Rokel River Basin Management Plan

National Water Resources Management Agency

Contents

1 Introduction

The Rokel River Basin Management Plan (RRBM) is designed to serve as a response plan for the protection and management of the water and other natural resources in the Rokel River basin. The RRBM is informed by the findings from the routine water quality monitoring that commenced from November 2019 to the present and the delineation and mapping of catchments and sub-catchments in the Rokel that are in critical danger. The general aim of the RRBM is to ensure that there is sufficient quantity and quality of water resources to meet the needs of all water users and at the same time ensure the presence of a rich and balanced aquatic ecosystem.

1.1 The vision and objectives of the Rokel river basin management plan

The following are the visions and objectives for the implementation of the Rokel river basin management plan

1.1.1 Vision

The vision of the Rokel river basin management plan is

To ensure that the population of the Rokel basin has access to sufficient quantity and quality of water resources for all uses, ecosystems are preserved and protected, adapt to climate change impacts, and mitigate water-related disasters for their well-being and socio-economics benefits.

1.1.2 Objectives

The following are the objectives of the Rokel River basin management plan:

1. To determine pollution sources and restore the river and groundwater quality
2. To establish a platform for stakeholder collaboration and coordination, data collection and sharing for the effective protection and management of the natural resources
3. To restore all ecosystems and ensure they provide their requisite ecosystem services

4. To facilitate the operationalisation of the hydrometric data collection system to inform effective and efficient water resources distribution and planning and early warning systems
5. To establish river basin management committees at the community and sub-catchment level for the protection and management of the basin's natural resources

2 Stakeholders, policy, and regulation analysis

2.1 The state of Affairs in the Rokel River basin

Water resources management is a wide phenomenon and cuts across many sectors, and stakeholders, and can be influenced by diverse policies, laws, and regulations. This situation is typical in Sierra Leone where the Rokel river basin lies.

2.1.1 Natural resources stakeholders in Sierra Leone

The management of Sierra Leone's water resources lies under the management of several stakeholders that are in the form of Ministries, Departments and Agencies (MDAs): the National Water Resources Management Agency (NWRMA), the Sierra Leone Meteorological Agency, the Ministry of Mines and Mineral Resources and its National Mineral Agency, the Ministry of Environment and it's Environment Protection Agency (EPA), National Protected Area Authority (NPAA), the Ministry of Local Government and Rural Development and its District Councils (DCs), and the Ministry of Agriculture and Food Security (MAF).

2.1.2 The National Water Resources Management Agency (NWMRA)

The NWRMA was established in 2019 by a 2017 EAct No.5 of parliament with the mandate to effectively manage and protect all water resources (surface and groundwater) in Sierra Leone. It also has the mandate to protect all water catchments which includes water and its drainage areas, and issue tariffs and licenses to all water users for abstraction, effluent discharge, dam construction, diversion, and vessels.

The NWRMA has been working towards achieving its policy objectives by establishing 25 and 30 surface and groundwater monitoring stations that automatically record groundwater level, rainfall, discharge measurement and some water quality parameter meters. It has also established 21 and 19 surface and groundwater quality monitoring stations in the Rokel river basin and reports SDG 632 indicator and conduct land use and land cover mapping of critical river basins amongst others.

2.1.3 The Environment Protection Agency (EPA)

The EPA was established by a 2008 Act of parliament with the mandate to protect and manage the country's environment with a focus to enhance human health and ecosystems. Also, the Agency has the function of prescribing standards and guidelines that are related to pollution, ambient air, water and soil quality, land and the discharge of wastes or toxic substances. In addition, it has the responsibility to formulate policies on areas of the environment. Similarly, the Agency has the right to issue environmental permits to regulate the volume and effect of waste discharges into the environment (Anon n.d.).

2.1.4 The National Protected Area Authority (NPAA)

The NPAA was established by a 2012 act of parliament with the mandate to provide oversight of protected areas and national parks to protect both plants and animals in their normal state, enhancing improved land use patterns and the management of the environment (The National Protected Area Act, 2012). The NPAA has about 35 national parks which are mostly forest reserves across Sierra Leone (National Parks of Sierra Leone, 2022)

2.1.5 The National Minerals Agency (NMA)

The NMA operates under the mandate of the National Minerals Agency Act N0.3 of 2012. The Agency was formed for the purpose of developing the minerals sector by efficiently managing the administrative and regulation of mineral rights and the trading of minerals in Sierra Leone. They also have the right as per their mandate to promote the rights of communities where mining operations occur (Legal & Regulatory Instruments - NMA, 2022).

2.1.6 The Sierra Leone Meteorological Agency (SLMET)

The SLMET has its current mandate from its 2017 Act No.8 of parliament. The Agency has the function of providing meteorological and climatological services throughout Sierra Leone and advising the government on aspects of climate change, facilitating the use of meteorology in flood, drought, and desertification amongst others. The Agency has established a wide network of rain gauge stations across Sierra Leone and usually collaborates with the NWRMA regarding data exchange.

2.1.7 The Sierra Leone Water Company (SALWACO)

The Sierra Leone Water Company which was established in 2001 has the mandate to provide water supply to the entire country excluding the Western Area. Under the Sierra Leone Water Company 2017 Act, they have the responsibility to provide water supply and related sanitation services in their areas of operations including rural communities and small towns. They are also mandated to ensure that water supplied to consumers meets the prescribed water quality standards (SLWACO, 2022). SALWACO operates a water supply system at Magburaka town which is in the Rokel River basin and abstracts raw water from the Rokel River.

2.1.8 The Ministry of Agriculture, Forestry and Food Security

They have the mandate to develop agricultural policies and advice the government of Sierra Leone on the policy administration and management of the agricultural sector. The focus area of the MAF is forestry, diversification of crops, and livestock, self-sufficiency in rice and the use of technology for agricultural development (Ministry of Agriculture & Forestry, 2022).

3 Characteristics of the Rokel river basin

The Rokel river basin originates from the northeast of Sierra Leone and empties into the Atlantic Ocean, West of Sierra Leone. It has a length of about 386 km with an area of 8,236 km^2. It is the second-largest river in Sierra Leone after the Sewa River. The figure 1 below shows the location of the Rokel river in Sierra Leone.

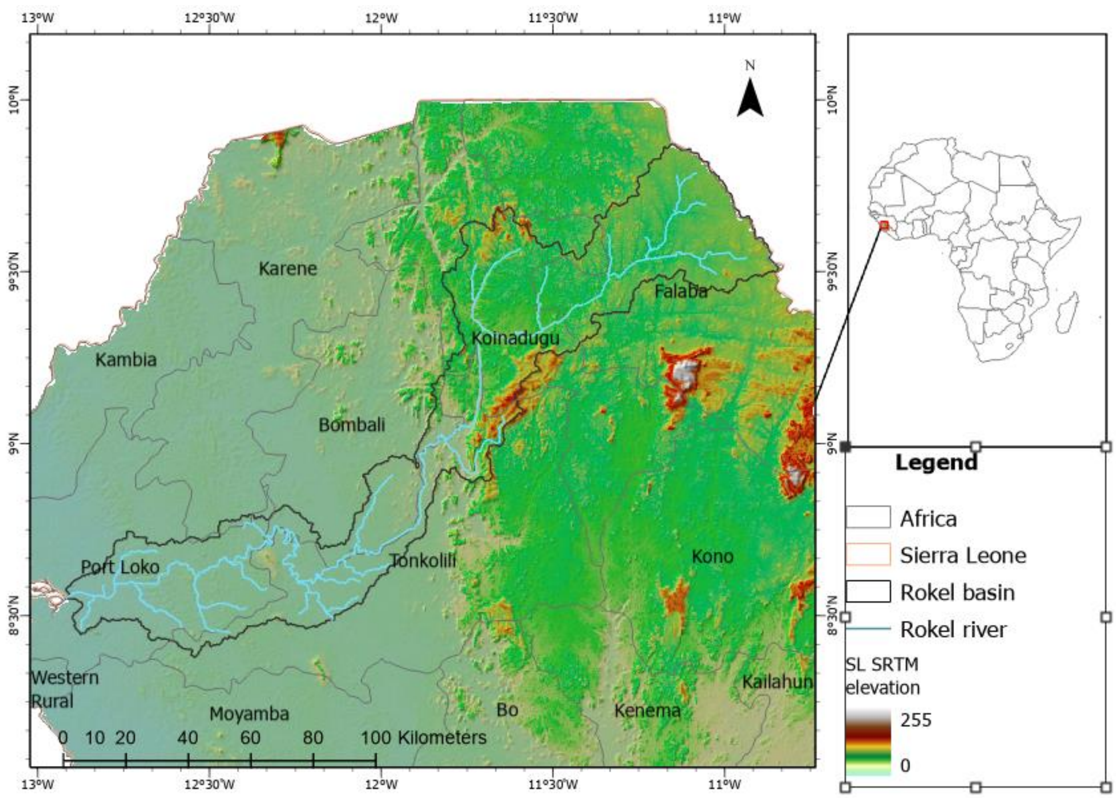

Figure 1 Rokel river basin

The Rokel River provides a wide range of ecosystem services and serves as a source of livelihood for thousands of Sierra Leoneans. For example, fishing alone scores 50% of the land-use practices in the Tonkolili district (Kamara, 2022). Furthermore, the Rokel river serves as a water source for the Bumbuna Hydroelectric plant, the Magburaka water supply system, Sunbird Bioenergy, which is an agricultural company, and Kingho Mining company amongst others. This has created high competition for water resources in the face of climate change impacts like reduction in rainfall, deforestation, mining impacts, increase in population and urbanisation (Kamara, 2022).

3.1 Population

The Rokel river basin's current population is 1,334,071 (Sierra Leone Statistics 2015). The basin boundaries cuts across 25 administrative chiefdom boundaries. Figure below shows the different chiefdoms and populations in the Rokel river basin.

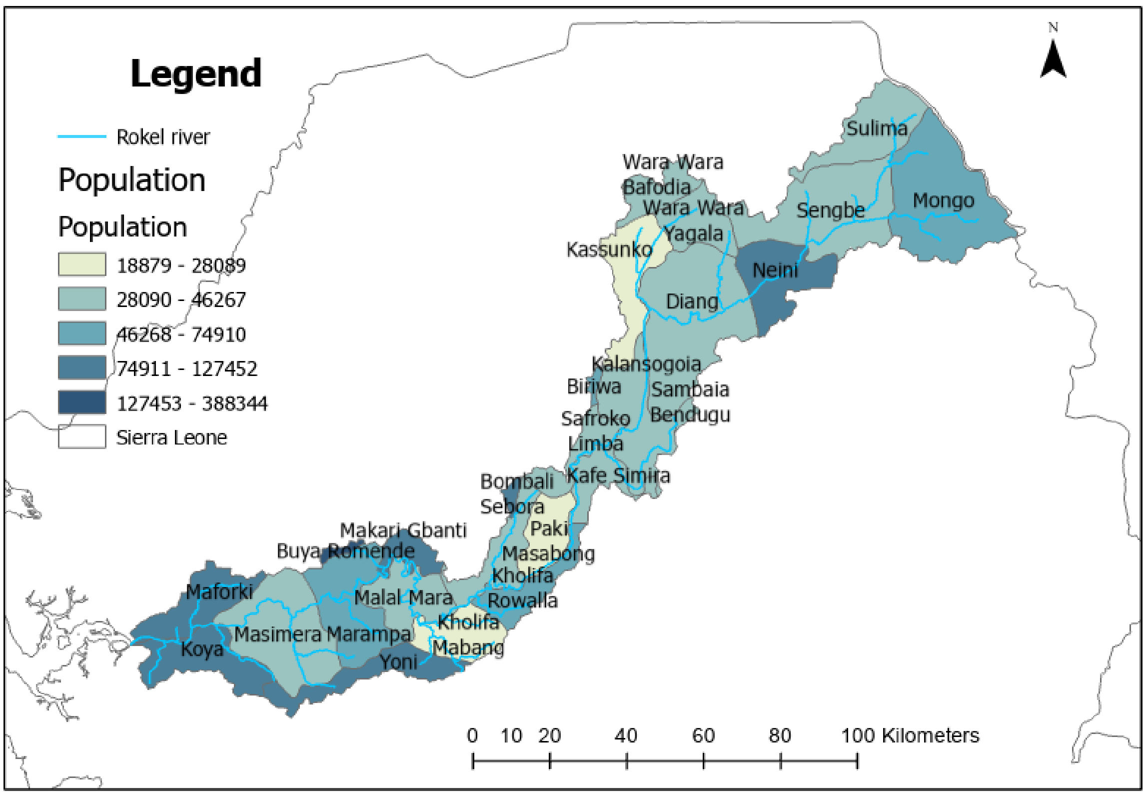

Figure 2 Population by chiefdoms in the Rokel river basin

3.2 Climate

The Rokel river basin like the rest of the country experiences two seasons, the dry and rainy seasons. The dry season runs from November to April whilst the rainy season runs from May to October. The mean annual temperature of Sierra Leone has been increasing by 0.8 ^{0}C since 1960 which suggests a rising temperature due to climate change and it is projected to rise by 1.0 to 2.6 ^{0}C by the 2060s. Also, the overall precipitation has decreased since the 1960s and it is projected to increase especially in JAS and OND (McSweeney 2010).

The increase in the atmospheric temperature has impacted the Rokel river temperature with an observed average increase of 1.2 ^{0}C between 2019 to 2021.

The descriptive statistics for rainfall data from 2015 to 2020 is shown in table 1 below

Table 1 Descriptive statistics Makeni rainfall data (2015 - 2020)

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Rainfall (mm)	2190	150.00	.00	150.00	7.1747	.34540	16.16389	261.271	3.521	.052	16.045	.105
Valid N (listwise)	2190											

Also figure 3 below shows the seasonal rainfall pattern in the Rokel river basin with the dry months of January, February March, and December.

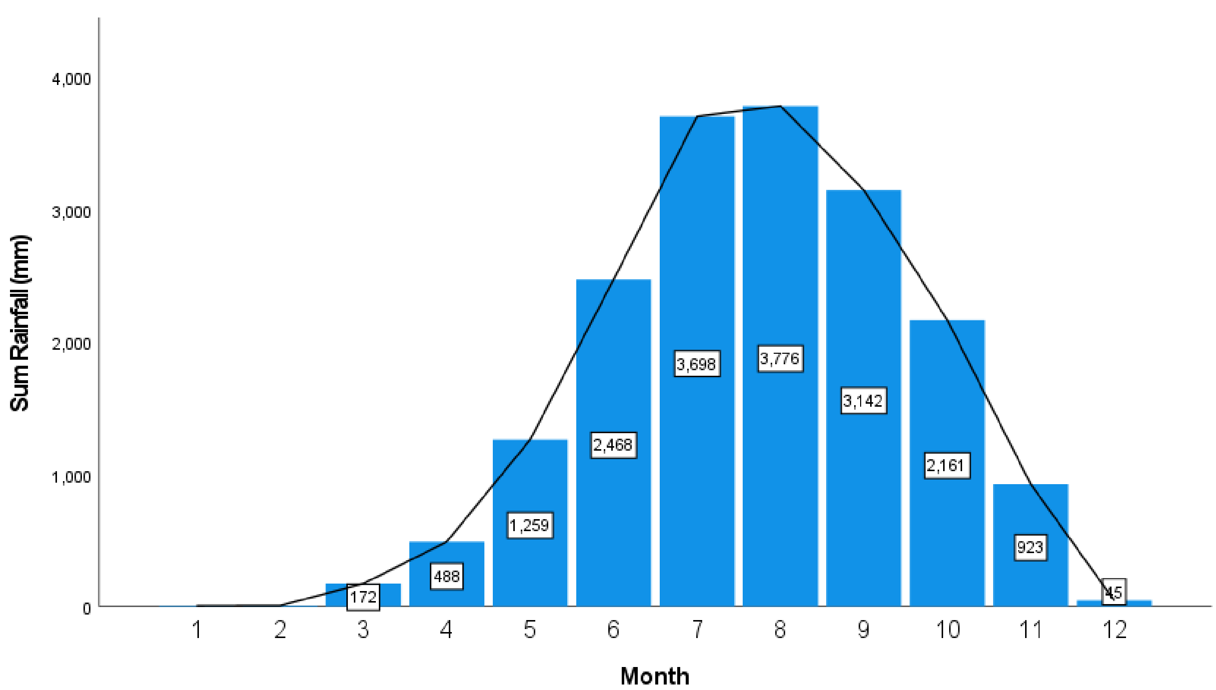

Figure 3 Sum of rainfall by months (2015 to 2021)

In the last five years, 2019 and 2018 had the highest and lowest rainfall respectively as shown in figure 4 below. The mean rainfall in the last five years is 2,619 mm.

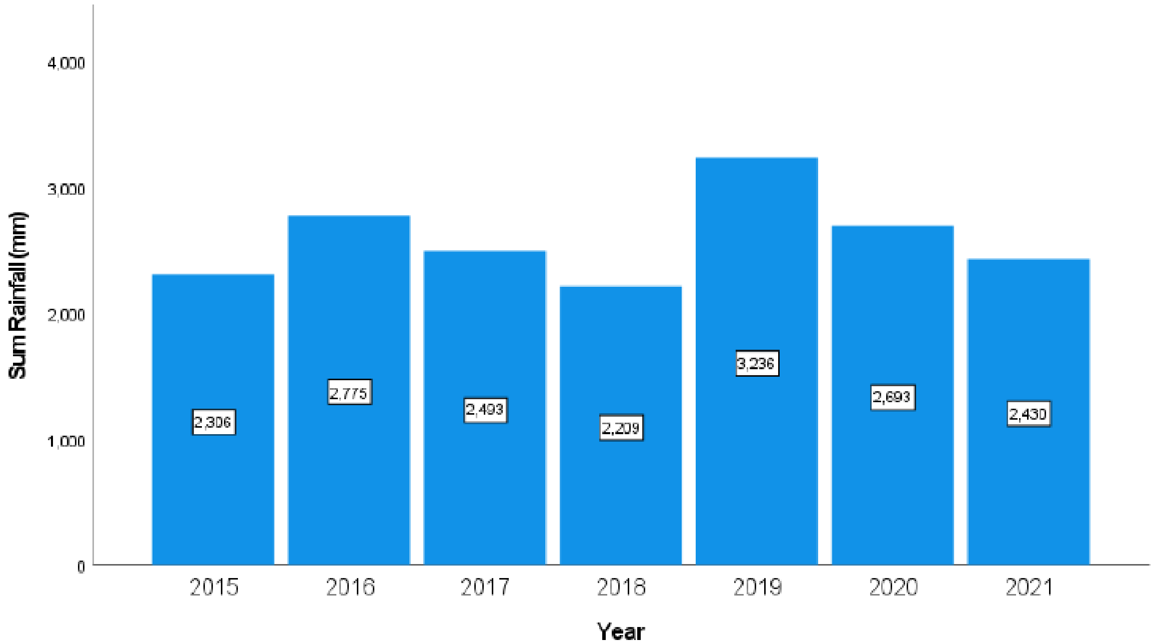

Figure 4 Sum of annual rainfall

3.3 Geology

The Rokel river basin is made up of five geological units, which are the basement complex, Bullom, Kasila, Marampa and Rokel River group as shown in the geological map below

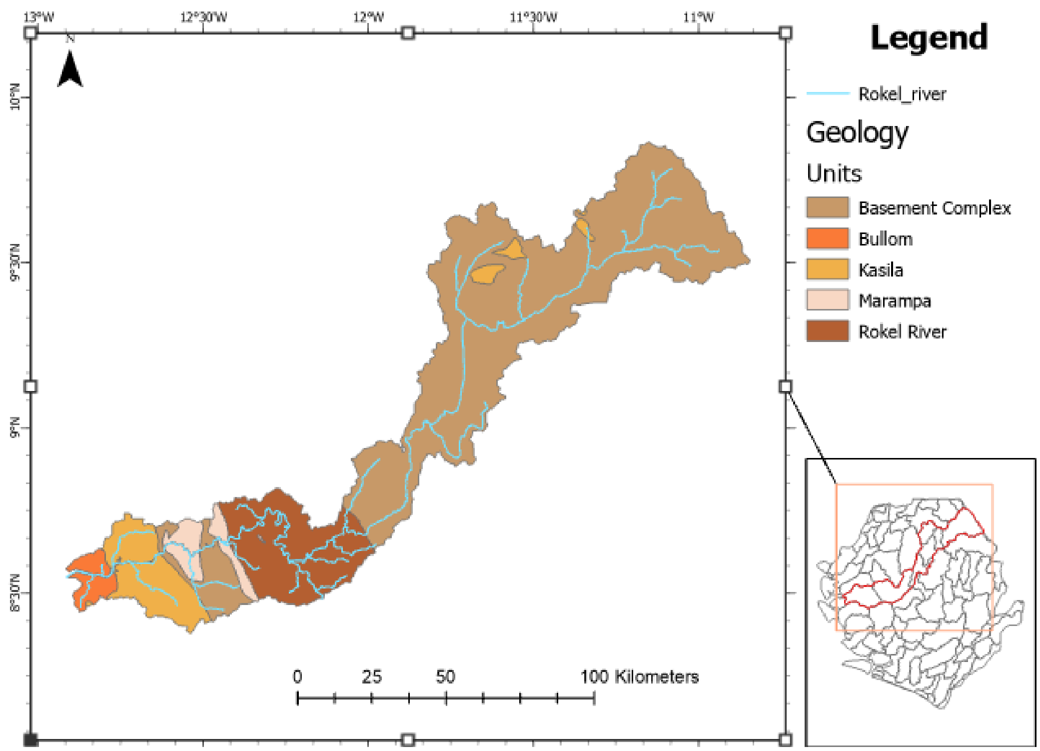

Figure 5 Rokel river basin geology

3.4 Basement complex

This formation occupies about 75% of the entire geology of Sierra Leone and comprises granitic rocks that date to the Archaean age. The crystalline basement complex has two major units which are the north-south granite/green-stone and the northwest-southeast Kasila group. The granite/green-stone is primarily comprised of iron and magnesium-rich rocks, whilst the Kasila Group is made up of migmatite and gneiss which are of high grade.

3.5 Rokel river group

This group is about 225 km and 30 km long and comprises sandy and clayey sediments.

3.6 Bullom Group

This group is found almost along the entire coastline of Sierra Leone and is made up of sands and clays. It also has almost horizontal beds of estuarine, marine, and fluvial gravels. Also, most of the river alluvial valleys and flood plains fall within this geological unit.

3.7 Hydrology

The Rokel river originates from the northeast and cuts across Falaba, Koinadugu, Tonkolili, Bombali and Port Loko districts before emptying into the Atlantic Ocean, west of Sierra Leone. The river has a length of 386 km and occupies an area of 8,233 km^2 (ECREE, 2016). The figure below shows the drainage network of the Rokel river basin

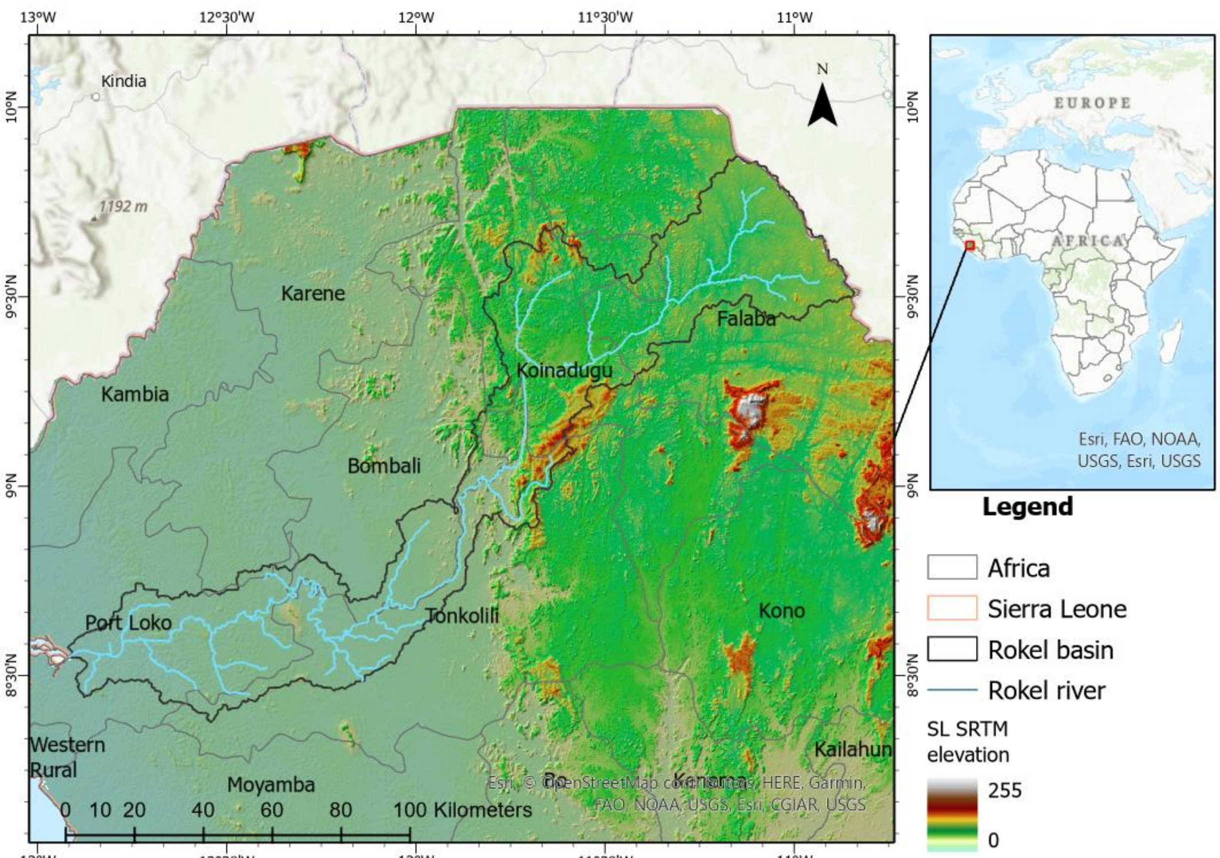

Figure 6 Rokel river basin

From figure 6 above, the river is fed by several tributaries as it flows down to the Atlantic Ocean.

Also, river flow has been decreasing from 1979 to 2021, with an observed significant decline noted in the early 2000s as shown in 7 below.

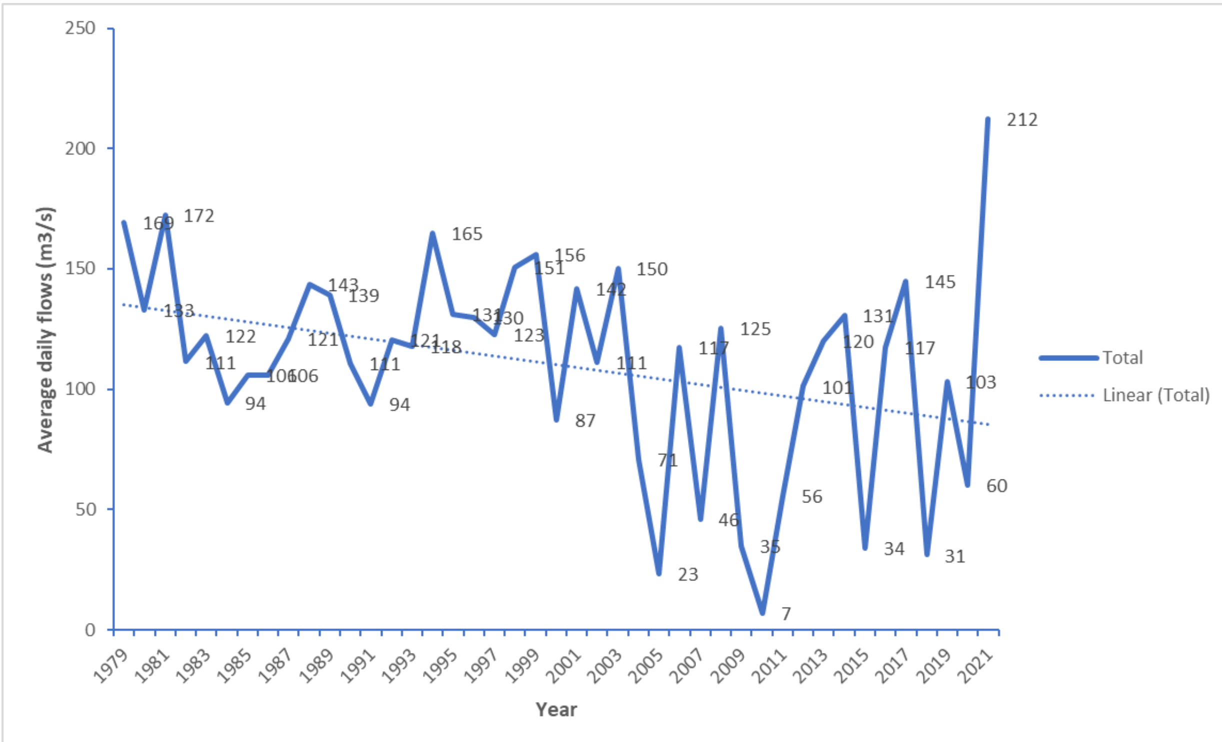

Figure 7 Average daily flow over the years of the Rokel river

The minimum and maximum statistics are 0.05 and 1,029 m^3/s, and a mean flow of 113 m^3/s (AGHRYMET, 2022).

Also, the river flow data is highly responsive to rainfall. This is seen in figure 8 below in which Makeni rainfall is plotted against the river flow data (2015-2020).

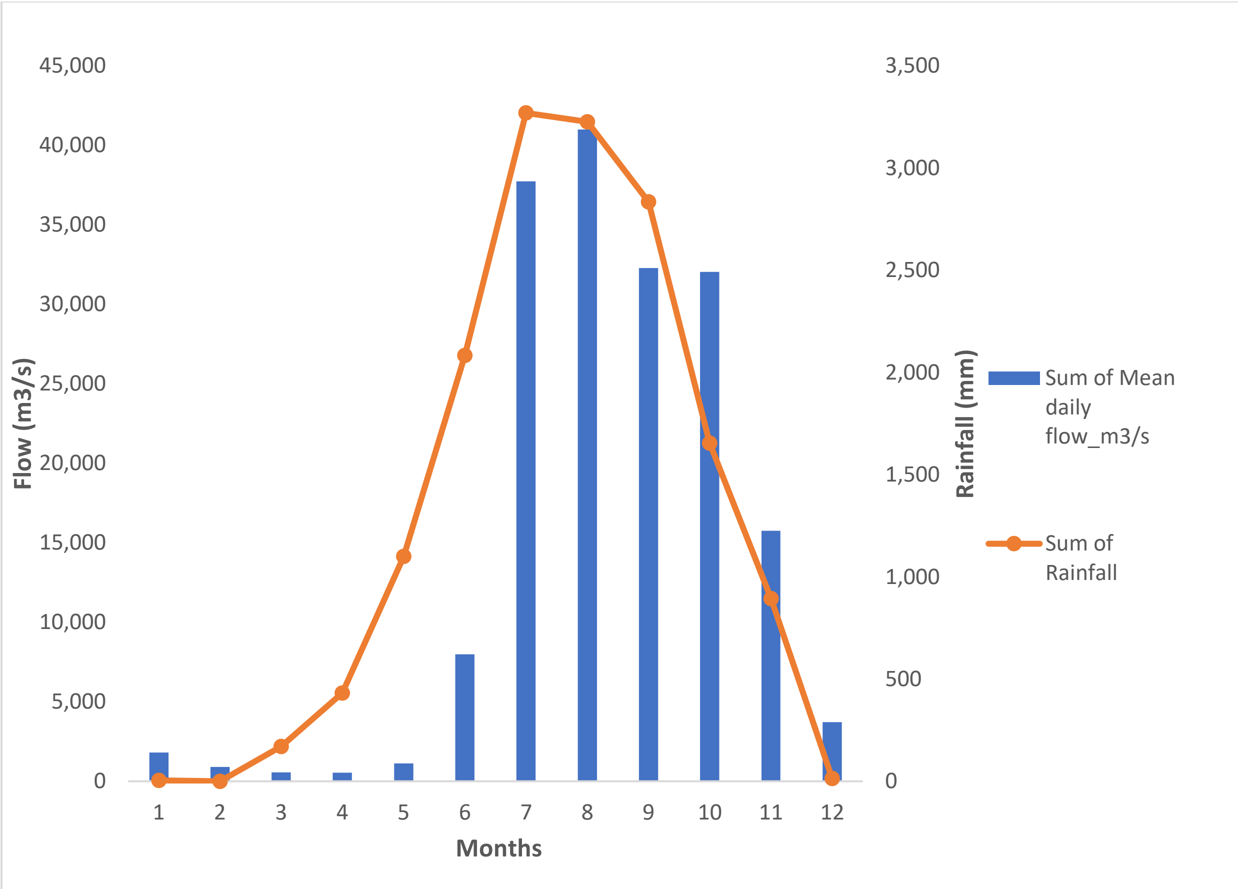

Figure 8 Flow against rainfall at the Rokel river basin

3.7.1 Hydrological monitoring stations

The National Water Resources Management Agency (NWRMA) has established surface and groundwater monitoring stations in the Rokel river basin. The stations are recording data automatically and transferred through a telemetric system to a central server. The parameters that are been monitored are rainfall, temperature, surface and groundwater levels, TDS, Ph, DO and EC. Figure 9 below shows the locations of surface and groundwater monitoring stations in the Rokel river basin.

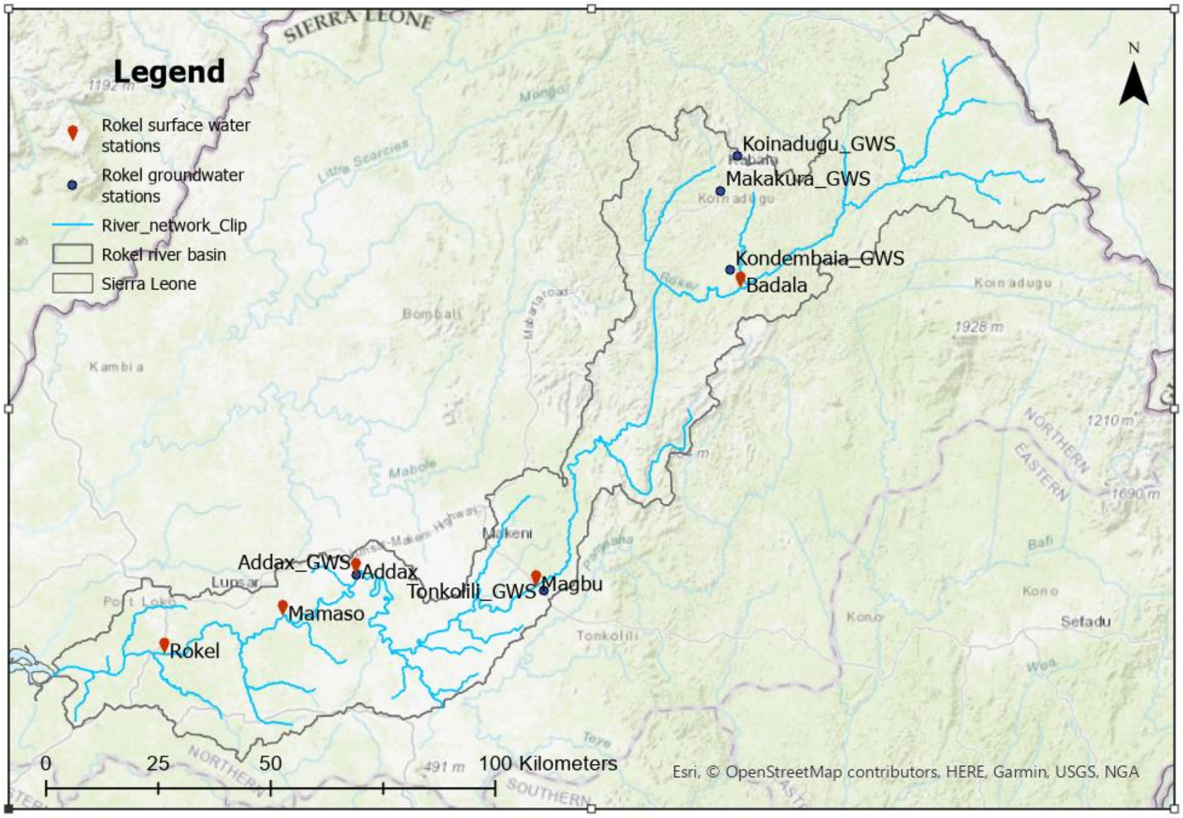

Figure 9 Surface and groundwater monitoring stations at the Rokel river basin

3.8 Water quality

The NWRMA has established 21 surface and 19 groundwater quality monitoring stations across the Rokel river basin. The locations of the surface and groundwater monitoring stations are shown in figure below.

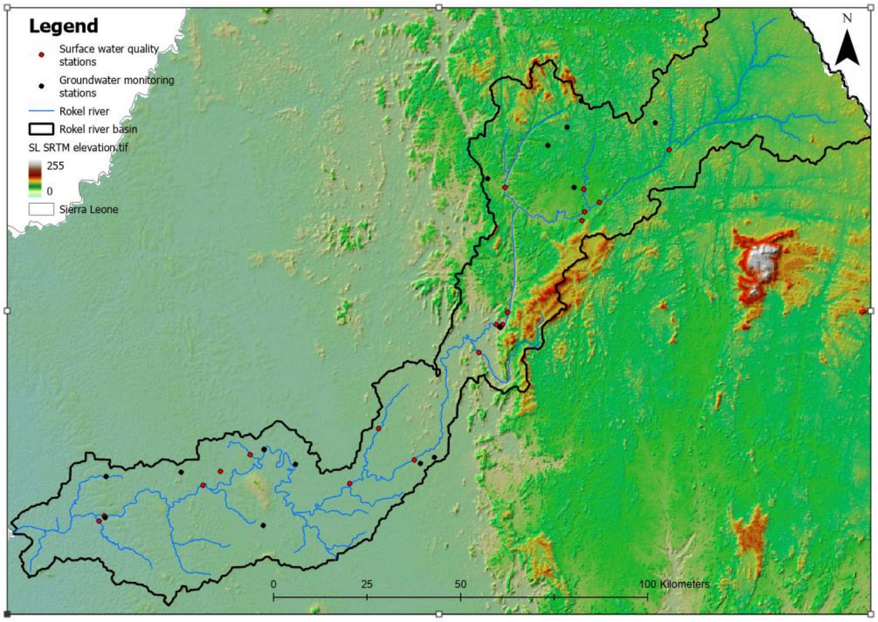

Figure 10 Surface and groundwater quality monitoring stations

These stations are routinely monitored almost on a monthly basin of the following parameters shown in table below

Table 2 Water quality parameters tested for at the Rokel river basin

	Parameters	Parameter Short Name	Target Value	Unit	Target Type
Core or Level 1 Parameters	Dissolve Oxygen	DO	6	mg/l	Lower
	Electrical Conductivity	EC	500	us/cm	Upper
	pH	pH	6.5 – 8.5		Range
	Orthophosphate	OP	0.0215	mg P/l	Upper
	Total Oxidised Nitrogen (Nitrate + Nitrite)	TON	1.8	mg N/l	Upper
	Progressive Parameters (WHO)				
Progressive or Level 2	Water Temperature (°C)				
	Turbidity		<5.0	NTU	Upper
	Conductivity		<450	µS/Cm	Upper
	Total Dissolve Solids	TDS	<248	ppm	Upper
	Fluoride	F	<1.5	mg/l	Upper
	Iron	Fe	<0.3	mg/l	Upper
	Nitrite	NO_2^-	3	mg/l	Upper
	Nitrate	$NO3^-$	<10	mg/l	Upper

Parameters	Potassium	K	<6.0	mg/l	Upper
	Phosphate	P	<20	mg/l	Upper
	Sulphate	S04	<400	mg/l	Upper
	E. Coli		0		Lower

3.8.1 Surface water quality status

The results of the water quality parameters monitored at the Rokel river basin is summarised in the table below.

Table 3 Summary of surface water quality results at the Rokel river basin

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Temperature (oC)	449	17.53	20.07	37.60	28.1447	.14097	2.98715	8.923	-.069	.115	.176	.230
pH	449	4.72	3.78	8.50	6.9583	.02656	.56290	.317	-.771	.115	2.380	.230
EC (µS/Cm)	449	72.00	5.00	77.00	26.8244	.60724	12.86724	165.566	1.049	.115	1.032	.230
TDS (ppm)	449	36.00	2.50	38.50	13.4793	.30717	6.50886	42.365	1.033	.115	.914	.230
DO (mg/l)	449	13.40	1.70	15.10	7.3025	.08530	1.80754	3.267	.157	.115	2.420	.230
Turb(NTU)	449	244.00	.00	244.00	23.3273	1.48088	31.37926	984.658	3.343	.115	14.952	.230
Orthophosphate (mg/l)	449	9.975	.025	10.000	.81865	.046789	.991437	.983	3.574	.115	19.620	.230
TON (mg/l)	449	2.170	.030	2.200	.59786	.024443	.517942	.268	.864	.115	.256	.230
Nitrite (mg/l)	449	.495	.005	.500	.02453	.001962	.041584	.002	8.820	.115	91.290	.230
Nitrate (mg/l)	449	1.96	.04	2.00	.5737	.02428	.51445	.265	.881	.115	.276	.230
Sulphate (mg/l)	432	97.5	2.5	100.0	7.517	.7038	14.6284	213.990	5.089	.117	27.125	.234
Potassium (mg/l)	449	15.65	.35	16.00	2.2231	.12408	2.62926	6.913	2.664	.115	7.442	.230
Fluoride (mg/l)	398	1.975	.025	2.000	.45377	.030108	.600649	.361	1.281	.122	.484	.244
Iron (mg/l)	449	1.090	.010	1.100	.16109	.007384	.156455	.024	2.591	.115	9.121	.230
Choloride(mg/l)	117	19.65	.25	19.90	2.8019	.31542	3.41181	11.640	2.122	.224	6.325	.444
Chromium mg/l	137	3.59	.01	3.60	.0704	.02624	.30714	.094	11.329	.207	130.954	.411
Ammonia mg/l	137	.99	.01	1.00	.0839	.01204	.14088	.020	3.535	.207	15.459	.411
Copper mg/l	118	1.825	.025	1.850	.12352	.020351	.221066	.049	5.268	.223	34.942	.442
TSS (mg/l)	78	164	5	169	32.97	3.719	32.850	1079.090	2.066	.272	4.784	.538
Valid N (listwise)	78											

3.8.1.1 Temperature of the river water

The temperature of the Rokel river ranges between 20.1 to 37.6 ^{0}C with an average value of 28.1 ^{0}C. The yearly mean river temperature has been changing with 2019 recording 26.4 ^{0}C, 2020 at 27.9 ^{0}C and 2021 at 28.8^{0}C. Also, the temperature is highest at downstream of the river than upstream as shown in figure 11 below.

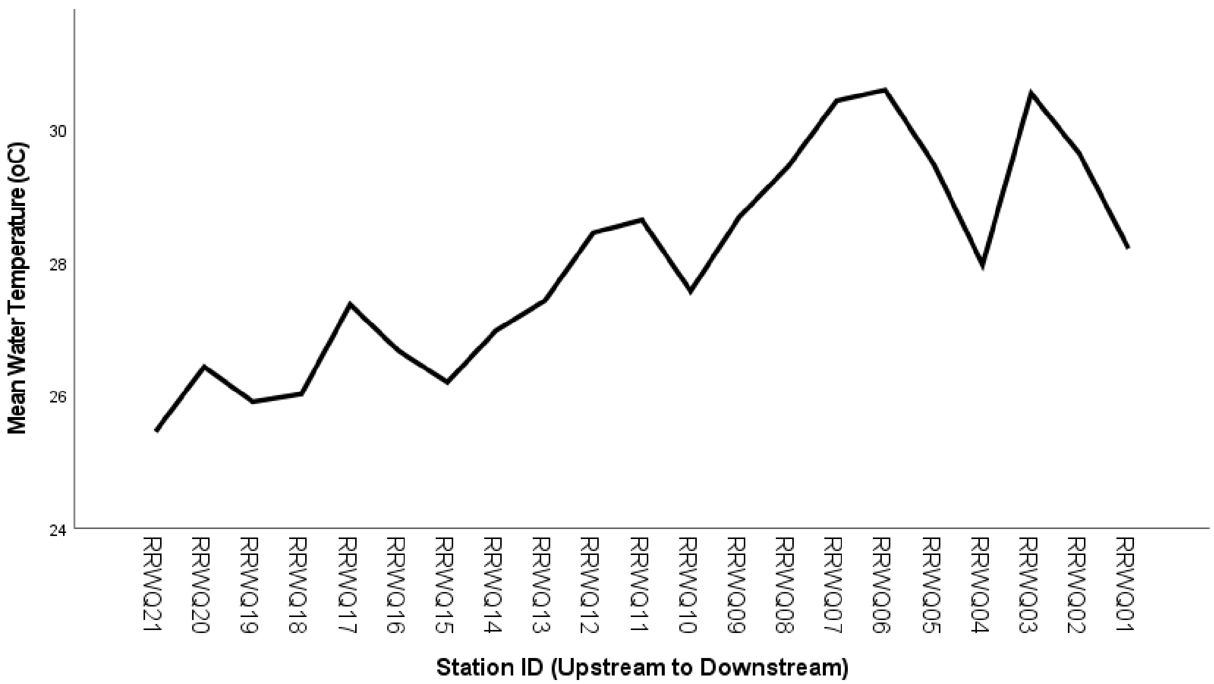

Figure 11 Increase in the river temperature as you move downstream of the Rokel river

McSweeney, (2010) shows that the mean atmospheric temperature has been increasing annually by 0.8 ^{0}C and it is projected to increase by 1.2 ^{0}C to 2.6 ^{0}C by the 20160s. Such a rise in the atmospheric temperature will lead to an increase in evaporation of the water bodies and consequently affecting the water quantity. Not limited to the above, thermal stress affects aquatic organisms negatively by impacting their reproductive cycles (Chen et al. 2015).

3.8.1.2 Nitrate

Nitrate can be largely traced to agriculture due to its use as fertilisers and its concentration in the Rokel river ranges between 0.04 to 2.0 mg/l, with a mean of 0.57 mg/l. The SDG upper target for Nitrate is 5 mg/l. Although, all the surface water quality stations do not exceed the nitrate target, it is noted that concentrations of nitrate are higher midstream than the other stream sections as shown in figure 12 below. The land use and land cover mapping shows that agriculture is highly practiced at midstream.

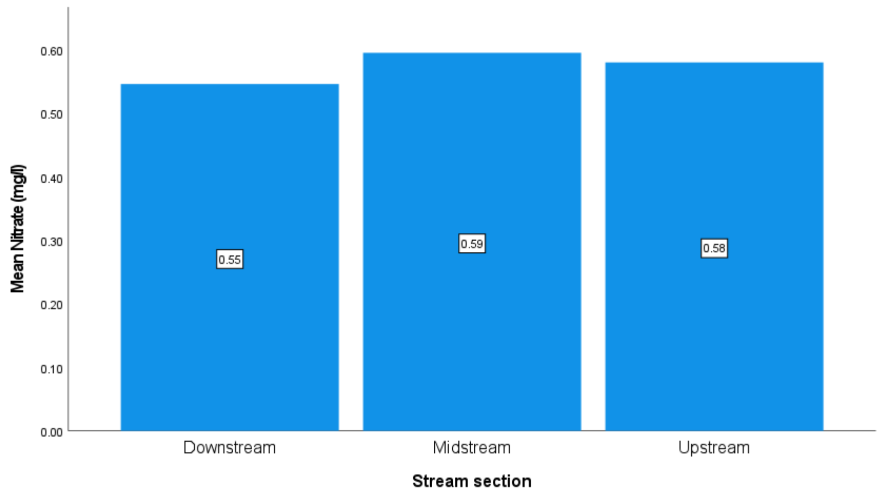

Figure 12 Differences in the mean nitrate concentration across stream sections

3.8.1.3 Orthophosphate

The orthophosphate results in the Rokel river basin ranges between 0.025 to 10 mg/s, with a mean of 0.8 mg/l which is above the SDG 632 indicator target of 0.215 mg/l. Figure 13 below shows that the concentration of orthophosphate is highest in surface water than groundwater, although both are above the target value.

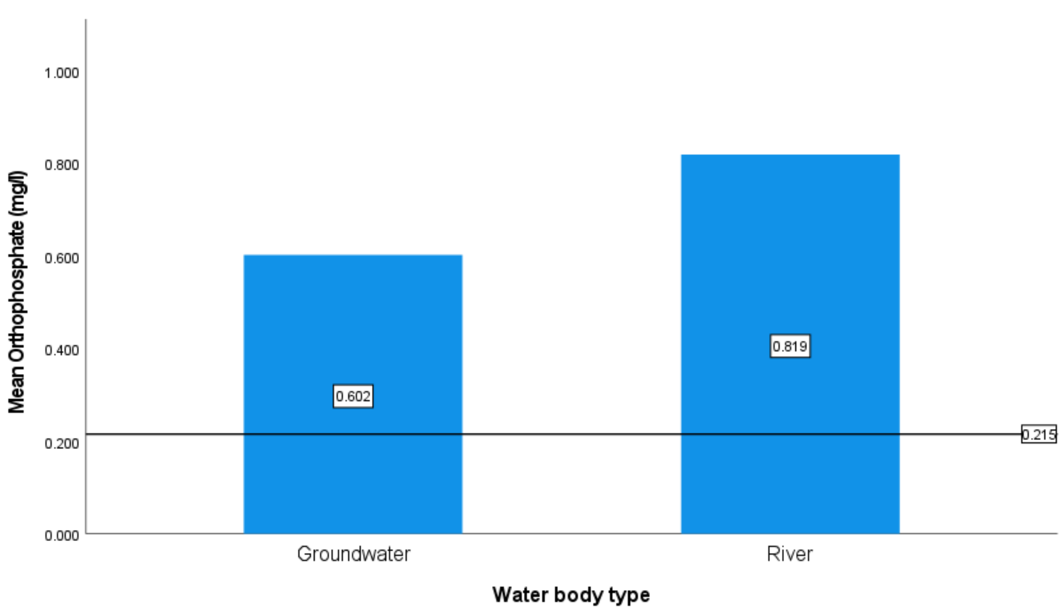

Figure 13 Variations of the mean orthophosphate values in surface and groundwater in the Rokel river basin.

One of the major sources of orthophosphates is from agriculture due to the use of phosphate-based fertilisers and its presence in the river and groundwater could be due to surface runoffs and seepage respectively.

3.8.1.4 Turbidity

The turbidity of the Rokel river basin ranges between 0 to 244 NTU with an average of 23 NTU. This suggest that the river is very turbid. The turbidity is due to the increase in the operations of artisanal miners at the banks of the river. It can also be attributed to the runoffs from deforested land due to timba logging, slash and burn for agricultural purposes and charcoal burning. Also, the Rokel river is more turbid at midstream, followed by upstream as shown in figure 14 below.

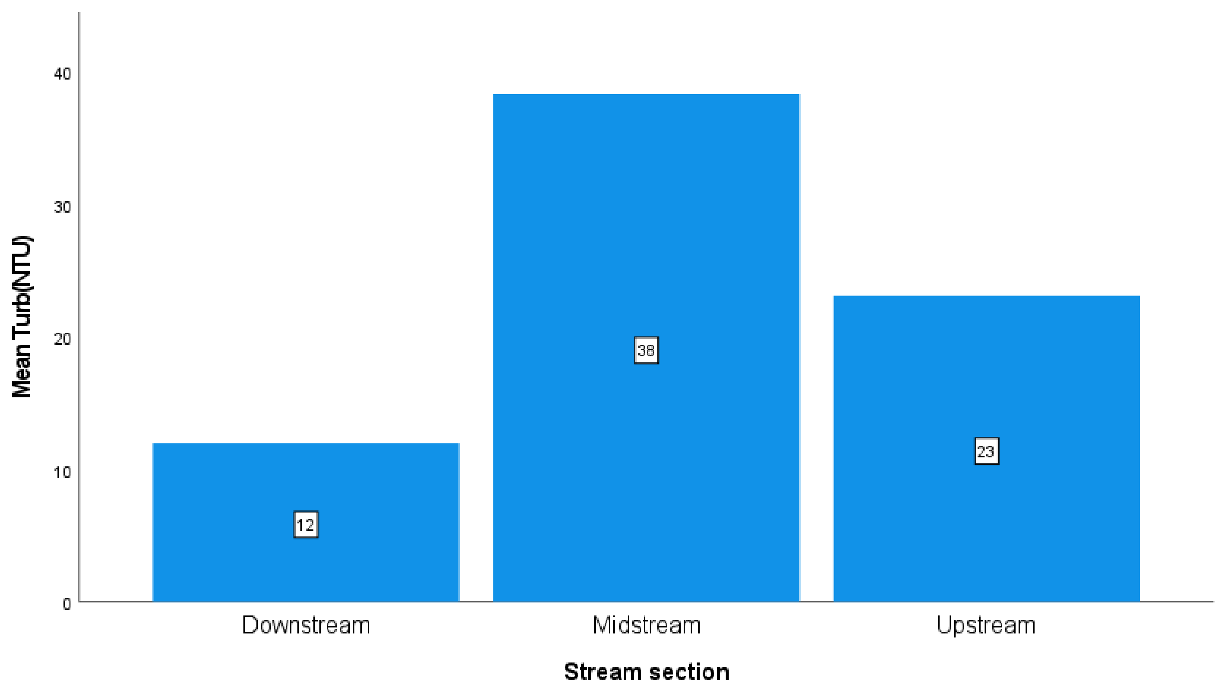

Figure 14 Variation of turbidity across the different stream sections

3.8.2 Groundwater quality

Groundwater quality is monitored at the 19 groundwater quality monitoring stations that are represented at the different geological units in the Rokel basin. The summary results of the water quality parameters monitored is shown in table below.

Figure 15 Summary statistics of groundwater quality parameters

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Temperature (oC)	140	8.7	23.9	32.6	29.240	.1291	1.5279	2.335	-.866	.205	1.583	.407
pH	141	7.90	3.40	11.30	5.6250	.07025	.83412	.696	2.412	.204	14.680	.406
EC (µS/Cm)	141	343.7	.3	344.0	105.413	7.2542	86.1393	7419.986	1.069	.204	.269	.406
TDS (ppm)	143	723.0	.0	723.0	51.833	5.9520	71.1758	5065.991	6.189	.203	55.472	.403
DO (mg/l)	141	15.90	.60	16.50	6.0476	.24199	2.87351	8.257	1.340	.204	2.867	.406
Turb(NTU)	141	144	0	144	11.84	1.999	23.734	563.309	3.523	.204	14.525	.406
Orthophosphate (mg/l)	141	9.975	.025	10.000	.61433	.088523	1.051153	1.105	6.146	.204	47.632	.406
TON (mg/l)	142	4.000	.000	4.000	.63134	.042874	.510900	.261	2.680	.203	14.582	.404
Nitrite (mg/l)	141	.195	.005	.200	.01404	.001842	.021876	.000	6.201	.204	42.979	.406
Nitrate (mg/l)	141	2.76	.04	2.80	.6009	.03534	.41963	.176	1.141	.204	4.290	.406
Sulphate (mg/l)	141	97.5	2.5	100.0	7.745	1.0935	12.9846	168.600	5.534	.204	35.806	.406
Potassium (mg/l)	140	15.65	.35	16.00	3.5707	.31611	3.74027	13.990	1.678	.205	2.481	.407
Fluoride (mg/l)	141	1.235	.025	1.260	.09727	.019182	.227770	.052	3.786	.204	13.918	.406
Iron (mg/l)	141	1.990	.010	2.000	.16174	.028515	.338595	.115	3.387	.204	12.727	.406
Choloride(mg/l)	109	24.75	.25	25.00	5.4546	.59542	6.21639	38.643	1.492	.231	1.758	.459
Chromium mg/l	141	7.09	.01	7.10	.1323	.05177	.61470	.378	10.673	.204	120.336	.406
Ammonia mg/l	141	24.99	.01	25.00	1.0585	.30057	3.56906	12.738	4.625	.204	23.170	.406
Copper mg/l	16	.975	.025	1.000	.24656	.081177	.324709	.105	1.859	.564	2.297	1.091
Valid N (listwise)	0											

3.8.2.1 Groundwater pH

The pH of the groundwater in the Rokel basin ranges between 3.4 to 11.3 with a mean of 5.63. This suggest that the overall groundwater quality is acidic. The lower target value of SDG 6.3.2 id 6.5 and from figure 15 below, all the groundwater stations are below the target value except Fadugu groundwater station.

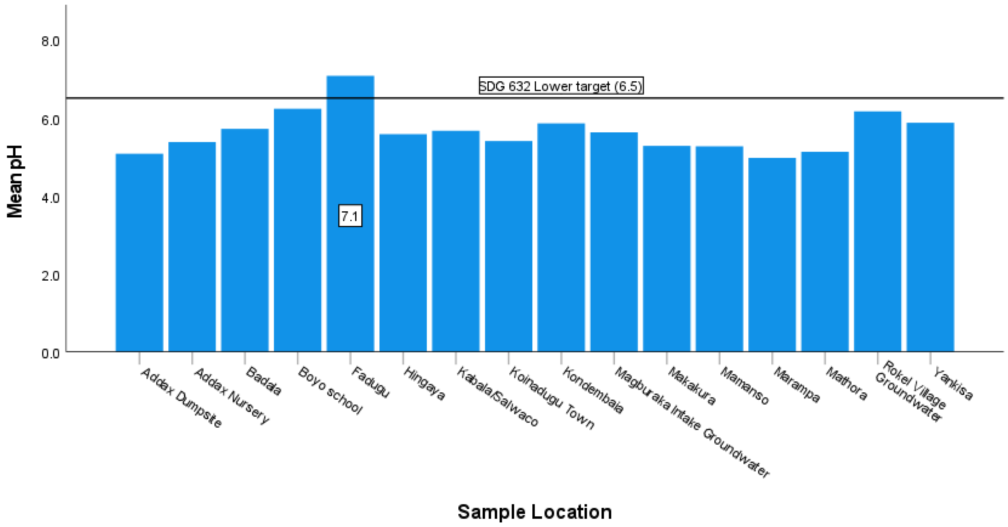

Figure 16 Mean pH across groundwater monitoring stations in the Rokel basin

The findings that the ground water is acidic is similar to the findings of Jalloh, Sasaki and B. Jalloh, (2018), that shows that 54% of the water quality assessment conducted in boreholes in Sierra Leone are acidic. The acidity could also be due to the geology as 75% of Sierra Leone's geology is made of crystalline rocks (Fileccia et al. 2017).

3.8.3 Sierra Leone's SDG 6.3.2 water quality indicator report

The SDG 6.3.2 indicator which is the "proportion of water bodies that meet ambient water quality" is used to report the overall water quality status of the Rokel river water. It is calculated usinThe indicator is calculated by using the following equation:

Equation 1 SDG 632 indicator calculation $\boldsymbol{Indicator\ 6.3.2 = \frac{n_g}{n_t} \times 100}$

Where **ng**: Number of waterbodies that is good

nt: total number of waterbodies monitored

A water body that has a percentage compliance of 80% and above is classed "good" and below 80% is classed as "not good".

The indicator score of the Rokel river basin is shown in the table below

Table 4Rokel basin indicator score

Indicator Summary	
Water body Count	39
Water body "classified as "good"	8
National Indicator Score	**21**
GW Water body Count	17
GW Water body "classified as "good"	0
GW Indicator Score	**0.0**
River Water body Count	22
River Water body "classified as "good"	8
River Indicator Score	**36**

The overall indicator scores of 21% shows that the Rokel river basin is not "good" as it fails to meet the 80% target. To compute the percentage compliance "0" is assigned to the parameters that does not meet the target and "1" is assigned to parameters that meets the target. Also, indicator score for the Rokel river has been declining over the years is shown in figure 17 below.

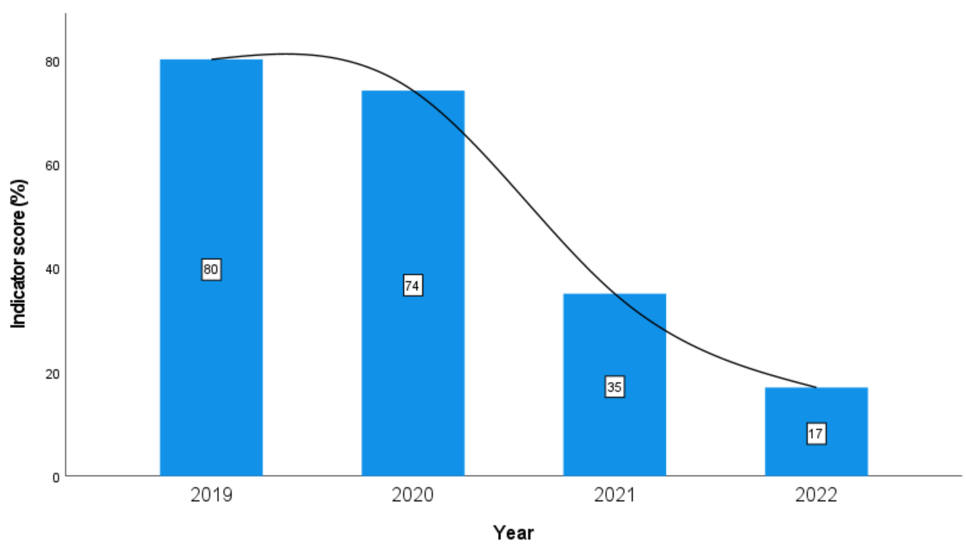

Figure 17 Variation in SDG 632 indicator score over the years

The decrease in the indicator score is due to the increasing pressures in the Rokel river basin that are affecting the percentage compliance of the indicator parameters. In addition, another major reason is the inclusion of the groundwater monitoring stations in 2021 that are acidic and hence reduce the percentage compliance of pH which affects the overall indicator score.

The percentage compliance of each station for both surface and groundwater are shown in the table below.

Table 5 Percentage compliance of surface and groundwater stations

No	Groundwater	0	1	Percentage Compliance	Target Met
1	Addax Dumpsite	17	10	37	0
2	Addax Nursery	12	15	56	0
3	Badala	9	18	67	0
4	Boyo school	6	6	50	0
5	Fadugu	11	16	59	0
6	Hingaya	18	9	33	0
7	Kabala/Salwaco	10	17	63	0
8	Koinadugu Town	12	12	50	0
9	Kondembaia	13	11	46	0
10	Magburaka Intake Groundwater	9	18	67	0
11	Makakura	9	18	67	0
12	Makeni	16	26	62	0
13	Mamanso	10	20	67	0
14	Marampa	10	20	67	0
15	Mathora	9	18	67	0
16	Rokel Village Groundwater	13	14	52	0
17	Yankisa	7	17	71	0
River					
1	Addax	24	101	81	1
2	Badala	26	99	79	0
3	Bumbuna Bridge	21	104	83	1
4	Bumbuna Bridge Tributary	30	95	76	0
5	Bumbuna Reservoir	5	25	83	1
6	Bumbuna Waterfall	16	79	83	1
7	Bumbuna Waterfall Tributary	35	115	77	0
8	Magburaka Highway	32	93	74	0
9	Magburaka Intake	22	103	82	1
10	Maken	26	94	78	0
11	Makiler	9	26	74	0
12	Mamaeli	28	97	78	0
13	Mamansu	26	99	79	0
14	Mane	6	14	70	0
15	Mangay	10	25	71	0
16	Masafi	29	96	77	0
17	Rokcamp	8	17	68	0
18	Rokel Village	21	104	83	1
19	Seli	26	99	79	0
20	Yebeni Tributary	24	96	80	1
21	Yilsaia	34	91	73	0
22	Yirafilaia	25	100	80	1

The percentage compliance of the surface water stations in table 5 above are averaged into sub-catchments based on the number of surface water monitoring stations that are in the sub-catchment(s) to give the percentage compliance of the sub-catchments as shown in the

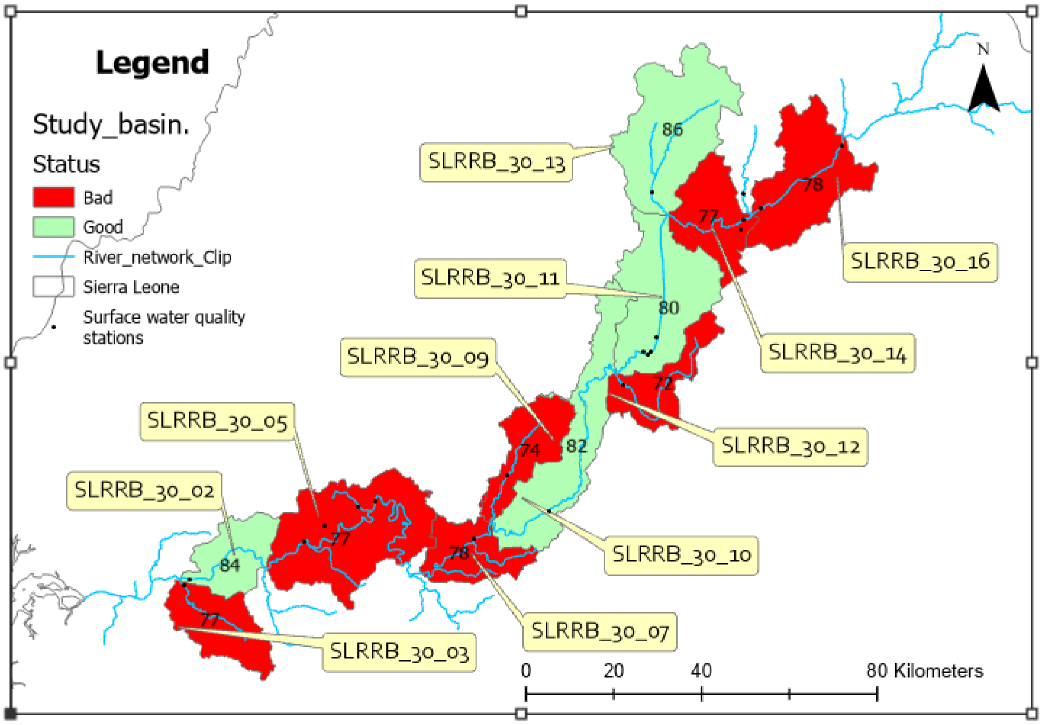

Figure 18 Percentage compliance of sub-catchments in the Rokel river basin

3.9 Land use and land cover mapping

The NWRMA conducted a land use and land cover mapping at the Rokel river basin to determine the current land use and land cover status amidst the growing anthropogenic pressures. The results obtained from the land use and land cover mapping conducted in the Rokel River basin is shown in Figure 18 below.

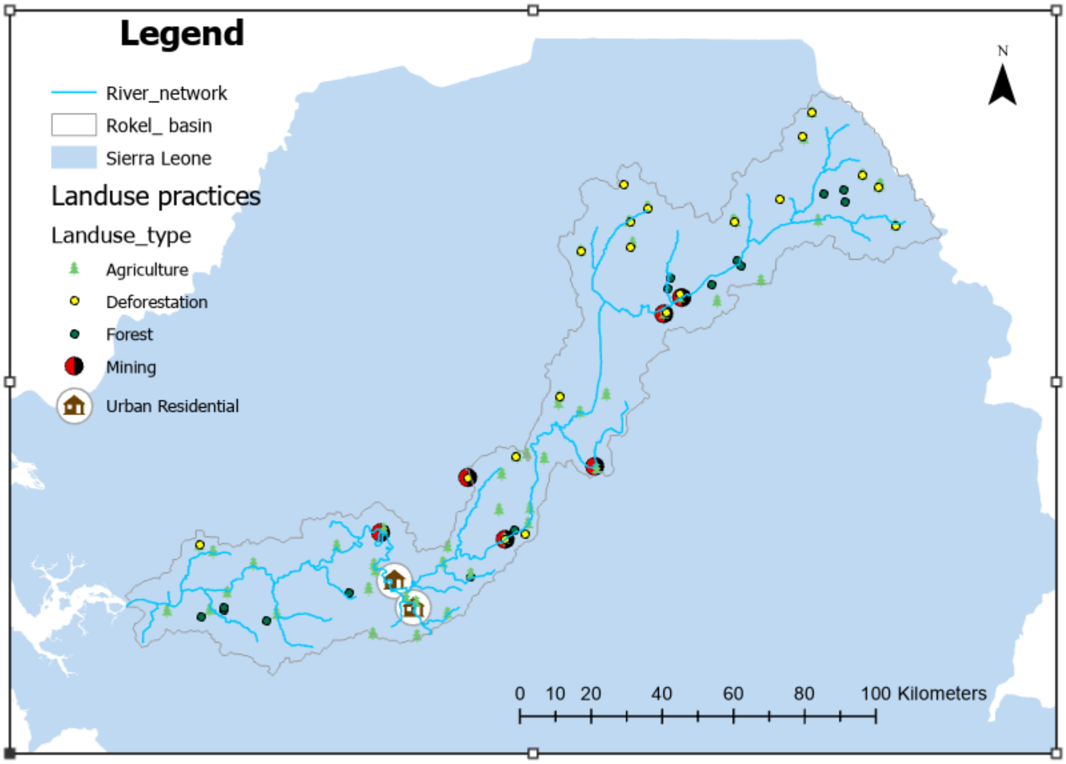

Figure 19 Major land use practices in the Rokel River basin

The major land use practices in the Rokel river basin are Agriculture, mining and deforestation. Also, the land use practices when categorised by the districts in the basin, it shows that timber logging is highest at Koinadugu district (83%), followed by Tokolili district (17%). In addition, fishing which is a secondary land use practice is practiced more at Tonkolil district (50%). Further details are shown in figure 19 below of the land use practices across the different districts in the Rokel river basin

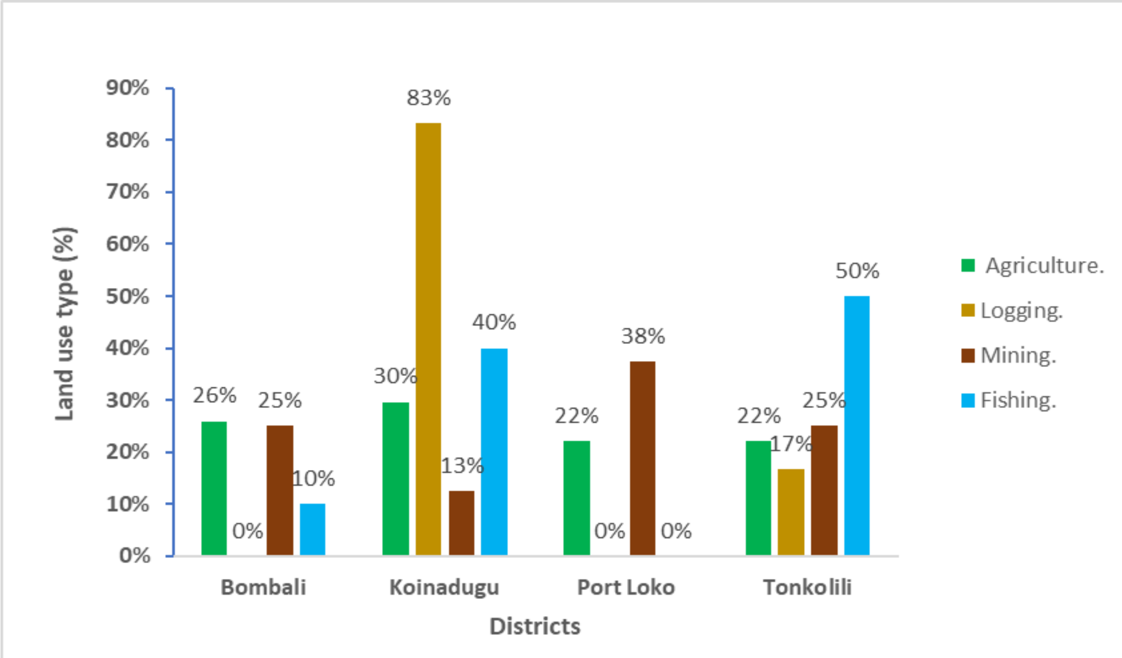

Figure 20 Landuse practices across the districts in the Rokel River basin

Agriculture is the highest land use practice in the basin (53%) and has major agricultural company like Sunbird Bioenergy that grows sugar cane for ethanol and energy production and sits on 100,000 hectares of land. It is a major source of livelihoods of many Sierra Leoneans and contribute about 59.5% of the country's GDP ("Agriculture, forestry, and fishing, value added (% of GDP) - Sierra Leone | Data," 2022.).

Second to agriculture is mining which scores 16% of the total land use practice in the basin. The most common types of mining identified are small- and large-scale mining that are abstracting iron ore and gold. The major problem with mining is the proliferation of the unregulated artisanal miners that are mining gold in the riverbanks, thereby releasing pollutant in the river like sediments which has increased the river turbidity. It is also reported that mercury is used by artisanal miners as they abstract gold. Mercury is carcinogenic and has serious health implications for both aquatic organisms and humans.

Also, deforestation score 12% of the total land use practices in the basin. The major cause of the deforestation is timber logging which has now turned into a lucrative business. One of the major impacts of deforestation is it reduces infiltration of water into the aquifers thereby contributing to groundwater decline. In addition, deforestation also leads to an increase in surface runoffs that ends into the river and stream network thereby increasing the river turbidity due to sediment transport.

3.9.1 Quantification of risks associated with the sub-catchments in the Rokel River basin

To quantify the risks in the different sub-catchments in the Rokel River basin, based on the population density, the river flow variation, the water quality status, the vegetation cover using NDVI, and deforestation; these parameters were combined as individual raster files using the weighted overlay spatial analysis tool on ArcGIS Pro 3.0. The results of the risk quantification (low, medium and high) are shown in Figure 20 below

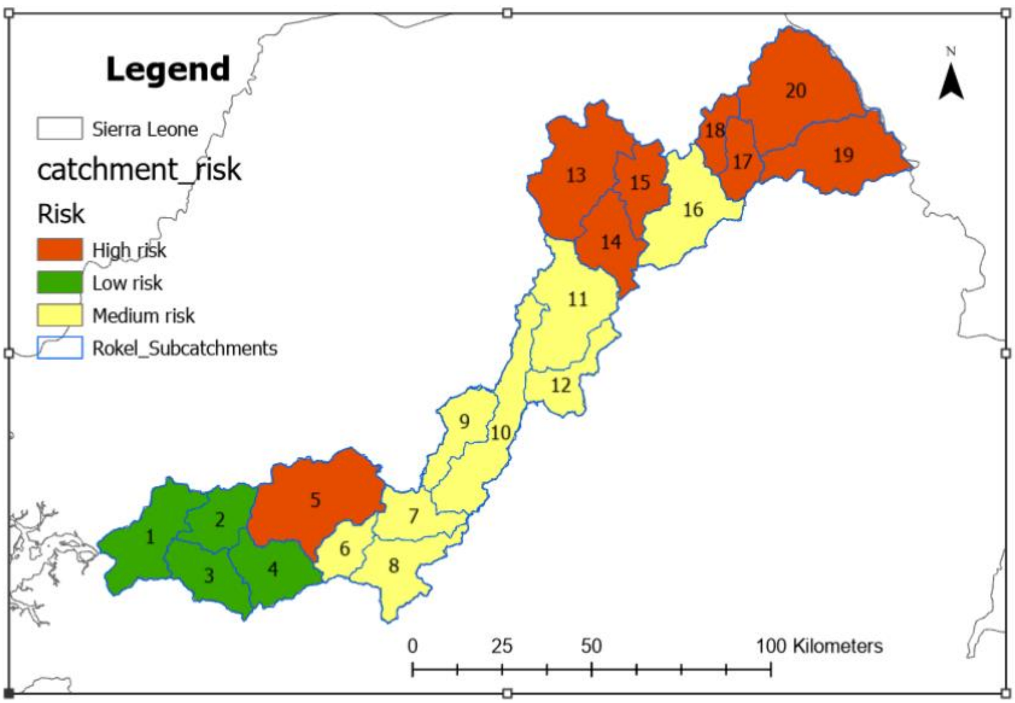

Figure 21 Risk ranking of the sub-catchments in the Rokel River basin

From figure 20 above, most of the sub-catchments downstream have low risk except of sub-catchment 5 that hosts Sunbird Bioenergy. The reason for the low risk associated with sub-catchments downstream is because vegetation and forest cover are high, the river flow is also high due to the accumulation of the waters downstream, less populated and have good percentage compliance water quality score. However, most of the midstream sub catchments have medium risk which could be due to the high agricultural practices, some deforestation and not too good water quality percentage compliance. Finally, the upstream sub catchments have high risk, possibly due to the high deforestation, low flows, and high population.

3.10 Water uses and water balance in the Rokel River basin

Rokel River serves has a high economic value due to its use for a variety of socio-economic activities, hence there is the need to ensure that all water users have water security, wherein there is sufficient quantity and quality of water for all, whilst at the same time maintain environmental flows.

3.10.1 Major water users in the Rokel River basin

The major water users and classes of use in the Rokel basin are given below:

3.10.1.1 Bumbuna Hydroelectric Plant (Hydropower)

The Bumbuna hydropower electric plant is the largest hydropower plant in Sierra Leone with a 50MW electricity generation capacity using twin turbines. The dam was constructed in the 1970s and has a reservoir that spans about seven (7) kilometres in length. The operating capacity of the reservoir is 350 Mm^3, with this operating capacity and assuming there is no inflow after October, the dam could provide an out flows of 60 Mm3 per month with a mean flow of 22 m^3/s (Carter, 2016). Also, the mean monthly flow using flow data from 1979 to 2021 is shown in the Figure 21 below.

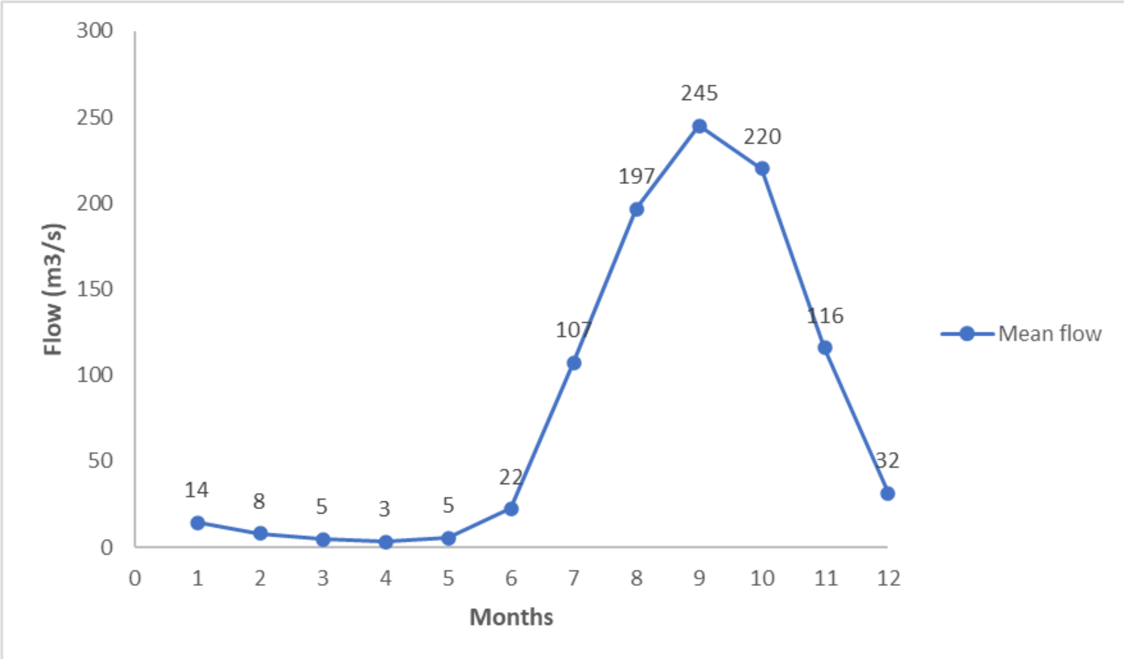

Figure 22 Mean monthly flow at Bumbuna from 1979 to 2021

From the figure above, the peak flow is recorded in September (245 m^3/s), whilst the least flow is in April ($4m^3/s$). The critical question is how much water is available for downstream users and environmental flows in the peak of the dry season? Part of this problem is solved by the tributaries that contribute to the river flow downstream of Bumbuna dam.

3.10.1.2 Kingho Mining Company Limited (Mining)

Kingho mining is one of the largest iron ore production company in Sierra Leone. Its major source of water is from groundwater. The company abstracts about 57,970 m^3 in 2021 for its operations.

3.10.1.3 Sunbird Bioenergy (Agriculture)

This is the largest agricultural company in Rokel basin and occupies about 100,000 hectares of land. The company produces ethanol and energy from its sugar cane plantation. It uses an estimated 13,927,680 m^3 of water abstracted from the Rokel River.

3.10.1.4 SALWACO's Water Supply System at Magburaka (Water supply)

The Magburaka water supply system abstracts and process the raw water from the Rokel river and supply it to the township for drinking purposes. The water supply utility abstracts 350,400 m^3 annually from the Rokel river.

3.10.1.5 Domestic water supply (hand dug wells and boreholes)

Almost all the rural areas rely on community hand dug wells and boreholes for their water supply. The 2017 water point mapping indicates that there are about 28,000 water points across the entire Sierra Leone, however, 2,471 water points with different water supply technology types were mapped in the Rokel River basin as shown in Figure 22 below.

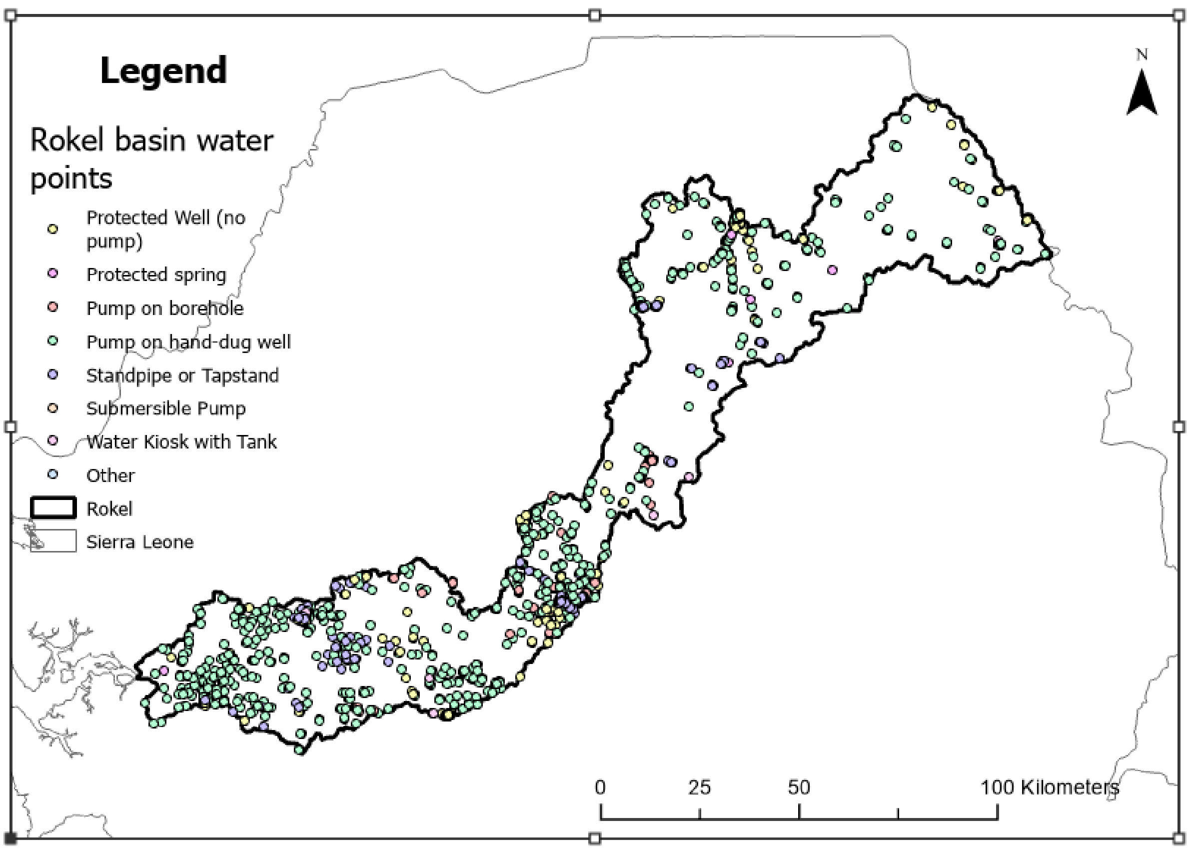

Figure 23 Water supply points in the Rokel River basin

It is estimated that each waterpoint serves between 100 to 250 people with an average of 175 people. Also, it is estimated that each person uses at least 40 litres of water a day (WHO recommendation), thus the daily and yearly domestic abstraction are 17,297 m^3

and 6,313, 405 m^3 in the Rokel river basin, with the assumption that all the water points are functional all year round.

3.10.2 Water balance of the Rokel River basin

The water balance of the Rokel River basin is determined using the water balance equation below:

Equation 2 $$\mathbf{P = R + ET \pm \Delta S}$$

Where:

P = Precipitation

R: River flow

ET: Evapotranspiration

ΔS: Change in storage

Table 6below shows the data in estimating the water balance

Table 6 Key water balance parameter's monthly results

Months	Mean rainfall (mm)	Potential ET (mm)	Flow (mm)
January	1	157	22
February	1	171	11
March	25	195	7
April	70	163	7
May	180	144	14
June	353	117	98
July	528	108	462
August	540	100	502
September	449	107	395
October	309	118	392
November	132	116	231
December	7	138	55
Total (mm)	2,592	1,634	2,195

Also, from Figure 24 below, evapotranspiration is higher than rainfall and flow, in the months of January, February, March, and April. At these points, the soil is losing water which serves as the base flow which is the dry season.

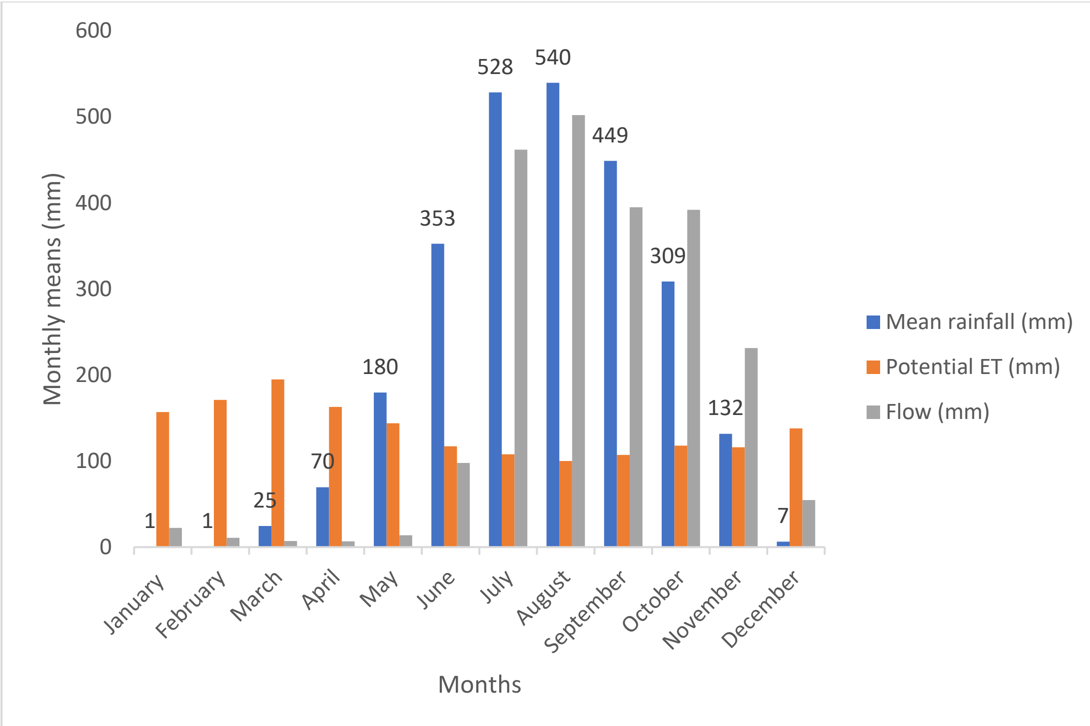

Figure 24 Monthly variations of rainfall, ET, and flow in the Rokel River

This raised the question of how much water will be left for abstraction by the various water users and what will be left for environmental flows. It is possible that the data obtained from AGHRYMET overestimate the flow, or the data obtained Makeni weather station with the only long-term data does not reflect the spatial variation of the rainfall across the basin.

However, Figure 24, is clearly indicating that the dry season is the critical period and with the many water users, there is obviously water scarcity at the Rokel River basin in the dry season.

3.11 Rokel river basin management board

The Rokel river basin management board will comprise stakeholders that have the responsibility to manage the natural resources at the basin level as provided by NWRMA's 2017 Act No. 5 of parliament (NWRMA, 2017). The basin board will receive oversight, supervision, and directions from the Agency, and it will have the mandate to form a catchment management committee. The functions of the Rokel River basin (RRB) board are:

1. Manage the water resources in the basin with regards to conservation, development, use and protection.
2. Establish Water Catchment Management Committees (WCM)
3. Coordinate the activities of the WCM
4. Resolve conflicts between water users and WCM by serving as an arbitration body.
5. Improve water quality and pollution control through collaboration with the relevant stakeholders
6. Monitor water use and quality and take actions when the water quality is impacted negatively
7. Monitor and regulate other activities that have the potential to affect the quantity, such activities include dredging, clearing and containment activities, amongst others.

The composition of the Rokel River basin management board is show in Figure below

Figure 25 Composition of the Rokel Basin Management Board

The basin board Officer or Manager has the responsibility of the daily operations of the basin board and implements the recommendations of the board regarding the management of the water resources in the basin.

However, apart from the board, the following committees should be formed for effective and efficient management of the basin:

1. Technical committee

   The technical committee has the following functions:

   a. Provide technical inputs in the implementation of activities in the basin
   b. Advice the board on technical issues in the basin
   c. Provide technical advice to water users in the basin
   d. Monitor the activities in the basin and provide support and guidance to the catchment management committees

2. Social mobilisation committee

   This committee has the following functions:

a. Regularly collaborate with the catchment management committee
b. Identify and mapped the water resources related problems faced by communities
c. Sensitise the communities on climate change impacts and adaptation measures
d. Collaborate with the regular stakeholders to inform the communities or serve as an early warning system link regarding disasters like flooding, drought etc.

3. Community catchment management committee

   This committee has the following functions:

   a. Monitor the water quality of river using the citizen scientist platform
   b. Monitor the water quantity as volunteer staff gauge reads
   c. Work with forest guards to protect the catchments in their communities
   d. Conduct community awareness and sensitisation on catchment degradation issues
   e. Use the monitoring data gathered to inform their community members on planting seasons and other water related activities

3.12 Response plan

The development of the Rokel River basin management plan is informed by the water quality monitoring and assessment of surface and groundwater quality monitoring stations that are spatially dispersed to determine point and diffuse sources of pollution. Also, it the RRMP plan is informed by the land use and land cover mapping and the quantification of the risks in the sub-basins of the Rokel basin. Furthermore, the water balance calculation helps to identify the current and potential pressures regarding the abstraction volume especially in the dry season and how that can impact both humans and the aquatic ecosystem.

The response plan of the water quality, water quantity

No	Pressure	Impact	Location	Action required	Responsible authority
1	Mining waste discharge	1. Elevate levels of sediments causing an increase in the turbidity of the river which affects aquatic organisms and increase the cost of water treatment. 2. Higher iron concentration at up and downstream for surface water and can increases the cost of water treatment and impact the aquatic ecosystem. 3. Introduction of mercury which can cause fish kills and cancer in human	1. Midstream and upstream 2. Upstream and downstream. Also, in sub catchments SLRRB_30_16, SLRRB_30_14, SLRRB_30_13, SLRRB_30_11, SLRRB_30_05 and SLRRB_30_03 3. Artisanal mining locations in the basin 4. All the groundwater quality monitoring stations	1. Issue discharge permits as prescribed in the newly enacted pollution control regulation. Also conduct monthly or quarterly monitoring at point sources 2. Use ecohydrology systemic solutions like constructed wetlands to treat sediment load and remove heavy metals	1. NWRMA 2. EPA, NMA, NWRMA 3. SALWACO

		4. Low pH probably from Acid Mine Drainages from mining tailings or possible natural occurrence. It can cause aesthetic rejection, harmful to aquatic organisms and corrodes pies.		3. Stop the operations of all artisanal miners in and along the banks of the Rokel River 4. Include pH treatment system at community water supply systems and use systemic solutions to treat the raw water resources	
2	Agricultural pollution	1. High concentration of orthophosphate in both surface and groundwater due to the use of phosphate-based fertilizers and can cause eutrophication.	1. Much higher in surface water than groundwater. Also higher at Addax Nursery groundwater station	1. Develop a strategy to manage the risk of runoffs from farms with crops and livestock 2. Construct ecotones to treat nitrate and phosphate from agricultural runoff locations	3. Ministry of Agriculture and Food Security, NWRMA, Water users (Sunbird), etc.
3	Deforestation	1. Reduce groundwater recharge with	1. Common in the upper and middle	1. Afforestation or plant trees in degraded and	1. MAFFS 2. NWRMA 3. MAFFS, USL

		implications of less groundwater available for domestic and industrial use 2. Causes runoffs loaded with sediments into open water bodies. This increases the turbidity which affects aquatic organisms and make treatment of water expensive. 3. Biodiversity loss and reduction in ecosystem services, disruption in the food chain 4. Increase in evapotranspiration and soil water loss due to wind actions	catchments. Highest in Koinadugu (83%) followed by Tonkolili district (17%) 2. Midstream and upstream 3. Upper and middle catchment 4. Upper and midstream	the riparian zones 2. Construct wetlands to reduce the turbidity and other nature-based green infrastructures 3. Designate the upper catchment as a national part, plants trees and improve the biodiversity 4. Construct shelterbelts	
4	Water abstraction	1. Reduce the flow below the ecological minimum target which affects aquatic organisms by causing water stress. This affects their reproductive and growth pattern	1. Upstream and midstream	1. Review abstraction permits for the dry months (Feb, Mar, and Apr) and establish ecological flow standards	NWRMA NWRMA

		2. Cause conflict between water users		2. Allocate and regulate water use judiciously 3. Establish a platform for mediation and conflict resolution	
	Climate change	1. Increase in water temperature which causes a reduction in Dissolved oxygen, thus depriving fish and other organisms of their source of life. Also causes a reduction in fish population and threatens food security. 2. Decrease in river flow can impact the ecological minimum target which affects aquatic organisms by causing water stress. This also affects their reproductive and growth pattern 3. Low energy generation from	1. Downstream 2. Entire basin 3. Up and midstream	1. Implement the activities in the National Adaptation Plan (Nap), reforestation of the riparian vegetation. 2. Review abstraction permits for the dry months (Feb, Mar, and Apr) and set not to affect the derived ecological flows 3. Conduct an assessment on the fish and other aquatic species, and rei-introduction of local fish	`NWRMA, EPA,

		Bumbuna Hydropower plant, less water available for abstraction by SALWACO and Sunbird Bioenergy. 4. Low revenue generation by NWRMA from abstraction fees due to low readings from bulk flow meters		species to balance	
	Solid and liquid waste management	1. High suspended solid matter, high fecal matter in the river from domestic and open defecation. These causes negative impact on the aquatic organisms, make water treatment expensive and the prevalence of water borne diseases.		1. Implement solid waste management interventions for riverine communities. 2. Provide access to improved sanitation facilities 3. Implement Community Led Total Sanitation (CLTS) in the riverine communities	Ministry of Health and Sanitation, District Health Medical Teams, UNICEF, WASH partners and others District Councils