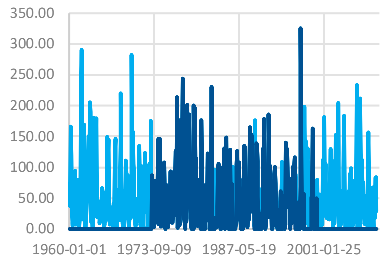
9135013 KEEKOROK HYDROMET STATION NAROK



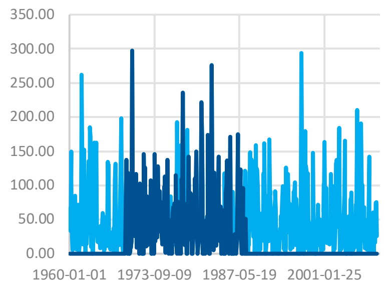
9135019 LEMEK



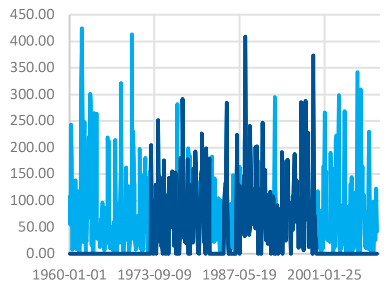
9135025 ILKERIN INTEGRAL DEVELOPMENT PROJECT



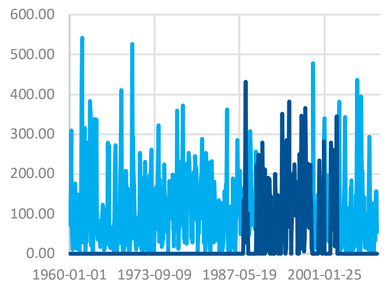
9135022 AFRICA GOSPEL CHURCH NAIKARA



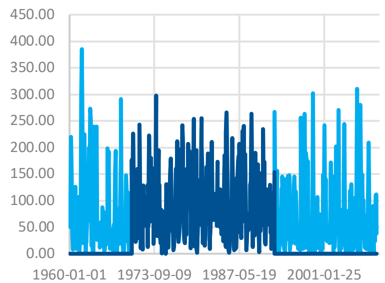
9135026 GOVERNORS CAMP



9135035 KICHWA TEMBO CAMP



9134033 MUGUMU



BLUE = original data; RED = filled data

APPENDIX C

C1: Hydrometric station details (original data)

NO.	Station_ID	Station_Name	LON	LAT	ANN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEARS
1	1LA03	Bomet Bridge	35.35	-0.79	7.60	3.52	3.04	2.78	7.76	12.34	9.35	9.29	10.93	12.80	8.23	6.63	4.99	51.4
2	1LA04	Kichwa Tembo	35.04	-1.22	7.55	5.00	6.82	6.39	7.65	10.28	8.91	10.01	9.22	8.67	6.48	6.97	5.86	45
3	1LA06	Emarti	35.23	-1.06	20.05	5.24	10.34	19.42	37.69	42.97	22.82	20.16	28.59	17.77	11.74	10.10	11.84	2.7
4	1LB02	Kapkimolwa	35.44	-0.89	7.19	5.46	2.69	3.81	8.58	14.47	7.49	6.98	11.62	11.37	6.75	3.77	4.56	59.5
5	5H2	Mara Mines	34.55	-1.55	30.47	15.79	17.23	39.57	83.09	60.50	38.23	22.96	22.54	27.73	15.85	23.26	35.99	42.9

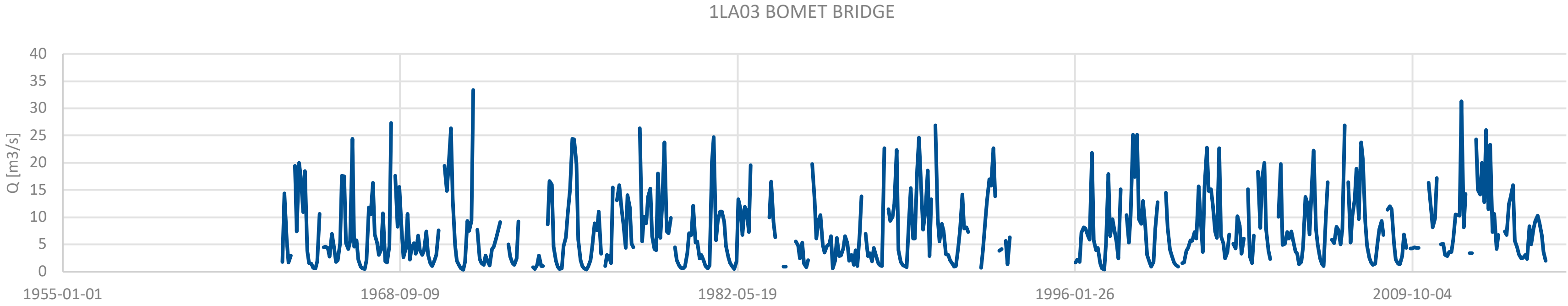
LON/LAT = longitude/latitude [°], ANN = average annual discharge [m^3/s], JAN…DEC = average monthly discharge [m^3/s], YEARS = data series length [a]

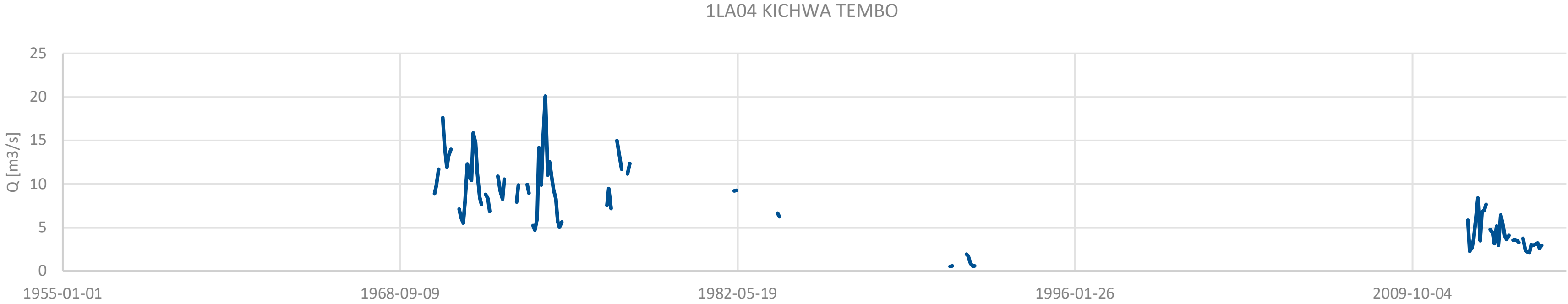
C2: Hydrometric station details (filled data)

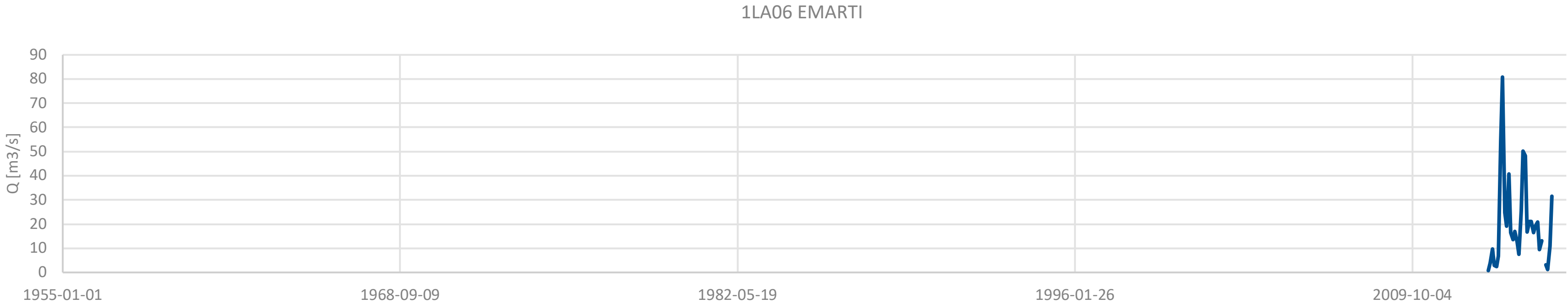
NO.	Station_ID	Station_Name	LON	LAT	ANN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEARS
1	1LA03	Bomet Bridge	35.35	-0.79	7.76	4.10	3.60	3.29	8.12	13.20	9.26	8.88	10.48	12.45	8.13	6.31	5.48	64
2	1LA04	Kichwa Tembo	35.04	-1.22	20.28	14.73	11.17	11.01	26.42	37.01	21.61	19.27	24.54	30.16	18.43	14.67	15.24	64
3	1LA06	Emarti	35.23	-1.06	19.68	12.43	9.25	10.05	25.18	36.14	21.69	19.74	26.60	30.03	17.95	13.63	13.69	64
4	1LB02	Kapkimolwa	35.44	-0.89	7.37	4.75	2.60	3.43	9.52	14.31	7.57	7.19	11.73	11.98	6.98	4.31	4.23	64
5	5H2	Mara Mines	34.55	-1.55	31.24	23.01	18.75	25.95	53.90	63.44	33.68	24.44	27.24	33.93	21.21	21.59	28.66	64

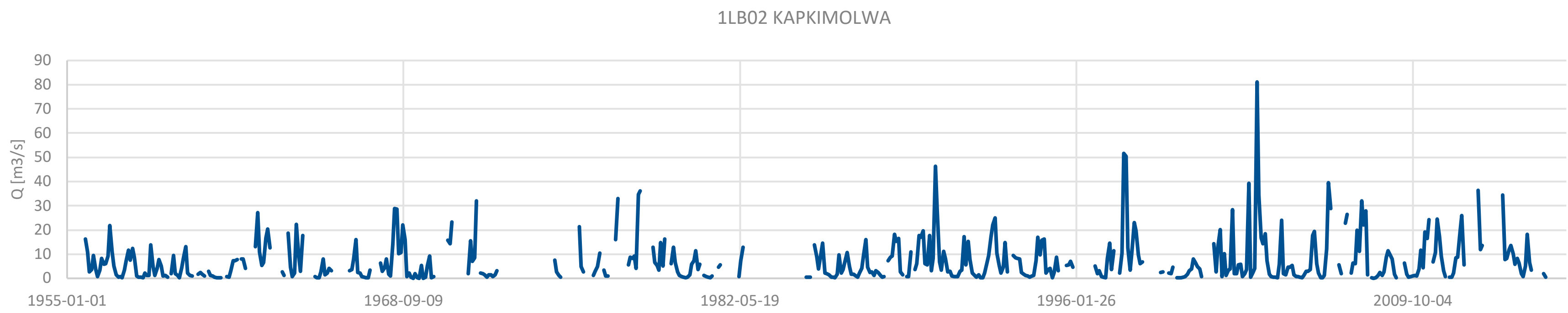
LON/LAT = longitude/latitude [°], ANN = average annual discharge [m^3/s], JAN…DEC = average monthly discharge [m^3/s], YEARS = data series length [a]

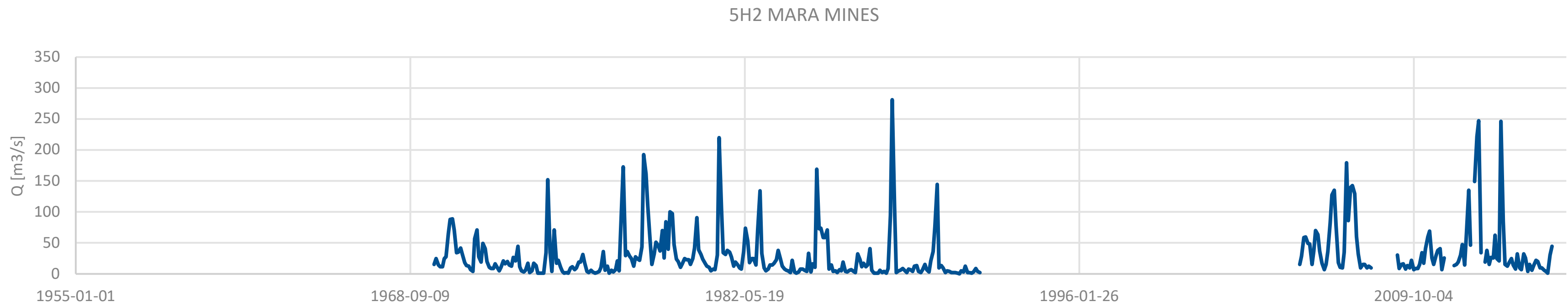
C3: Available monthly discharge time series



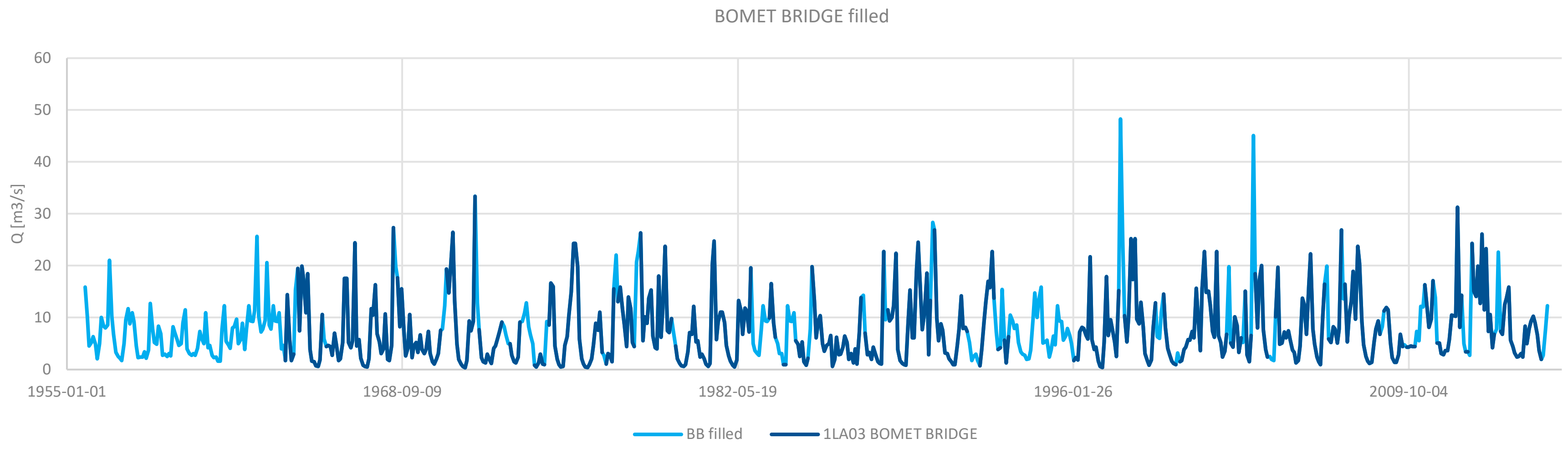


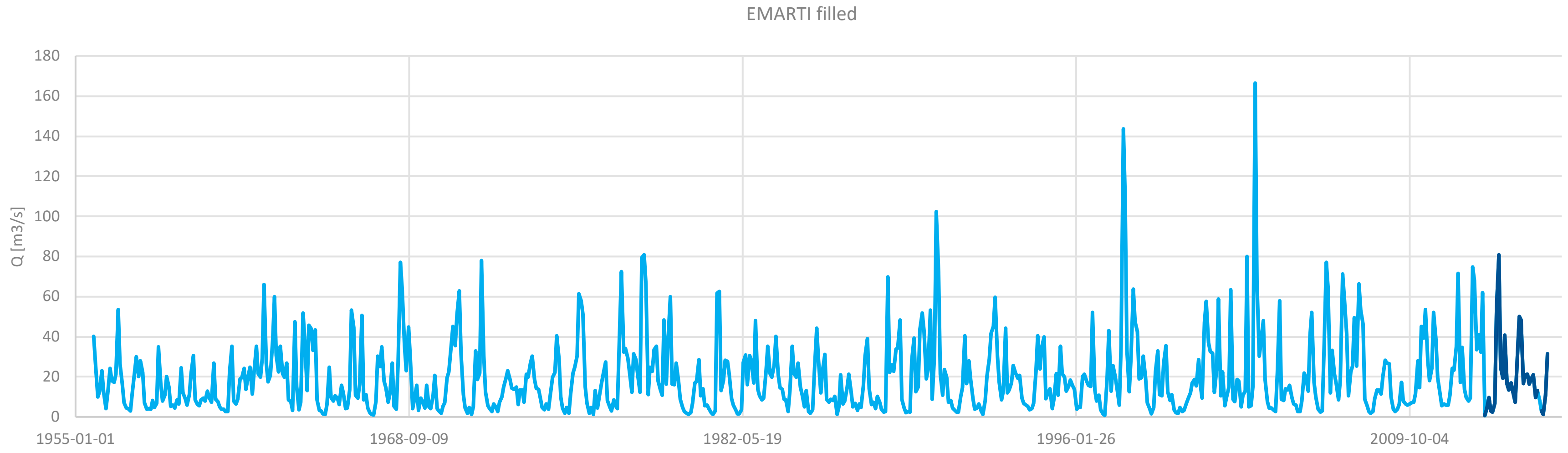


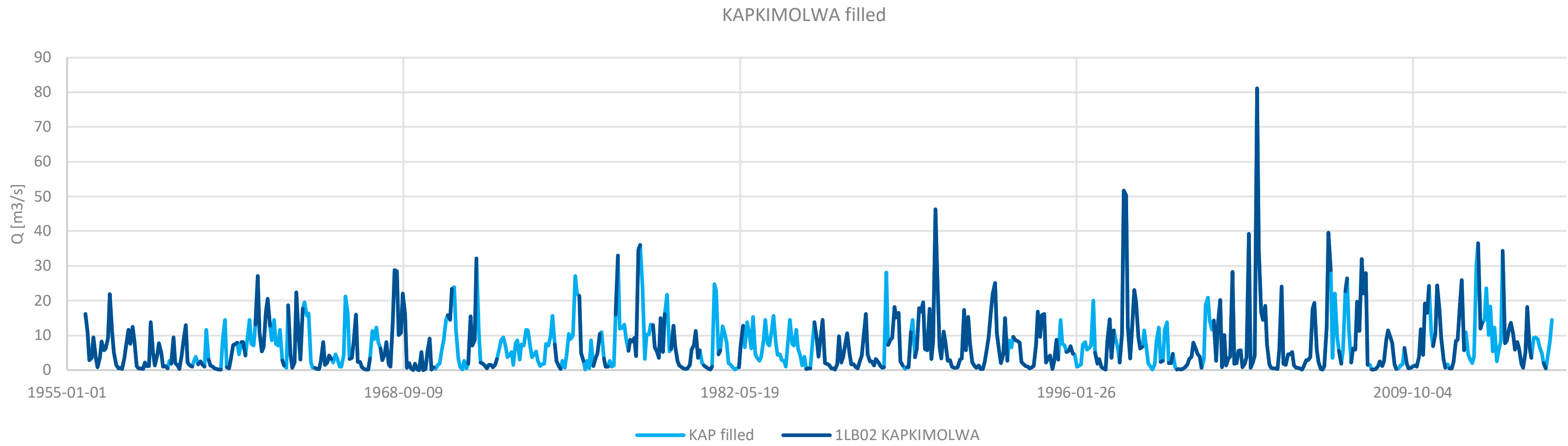

1LB02 KAPKIMOLWA
Q [m3/s]
90
80
70
60
50
40
30
20
10
0
1955-01-01
1968-09-09
1982-05-19
1996-01-26
2009-10-04

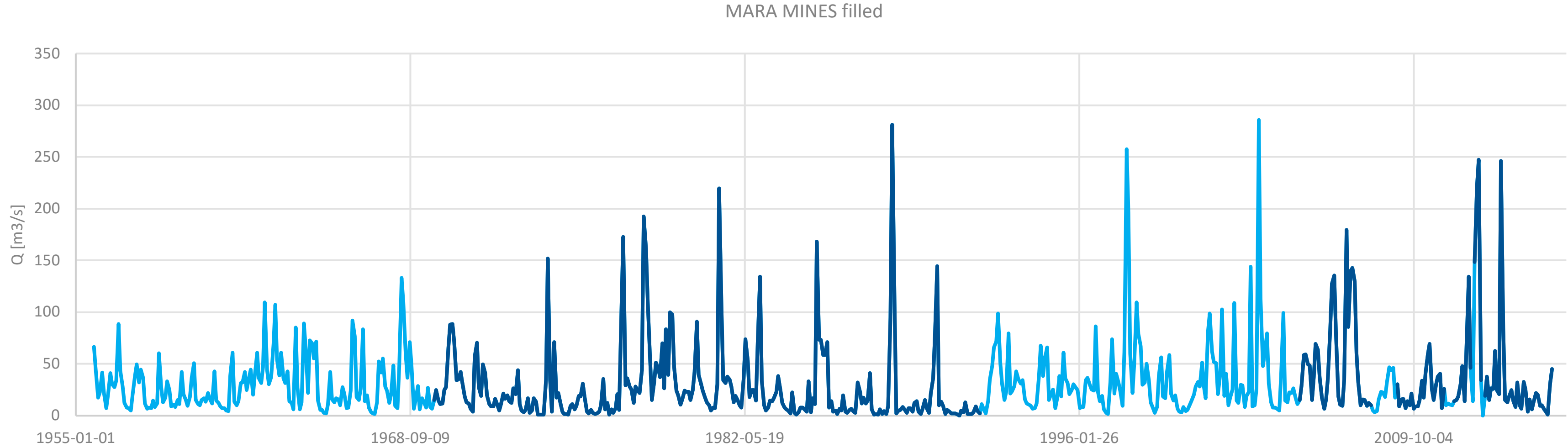

5H2 MARA MINES
Q [m3/s]
350
300
250
200
150
100
50
0
1955-01-01
1968-09-09
1982-05-19
1996-01-26
2009-10-04

C4: Filled monthly discharge time series









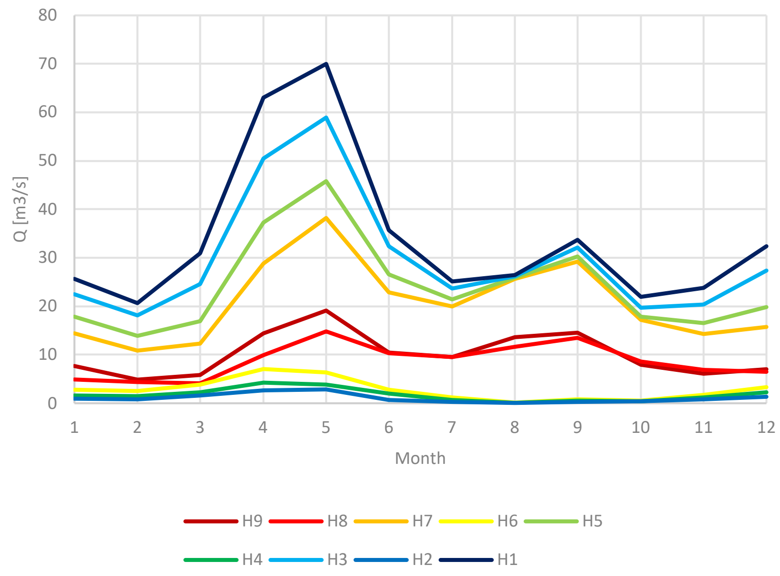
BLUE = original data; RED = filled data

APPENDIX D

D1a: Regionalized mean flow values for hydrological units level 1 (HU1)

Q [m³/s]									
MONTH	H9	H8	H7	H6	H5	H4	H3	H2	H1
1	7.61	4.92	14.33	2.82	17.69	1.60	22.28	0.94	25.46
2	4.81	4.32	10.71	2.54	13.71	1.44	17.88	0.83	20.37
3	5.75	4.08	12.21	3.76	16.72	2.27	24.25	1.53	30.49
4	14.32	9.87	28.73	7.02	37.13	4.23	50.31	2.60	62.74
5	19.24	14.93	38.46	6.37	46.07	3.81	59.21	2.85	70.24
6	10.37	10.27	22.74	2.79	26.38	2.04	32.09	0.73	35.38
7	9.50	9.48	19.96	1.16	21.42	0.73	23.62	0.28	25.12
8	13.60	11.59	25.71	0.13	25.88	0.09	26.21	0.06	26.42
9	14.51	13.55	29.16	0.87	30.26	0.52	32.15	0.34	33.76
10	7.93	8.58	17.20	0.54	17.91	0.39	19.75	0.40	21.98
11	6.14	6.89	14.31	1.79	16.47	1.17	20.41	0.82	23.80
12	6.98	6.43	15.78	3.29	19.89	2.29	27.33	1.31	32.36
ANNUAL	9.95	8.67	20.58	2.72	23.89	1.69	29.37	1.06	33.68

H9…H1 = Number of catchment for hydrological units level 1; discharge [m³/s]



D1b: Regionalized water availability for hydrological units level 1 (HU1)

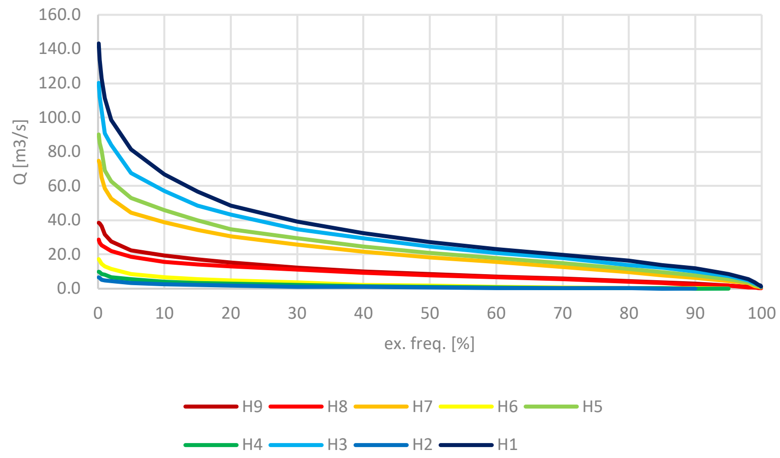
Q [m³/d]									
MONTH	H9	H8	H7	H6	H5	H4	H3	H2	H1
NAME	Amala	Nyangores	Mara	Talek	Mara	Sand	Serengeti	Somoche	Mara
1	662782	428421	1247778	245609	1540341	139615	1940079	81723	2217596
2	420982	377959	938153	222258	1200934	126598	1566108	72446	1784524
3	502431	355384	1067546	329885	1463413	199112	2124274	134442	2672524
4	1240600	852306	2486667	609724	3216893	367406	4361633	226143	5445450
5	1651857	1280481	3301763	549087	3957950	328550	5091532	246637	6047262
6	903051	896532	1981428	241476	2297070	176935	2792738	62944	3078530
7	820717	818888	1724771	99862	1850594	63003	2041027	23936	2170150
8	1175177	1001286	2221236	11497	2235934	7648	2264324	5245	2282526
9	1253960	1170910	2519769	75288	2614698	45040	2777617	29227	2917218
10	685285	740970	1485811	46367	1547198	33868	1706000	34460	1899067
11	530405	595100	1236308	154654	1423235	100828	1763728	70580	2056659
12	603218	555447	1363366	284306	1718913	197819	2361169	112999	2795777
ANNUAL	870872	756140	1797883	239168	2088931	148869	2565852	91732	2947274

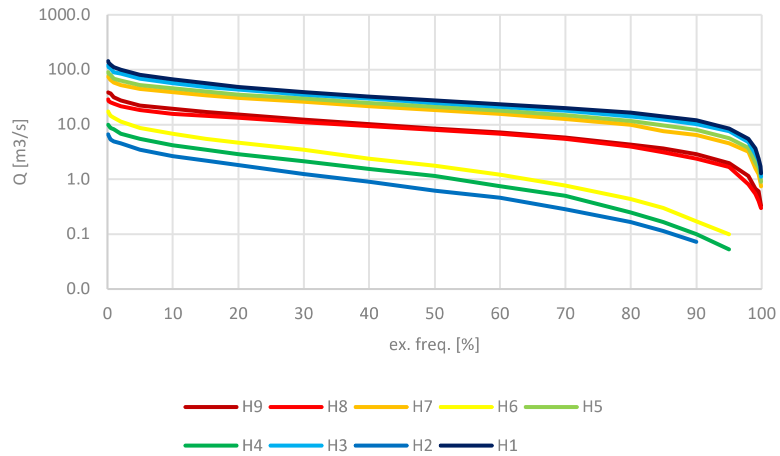
H9…H1 = Number of catchment for hydrological units level 1; water availability [m^3/d]

D2: Regionalized annual flow duration curves for hydrological units level 1 (HU1)

Percentile	H9	H8	H7	H6	H5	H4	H3	H2	H1
0.1	38.5	28.7	74.7	17.3	90.1	9.9	120.2	6.6	143.2
0.2	38.1	26.8	73.0	16.6	85.2	9.6	112.1	6.3	133.7
0.5	36.7	25.4	65.0	14.4	80.6	8.7	104.0	5.3	122.9
1	31.6	24.1	58.6	13.2	68.9	8.1	90.7	5.0	111.1
2	27.7	21.8	52.7	11.4	62.8	6.8	84.0	4.5	98.5
5	22.4	18.5	44.3	8.6	52.9	5.4	67.7	3.4	81.4
10	19.3	15.7	38.8	6.7	46.0	4.2	57.2	2.6	66.8
15	17.0	14.3	34.4	5.5	40.1	3.5	48.4	2.2	56.6
20	15.2	13.2	30.4	4.7	34.8	2.9	43.2	1.8	48.4
30	12.3	11.0	25.8	3.5	29.6	2.1	34.8	1.2	39.3
40	10.2	9.4	21.8	2.4	24.6	1.5	29.5	0.9	32.6
50	8.5	8.0	18.1	1.8	20.8	1.1	24.8	0.6	27.4
60	7.1	6.8	15.6	1.2	17.7	0.8	20.7	0.5	23.2
70	5.8	5.5	12.7	0.8	14.8	0.5	17.9	0.3	19.7
80	4.4	4.0	9.8	0.4	11.6	0.2	13.9	0.2	16.3
85	3.6	3.1	7.6	0.3	9.7	0.2	12.4	0.1	13.9
90	2.9	2.4	6.5	0.2	7.9	0.1	10.1	0.1	12.1
95	2.0	1.7	4.5	0.1	5.7	0.1	7.6		8.4
98	1.1	0.8	3.2		3.7		4.7		5.5
99	0.7	0.5	1.6		2.0		2.9		3.6
99.5	0.6	0.4	1.2		1.6		2.2		2.4
99.8	0.4	0.3	0.9		1.1		1.5		1.7

H9…H1 = Number of catchment for hydrological units level 1; discharge [m³/s]





D3: Regionalized monthly flow duration curves for hydrological units level 1 (HU1)

H9

Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	27.36	11.78	14.36	26.77	38.62	21.44	24.21	29.19	31.41	22.89	21.47	26.71
0.2	27.04	11.69	14.25	26.75	38.61	21.38	24.05	28.97	31.30	22.56	21.25	26.47
0.5	26.08	11.44	13.94	26.69	38.58	21.21	23.55	28.29	30.99	21.58	20.61	25.77
1	24.47	11.01	13.42	26.59	38.53	20.92	22.71	27.17	30.45	19.93	19.53	24.60
2	21.27	10.15	12.39	26.39	38.42	20.35	21.05	24.91	29.39	16.65	17.37	22.26
5	19.27	9.91	11.92	24.49	36.78	19.00	18.49	22.43	28.11	14.34	12.73	17.67
10	16.22	9.78	10.65	21.98	32.00	15.17	16.03	20.89	25.18	12.22	11.56	14.76
15	13.97	9.29	9.68	20.51	27.43	14.66	14.98	20.06	21.43	10.61	10.76	10.98
20	12.71	7.44	8.08	18.98	23.89	13.11	13.26	17.42	19.80	10.25	9.45	9.31
30	8.87	5.78	7.26	17.15	20.38	12.20	11.12	16.06	17.47	8.72	7.22	7.64
40	7.04	4.42	6.32	15.43	19.28	11.69	9.05	15.10	15.25	8.08	5.82	6.59
50	6.07	4.06	5.32	14.01	18.26	9.85	8.51	13.31	13.53	7.56	4.96	5.87
60	4.44	3.48	4.38	12.85	17.21	8.81	7.87	11.06	12.00	6.07	4.33	5.32
70	3.68	2.94	3.35	11.64	15.42	8.04	6.65	10.01	10.10	5.74	3.68	4.87
80	2.88	2.54	2.84	9.51	13.77	7.38	5.87	9.48	8.48	5.28	2.95	3.42
85	2.67	1.59	2.30	8.82	12.36	6.99	5.55	8.44	8.11	5.08	2.84	2.66
90	2.40	1.30	1.92	7.66	8.66	6.70	4.84	7.82	6.02	4.12	2.25	2.34
95	1.64	0.99	1.63	5.28	7.54	5.46	4.18	6.33	5.01	2.79	1.58	1.56
98	0.70	0.38	1.12	3.74	5.79	4.71	3.51	4.06	3.44	2.24	1.31	0.82
99	0.66	0.38	0.87	3.16	5.09	3.92	2.09	3.86	2.81	2.11	1.20	0.74
99.5	0.65	0.38	0.74	2.86	4.74	3.52	1.37	3.76	2.49	2.04	1.15	0.71
99.8	0.64	0.38	0.66	2.69	4.53	3.29	0.95	3.70	2.30	2.00	1.11	0.69
99.9	0.63	0.38	0.64	2.63	4.46	3.21	0.80	3.68	2.24	1.98	1.10	0.68

H8

Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	13.62	10.66	9.73	16.73	26.28	19.00	21.72	23.09	30.91	26.45	23.84	17.73
0.2	13.61	10.62	9.70	16.71	26.23	18.91	21.55	23.03	30.64	25.98	23.48	17.72
0.5	13.57	10.49	9.62	16.66	26.06	18.67	21.03	22.82	29.83	24.58	22.43	17.70
1	13.51	10.29	9.50	16.56	25.77	18.27	20.16	22.48	28.48	22.25	20.67	17.67
2	13.38	9.87	9.24	16.38	25.21	17.45	18.43	21.79	25.78	17.58	17.16	17.61
5	12.43	9.65	8.59	15.66	21.49	16.95	17.45	19.27	23.79	15.54	14.35	15.60
10	10.33	8.32	7.22	14.33	20.07	15.52	15.66	15.67	21.90	14.91	11.89	13.87
15	9.47	8.09	7.17	13.15	19.37	13.56	14.39	15.18	20.40	12.46	10.93	10.35
20	7.12	7.18	5.57	12.75	18.82	13.34	13.92	14.46	18.42	11.65	10.55	8.67
30	6.04	4.81	5.12	12.19	18.37	11.39	11.11	13.51	16.25	9.29	7.48	6.89
40	5.15	4.25	4.48	11.33	15.97	10.85	9.92	12.61	13.46	7.85	6.49	6.44
50	4.07	3.65	4.06	9.31	14.80	10.23	9.05	12.10	12.26	7.51	5.69	5.92
60	2.89	3.22	3.64	8.82	13.90	9.55	8.16	10.01	11.28	7.10	5.37	5.47
70	2.38	2.40	2.37	7.85	12.55	8.83	7.58	9.41	10.48	6.73	4.70	4.26
80	2.23	2.11	1.96	7.00	11.18	8.14	6.07	9.02	9.10	5.54	3.83	3.09
85	1.95	1.59	1.43	6.78	9.89	7.43	5.64	7.88	8.82	5.31	3.12	2.50
90	1.76	1.35	1.12	5.79	8.50	6.88	5.16	7.52	7.16	5.14	2.48	2.16
95	1.19	0.77	0.89	3.99	7.79	6.29	3.33	5.94	5.63	2.44	1.76	1.75
98	0.54	0.45	0.64	2.80	4.45	5.22	2.47	3.54	2.43	1.63	1.67	0.60
99	0.43	0.38	0.64	2.79	4.41	4.32	1.46	3.25	1.90	1.59	1.60	0.50
99.5	0.38	0.35	0.64	2.78	4.39	3.87	0.96	3.10	1.63	1.57	1.57	0.45
99.8	0.34	0.33	0.64	2.77	4.38	3.60	0.66	3.02	1.47	1.56	1.56	0.43
99.9	0.33	0.32	0.64	2.77	4.38	3.51	0.56	2.99	1.42	1.56	1.55	0.42

H7

Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	47.81	24.70	30.03	52.19	75.66	42.95	49.17	53.75	63.42	50.09	50.08	53.27
0.2	47.33	24.59	29.85	52.09	75.58	42.91	48.76	53.24	63.01	49.25	49.48	52.93
0.5	45.89	24.29	29.31	51.79	75.34	42.78	47.53	51.71	61.77	46.73	47.67	51.92
1	43.48	23.78	28.41	51.30	74.94	42.58	45.47	49.17	59.72	42.53	44.67	50.22
2	38.67	22.76	26.60	50.32	74.13	42.17	41.36	44.08	55.60	34.14	38.66	46.84
5	35.76	21.91	24.77	48.14	67.34	40.00	37.46	41.99	54.05	32.27	29.64	38.36
10	28.05	20.62	21.84	43.50	58.85	34.46	33.51	39.28	48.26	27.01	25.65	33.81
15	26.64	20.39	21.05	40.47	50.93	30.71	31.20	34.78	44.21	24.85	24.42	24.60
20	23.67	17.31	16.05	37.36	48.75	27.40	29.26	33.25	39.85	22.99	21.83	21.45
30	17.28	12.57	15.40	35.38	42.62	26.38	22.86	30.14	35.34	18.09	16.03	16.92
40	13.89	10.63	13.74	31.14	39.49	25.67	20.26	27.73	28.39	16.81	12.91	14.61
50	11.51	9.11	12.69	28.12	38.83	22.87	17.90	26.13	26.76	15.73	11.50	13.26
60	8.55	7.62	9.61	26.21	35.53	20.55	17.06	22.03	23.45	13.67	10.96	12.49
70	7.34	7.04	6.92	23.50	32.17	18.75	14.50	20.06	21.92	12.66	9.25	11.57
80	5.95	5.45	6.08	19.24	26.40	16.32	12.89	18.23	19.17	11.73	7.24	7.93
85	5.36	3.82	5.19	18.21	25.69	15.85	11.78	17.72	17.42	11.34	6.13	6.55
90	4.93	3.21	4.29	16.42	18.67	14.78	10.41	15.56	14.51	9.36	5.11	5.50
95	3.71	2.48	3.97	10.87	17.28	12.69	8.42	12.68	9.75	5.78	3.51	3.92
98	1.43	0.88	3.22	7.63	11.71	10.68	6.96	7.83	7.75	5.34	3.48	1.59
99	1.35	0.87	2.61	6.94	10.40	8.65	4.39	7.60	7.29	4.48	3.42	1.56
99.5	1.31	0.86	2.30	6.60	9.75	7.63	3.10	7.49	7.06	4.05	3.40	1.55
99.8	1.29	0.86	2.11	6.39	9.36	7.02	2.33	7.43	6.93	3.80	3.38	1.54
99.9	1.28	0.86	2.05	6.32	9.22	6.82	2.07	7.40	6.88	3.71	3.37	1.54

H6
Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	10.70	5.12	11.08	16.86	17.52	7.40	5.45	0.41	3.20	1.53	6.54	12.89
0.2	10.53	5.11	11.02	16.76	17.37	7.37	5.36	0.41	3.17	1.53	6.50	12.73
0.5	9.99	5.06	10.83	16.45	16.92	7.29	5.11	0.39	3.06	1.52	6.37	12.25
1	9.11	4.97	10.51	15.95	16.18	7.16	4.68	0.36	2.89	1.50	6.17	11.44
2	7.33	4.80	9.87	14.93	14.68	6.90	3.83	0.31	2.54	1.45	5.75	9.83
5	6.00	4.73	7.82	14.09	12.61	6.39	3.45	0.30	1.91	1.13	5.51	8.13
10	5.57	4.43	6.59	12.03	10.79	5.58	2.46	0.25	1.71	0.95	4.33	6.53
15	5.33	4.25	5.82	11.07	9.72	4.86	2.17	0.24	1.47	0.87	3.40	5.53
20	4.72	4.03	5.01	9.85	8.99	4.43	1.90	0.21	1.26	0.78	2.94	4.66
30	3.26	3.30	4.65	8.44	8.29	4.04	1.44	0.17	1.11	0.65	1.82	3.67
40	2.86	2.65	4.13	7.53	6.96	3.58	1.03	0.13	0.87	0.54	1.52	3.21
50	2.37	2.37	3.45	6.71	6.27	2.76	0.90	0.12	0.69	0.44	1.23	2.44
60	1.96	1.90	2.77	6.15	5.49	1.82	0.67	0.11	0.53	0.39	0.95	2.29
70	1.68	1.62	2.06	5.01	4.27	1.41	0.55	0.09	0.47	0.34	0.83	2.05
80	1.34	1.35	1.87	4.28	3.25	0.98	0.27	0.05	0.34	0.28	0.62	1.81
85	0.81	1.22	1.69	3.70	2.55	0.77	0.22	0.04	0.27	0.26	0.57	1.49
90	0.72	1.02	1.48	3.08	2.13	0.41	0.17	0.03	0.19	0.16	0.47	1.27
95	0.52	0.55	1.18	1.51	1.37	0.16	0.07	0.02	0.16	0.13	0.27	0.56
98	0.35	0.16	0.92	1.11	1.19	0.09	0.03	0.00	0.10	0.02	0.20	0.50
99	0.32	0.08	0.79	1.11	0.78	0.05	0.01	0.00	0.05	0.02	0.18	0.41
99.5	0.31	0.04	0.72	1.10	0.58	0.02	0.01	0.00	0.02	0.02	0.17	0.36
99.8	0.30	0.02	0.68	1.10	0.46	0.01	0.00	0.00	0.01	0.02	0.16	0.34
99.9	0.30	0.01	0.66	1.10	0.42	0.00	0.00	0.00	0.00	0.02	0.16	0.33

H5
Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	60.15	30.23	42.70	67.78	96.23	50.21	56.01	54.34	64.92	51.05	57.96	68.82
0.2	59.48	30.12	42.48	67.65	95.70	50.20	55.49	53.82	64.58	50.24	57.30	68.30

0.5	57.46	29.82	41.81	67.27	94.13	50.14	53.93	52.25	63.56	47.80	55.34	66.73
1	54.09	29.30	40.70	66.63	91.52	50.06	51.32	49.62	61.86	43.73	52.08	64.11
2	47.34	28.27	38.49	65.35	86.28	49.89	46.11	44.38	58.46	35.60	45.55	58.87
5	42.34	27.15	32.80	63.22	83.04	46.62	40.16	42.20	56.17	33.42	36.15	47.34
10	34.53	25.67	29.75	60.30	70.76	41.06	37.60	39.50	50.07	27.72	31.10	41.58
15	32.93	24.41	26.41	53.04	62.63	36.96	33.83	35.09	45.90	25.79	27.55	31.17
20	28.13	22.27	23.11	50.79	57.95	32.82	31.78	33.39	41.11	24.44	25.15	25.70
30	21.00	17.37	20.83	44.60	50.31	30.93	23.64	30.41	36.32	19.02	18.18	21.86
40	17.08	14.14	18.85	39.89	48.12	29.93	20.98	28.09	29.40	17.92	14.78	18.72
50	14.10	11.90	17.29	35.42	46.26	26.36	19.09	26.31	27.47	16.24	13.39	16.60
60	10.84	10.19	11.93	33.02	43.54	23.45	18.23	22.13	24.21	14.13	11.97	15.18
70	9.10	9.00	9.22	30.56	39.47	20.24	15.71	20.25	22.74	13.47	10.18	14.31
80	7.57	7.54	8.13	25.03	31.41	18.50	13.30	18.27	19.58	12.04	8.03	10.94
85	6.97	5.06	7.59	22.89	29.97	16.85	12.24	17.82	17.86	11.81	7.06	9.15
90	6.26	4.32	6.16	20.36	21.26	16.40	10.50	15.61	15.51	9.63	5.43	7.12
95	4.46	3.19	5.46	12.82	19.00	13.41	9.19	12.72	9.92	6.44	4.12	4.69
98	1.95	1.45	5.03	9.04	14.42	10.69	7.88	7.96	7.99	5.50	3.74	2.19
99	1.79	1.26	4.38	8.44	12.04	8.71	4.95	7.73	7.74	4.58	3.69	2.06
99.5	1.71	1.17	4.06	8.14	10.85	7.73	3.49	7.61	7.62	4.11	3.66	2.00
99.8	1.66	1.11	3.86	7.96	10.14	7.14	2.62	7.54	7.55	3.83	3.64	1.96
99.9	1.65	1.09	3.80	7.90	9.90	6.94	2.32	7.52	7.52	3.74	3.64	1.95

H4
Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	5.44	3.07	5.56	9.56	10.26	5.74	4.03	0.39	1.81	1.51	4.31	8.03
0.2	5.37	3.06	5.55	9.52	10.22	5.71	3.98	0.38	1.80	1.48	4.30	7.98
0.5	5.16	3.04	5.50	9.38	10.10	5.62	3.83	0.36	1.78	1.40	4.26	7.82
1	4.81	3.00	5.42	9.16	9.91	5.46	3.58	0.32	1.74	1.26	4.20	7.55
2	4.11	2.91	5.27	8.71	9.52	5.15	3.08	0.24	1.66	0.98	4.09	7.01
5	3.27	2.77	4.93	8.09	8.22	4.82	2.16	0.19	1.48	0.83	3.42	6.10
10	3.14	2.60	4.16	6.79	7.17	4.15	1.36	0.18	1.26	0.64	2.81	4.16
15	3.04	2.45	3.68	6.48	6.62	3.93	1.26	0.17	0.97	0.63	2.39	3.72
20	2.74	2.28	3.40	6.01	5.45	3.14	1.12	0.14	0.77	0.56	1.82	3.15
30	1.94	1.88	2.71	5.20	4.78	2.79	0.92	0.10	0.61	0.51	1.27	2.47
40	1.69	1.39	2.46	4.58	4.34	2.39	0.70	0.09	0.55	0.41	0.94	2.09
50	1.48	1.25	2.11	4.15	3.41	1.95	0.54	0.08	0.32	0.33	0.75	1.97
60	1.17	1.21	1.68	3.64	2.95	1.57	0.47	0.06	0.27	0.27	0.58	1.86
70	0.98	0.98	1.35	3.08	2.31	1.18	0.30	0.05	0.20	0.23	0.50	1.51
80	0.66	0.77	1.16	2.64	1.70	0.83	0.14	0.04	0.12	0.19	0.45	1.21
85	0.45	0.67	1.13	2.10	1.41	0.52	0.12	0.03	0.11	0.15	0.36	0.91
90	0.40	0.60	1.01	1.92	1.23	0.13	0.07	0.02	0.09	0.11	0.28	0.71
95	0.31	0.35	0.57	1.10	0.83	0.08	0.04	0.02	0.08	0.05	0.17	0.37
98	0.17	0.05	0.33	0.78	0.56	0.06	0.02	0.00	0.06	0.01	0.13	0.31
99	0.14	0.02	0.28	0.72	0.48	0.03	0.01	0.00	0.03	0.01	0.11	0.24
99.5	0.13	0.01	0.26	0.69	0.44	0.02	0.00	0.00	0.01	0.01	0.10	0.21
99.8	0.12	0.00	0.24	0.67	0.41	0.01	0.00	0.00	0.01	0.01	0.09	0.19
99.9	0.12	0.00	0.24	0.66	0.41	0.00	0.00	0.00	0.00	0.01	0.09	0.18

H3
Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	71.50	38.30	57.68	89.93	129.15	65.00	64.74	55.26	66.83	52.92	70.41	94.61
0.2	70.84	38.17	57.63	89.86	128.39	64.82	64.20	54.71	66.60	52.20	69.69	93.73
0.5	68.88	37.78	57.51	89.66	126.11	64.30	62.61	53.05	65.91	50.06	67.52	91.09
1	65.60	37.12	57.30	89.31	122.31	63.42	59.94	50.29	64.75	46.49	63.91	86.69
2	59.04	35.79	56.87	88.62	114.71	61.66	54.62	44.78	62.44	39.34	56.69	77.89

5	51.04	34.95	46.34	87.78	105.22	59.00	44.36	42.59	59.99	36.98	46.08	62.83
10	44.16	32.46	44.52	80.94	89.96	50.57	41.32	39.81	53.13	30.88	39.12	53.21
15	41.35	30.03	37.57	73.22	77.80	46.90	38.10	35.80	48.89	28.75	34.41	44.68
20	35.04	29.03	33.84	70.19	75.08	44.11	34.21	33.70	43.56	26.54	31.00	34.40
30	27.42	22.14	30.15	60.35	70.19	39.52	25.58	30.81	37.98	21.39	22.70	29.68
40	22.07	17.80	26.15	54.87	63.35	35.55	22.47	28.63	31.32	20.10	18.56	27.58
50	17.62	15.85	24.46	47.98	58.43	31.12	20.81	26.58	28.68	18.04	16.45	23.00
60	14.42	13.75	18.85	45.44	56.69	28.89	20.18	22.32	25.30	16.00	14.46	21.27
70	12.56	12.14	14.30	41.50	44.18	25.06	17.59	20.71	24.69	14.60	12.30	19.13
80	9.94	10.23	12.52	35.78	40.05	20.53	15.47	18.34	20.37	12.93	9.81	16.64
85	9.78	7.57	11.80	30.02	36.94	19.32	12.82	17.92	19.26	12.50	9.09	13.18
90	8.43	6.01	9.78	26.48	25.50	18.06	10.89	15.76	15.91	10.50	5.99	10.34
95	5.50	3.92	7.71	17.15	21.80	14.40	9.88	12.79	10.21	8.03	5.82	5.91
98	2.79	2.16	7.45	12.03	19.12	10.70	9.22	8.27	9.41	6.58	4.93	3.17
99	2.45	1.76	6.75	11.27	17.54	8.82	6.04	7.97	8.88	5.13	4.55	2.85
99.5	2.28	1.56	6.40	10.89	16.75	7.87	4.45	7.82	8.62	4.41	4.37	2.69
99.8	2.18	1.44	6.19	10.66	16.28	7.31	3.50	7.74	8.46	3.98	4.26	2.59
99.9	2.14	1.40	6.12	10.59	16.12	7.12	3.18	7.71	8.40	3.84	4.22	2.56

H2
Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	2.47	2.11	3.83	5.22	6.87	2.37	1.22	0.19	1.14	1.91	2.38	5.07
0.2	2.47	2.10	3.80	5.21	6.85	2.37	1.21	0.19	1.13	1.89	2.38	4.98
0.5	2.45	2.07	3.69	5.17	6.79	2.37	1.17	0.18	1.10	1.82	2.36	4.71
1	2.43	2.02	3.52	5.10	6.67	2.37	1.11	0.17	1.06	1.72	2.33	4.27
2	2.37	1.91	3.16	4.95	6.45	2.36	0.99	0.16	0.97	1.51	2.28	3.37
5	2.33	1.70	3.02	4.58	5.57	2.18	0.88	0.15	0.86	1.12	2.15	3.06
10	1.87	1.50	2.85	4.41	4.82	1.78	0.62	0.12	0.64	1.00	1.76	2.54
15	1.72	1.39	2.64	4.14	4.33	1.35	0.53	0.11	0.50	0.59	1.49	2.21
20	1.59	1.25	2.25	4.03	4.04	1.16	0.49	0.10	0.48	0.49	1.22	2.07
30	1.21	1.08	1.76	3.28	3.64	0.92	0.36	0.08	0.41	0.43	1.02	1.44
40	0.99	0.84	1.62	2.72	3.22	0.77	0.23	0.06	0.35	0.32	0.84	1.32
50	0.73	0.75	1.53	2.41	2.67	0.52	0.20	0.05	0.30	0.29	0.62	1.17
60	0.68	0.60	1.26	2.23	2.50	0.43	0.13	0.05	0.21	0.23	0.48	1.07
70	0.55	0.55	0.90	1.99	2.20	0.28	0.10	0.04	0.17	0.20	0.44	0.77
80	0.39	0.46	0.74	1.55	1.68	0.22	0.08	0.02	0.14	0.16	0.38	0.53
85	0.34	0.29	0.72	1.41	1.14	0.16	0.06	0.02	0.10	0.15	0.27	0.49
90	0.25	0.20	0.59	1.21	0.85	0.14	0.02	0.01	0.07	0.13	0.18	0.36
95	0.20	0.09	0.57	0.99	0.61	0.07	0.01	0.01	0.04	0.08	0.16	0.20
98	0.08	0.04	0.51	0.40	0.55	0.03	0.00	0.00	0.02	0.01	0.09	0.16
99	0.06	0.02	0.42	0.37	0.52	0.01	0.00	0.00	0.01	0.01	0.09	0.13
99.5	0.06	0.01	0.37	0.36	0.50	0.01	0.00	0.00	0.00	0.01	0.09	0.12
99.8	0.05	0.00	0.35	0.35	0.49	0.00	0.00	0.00	0.00	0.01	0.08	0.11
99.9	0.05	0.00	0.34	0.35	0.49	0.00	0.00	0.00	0.00	0.01	0.08	0.11

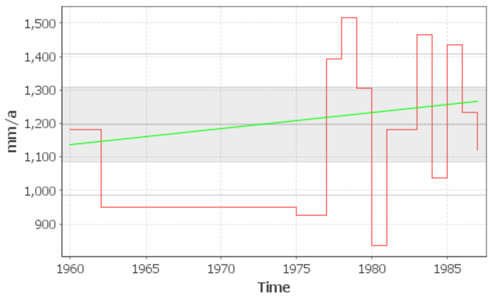
H1
Q [m3/s]

Percentiles	1	2	3	4	5	6	7	8	9	10	11	12
0.1	77.90	42.39	71.47	110.72	153.09	74.25	69.34	55.72	67.59	54.30	78.99	112.23
0.2	77.30	42.33	71.32	110.63	152.25	74.13	68.73	55.15	67.50	53.79	78.24	111.04
0.5	75.53	42.16	70.86	110.38	149.74	73.80	66.88	53.44	67.23	52.24	76.00	107.46
1	72.57	41.87	70.09	109.96	145.55	73.23	63.81	50.59	66.77	49.66	72.26	101.51
2	66.65	41.29	68.56	109.11	137.18	72.11	57.66	44.88	65.86	44.51	64.79	89.59
5	56.57	38.69	58.33	108.04	123.51	65.40	47.47	42.88	62.24	42.22	53.73	72.84
10	51.15	36.71	54.98	102.38	103.77	55.55	44.07	39.96	56.04	35.99	43.89	61.98
15	44.58	33.95	45.37	93.46	91.90	52.25	39.71	36.22	51.25	32.02	40.42	56.76

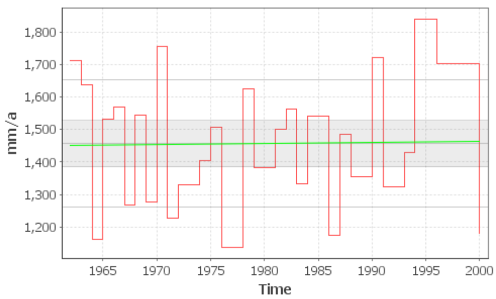
20	40.53	32.09	43.06	87.85	88.96	48.12	35.05	33.89	45.73	30.07	35.80	42.04
30	32.03	25.23	37.62	75.38	84.52	44.03	27.06	30.99	39.36	24.64	26.24	36.74
40	25.70	20.15	33.52	65.29	76.51	38.36	24.33	28.89	33.63	22.34	22.88	33.04
50	19.71	18.26	30.07	58.70	72.36	32.57	22.02	26.70	30.52	20.37	19.59	27.53
60	16.35	16.27	23.12	56.72	64.80	31.52	20.88	22.42	26.98	17.65	16.98	25.34
70	14.87	13.57	18.38	52.63	55.31	27.61	19.63	21.08	25.80	16.93	14.43	22.25
80	11.98	12.13	15.95	47.11	47.28	23.57	15.77	18.36	22.46	13.98	12.85	19.32
85	11.03	9.39	15.37	38.53	45.20	20.64	13.76	17.99	20.74	13.27	10.89	17.31
90	9.80	6.96	12.53	32.80	29.31	19.22	11.91	15.94	16.43	12.15	8.80	13.90
95	6.36	4.25	11.43	21.90	25.43	14.74	10.29	12.80	11.86	8.73	6.35	6.53
98	2.96	2.22	8.91	16.15	23.69	10.71	9.34	8.56	9.75	7.98	5.57	3.81
99	2.67	1.91	8.33	14.12	23.19	8.88	6.84	8.18	9.17	5.85	5.04	3.38
99.5	2.53	1.75	8.05	13.10	22.94	7.96	5.59	7.99	8.88	4.79	4.78	3.16
99.8	2.45	1.65	7.87	12.49	22.80	7.41	4.84	7.87	8.70	4.15	4.63	3.03
99.9	2.42	1.62	7.82	12.29	22.75	7.23	4.59	7.83	8.64	3.94	4.58	2.99

APPENDIX E

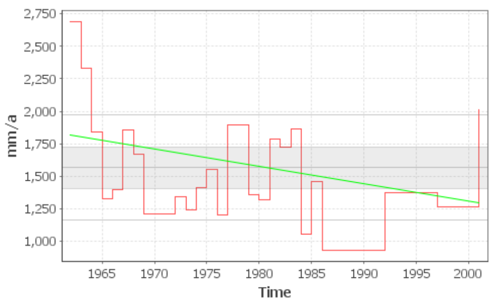
E1: Apparent trends: Annual precipitation



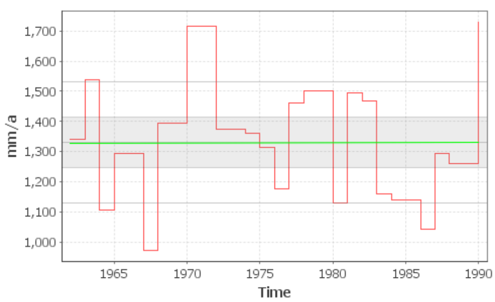
1 9035031 DANSON K NGUGI SAW MILL



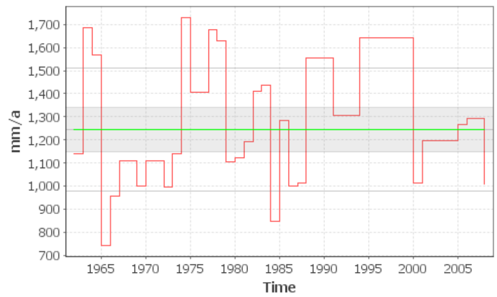
2 9035079 TENWEK MISSION SOTIK



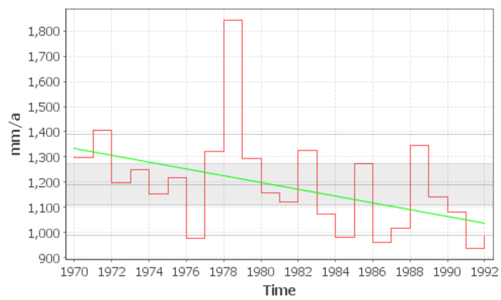
3 9035085 OLENGURUONE



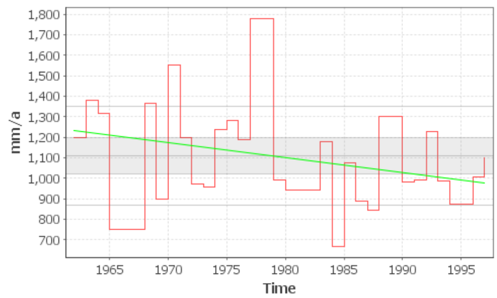
4 9035227 DISTRICT OFFICE BOMET



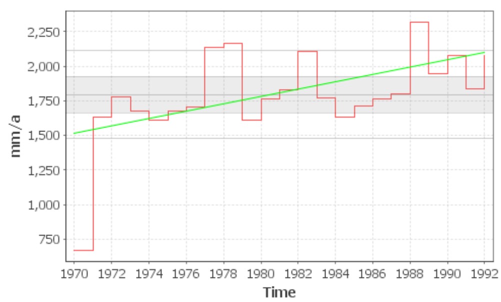
5 9035228 KIPTUNGA FOREST STATION ELBURGON



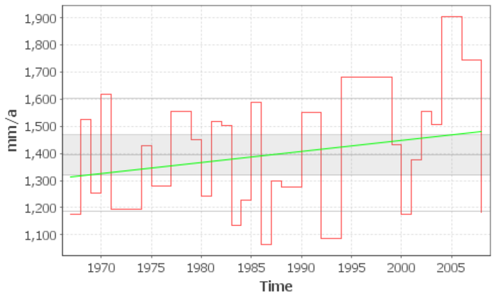
6 9035236 CHEPALUNGU FOREST STATION SOTIK



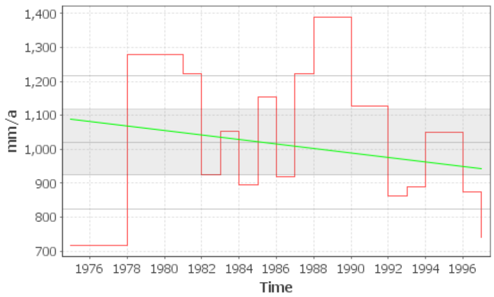
7 9035241 BARAGET FOREST STATION



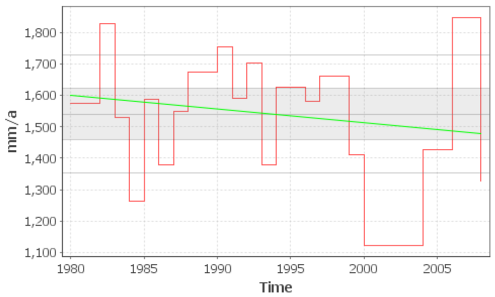
8 9035260 KOIWA ESTATE KERICHO



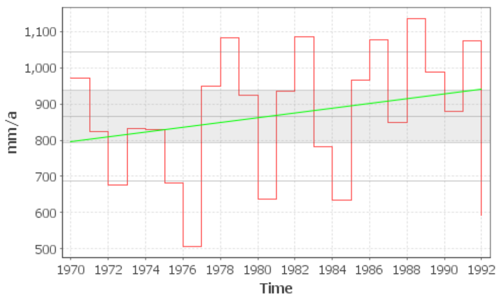
9 9035265 BOMET WATER SUPPLY



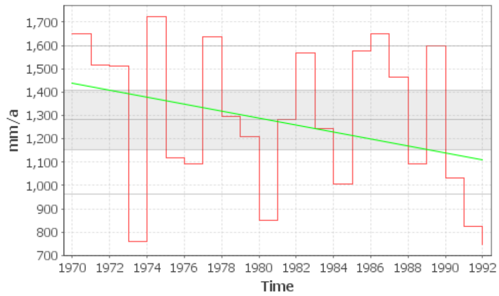
10 9035284 MULOT



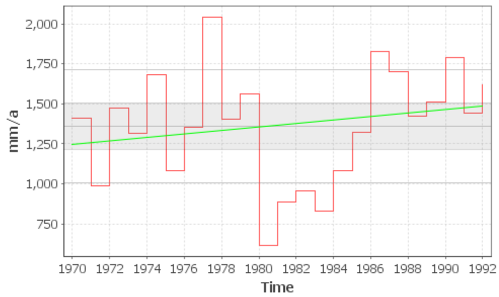
11 9035302 NYANGORES FOREST STATION



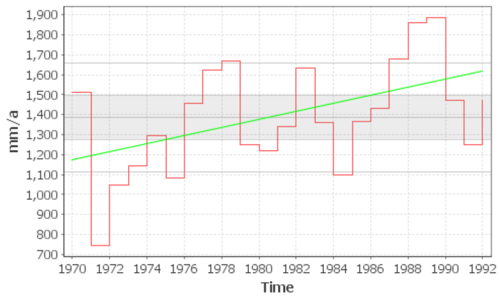
12 9133000 MUSOMA METEO STATION



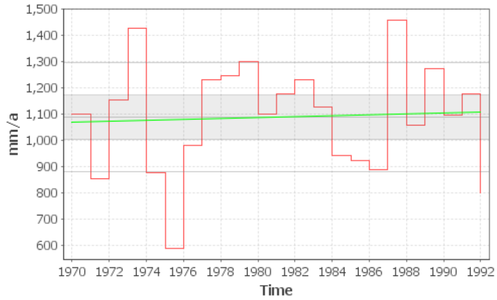
13 9134008 NYABASSI



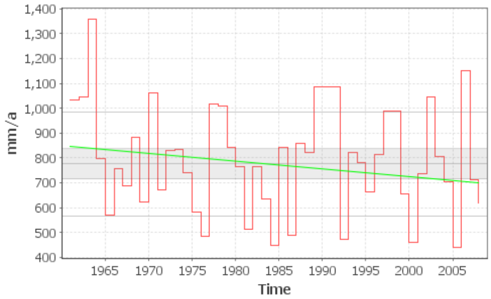
14 9134019 KISII NTIMARU AGRIC HOUSE



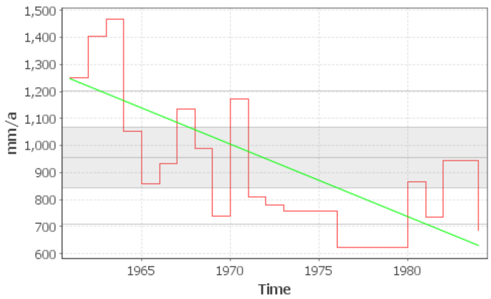
15 9134027 LOLGORIEN WS



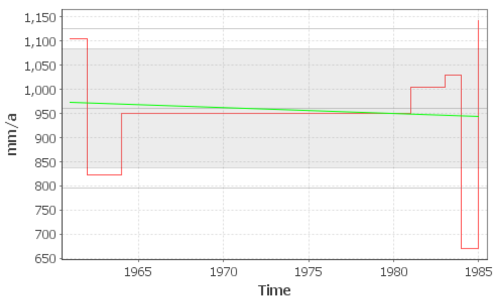
16 9134033 MUGUMU



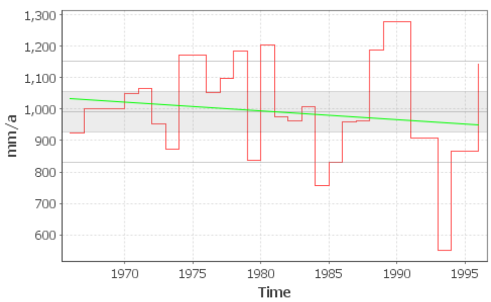
17 9135001 NAROK METEOROLOGICAL STATION



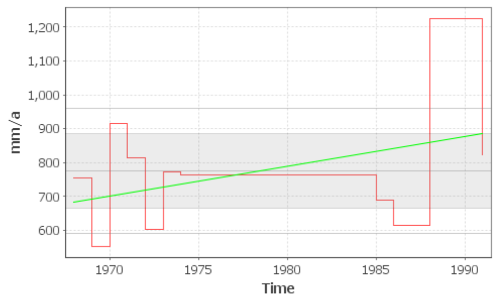
18 9135008 KABOSON GOSPEL MISSION SOTIK



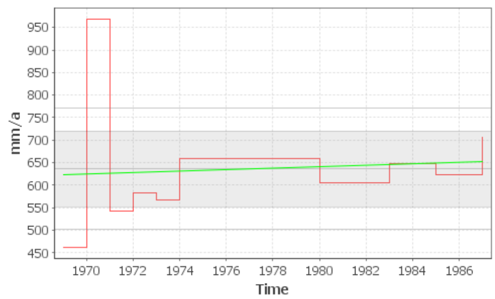
19 9135010 AITONG HYDROMET STATION SOTIK



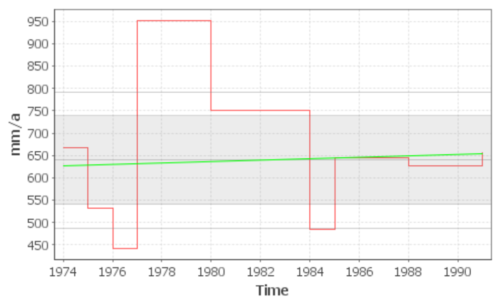
20 9135013 KEEKOROK HYDROMET STATION NAROK



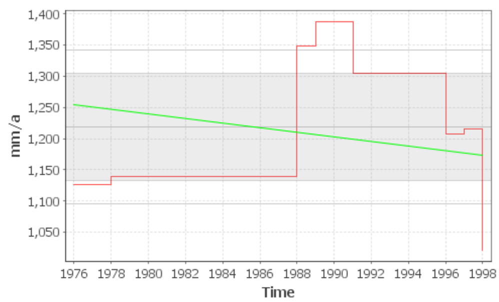
21 9135019 LEMEK



22 9135022 AFRICA GOSPEL CHURCH NAIKARA



23 9135025 ILKERIN INTEGRAL DEVELOPMENT PROJECT



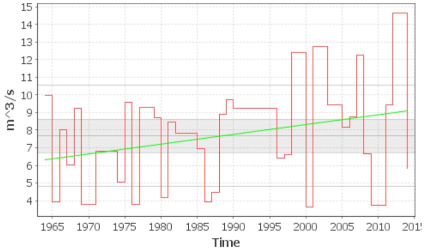
24 9135026 GOVERNORS CAMP

Station		Statistics								Apparent trend		Normal	Persistence				Trend		Pre-white trend		Stability	
	Name	Start	End	Length	Mean	SD	Skew	SE	CV	Const	Slope	Shapiro-Wilk p	r(1)	Alpha	UCL	LCL	Spearman p	Mann-Kendall p	Spearman p	Mann-Kendall p	Variance p	Mean p
1	9035031 DANSON	1960	1987	14	1197	211	-0.10	56.34	0.18	1138.0	9.2	0.75	0.01	0.05	0.524	-0.524	0.51	0.75	-	-	0.2498	0.5069
2	9035079 TENWEK	1962	2000	29	1456	196	0.08	36.36	0.13	1450.0	0.4	0.51	-0.3	0.05	0.364	-0.364	0.95	0.93	-	-	0.8661	0.5515
3	9035085 OLENGURUONE	1962	2001	25	1565	404	0.90	80.86	0.26	1816.0	-20.9	0.07*	0.28	0.05	0.392	-0.392	0.21	0.20	-	-	0.3364	0.2876
4	9035227 DISTRICT	1962	1990	22	1330	201	0.22	42.81	0.15	1329.0	0.1	0.82	0	0.05	0.418	-0.418	0.86	0.82	-	-	0.8789	0.9224
5	9035228 KIPTUNGA	1962	2008	31	1245	267	0.29	48.02	0.21	1244.0	0.0	0.13	0.16	0.05	0.352	-0.352	0.77	0.74	-	-	0.1613	0.669
6	9035236 CHEPALUNGU	1970	1992	23	1190	200	1.29	41.68	0.17	1332.0	-12.9	**0.009****	0.22	0.05	0.409	-0.409	**0.017***	**0.016***	-	-	0.187	0.0276
7	9035241 BARAGET	1962	1997	29	1109	241	0.63	44.83	0.22	1231.0	-8.8	0.37	-0.1	0.05	0.364	-0.364	0.09	0.12	-	-	0.06209	0.0132
8	9035260 KOIWA	1970	1992	23	1796	320	-1.51	66.62	0.18	1516.0	25.5	**0.001****	0.2	0.05	0.409	-0.409	**0.007****	**0.006****	-	-	0.04216	0.0828
9	9035265 BOMET	1967	2008	30	1394	209	0.37	38.14	0.15	1314.0	5.5	0.32	-0.1	0.05	0.358	-0.358	0.35	0.34	-	-	0.1077	0.3711
10	9035284 MULOT	1975	1997	16	1020	198	0.21	49.37	0.19	1089.0	-9.2	0.58	0.08	0.05	0.49	-0.49	0.29	0.23	-	-	0.7345	0.9924
11	9035302 NYANGORES	1980	2008	20	1541	188	-0.34	42.12	0.12	1599.0	-6.1	0.84	0	0.05	0.438	-0.438	0.65	0.72	-	-	0.4569	0.4653
12	9133000 MUSOMA	1970	1992	23	866	178	-0.31	37.05	0.21	797.0	6.2	0.35	0.06	0.05	0.409	-0.409	0.24	0.29	-	-	0.9146	0.1573
13	9134008 NYABASSI	1970	1992	23	1281	316	-0.24	65.90	0.25	1437.0	-14.2	0.08*	0	0.05	0.409	-0.409	0.13	0.13	-	-	0.8848	0.7192
14	9134019 KISII	1970	1992	23	1361	354	-0.23	73.80	0.26	1249.0	10.3	0.87	0.34	0.05	0.409	-0.409	0.20	0.23	-	-	0.8425	0.9643
15	9134027 LOLGORIEN	1970	1992	23	1387	272	-0.15	56.75	0.20	1173.0	19.5	0.95	0.45	0.05	0.409	-0.409	**0.04***	**0.014***	0.23	0.23	0.6402	0.0613
16	9134033 MUGUMU	1970	1992	23	1086	208	-0.32	43.33	0.19	1066.0	85.7	0.86	0.1	0.05	0.409	-0.409	0.90	1.00	-	-	0.4223	0.849
17	9135001 NAROK	1961	2008	45	777	209	0.41	31.18	0.27	848.0	60.7	0.21	0.01	0.05	0.292	-0.292	0.20	0.16	-	-	0.8671	0.2621
18	9135008 KABOSON	1961	1984	18	956	246	0.64	57.93	0.26	1248.0	76.4	0.21	0.49	0.05	0.462	-0.462	**0.001****	**0.001****	0.05	0.07	0.265	0.0135
19	9135010 AITONG	1961	1985	7	962	165	-0.56	62.46	0.17	973.5	123.2	0.57	-0.5	0.05	0.741	-0.741	0.74	0.77	-	-	0.6861	0.9837
20	9135013 KEEKOROK	1966	1996	25	992	162	-0.49	32.41	0.16	1032.0	63.5	0.58	0.15	0.05	0.392	-0.392	0.54	0.63	-	-	0.1574	0.2184
21	9135019 LEMEK	1968	1991	11	775	184	1.06	55.59	0.24	682.7	103.4	0.11	-0.2	0.05	0.591	-0.591	0.29	0.54	-	-	0.5137	0.4685
22	9135022 AFRICA GOSPEL	1969	1987	10	636	135	1.24	42.73	0.21	623.6	84.1	0.05*	-0.5	0.05	0.62	-0.62	0.15	0.10	-	-	0.007829	0.7993
23	9135025 ILKERIN	1974	1991	9	640	152	0.60	50.79	0.24	627.9	100.0	0.50	-0.1	0.05	0.653	-0.653	0.98	1.00	-	-	0.137	0.8914
24	9135026 GOVERNORS	1976	1998	8	1219	124	-0.09	43.80	0.10	1255.0	84.6	1	0.31	0.05	0.693	-0.693	0.82	0.90	-	-	0.822	0.5126

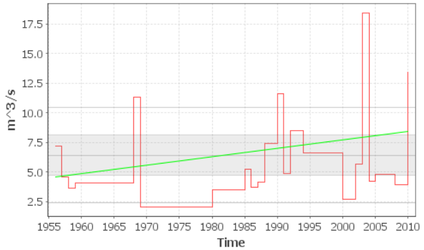
With: *** = p<0.05; ** = p<0.01; *** = p<0.001**

E2: Apparent trends: Discharge

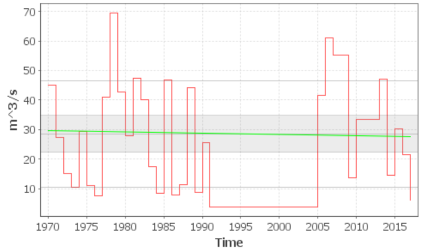
Trend analysis: Average annual discharge MQ_{year}



1 1LA03 Bomet Bridge (BB)

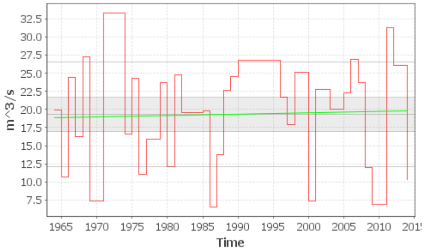


4 1LB02 Kapkimolwa (KA)

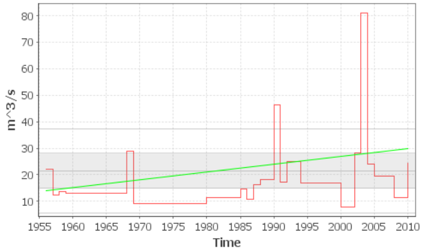


5 5H2 Mara Mine (MM)

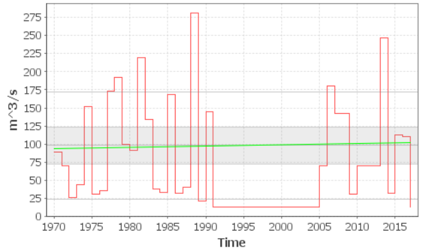
Trend analysis: Maximum monthly discharge HQ_{month}



1 1LA03 Bomet Bridge (BB)

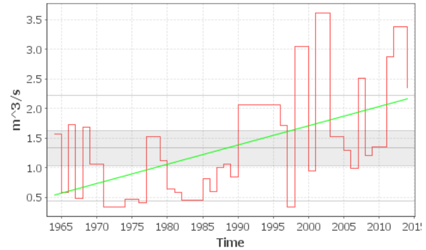


4 1LB02 Kapkimolwa (KA)

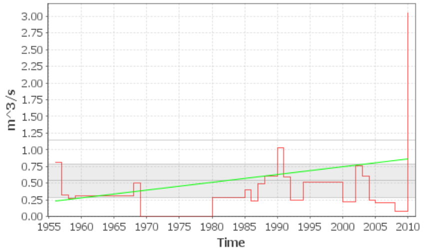


5 5H2 Mara Mine (MM)

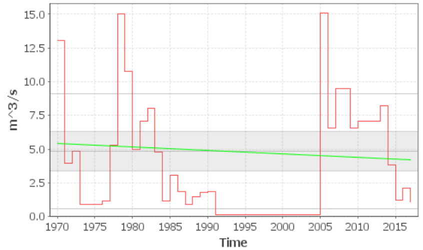
Trend analysis: Minimum monthly discharge NQ_{month}



1 1LA03 Bomet Bridge (BB)



4 1LB02 Kapkimolwa (KA)



5 5H2 Mara Mine (MM)

Trend analysis: Average annual discharge MQ_{year}

Station		Statistics								Summary					Apparent trend		Normal	Persistence				Trend		Pre-white trend		Stability	
	Name	Start	End	Length	Mean	SD	Skew	SE	CV	Min	Q1	Median	Q3	Max	Const	Slope	Shapiro-Wilk p	r(1)	Alpha	UCL	LCL	Spearman p	Mann-Kendall p	Spearman p	Mann-Kendall p	Variance p	Mean p
1	1LA03 BB	1964	2014	35	7.68	2.87	0.33	0.48	0.37	3.65	5.24	8.01	9.39	14.66	6.33	0.08	0.077	-0.2	0.05	0.331	-0.331	0.24	0.26	-	-	0.20	0.08
4	1LB02 KA	1956	2010	22	6.45	4.01	1.45	0.86	0.62	2.08	3.94	4.83	7.43	18.45	4.63	0.17	**0.001****	-0.1	0.05	0.418	-0.418	0.24	0.29	-	-	0.06	0.14
5	5H2 MM	1970	2017	32	28.55	18.13	0.38	3.21	0.63	3.83	11.19	27.62	43.43	69.58	29.56	-0.06	**0.048***	0.13	0.05	0.346	-0.346	0.88	0.83	-	-	0.89	0.56

With: *** = p<0.05; ** = p<0.01; *** = p<0.001**

Trend analysis: Maximum monthly discharge HQ_{month}

Station		Statistics								Summary					Apparent trend		Normal	Persistence				Trend		Pre-white trend		Stability	
	Name	Start	End	Length	Mean	SD	Skew	SE	CV	Min	Q1	Median	Q3	Max	Const	Slope	Shapiro-Wilk p	r(1)	Alpha	UCL	LCL	Spearman p	Mann-Kendall p	Spearman p	Mann-Kendall p	Variance p	Mean p
1	1LA03 BB	1964	2014	35	19.32	7.25	-0.24	1.23	0.38	19.32	7.25	-0.24	1.23	0.38	18.82	0.03	0.13	-0.3	0.05	0.331	-0.331	0.70	0.61	-	-	0.90	0.50
4	1LB02 KA	1956	2010	22	21.46	15.89	2.47	3.39	0.74	7.88	12.45	17.11	24.44	81.14	13.90	0.72	**<0.001*****	0.12	0.05	0.418	-0.418	0.15	0.14	-	-	0.00	0.08
5	5H2 MM	1970	2017	32	98.07	73.75	0.73	13.04	0.75	12.89	33.02	79.67	148.30	281.10	94.10	0.26	**0.008****	-0.2	0.05	0.346	-0.346	0.83	0.81	-	-	0.34	0.89

With: *** = p<0.05; ** = p<0.01; *** = p<0.001**

Trend analysis: Minimum monthly discharge NQ_{month}

Station		Statistics								Summary					Apparent trend		Normal	Persistence				Trend		Pre-white trend		Stability	
	Name	Start	End	Length	Mean	SD	Skew	SE	CV	Min	Q1	Median	Q3	Max	Const	Slope	Shapiro-Wilk p	r(1)	Alpha	UCL	LCL	Spearman p	Mann-Kendall p	Spearman p	Mann-Kendall p	Variance p	Mean p
1	1LA03 BB	1964	2014	35	1.34	0.90	0.99	0.15	0.67	0.34	0.59	1.07	1.71	3.62	0.55	0.05	**0.001****	0.2	0.05	0.331	-0.331	**0.004****	**0.004****	-	-	0.01	0.00
4	1LB02 KA	1956	2010	22	0.54	0.61	3.05	0.13	1.15	0.24	0.36	0.60	3.04	0.00	0.23	0.03	**<0.001*****	-0.1	0.05	0.418	-0.418	0.94	1.00	-	-	0.00	0.26
5	5H2 MM	1970	2017	32	4.84	4.26	0.97	0.75	0.88	0.15	1.18	3.90	7.07	15.07	5.43	-0.04	**0.001****	0.35	0.05	0.346	-0.346	0.96	0.94	0.87	0.80	0.79	0.50

With: *** = p<0.05; ** = p<0.01; *** = p<0.001**

IHA linear regression results: 1LA03 Bomet Bridge

	Slope	YInt	Sigma	Corr	PValue	FStat	R2
January	0.124	-242.5	6.445	0.2921	0.05	4.57	0.0853
February	0.05283	-101.9	3.695	0.2213	0.25	2.522	0.04896
March	0.0121	-20.13	7.306	0.02627	0.5	0.03385	0.00069
April	0.006801	-3.98	11.79	0.009155	0.5	0.004108	8.38E-05
May	0.006407	2.313	12.98	0.00783	0.5	0.003006	6.13E-05
June	0.04401	-79.29	4.527	0.1525	0.5	1.166	0.02324
July	-0.01	28.09	4.975	-0.03189	0.5	0.04987	0.001017
August	-0.00879	27.22	6.356	-0.02193	0.5	0.02358	0.000481
September	0.03647	-60.89	7.263	0.07943	0.5	0.3111	0.006308
October	0.01813	-28.75	4.969	0.05779	0.5	0.1642	0.00334
November	0.08736	-168.1	4.019	0.3261	**0.025***	5.829	0.1063
December	0.07711	-147.6	6.669	0.1805	0.25	1.649	0.03257
1-day minimum	0.01601	-30.93	0.6094	0.3848	**0.005****	8.517	0.1481
3-day minimum	0.02048	-39.73	0.6745	0.4341	**0.005****	11.38	0.1885
7-day minimum	0.02261	-43.89	0.7462	0.4334	**0.005****	11.33	0.1878
30-day minimum	0.02896	-56.15	0.9721	0.4274	**0.005****	10.95	0.1827
90-day minimum	0.04854	-93.9	2.007	0.3583	**0.01***	7.217	0.1284
1-day maximum	0.02601	-14.09	16.9	0.02441	0.5	0.02922	0.000596
3-day maximum	0.004153	28.25	16.8	0.003922	0.5	0.000754	1.54E-05
7-day maximum	-0.00662	47.65	16.23	-0.00647	0.5	0.002054	4.19E-05
30-day maximum	-0.03324	91.14	12.87	-0.04096	0.5	0.08235	0.001678
90-day maximum	-0.01579	47.27	7.71	-0.03248	0.5	0.05173	0.001055
Number of zero days	0	0	0	0	0.5	0	0
Base flow index	0.002563	-4.945	0.1309	0.2967	0.05	4.731	0.08805
Date of minimum	-0.8116	1724	118.3	-0.1082	0.5	0.5806	0.01171
Date of maximum	0.8974	-1600	90.63	0.1552	0.5	1.21	0.02409

With: Slope = slope of least-squares fit regression line; YInt = y-intercept of the least-squares fit regression line; Sigma = standard error
Corr = correlation coefficient; PValue = P-value for the slope of the regression line; FStat = F statistic for the regression line
R2 = R^2 for the regression line; *** = p<0.05; ** = p<0.01; *** = p<0.001**

IHA linear regression results: 1LB02 Kapkimolwa

	Slope	YInt	Sigma	Corr	PValue	FStat	R2
January	0.1319	-255.9	10.19	0.2294	0.1	3.167	0.05264
February	0.02648	-48.28	7.607	0.06327	0.5	0.2291	0.004004
March	0.06915	-132.3	9.333	0.1337	0.5	1.038	0.01788
April	0.0831	-156.7	11.77	0.1275	0.5	0.9424	1.63E-02
May	0.1899	-365.1	13.53	0.2476	0.1	3.722	6.13E-02
June	0.02146	-35.56	5.663	0.06885	0.5	0.2715	0.00474
July	-0.003772	14.44	5.257	-0.01307	0.5	0.009737	0.0001708
August	-0.02456	59.51	7.893	-0.05659	0.5	0.1831	0.003202
September	-0.05087	112.8	8.429	-0.1093	0.5	0.6886	0.01194
October	0.04612	-84.83	6.361	0.1309	0.5	0.9939	0.01714
November	0.06095	-116.2	5.217	0.2081	0.25	2.58	0.0433
December	0.06107	-116.3	7.524	0.1462	0.5	1.245	0.02138
1-day minimum	0.005458	-10.33	0.9261	0.1067	0.5	0.6567	0.01139
3-day minimum	0.007111	-13.56	1.026	0.1253	0.5	0.9085	0.01569
7-day minimum	0.007951	-15.18	1.097	0.1308	0.5	0.9929	0.01712
30-day minimum	0.01737	-33.48	1.746	0.1783	0.25	1.871	0.03178
90-day minimum	0.02634	-50.07	2.662	0.1774	0.25	1.852	0.03147
1-day maximum	0.317	-590.1	24.22	0.2319	0.1	3.24	0.05378
3-day maximum	0.306	-571	23.01	0.2353	0.1	3.342	5.54E-02
7-day maximum	0.2907	-544.1	21.14	0.2429	0.1	3.575	5.90E-02
30-day maximum	0.2149	-403.2	14.92	0.2538	0.05	3.924	0.06441
90-day maximum	0.1265	-235.3	9.522	0.2351	0.1	3.335	0.05527
Number of zero days	-0.06198	124.3	9.52	-0.1177	0.5	0.8013	0.01386
Base flow index	0.0004252	-0.7752	0.06962	0.1105	0.5	0.7052	0.01222
Date of minimum	-0.1685	468.7	127.1	-0.02415	0.5	0.03326	0.0005831
Date of maximum	-1.008	2194	99.5	-0.1814	0.25	1.939	0.03289

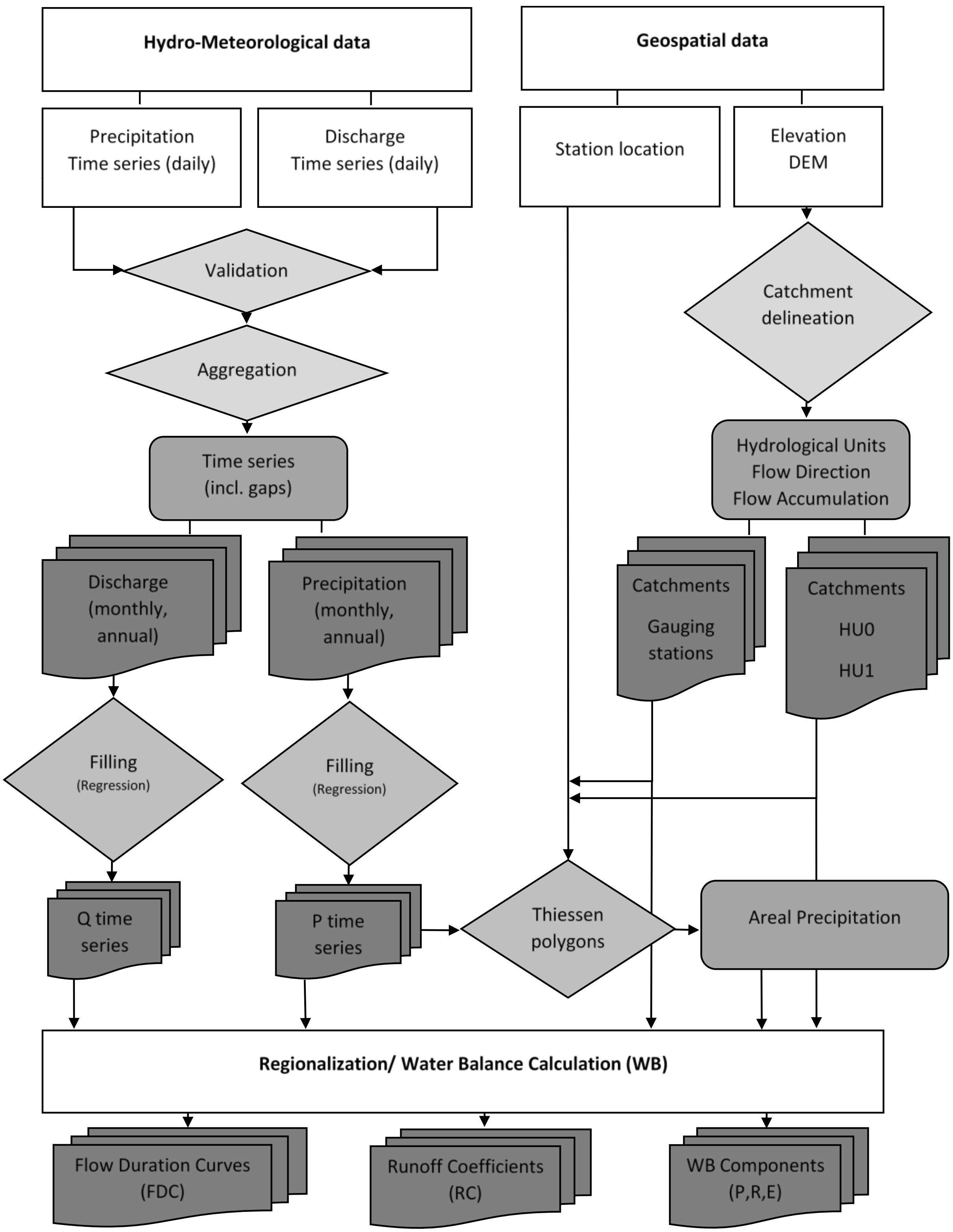
With: Slope = slope of least-squares fit regression line; YInt = y-intercept of the least-squares fit regression line; Sigma = standard error
Corr = correlation coefficient; PValue = P-value for the slope of the regression line; FStat = F statistic for the regression line
R2 = R^2 for the regression line; *** = p<0.05; ** = p<0.01; *** = p<0.001**

IHA linear regression results: 5H2 Mara Mine

	Slope	YInt	Sigma	Corr	PValue	FStat	R2
January	0.1816	-348.7	11.96	0.2473	0.25	2.215	0.06116
February	0.1548	-293.3	25.38	0.102	0.5	0.3575	0.01041
March	0.2447	-463.7	41.63	0.09835	0.5	0.3321	0.009673
April	0.4532	-849.9	64.39	0.1175	0.5	0.476	1.38E-02
May	0.4328	-806.6	62.24	0.1161	0.5	0.4647	1.35E-02
June	0.1403	-250.9	31.11	0.07561	0.5	0.1955	0.005717
July	-0.05634	130.6	19.06	-0.04963	0.5	0.08396	0.002463
August	-0.04457	106.8	14.69	-0.05093	0.5	0.08843	0.002594
September	0.02252	-22.03	19	0.01992	0.5	0.0135	0.0003969
October	0.1371	-257.2	15.71	0.1452	0.5	0.7321	0.02108
November	0.2939	-570.8	16.18	0.292	0.1	3.169	0.08527
December	0.5738	-1120	36.48	0.2556	0.25	2.377	0.06535
1-day minimum	-0.02259	46.8	2.01	-0.1856	0.5	1.213	0.03444
3-day minimum	-0.03492	72.06	2.465	-0.2316	0.25	1.927	0.05364
7-day minimum	-0.02195	46.64	2.816	-0.1299	0.5	0.5837	0.01688
30-day minimum	-0.007603	19.78	4.041	-0.03161	0.5	0.03401	0.0009994
90-day minimum	0.1055	-199.8	8.753	0.1986	0.25	1.397	0.03946
1-day maximum	4.467	-8583	209	0.3381	0.05	4.39	0.1143
3-day maximum	2.619	-4968	169.9	0.2509	0.25	2.285	6.30E-02
7-day maximum	1.678	-3147	140.2	0.1973	0.25	1.376	3.89E-02
30-day maximum	1.168	-2205	91.82	0.2091	0.25	1.554	0.04371
90-day maximum	0.6687	-1262	52.89	0.2079	0.25	1.536	0.04322
Number of zero days	-0.01972	39.82	2.383	-0.1377	0.5	0.6574	0.01897
Base flow index	-0.001669	3.429	0.09851	-0.274	0.25	2.759	0.07507
Date of minimum	0.1242	-86.68	138.8	0.01504	0.5	0.00769	0.0002261
Date of maximum	0.03614	89.83	113.7	0.005346	0.5	0.0009725	2.86E-05

With: Slope = slope of least-squares fit regression line; YInt = y-intercept of the least-squares fit regression line; Sigma = standard error
Corr = correlation coefficient; PValue = P-value for the slope of the regression line; FStat = F statistic for the regression line
R2 = R^2 for the regression line; *** = p<0.05; ** = p<0.01; *** = p<0.001**

APPENDIX F



Hydro-Meteorological data
Geospatial data
Precipitation
Time series (daily)
Discharge
Time series (daily)
Station location
Elevation
DEM
Validation
Catchment
delineation
Aggregation
Time series
(incl. gaps)
Hydrological Units
Flow Direction
Flow Accumulation
Discharge
(monthly,
annual)
Precipitation
(monthly,
annual)
Catchments
Gauging
stations
Catchments
HU0
HU1
Filling
(Regression)
Filling
(Regression)
Q time
series
P time
series
Thiessen
polygons
Areal Precipitation
Regionalization/ Water Balance Calculation (WB)
Flow Duration Curves
(FDC)
Runoff Coefficients
(RC)
WB Components
(P,R,E)