Diagnostic Assessment on availability and Utilisation of water Resources: A case study of Kisumu County and 20km adjacent area

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***Abstract*- Water crisis keeps looming because of the intense pressure on water sources. The purpose of this research is diagnosis of available water resources in Kisumu County and to make sure that the area drinking water needs at all time. Without indigenous practices, knowledge is limited. It is important to recognise that the planning of water supply resources cannot be done in isolation of other water demands in the various existing and potential source areas. The domestic water supply demand has been estimated specifically for the present situation. The objective of the diagnostic assessment is to provide the information necessary for the development of sustainable water resources plans for the County and its environs.**

Water production is not really the main issue since most times the tanks are full but distribution. The demand exists but the distribution infrastructure is not able to satisfy it. Through exploiting the available water resources continually to meet the increasing water demands experienced in the city both during dry and wet seasons would result in a steady supply of water thereby helping the city in the implementation of sustainable development goal no 6. The biggest gap is under-investment in water storage and water infrastructure which is not in line with the population as well as the development of the area. There are opportunities for the development of water resources that could provide a source of water for Kisumu County.

***Keywords*: Climate change, Hydrology, Kisumu County, Water Balance, Water Resources**

I. INTRODUCTION

Provision of adequate water has been a concern since civilisation. Local supplies being inadequate in ancient cities, aqueducts were built to convey water from distant sources. Provision of water responds to part of the need since most natural waters are not suitable for direct consumption as a result of urbanisation.

Access to safe and reliable water is a vital human right but this should not mean free water. Governments ought to purpose to make available to all families basic water required for sustaining existence as well as health [4].Domestic water demand is at the core of both the waste water and the water resources planning. Sometimes water use are less than water needs, for example when there is not enough water in the river. A times water use are greater than water needs, for example, in agriculture when farmers are abstracting more water than crops need. This distinction is sometimes difficult to make. Indeed, if there is no metering instrument to actually measure how much water is abstracted, this distinction is hard to make [17]. Water is used for rural and urban domestic water supply for drinking, laundry, dish washing, car washing, irrigation, industrial supply for cooling, solvent, hydropower, livestock, fish ponds wildlife, etc. Water uses are divided into four types of water uses:

- *Domestic water supply* (includes urban and rural water supply). This water use encompasses all the water that households are using for daily house activities: drinking water, cooking, washing, etc.
- *Agriculture*- In the study area, most of the agriculture is rain fed. However, some of the agricultural lands are also irrigated with surface water and groundwater. Only irrigated agriculture is taken into account as a water use (rain fed is not accounted for).
- *Industry*- In the Kisumu County, there are some agri-food factories such as sugar cane factories. These industries usually do not have a big impact on water quantity availability because abstraction is usually low. However, they are of big interest because they may have a great impact on water quality and they are also major social players in terms of employment.
- *Environment*- The environment has to be taken into account within water user, because aquatic ecosystem do rely on certain level of water availability [16].

The northern half of Lake Victoria South Catchment Area has ample annual rainfall (1,000-1,600mm) and has a wet climate, while the southern Half has a semi-arid climate [7]. The total cropping area in 2011 was 553,655Ha which are mostly under rain fed conditions but have lower productivity. The total existing irrigation area in Lake Victoria South Catchment Area in 2010 was 13,218 ha, consisting of 1,800Ha (14%) of public irrigation schemes, 10,225ha (77%) of smallholder irrigation schemes, and 1,193ha (9%) of private schemes. The share of irrigation Area against cropping area is 2.4% only. Most of all existing irrigation systems need rehabilitation of deteriorated facilities due to insufficient maintenance [5].

Large-scale irrigation schemes in the Lake Victoria South Catchment Area are summarized in Table 1, while Table 2 provides details of projects to be implemented by Lake Basin Development Authority.

No	Name of Project	County	Sub-basin Code	Irrigation Area (ha)	Project Type*1	Water Source Facilities*2		Present Status*3	Estimated Cost*4 (KSh mil.)	Executing Agency
						Type	Name of Dam			
1.	Ahero and West Kano Irrigation	Kisumu	1HD	1,800	Reh+Ext	Weir	-	F/S done	871	NIB
2.	Amala Irrigation	Bomet	1LB1	5,000	New	Multi-dam	Amala	Proposed	2,860	LBDA
3.	Ilooiterre Irrigation	Narok	1KC	3,000	New	Multi-dam	Ilooiterre	Proposed	1,716	LBDA
4.	Kano Plain Irrigation	Nyamira/Kericho	1JG1	15,000	New	Multi-dam	Magwagwa	D/D on-going	14,300	LBDA
5.	Lower Kuja Irrigation (Stage-1)	Migori	1KB	7,800	New	Weir	-	D/D done	6,578	NIB
6.	Lower Kuja Irrigation (Stage-2)	Migori	2KB	32,700	New	Multi-dam	Katieno	Proposed	17,160	NIB
7.	Nandi Forest Irrigation	Vihiga/Nandi	1HA2	7,272	New	Multi-dam	Nandi Forest	F/S done	15,730	LBDA
8.	Nyando Irrigation	Kericho	1GD	3,000	New	Multi-dam	Nyando	Proposed	1,716	LBDA

Note: *1: Reh = Rehabilitation, Ext = Extension; *2: Multi = Multipurpose, E = Existing; *3: F/S = Feasibility study, D/D = Detailed design,
*4: Estimated Cost = Construction cost for irrigation sytem (excluding cost allocation of multipurpose dam)

Source: JICA Study Team, based on information from government authorities.

Table 1: Large Scale Irrigation Projects for implementation by 2030 in LVSCA (GoK, 2013a)

As of September 2012

No	Name of Project	River Catchment	County	Irrigation Area (ha)	Type of Project	Water Source	Cost (Ksh. mil)	Work Progress as of 2012			Priority	Remarks
								F/S	D/D	Const		
1.	Kimira-Oluch	LVS	Homa Bay	1,474	New	Weir	161	Done	Done	On-going	On-going	Irrigation system for 1,474 ha is under construction since 2006 with AfDB fund and GOK fund.
2.	Kano Plain (with Magwagwa HP dam)	LVS	Kisumu/ Homa Bay	12,550	New	Dam (new)	Irrigation 8,000	Done in 1992 On-going (dam)	On-going (dam)		High	Kano plain irrigation project can be developed only after the completion of the Magwagwa Hydropower Project having a dam of 103 MCM capacity and HP generation of 60 MW. F/S and D/D for the dam are on-going since 2010.
3.	Nandi HP Integrated Development Program	LVN	Vihiga / Nandi/ Kisumu	7,140	New	Multi purpose Dam	Total 22,800	Done	Phase 1 done, Phase 2 for irrigation on-going		High	New multipurpose project to construct a multipurpose dam with 275 MCM storage, HP generation of 60 MW, and irrigation of 7,140 ha of farm land in Kano Plains (Miwani, Chemase, Kibigori, Nyakoko & Ramula Area for Irrigations). DD for dam has completed. DD for irrigation system is on-going.
4	Yala Swamp	LVN	Siaya	4,600	New	Weir	516	Done in 1975	Done in 1975		Low	A total of 4,600 ha is planned for development. Other area of 6,500 ha will remain as environmental buffer zone.
5.	Nandikinya-Magombe-Makunda	LVN	Busia	600	New	Pumping	500				Medium	Conceptual & Pre-feasibility stage. Water Resources User Association already establis
6.	Sabwani-Kapsitwet-Namanjalala	LVN	Trans Nzoia	800	Reh+Ext	Weir	500				Medium	Conceptual & Pre-feasibility stage; Water Resources Users Association (BUCAWRUA) already established

Source: Prepared by JICA Study Team 2012
Remarks: Type of Project: Ext = Extension, Reh = Rehabilitation

Table 2: Irrigation projects proposed by LBDA (GoK, 2013b)

As per the Water Act 2016, the reserve flow corresponds to the quantity and quality of water required (a) to satisfy basic human needs for all people who are or may be supplied from the water resource; and (b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the water resource [9].

The reserve flow is set at 95% value of the naturalized present daily flow duration curve with a probability of once in 10 years [5], [21]. The National Water Master Plan 2030 provides reserve flow value at the downstream end of each sub-basin Table 3.

Sub-basin ID	River name	catchment area (km²)	Accumulated catchment area (km²)	Reserve (m³/s)	NWMP 2030 node ID
1FA	Yala	238		0.2	167
1FB	Yala	370	608	1.8	171
1FC	Yala	272	879	3	179
1FD	Yala	476		1.5	189
1FE	Yala	661	2,017	6.8	198
1FF	Yala	273		0	204
1FG	Yala	970	3,259	4.3	210
1GA	Nyando	454		0.6	2
1GB	Nyando	522	976	0.8	6
1GC	Nyando	902		2	12
1GG	Nyando	385		0.3	14
1GD	Nyando	652	2,915	1.3	29
1GE	Nyando	371		0	31
1GF	Nyando	317	3,604	0	38
1HA1	Kibos	350		0.4	45
1HA2	Oroba	543		0	48
1HB1	Awach Seme and others	487		0	50
1HB2	Awach Muguruk, Kysian and others	267		0	53
1JB	Sondu	178		0.5	69
1JA	Sondu	849	1,028	3.2	74
1JC	Sondu	340		1.7	76
1JD	Sondu	217	1,585	6.6	82
1JE	Sondu	581		0.7	85
1JF	Sondu	990	1,570	3.9	92
1JG1	Sondu	230	3,385	10.2	101
1JG2	Sondu	89	3,474	10.5	109

Table 3: Reserve flow by sub-basin in the area of interest, as per the NWMP 2030; volume II, Part B (LVNCA) and Part C (LVSCA). (GoK 2013a)

The water consumption ratio per capita is defined differently considering the type of habitat, the existence of a water supply network, the connection rate to water supply network and the income level.

Domestic water consumption = urban consumption (low, medium and high income) + rural consumption (low, medium and high income)

Consumption (for each type of habitat and level of income) = Rate of connection * water consumption per capita (by type of habitat and income)

Water demand is obtained by adding water consumption and non-revenue water (NRW). Non-Revenue Water corresponds to water losses in the network and unpaid bills, and is computed by applying a ratio on total water consumption [3].

WEAP and Model set up

Water Evaluation and Planning (WEAP) is a water balance model tool, with different modules for simulation of all components of an integrated water resource system. The model can simulate all processes in a watershed like its surface and sub-surface hydrology, water supply demands, irrigation demands, dams and water transfers. It can also model the economics of construction and operation of water infrastructure and generation of hydropower. Its main strength is its ability to cope with water supply priorities using an optimization method. Therefore, the model attempts to satisfy all demands on the water resource system according to the defined priorities. The highest priority is 1 and lowest is 99.

Objectives

The main objective of the study is to make sure that the Kisumu county drinking water needs will be met at all times.

Specific Objectives

1. Assess the water resources within the basins from which water is or could potentially be abstracted taking into account existing and future water demands across the full range of demands (both consumptive and non-consumptive).
2. Identify and assess existing and potential sources for the provision of a sustainable (taking account of other demands on the sources upstream and downstream) supply of water for Kisumu County through to 2050.

II. MATERIALS AND METHODS

Study area

The study area lies on the north-eastern shore of Lake Victoria. It lies between latitude 0°20'S 0°50'S and longitude 33°20'E 35°20'E occupying a land area of about 2,086 km² and a water area of about 576km^2 as show in

Figure 1. The mean annual maximum temperature ranges 25°C to 35°C and the mean annual minimum temperature ranges 9°C to 18°C. The altitude in the county varies from 1,144 metres above the sea level on the plains to 1,525 metres above sea level in the Maseno and Lower Nyakach areas [4, 11, and 18].

The mean annual rainfall varies with altitude and proximity to the highlands along the Nandi Escarpment and Tinderet ranging from 1,000mm to 1,800mm.

In 2009, Kisumu County had a population of 968,909 people and was estimated to reach more than 1.2 million by 2018 according to Kisumu Integrated Plan 2018-2022 [1, 15].

The primary water source for the Kisumu city is from Lake Victoria and the rivers are the greatest contributor being the surface water.

The mean household water consumption is 149.50 litres per day, resulting in a mean per capita of 32.92 litres per day [20] with an average Non-revenue water being 41% [14].

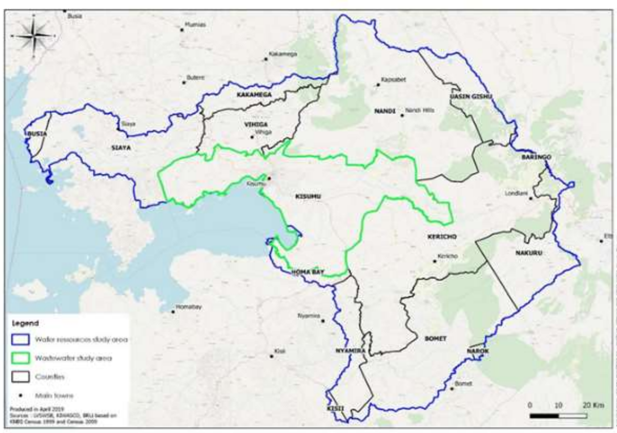

Figure 1: Kisumu County and adjacent Administrative boundaries

The area of interest is divided among the following basins [21, 22]:

a) Kibos River basin (1HA1);

Kibos River basin covers a surface area of about 310 km^2. The Kibos River basin covers only two administrative Counties namely: Nandi and Kisumu counties. River Kibos drains into the Winam Gulf via Nyamasaria River after it has been joined by Awach and Kajulu River. It rises from the foot hills of the Nandi Escarpment. There are severally operational and non-operational stations [13].

b) Oroba River basin (1HA2);

Oroba River basin covers a surface area of about 575 km^2. The Oroba River basin covers only two administrative Counties namely: Nandi and Kisumu counties as shown in Figure 1. Oroba River is a highly seasonal river and not perennial.

c) Nyando River basin (1G);

The total catchment area of the Nyando River Basin up to the Winam Gulf is about 3,625 km. This area includes Awach Kano River and the floodplain of about 367 km^2. It drains into the Winam Gulf, The main Nyando upstream of Ahero Market centre has a catchment area of about 2,911 km. The upper Nyando basin is also characterized by steep slopes. Consequently, the upper basin is threatened by soil erosion which generates siltation issues downstream.

d) Sondu river basin (1J);

The Sondu River has a drainage area of about 3 510 km^2. The annual mean discharge at station 1JG04 is 42 m^3/s. The Sondu River basin covers mostly the counties of Bomet, Kericho, Nakuru and Nyamira. It also covers some parts of Homa Bay, Kisumu and Narok counties.

The average annual rainfall ranges from 1400 to 1900 mm/year [12, 13]. The wettest part of the basin are located around the town of Kimulot on the foot hills of the South Western Mau Forest.

Main tributaries of the Sondu River are the Kipsonoi (sub-basin 1JF) in the South Eastern part, and we can cite also Yurith and Itare as main tributaries. As a results of various infrastructure on design of Magwagwa Multipurpose dam [11, 19].

e) Yala River basin (1F);

Yala River Basin covers a surface area of about 3,300 km^2. The Yala River basin covers mostly five administrative Counties namely: Uasin Gishu, Nandi, Kakamega, Vihiga and Siaya counties. The average annual rainfall ranges from 1,200 to 2,000 mm/year. There are two major rainfall seasons that are experienced that is long rainy season (experienced between March and May), and the short rainy season experienced between October and December.

The altitude of the basin ranges from around 1,140m at the Lake Victoria shore to the nearly 2,800m in Timboroa/ Nabkoi Forests at its furthest reach. The general elevation in the mid Yala basin is between 1,300 and 1,700 m. The characteristic feature of the topography is composed of hills and valleys, rivers and streams. The lower section of Yala basin has moderate lowlands, river valleys. Near Lake Victoria shoreline, Yala River reaches a low, flat and humid land: the Yala swamp [22]. The Yala River has five major tributaries joining it upstream. The tributaries are Mokong (1FD), Kibutie (1FC), Kimondi in upper reaches in Uasin Gishu and Nandi Counties and Edzava (1FF) and Garagoli (1FE) in the Lower basin.

f) West shoreline rivers basin (1HB).

West Shorelines Rivers refer to the set of little rivers located to the West of Kisumu city. Among them, main rivers are Awach Seme, Awach Muguruk and Kysian. Some of them take their source within the Nandi escarpment.

They are mostly located in Kisumu and Siaya counties, while the upper part relies in the Vihiga County. [10, 11].

III. METHODOLOGY

The main steps followed in achieving the objectives are as follows:-

- Assessment of the naturalised hydrology. This is essentially an approximation of the "pre-development" water resources and represents the time when anthropogenic demands and impacts were minimal or minor. This assessment is carried out for each of the concerned basins.
- Assessment of current water balance. This was achieved by investigating and comparing (in space and time) the available water resources and the existing water demand.
- Assessment of future water balance. This is effectively the same as the previous step only that it considers future demands which are in most cases greater than current demands. There may also be some future impacts on the hydrology as a result of climate change or anthropogenic pressures.
- Considerations of impacts of climate change. When looking into the future it will be important to take into account climate change, which will have an impact on both the available water resources and the level of water demand.
- Preliminary assessment of potential water supply sources for Kisumu County. Within each of the catchments investigated there are opportunities for the development of water resources that could provide a source of water for Kisumu County.

Nevertheless, the Area of Interest of the water resources planning will also include a buffer zone of 20km around the Kisumu County which can be prioritised to enable proper planning and ensure water needs are met [13, 21]. Moreover, the area of Interest will also include the entire river basins which could potentially release water to the Kisumu County, specifically the Yala, Kibos, Nyando, Sondu river basins, as well as some urban minor tributaries of Lake Victoria. Lake Victoria itself is a potential source. The Area of Interest is indicated in Figure 2

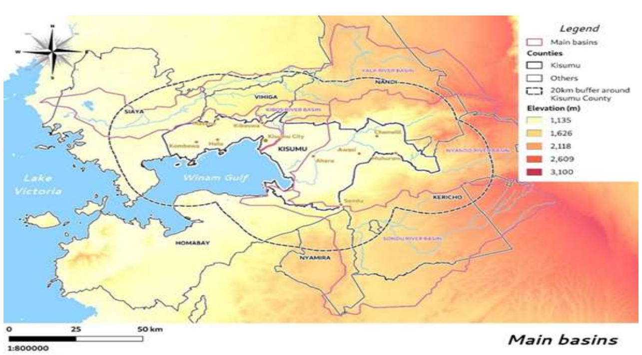

Figure 2: Area of Interest of water resources including all potential sources basins

The area of interest includes not only the Kisumu County and its 20 km buffer zone, but it encompasses all the river basins related to Kisumu County. Some of these basins only have their lower reaches within the county, but the entire catchments are taken into consideration. The following basins are considered as part of the Area of Interest: Kibos River basin, Nyando River basin, Sondu River basin, Yala River basin, Shoreline rivers basins.

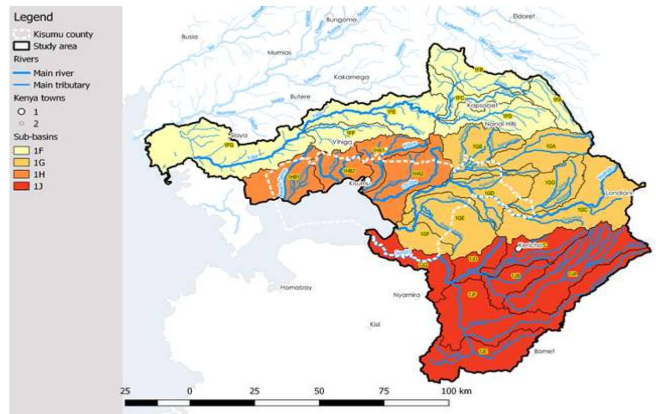

Figure 3: Kisumu area of Interest sub-basins delineation

These basins are also divided into sub-basins. This sub-delineation is based entirely on the delineation provided by the Water Resources Authority. Each main basin is coded by one figure and one letter. For example Nyando basin is coded "1G". And then within main basins there are sub-basins. For example the Nyando sub basin upstream the confluence between Nyando and Namuting River is coded "1GC". The whole sub-delineation is displayed in the Figure 3.

I) Estimates of water demand

a. Domestic water supply

Domestic water supply demand is estimated on the basis of 2009 census data. A difference is made between unit water demand in urban and in rural areas. Water demand for 2009, and then projections for 2020, 2030, 2040 and 2050 are calculated. Also, an abstraction or network efficiency has been introduced to derive water consumption from water demand. It means, that water consumption – equivalent to raw water abstracted from the water source – is also computed for each sub-location of the area of interest. Water consumption is thus higher than water demand.

For the purpose of the water resources planning, domestic water demand is aggregated for each sub-basin (see sub basin delineation in Figure 3). However the following cities and satellite towns have been subtracted to the aggregated basin water demand in order to have a focus on those areas: Kisumu city, Ahero, Chemelil, Katito, Kericho, Kombewa, Londiani, Maseno, Miwani, Muhoroni, Pau Akuche and Sondu.

b. Irrigation

Actual irrigation abstraction quantities have been used where available. Where these figures are not available, typical abstraction rates have been assumed.

c. Industry

Actual abstraction quantities have been used where available. Where these figures are not available, typical abstraction rates have been assumed.

Current Situation

Two different methodologies were applied to Kisumu County and the remainder of Water Resources study area to calculate water consumption and demands. Water consumption is computed considering population and a water consumption ratio per capita. Water consumption is composed of domestic water consumption, which corresponds to water consumed by households, and non-domestic water consumption, which is composed by industrial, institutional and commercial water uses.

Water consumption = domestic water consumption + non-domestic water consumption

Water demand = water consumption / Non-Revenue Water (NRW) percentage

Within Kisumu County, the connection rate is distinguished between zones supplied by a water network and sectors not supplied by a network. The hypothesis undertaken were:-

a) As at the year 2018, the level of Income distribution within Kisumu was were 56% for high income, 28% for medium income and 16% for low income respectively (Kisumu Integrated Urban Development Plan (ISUD).

b) The type of habitat within the Kisumu County is as shown in Table 4.

Table 3: Type of habitat within Kisumu County

Type of Habitat	Urban Population	Rural population
Urban	100%	0%
Informal settlement	100%	0%
Peri-Urban	60%	40%
Rural	0%	100%

c) The connection rate to the drinking water supply system for the sectors as shown in the Table 4[3]

Table 4: Sectors supplied by a water network depending on the type of habitat and level of income

Type of Habitat	Rural			Urban		
Level of Income	High	Medium	Low	High	Medium	Low
2009	20%	10%	5%	100%	100%	10%
2018	27%	14%	7%	100%	100%	14%

Sectors not supplied by a water supply network is as shown in Table 5.

Table 5: Sectors not supplied by a water supply network depending of the type of habitat and level of income

Type of Habitat	Rural			Urban		
Level of Income	High	Medium	Low	High	Medium	Low
2009	0%	0%	0%	0%	0%	0%
2018	0%	0%	0%	0%	0%	0%

d) Water consumption per capita in Kisumu County: [3] shown in Table 7.

Table 6: Water consumption per capita depending of the type of habitat and level of income

Type of Habitat		Rural			Urban		
Consumer	Units	High	Medium	Low	High	Medium	Low
With drinking water individual piped connection	L/cap/day	48	40	32	200	120	60
Without drinking water individual piped connection	L/cap/day	16	12	8	40	25	16

e) Non domestic consumption is computed by applying a ratio on domestic consumption as in Table 8.

Table 7: Non-domestic consumption ratio on domestic consumption

Type of consumption	Adopted As % of domestic volume billed
Commercial	20
Institutional	10
Industrial	7

The methodology used for the other counties consist of applying a ratio of consumption per capita to the urban and rural population. The following hypothesis were taken:-

a) The type of habitat outside the Kisumu County is as shown in Table 8.

Table 8: Type of habitat outside Kisumu County

Type of Habitat	Urban Population	Rural population
Urban	100%	0%
Informal settlement	100%	0%
Peri-Urban	60%	40%
Rural	0%	100%

b) Water consumption per capita outside Kisumu County is shown in Table 10:

Table 9: Water consumption per capita, outside Kisumu County

Consumer	Units	Urban	Rural
All type	L/cap./day	32	12

c) Non domestic consumption is computed by applying a ratio on domestic consumption as in Table 8 for outside Kisumu County.

d) The NRW percentage is considered to be equal to zero as no information was available for outside Kisumu County.

Future Situation

For the future horizons on the project, hypothesis were taken on the evolution of calculation assumptions. The following factors don't evolve:

- Percentage of urban and rural population for each zone of habitat,
- Ratio of domestic water consumption per capita,
- Ratios of non-domestic water consumption.

On the contrary, the following factors are evolving as presented in the tables below:-

a) Level of income (Kisumu Integrated Urban development plan) as projected in Table 11.

Table 10: Projected levels of income

Income	2018	2020	2030	2040	2050
Low	56%	51%	50%	40%	40%
Medium	28%	33%	34%	35%	35%
High	16%	16%	16%	19%	25%

b) Connection rate

Sectors supplied by a water supply network in Table 12.

Table 11: Projected sectors supplied by a water supply network

Type of Habitat	Rural			Urban		
Level of Income	High	Medium	Low	High	Medium	Low
2009	20%	10%	5%	100%	100%	10%
2018	27%	14%	7%	100%	100%	14%
2020	29%	15%	7%	100%	100%	15%
2030	41%	20%	10%	100%	100%	23%
2040	57%	29%	14%	100%	100%	34%
2050	80%	40%	20%	100%	100%	50%

Sectors not supplied by a water supply network as in Table 13.

Table 12: Projected sectors not supplied by a water supply network

Type of Habitat	Rural			Urban		
Level of Income	High	Medium	Low	High	Medium	Low
2009	0%	0%	0%	0%	0%	0%
2018	0%	0%	0%	0%	0%	0%
2020	0%	0%	0%	0%	0%	0%
2030	0%	0%	0%	0%	0%	0%
2040	0%	0%	0%	0%	0%	0%
2050	0%	0%	0%	0%	0%	0%

c) Non-Revenue Water percentage [3] in Table 14 as Target of 20% in 2050 from Kenyan Design Manual

Table 13: Projected non-revenue water percentage

Adopted As % of domestic volume billed	2018	2020	2030	2040	2050
With a water supply network	51.7%	48.7%	36.2%	26.9%	20%
Without a water supply network	0%	0%	0%	0%	0%

Water balance modelling: WEAP model topology

The management of water resources of Kisumu County simulated using the WEAP model. A WEAP model has been developed to simulate the whole water resource system of the area of interest for the Kisumu Water Resources Planning. Figure 4 shows the global schematic of the model topology. It is important to take into account the whole area of interest because it allows to cope with inter-basin transfers. As this could provide for future options of sourcing water for Kisumu County.

The topology follows the sub basin delineation adopted by WRA (see Figure 3). Then, within each sub-basin, the model topology follows the same logic:

- 1 demand site for diffuse abstraction of irrigated crops (e.g. small pumps in the river).
- 1 demand site for diffuse abstraction for drinking water supply (from surface water).
- 1 demand site for each major town water supply (optional, depends on whether a major town is located or not within the sub basin).
- 1 demand site for main industries.
- 1 demand site for each large scale irrigation scheme.
- 1 reservoir for each main dam.
- 1 inflow node corresponding to net runoff on the sub-basin.
- Junction nodes with upstream and downstream sub-basins.
- 1 node for reserve flow (also known as minimum environmental flow)

Consequently, each sub-basin is made of at least a minimum topology: one inflow node, one node for diffuse irrigation, one node for diffuse drinking water supply and one outflow node. Figure 5 shows an example of the schematic for a moderately complex sub basin. On this example, there are three (3) demand sites for drinking water supply of major towns (Muhoroni, Chemelil and Ahero), one demand site for a major irrigation scheme (National Irrigation Board, Ahero rice irrigation scheme) and one demand site for major industries that abstract water (sugar factories, such as the Muhoroni Sugar Company).

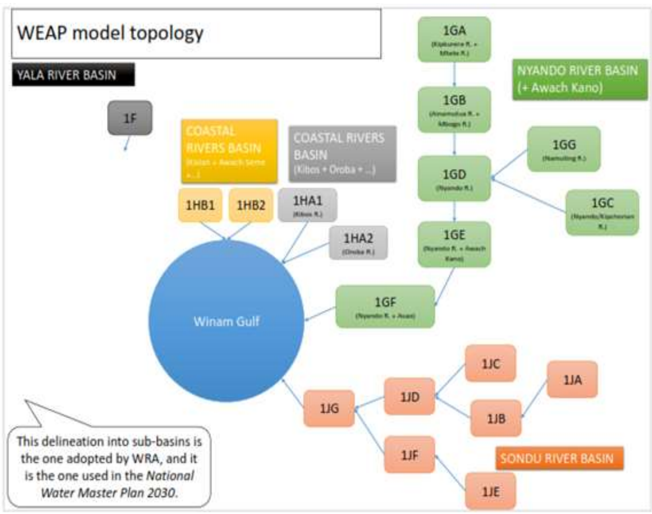

Figure 1: Schematic of the WEAP model global topology

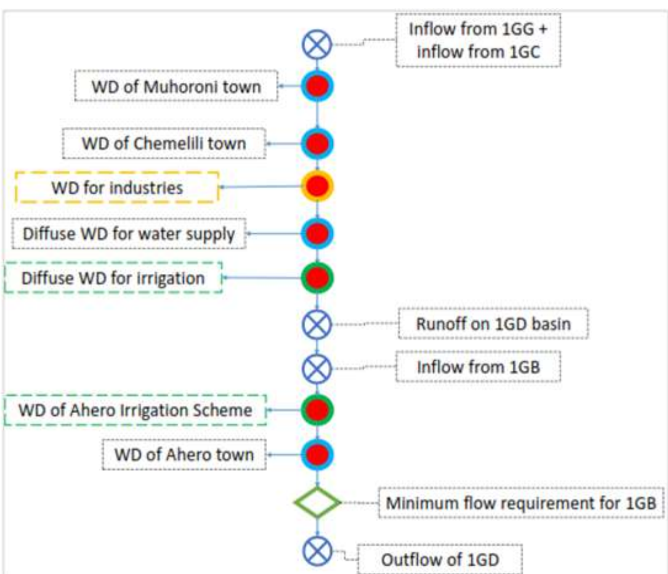

Figure 2: Schematic of sub basin, example of Nyando River basin 1GB

WEAP modelling – naming convention

Inflow nodes convention

As inflows are set for each sub-basin, the following convention has been adopted: "BAS_XXXXy", where:

- XXXX stands for the national identifier of the sub basin (e.g. 1GD), it could be either 3 or 4 characters long (e.g. 1GD or 1JG1).
- **y** is a facultative character (a, b , c. etc.). When necessary, the official sub-basin could have been split into several sub-sub basins in order to better capture the scale of the catchment. It is mostly the case on small catchments used for water supply such as the Kibos River basin (e.g. 1HA1a and 1HA1b).

Example: *BAS_1GD* is the inflow object for basin 1GD.

Diffused water demand: domestic, irrigation and industry

Three water demand nodes are created for each sub-basin: one for domestic/drinking water supply, one for irrigation and one for industry. The following convention has been adopted: "AAA_XXX_diff", where:

- AAA stands for either DWS when it is a drinking water supply water demand node, IRR when it is an irrigation water demand node, and IND when it is an industrial water demand node;
- XXXX stands for the national identifier of the sub basin (e.g. 1GD), it could be either 3 or 4 characters long (e.g. 1GD or 1JG1).

Example: *IRR_1JG1_diff* is the diffused irrigation water demand node for basin 1JG1.

Specific water demand node: domestic and irrigation

Within the model, we have also included specific water demand node. Especially, there is one water demand node for Kisumu city and each one of the satellite towns. The following naming convention has been adopted: "AAA_name", where:

- AAA stands for either DWS when it is a drinking water supply water demand node, IRR when it is an irrigation water demand node, and IND when it is an industrial water demand node;
- Name stands for the specific name of the water demand (e.g. Ahero)

Example: *DWS_Ahero* is the specific drinking water demand node for Ahero town.

The existing infrastructure characteristics are included within the WEAP model. It includes the following infrastructure:

- Dunga water treatment plant with maximum treatment capacity of 45,600m^3/day;
- Kajulu water treatment plant with maximum treatment capacity of 36,000m^3/day;
- Ahero water supply scheme with maximum treatment capacity of 277m^3/day;
- Sondu-Miriu hydropower complex- Sondu Miriu installed capacity of 60MW and Sangoro power installed capacity of 21MW;

The detailed presentation of the WEAP model is given as in Figure 6.

In terms of how WEAP models priorities in the current situation, the way people are abstracting water is mostly based on the following principle: "Demand sites located upstream abstracts water before downstream demand sites, but always respect reserve flow". So, the demand priorities are set at "1" for every node of minimum flow requirement. Then, the next priority is given to the most upstream demand sites, and then the priority level decreases progressively while going towards downstream. This is showed on Figure 7.

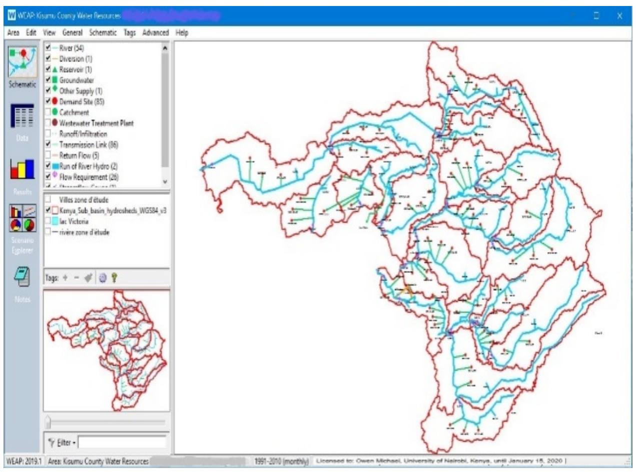

Figure 3: Image of the WEAP model

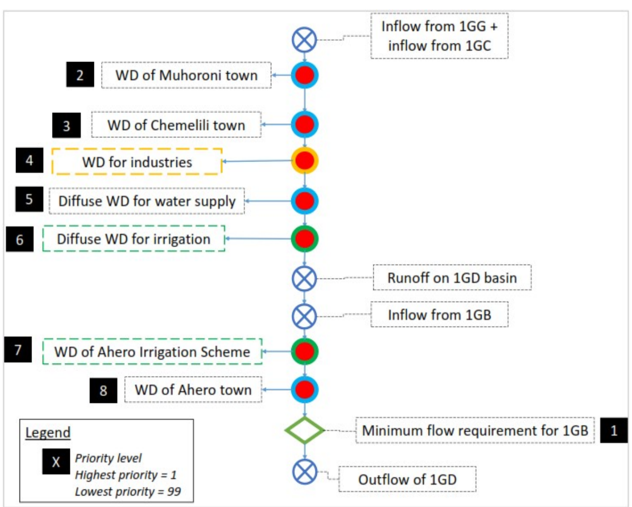

Figure 4: WEAP model, the water demand priority approach

The area of interest is divided among the following basins:

a) Kibos River basin (1HA1);

Kibos River basin illustrated in Figure 5. The naturalised hydrology used in here is the one from the Kenya National Water Resources Master Plan 2030. It is covering the period 1991-2010.

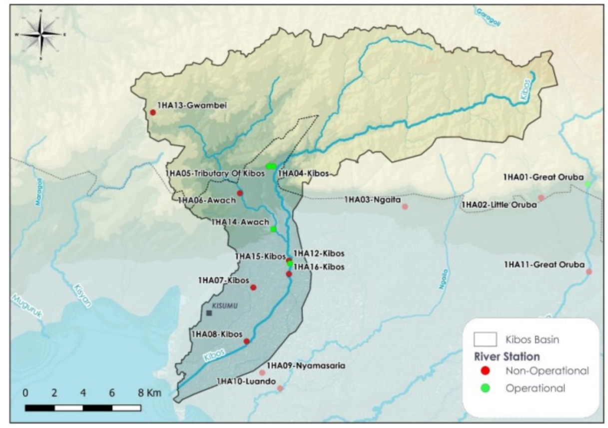

Figure 5: Kibos River basin (1HA1) and river stations

b) Oroba River basin (1HA2);

The river basin is illustrated as shown in Figure 9. The naturalised hydrology used in here is the one from the Kenya National Water Resources Master Plan 2030. It covers the period 1991-2010.

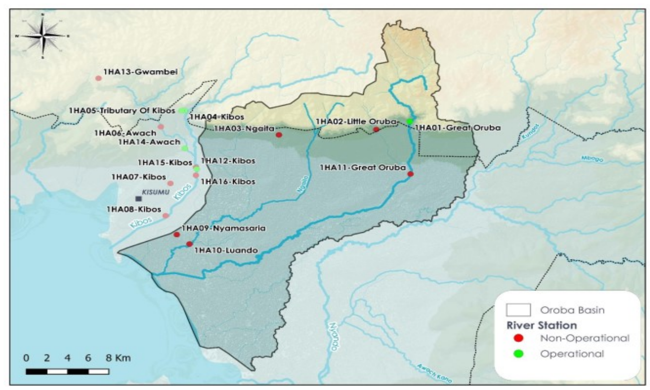

Figure 6: Oroba River basin (1HA2) and river stations

c) Nyando River basin (1G);

The Nyando River Basin is illustrated in Figure 10. The naturalised hydrology used in here is the one from the Kenya National Water Resources Master Plan 2030. It covers the period 1991-2010.

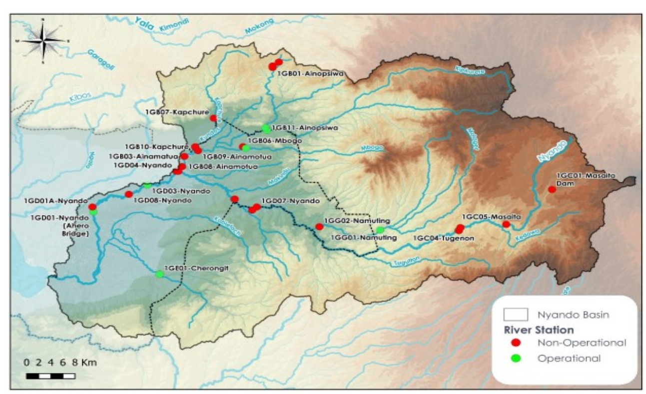

Figure 7: Nyando River basin overview

d) Sondu river basin (1J);

The Sondu River basin is illustrated in Figure 11. Surface water data only relies on NWMP 2030 data book volume [6]. The naturalised hydrology used in here is the one from the Kenya National Water Resources Master Plan 2030. It covers the period 1991-2010.

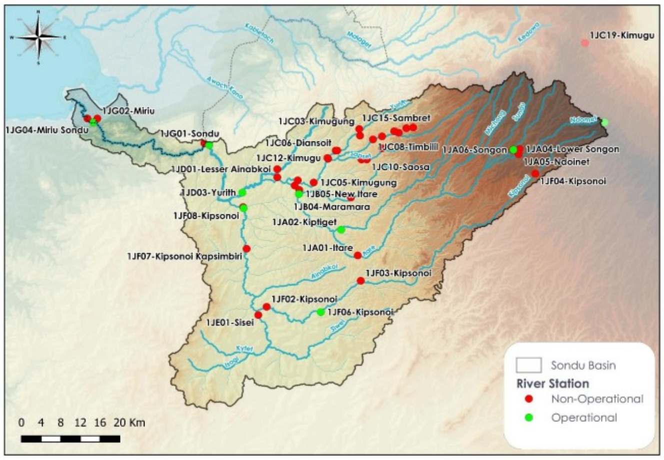

Figure 8: Sondu River basin overview

e) Yala River basin (1F);

Yala River Basin illustrated in Figure 12. Surface water data only relies on NWMP 2030 data book volume [6]. The naturalised hydrology used in here is the one from the Kenya National Water Resources Master Plan 2030. It covers the period 1991-2010.

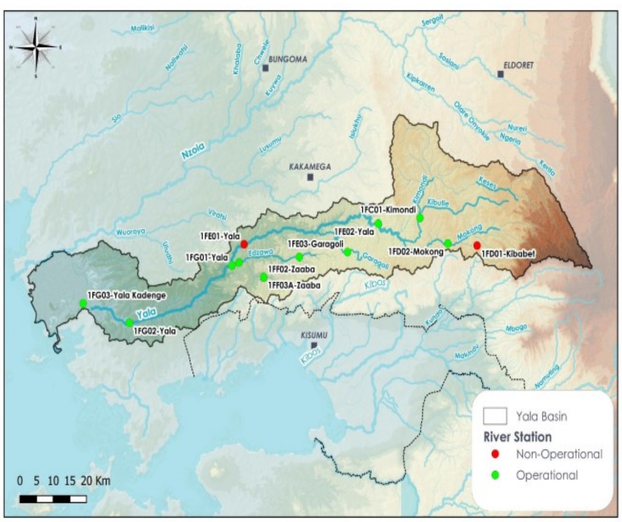

Figure 9: Yala river basin overview

f) West shoreline rivers basin (1HB).

West Shorelines Rivers is illustrated in Figure 13. The naturalised hydrology used in here is the one from the Kenya National Water Resources Master Plan 2030. It covers the period 1991-2010.

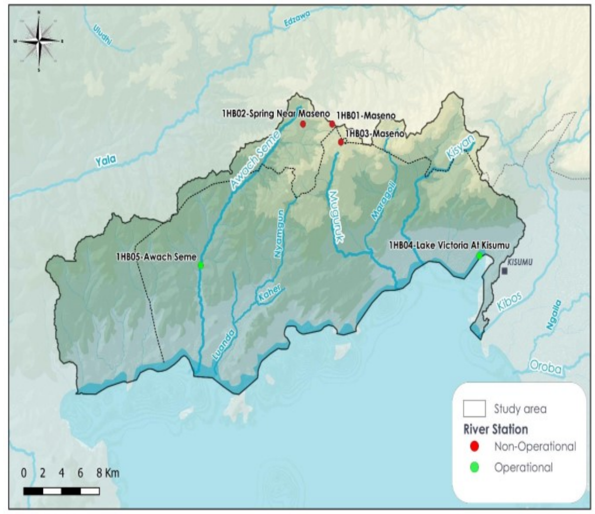

Figure 10: West shoreline rivers basin overview

The WEAP model is run for the current situation. It allows to define the baseline and to fully understand where and why the main, water shortages are lying. Results of the WEAP model are presented and analyzed. And, potential supply shortfalls are identified and quantified. Finally, the potential new water sources are presented, as potential additional water sources.

IV. RESULTS

Current water consumption and demand

The computations of water demand gave the following results on the study area is as in Table 15:

Table 14:2009 water demands

Project Area, part in	Water demand (m^3/d)
	2009
Baringo County	690
Bomet County	7,405
Busia County	391
Homa Bay County	1,130
Kakamega County	4,845
Kericho County	11,491
Kisii County	808
Kisumu County	**61,839**
Nakuru County	2,568
Nandi County	11,305
Narok County	87
Nyamira County	5,647
Siaya County	7,847
Uasin Gishu County	1,531
Vihiga County	11,716
Study area	**129,300**

Projections of water consumption and needs

The computations of water demand gave the following results on the study area:

Table 15: Water demand projections for 2020, 2025, 2030, 2040 and 2050 within study area

Project Area, part in	Water demand (m^3/d)				
	2009	2020	2030	2040	2050
Baringo County	690	623	901	1 211	1 630
Bomet County	7 405	9 376	12 597	16 490	21 439
Busia County	391	493	691	779	878
Homa Bay County	1 130	1 411	1 963	2 645	3 496
Kakamega County	4 845	5 750	7 559	9 696	11 769
Kericho County	11 491	14 763	20 261	31 116	43 093
Kisii County	808	921	1 147	1 402	1 670
Kisumu County	**61 839**	**76 068**	**111 548**	**126 414**	**139 575**
Nakuru County	2 568	4 186	5 847	7 927	10 750
Nandi County	11 305	14 597	20 625	27 525	36 232
Narok County	87	127	179	245	336
Nyamira County	5 647	6 976	8 523	10 213	12 134
Siaya County	7 847	9 227	11 754	14 135	16 996
Uasin Gishu County	1 531	1 955	2 604	3 380	4 386
Vihiga County	11 716	12 923	15 650	18 635	20 871
Study area	**129 300**	**159 396**	**221 849**	**271 813**	**325 255**

Current Irrigation

Table 16: Existing irrigation schemes within the area of interest

Irrigation scheme	Management	Area (ha)*	Water sources	Abstraction (million m^3 per year)
Ahero irrigation scheme	NIB	877	Nyando River (pumping)	15
West Kano irrigation scheme	NIB	900	Lake Victoria (pumping) + Ahero scheme drainage water (gravity)	unknown

** Area refers to the equipped area for irrigation. Irrigated area defer from that figure because each farmer decides whether he wants to cultivate or not. And some of the area is cultivated twice a year.*

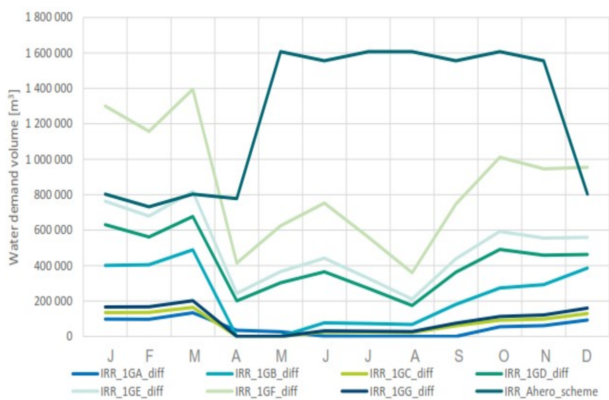

Figure 11: Mean monthly irrigation water demand in the Nyando basin (1G)

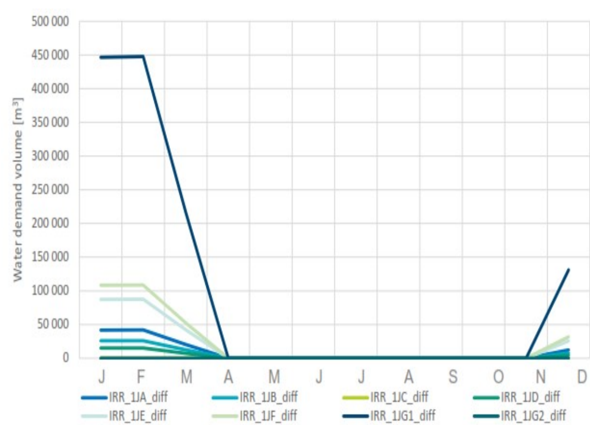

Figure 12: Mean monthly irrigation water demand in the Sondu basin (1J)

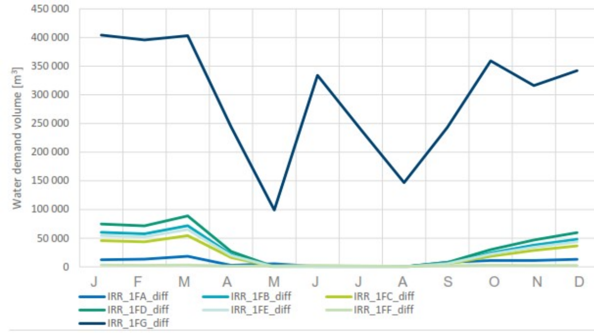

Figure 13: Mean monthly irrigation water demand in the Yala basin (1F)

Kibos river basin

The mean monthly naturalized flow of the Kibos river basin is of 2.8 m^3/s. The minimum monthly Q95 flow is of 0.5 m^3/s and occurs in March. The dry season is highly marked from January to March as illustrated in Figure 17. During the dry season, the Kibos flows are lower than the demand. When raining season begin February to April, the water quality deteriorates as upstream catchment is washed by the first rains, so the water quality is deteriorate.

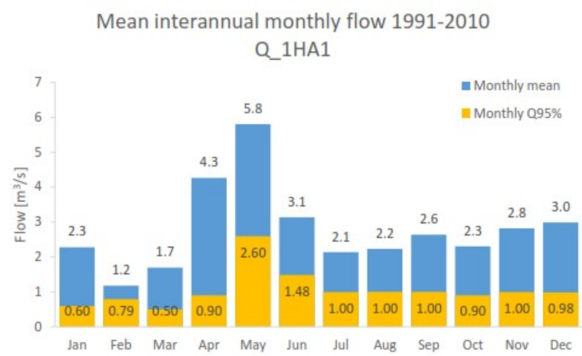

Figure 14: Mean inter annual monthly naturalized flow 1991-2010 of Kibos river basin (1HA1)

Current Situation (Baseline)

Simulation results of the WEAP model as follows:

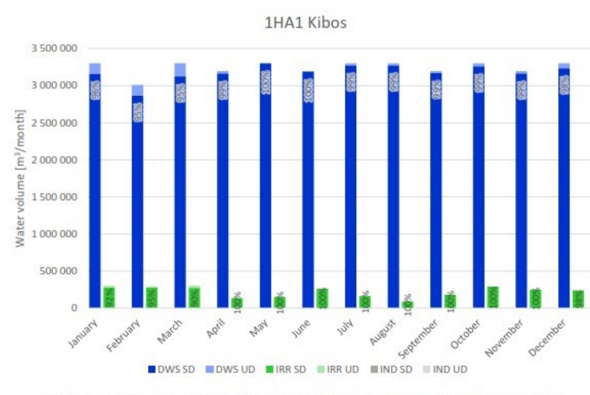

Figure 15: Simulated average demand coverage in Kibos basin (1HA1) per sector, period 1991-2010

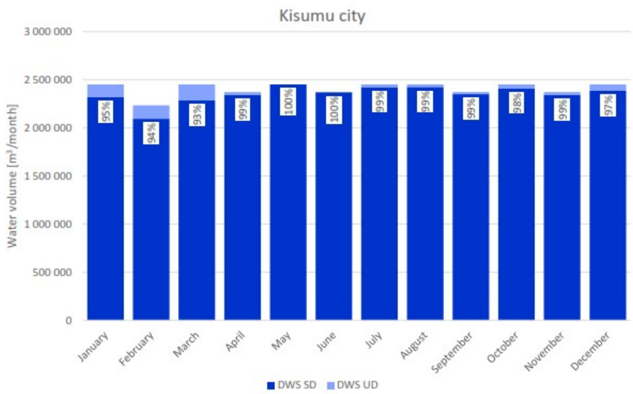

Figure 16: Simulated mean monthly water supply coverage of Kisumu city, period 1991-2010

Oroba River basin

The mean flow during that period is 0.4m^3/s (38 thousand m^3 per day). The minimum monthly Q95 flow is a dry flow that happen in every month of the year. The dry season is highly marked from February to March and from July to October as illustrated in Figure 20.

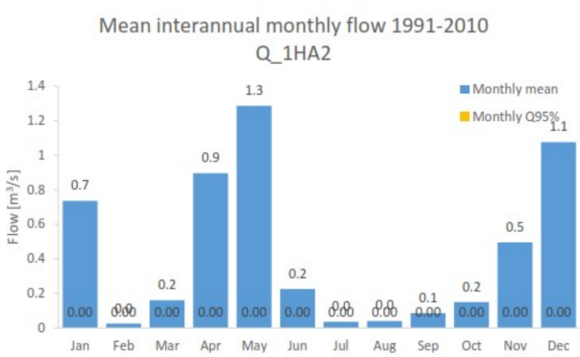

Figure 17: Mean inter annual monthly naturalized flow 1991-2010 of Oroba River basin (1HA2)

Current Situation (Baseline)

Simulation results of the WEAP model as follows:

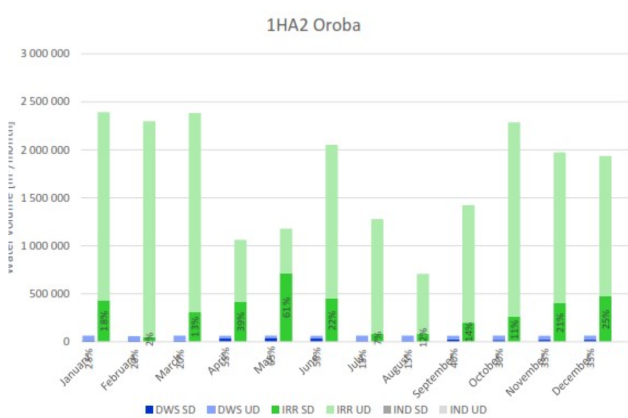

Figure 21: Simulated average demand coverage in Oroba basin (1HA2) per sector, period 1991-2010

Nyando River basin

The mean monthly naturalized flow of the Nyando river basin is of 31 m^3/s. The minimum monthly Q95 flow is of 3.2 m^3/s and occurs in March. The dry season is highly marked from February to March, but the dry season can start as early as December as shown in Figure 22.

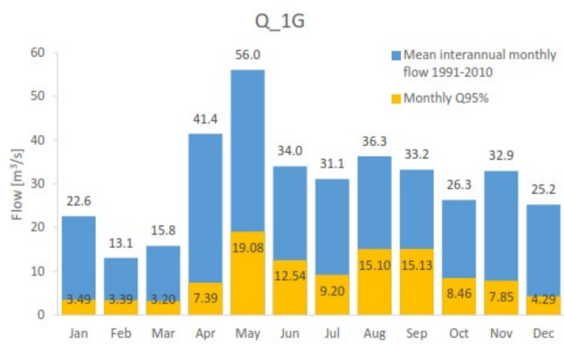

Figure 18: Mean inter annual monthly naturalized flow 1991-2010 of Nyando River basin (1HA2)

Current Situation (Baseline)

The Nyando basin do not show major water shortfalls as shown in Figure 23. Ahero town water demand coverage is only limited by the capacity of both boreholes used for water supply as illustrated in Figure 24.

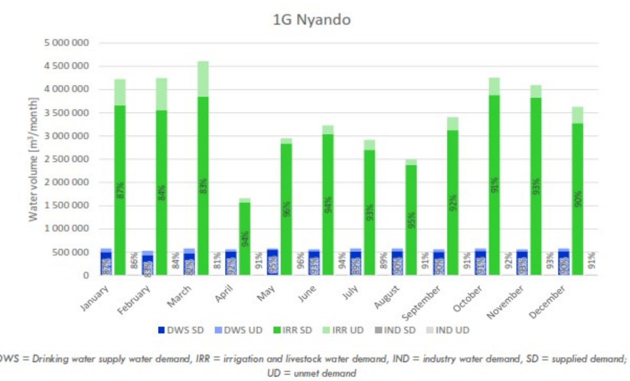

Figure 19: Simulated average demand coverage in Nyando basin (1G) per sector, period 1991-2010

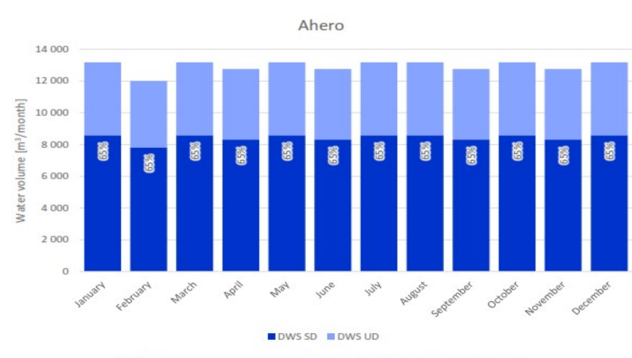

Figure 20: Simulated average demand coverage in Ahero town, period 1991-2010

The potential of the Basin is that there is need to have infrastructures that provide for function of regulating flows and controlling floods to enable harnessing the potential.

Sondu River basin

The mean monthly naturalized flow of the Sondu river basin is of 40 m^3/s. The minimum monthly Q95 flow is of 11.4 m^3/s and occurs in March. The dry season is highly marked from February to March, but the dry season can start in January.

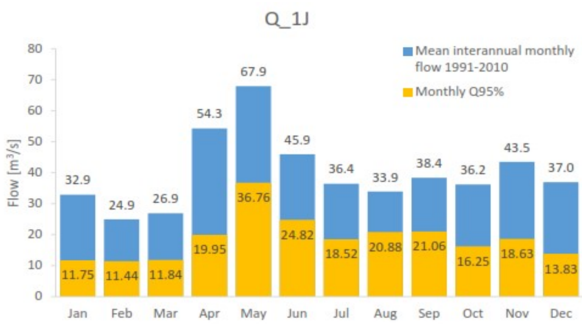

Figure 21: Mean inter annual monthly naturalized flow 1991-2010 of Sondu river basin (1J)

Current Situation (Baseline)

In the Sondu basin, almost all the water demand is met. The domestic water demand coverage is above 98% on average over the entire simulation period. It means there is no issue of water availability within the basin. Sondu town water supply is simulated to be satisfied at 100%.

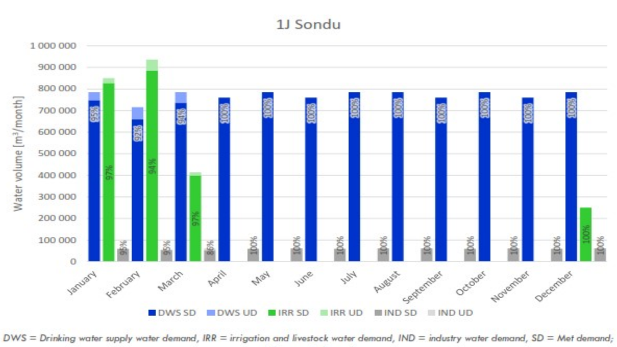

Figure 22: Simulated average demand coverage in Sondu basin (1J) per sector, period 1991-2010

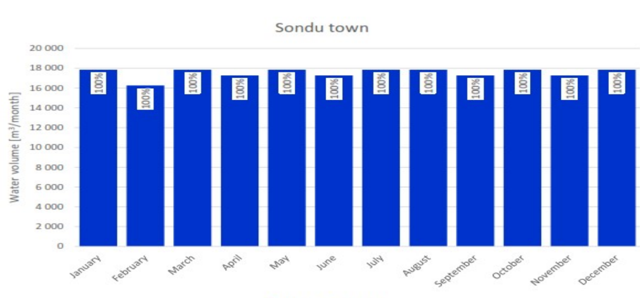

Figure 23: Simulated average demand coverage in Sondu town, period 1991-2010

There is great potential in this basin especially as Sondu town drinking water supply demand is met.

Yala River basin

The mean flow during that period is 26.6m^3/s (2.30 million m^3 per day). The minimum monthly Q95 flow is of 7.0 m^3/s and occurs in February and March. The dry season is highly marked from February to March, but the dry season can start in January and can extend to April as illustrated in Figure 28.

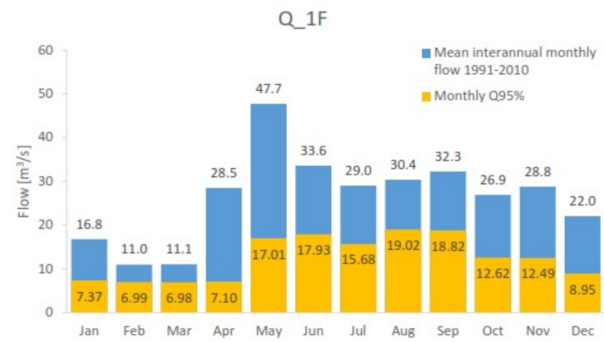

Figure 24: Mean inter annual monthly naturalized flow 1991-2010 of Yala River basin (1F)

Current Situation (Baseline)

The current situation shows little issues of water availability. Scarcity is somehow met (water demand coverage <90%) only during dry months from January to March. Simulation results of the WEAP model as depicted in Figure 29.

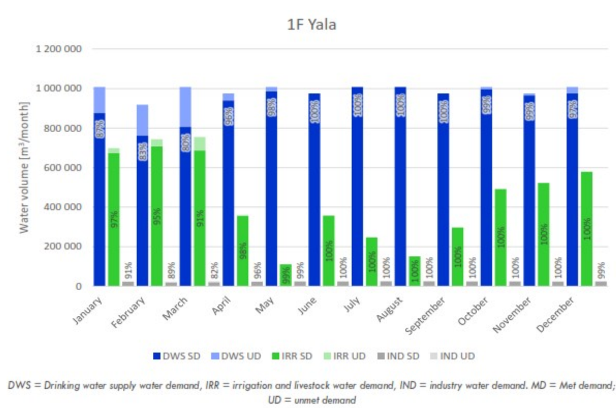

Figure 25: Simulated average demand coverage in Yala basin (1F) per sub-basin, period 1991-2010

West Shoreline River basin

a) Awach Seme and Others (1HB1)

The mean flow during that period is 1.3 m^3/s (112 thousand m^3per day). The minimum monthly Q95 flow is a dry flow and occurs nearly every month of the year except in June, July and November. The dry season is highly marked from February to March and in August.

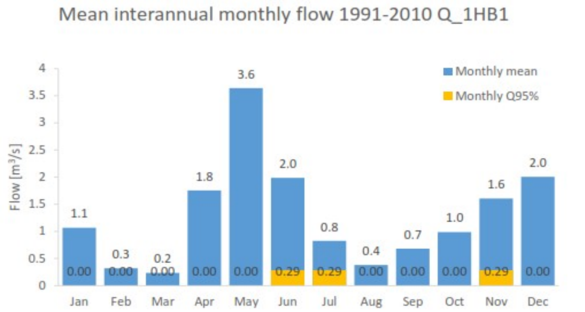

Figure 26: Mean inter annual monthly naturalized flow 1991-2010 of West Shoreline River basin (1HB1)

b) Awach Muguruk, Kysian Rivers and Others (1hb2)

The mean flow during that period is 1.0 m^3/s (84.6 thousand m^3 per day). The minimum monthly Q95 flow is a dry flow and occurs nearly every month of the year except in May, June and July. The dry season is highly marked from February to March and in August and September.

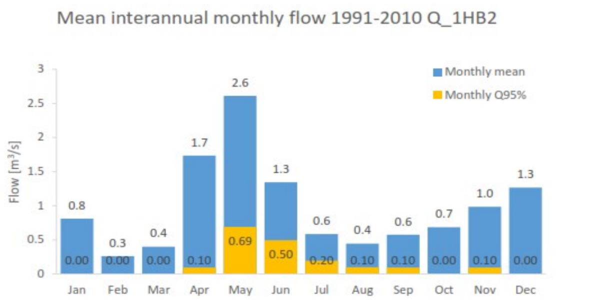

Figure 27: Mean inter annual monthly naturalized flow 1991-2010 of West Shoreline River basin (1HB2)

Current Situation (Baseline)

a) Awach Seme and Others (1HB1)

The simulation shows quite high level of water scarcity in basin 1HB1. Especially during the dry period, the domestic water demand falls down to 45% in February and 30% in March (on average over the whole simulation period).

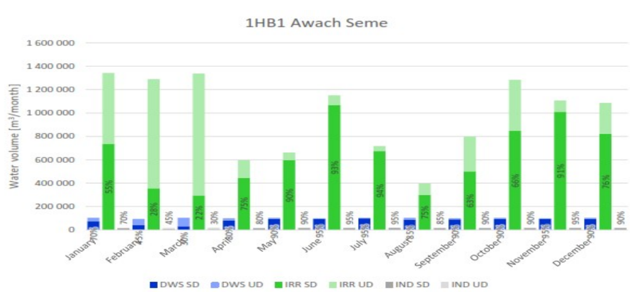

Figure 28: Simulated average demand coverage in Yala basin (1F) per sub-basin, period 1991-2010.

b) Awach Muguruk And Kysian (1HB2)

At least 3 satellite towns are abstracting water for domestic use from this sub-basin 1HB2: Maseno, Pau Akuche/Holo and Kombewa. However, the demand coverage is rather low because of water scarcity. On average, all the three towns are facing a water demand coverage of 67%, with a dry peak in February and March.

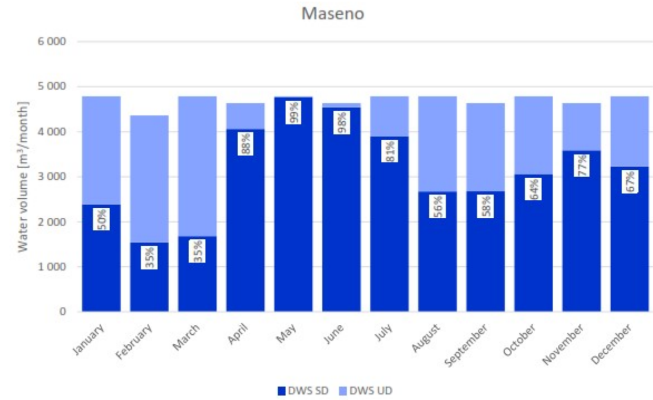

Figure 29: Simulated mean monthly water demand coverage for Maseno town water supply, period 1991-2010

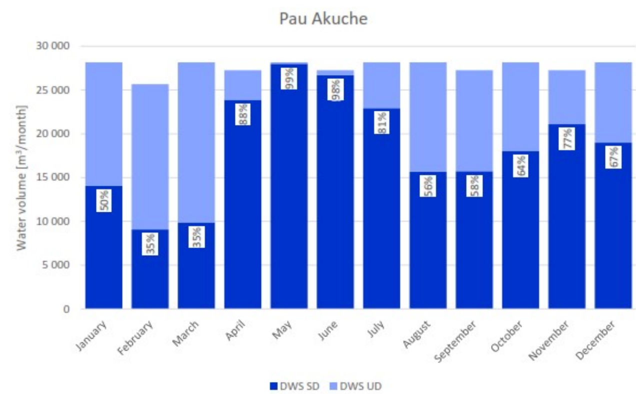

Figure 30: Simulated mean monthly water demand coverage for Pau Akuche and Holo town water supply, period 1991-2010

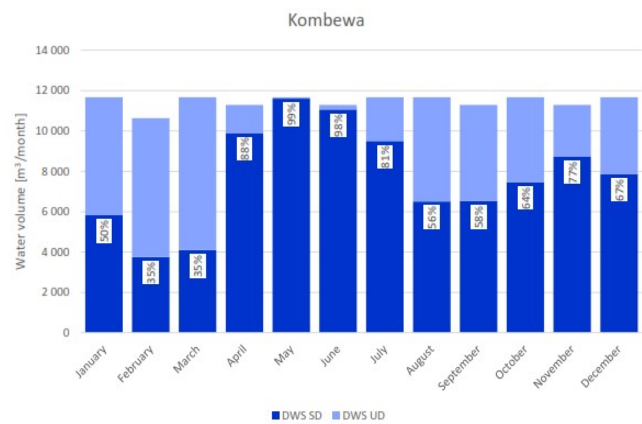

Figure 31: Simulated mean monthly water demand coverage for Kombewa town water supply, period 1991-2010

No water development opportunities have been identified within the west shoreline rivers basin (1HB) as the Lake Victoria has been invaded by water hyacinth.

V. CONCLUSIONS

The study concludes that

- One future option for Kisumu Water is to transfer water from the Yala River basin.
- The main issue is not really water production, since the main tanks are mostly full most of the times, but distribution. The demand exists but the distribution infrastructure is not able to satisfy it.
- Water availability is high within the area of interest, except for shoreline river basins including Oroba and Kibos Rivers.
- Main water issues occur during dry period, and mostly in densely populated areas, such as Kisumu city area.
- Kisumu city water supply issue is a combination of various constraints:
  - Kibos River flows can meet only 32.88% % of the Kajulu Water Works current capacity.
  - During the low flow period, Kibos River water is highly charged of suspended solids, it decreases the Kajulu Water Works capacity.
  - Dunga station is facing invasive aquatic plants problems. It limits the Dunga station capacity.

VI. RECOMMENDATION

Several infrastructure opportunities have to be identified to alleviate water scarcity in shoreline river basins.

ACKNOWLEDGMENT

We are grateful to the following; Water Resource Authority (WRA), JICA, Ministry of Water, Ministry of Transport, Infrastructure Housing and Urban Development (MoTIH&UD) and the staff for availing to us information thus creating an enabling environment during field work and useful discussions.

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