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Original Article

Contribution of the Hydrological Model WEAP in the Evaluation and Planning of Water Resources in the Lobo subbasin in the South-West of Côte D'ivoire

Bi Djè Désiré Djè[1], Mahaman Bachir Saley[2], Homian Jean Danumah[3], Charly Fernand Agoh[4]

[1,2,3,4]*UFR des Sciences de la Terre et des Ressources Minières,Université Félix HouphouetBoigny, Abidjan Côte d'Ivoire*

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Abstract *- The Lobo river basin has been the subject of several studies in the water resources framework. However, with WEAP (Water Evaluation and Planning system) a new approach experiments. WEAP model was used to assess the water resources and demands of the various sectors of activity in the Lobo basin from 2020 to 2050. According to the hydrological balance from 1980 to 2011 in both subbasins of Lobo, the comp multi-annual mean precipitation is estimated at 7,495 million Cubaicmeters(MCM) for the North Lobo and assessed to 8,448 MCM for the South Lobo. The mobilized surface water at both gauges of Nibehibe and Loboville are assessed be to 389 MCM and 1,140 MCM respectively. The groundwater potential is estimated at 1.9 and 2.83 billionCubaicmeters(BCM) respectively in North and South Lobo. The overall Water demand fluctuates between 26 MCM and 39.5 MCM from 2020 to 2050 in the baseline scenario. This demand reaches 46.15 MCM and 92.2 MCM at the end of the Rice Development Project and High population Growth scenarios respectively. in 2050, unmet demand is estimated at 17.59 MCM, 24.25 MCM, and 32.78 MCM in these three scenarios respectively.*

Keywords *- Côte d'Ivoire, Hydrological modeling, Lobo basin, Water resources, WEAP.*

I. INTRODUCTION

In Côte d'Ivoire, the climate variation, the demographic pressure, and the unequal distribution of the water resource make access to water difficult in some areas of the country. The period of rainfall disruption in the 1970s had a considerable impact on water resources[1]. With its periods of drought, climate variability has made rural populations vulnerable because they are largely dependent on rainfall for agricultural neds and has creat a dysfunction in the supply of electricity due to lower water levels in hydroelectric dams. Hence vigorous actions have been undertaken by the government to mitigate the adverse effects of the water deficit. These actions have enabled 725 of the 1,194 eligible areas to be equipped and 576,552 consumers to be supplied with urban drinking water. For village water supply 1,500 modern wells and 19,689 water points have been built out of an initial demand of 21,661 water points. in addition, the institutional framework for water resources has undergone several reforms that led to the drafting of an Integrated Water Resources Management (IWRM) master plan in 2000; the adoption of a national water vision, the validation of the national water policy docu,ment and the development of the National IWRM Plan in 2010.

The main objective of this work is to assess the quantities of surface water and groundwater available and to predict the future demands of different sectors of activities. Specifically, the objective is to assess the water resources of the basin using the soil moisture method of the WEAP (Water Evaluation and Planning system) hydrological model; and to model future demands under baseline (Bsc), High Population Growth (HPGS), and Rice Development Project (RDPS) scenarios with the WEAP model.

II. STUDY AREA

The Lobo River basin (Figure 1) is located in the West of Côte d'Ivoire and lies between longitudes 6°03'18" and 6°56'32" W, and latitudes 6°02'22" and 7°56'48" N. The Lobo River is 314 km long and drains a total area of 12,745 km^2. This basin includes practically the entire Upper Sassandra region with Daloa as its main town and capital.

Daloa is the main economic and administrative center of the West region. The population is estimated at 1,781,000 with more than 500,000 people in Daloa city. The population density of the basin is 75 inhabitants per km^2. It is one of the most important agricultural poles of the country.

The Lobo basin, like the whole country, belongs to the vast and ancient African platform that is the Precambrian craton. The rocks that support this platform belong to the Precambrian and are between 1.8 and 3 billion years old.

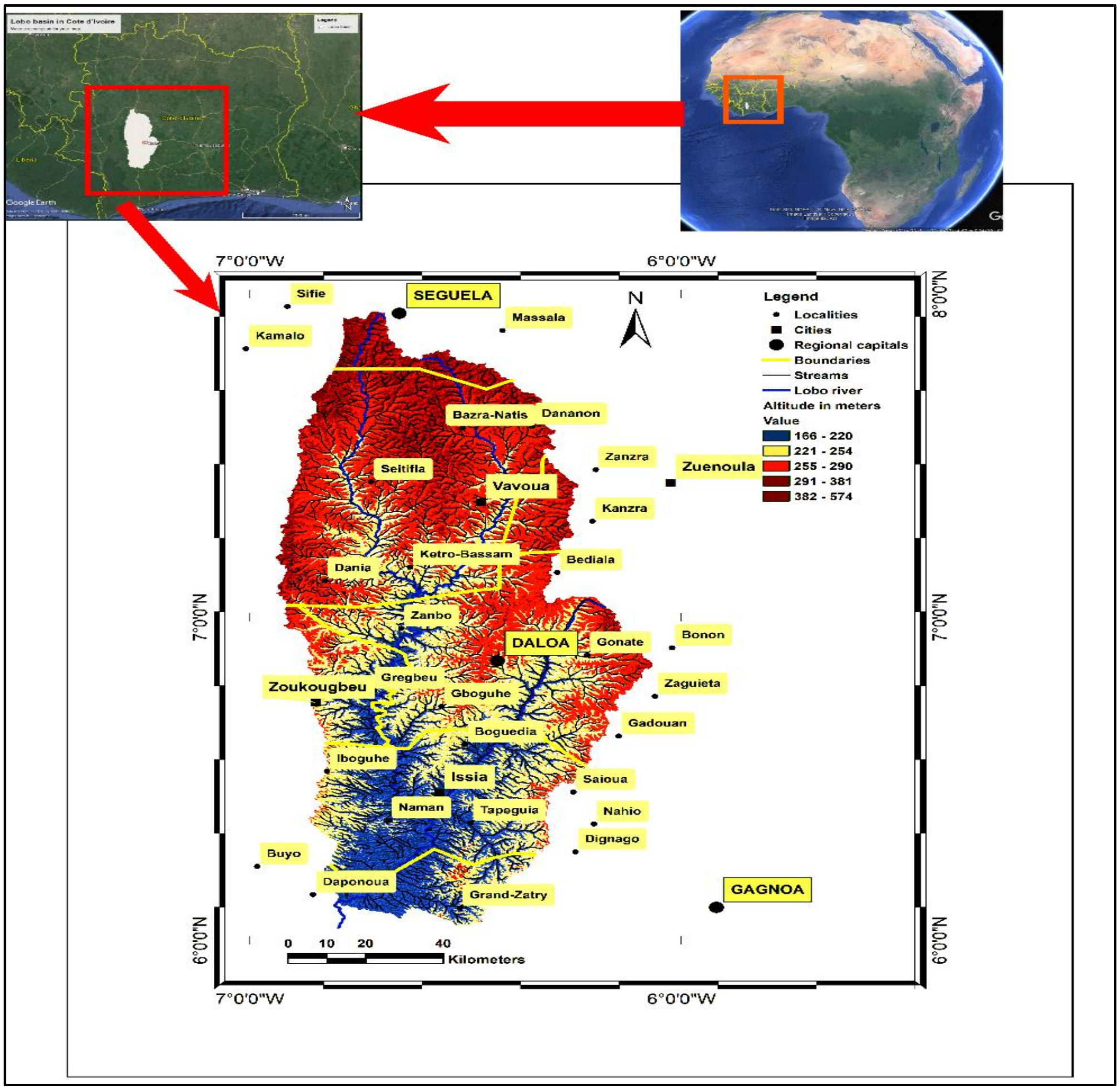


Fig. 1 Location of the study area: Lobo basin in Cote d'Ivoire

III. MATERIAL AND METHOD

A. Data

This hydro-economic study requires a vast amount of climatic, hydrologic, demographic, and socioeconomic information and data. Table 1 summarizes all data required and used for this study.

B. Model development approach

a) Estimation of the water supply of the Lobo River basin

WEAP seamlessly integrates water supplies generated by hydrologic processes at the watershed scale with a water demand-driven water management model[2].

Table 1. Summary of data for the development of the WEAP model in the Lobo basi

Data	Sources	Format
Satellite data		
Four Sentinel 2 images - S2A_MSIL1C_20190212T104141_N0207_R008_T29NQH_20190212T160330.SAFE - S2A_MSIL1C_20190212T104141_N0207_R008_T29NQJ_20190212T160330.SAFE - S2A_MSIL1C_20190212T104141_N0207_R008_T29NRH_20190212T160330.SAFE - S2B_MSIL1C_20180222T104029_N0206_R008_T29NQG_20180223T184036.SAFE	ESA (European Spatial Agency)	format Geotiff with resolution between 10 and 60 m
Climat data		
- Precipitations (mm), temperatures (°C)	SODEXAM	Monthly data from 1980 to 2011 Excel files
- Relative humidity (%), wind speed (m^3/s)	University of Princeton	Daily data from 1980 to 2011 in Netcdf format at 0.25°x 0.25° resolution
Water resources data		
- Streamflows (m^3/s)	Ministère de l'Hydraulique ; Direction de l'Hydrologie	Monthly data from 1980 to 2011; and from 1988 to 2011 Excel files
- National drilling data (m^3/s)	Ministère de l'Hydraulique Direction de l'Hydrologie	Excel files
Water demand data		
- Land cover: rice development area (Ha)	ONDR, MINAGRI	Excel files
- Demographics (capita/year)	Institut National de la Statistique (INS)	General population and housing census data of 2014
- Water consumption in an urban area (m^3/capita/year)	SODECI	Excel files
- Water consumption in a rural area (m^3/capita/year)	JICA, 2001	Documentary search
- Agriculture water demand (m^3/Ha/year) - Areas of rice-growing areas (Ha)	ONDR	Excel files
- Livestock water demand (m^3/capita/year)	MIPARH Direction de la planification et de la programmation (MIPARH/DPP)	Excel files

In addition, WEAP presents five methods for characterizing water resources. However, the soil moisture method (SMM) is the most realistic although more complex than the others. This method simulates potential evapotranspiration (PET) from the topsoil layer by accounting for precipitation and irrigation on agricultural and non-agricultural lands, surface runoff, hypodermic runoff, and changes in soil moisture (Figure 2).

The SMM is a two-compartment model based on empirical functions (Equation1) that describe evapotranspiration, surface runoff, hypodermic runoff, and deep percolation for the watershed unit[3].

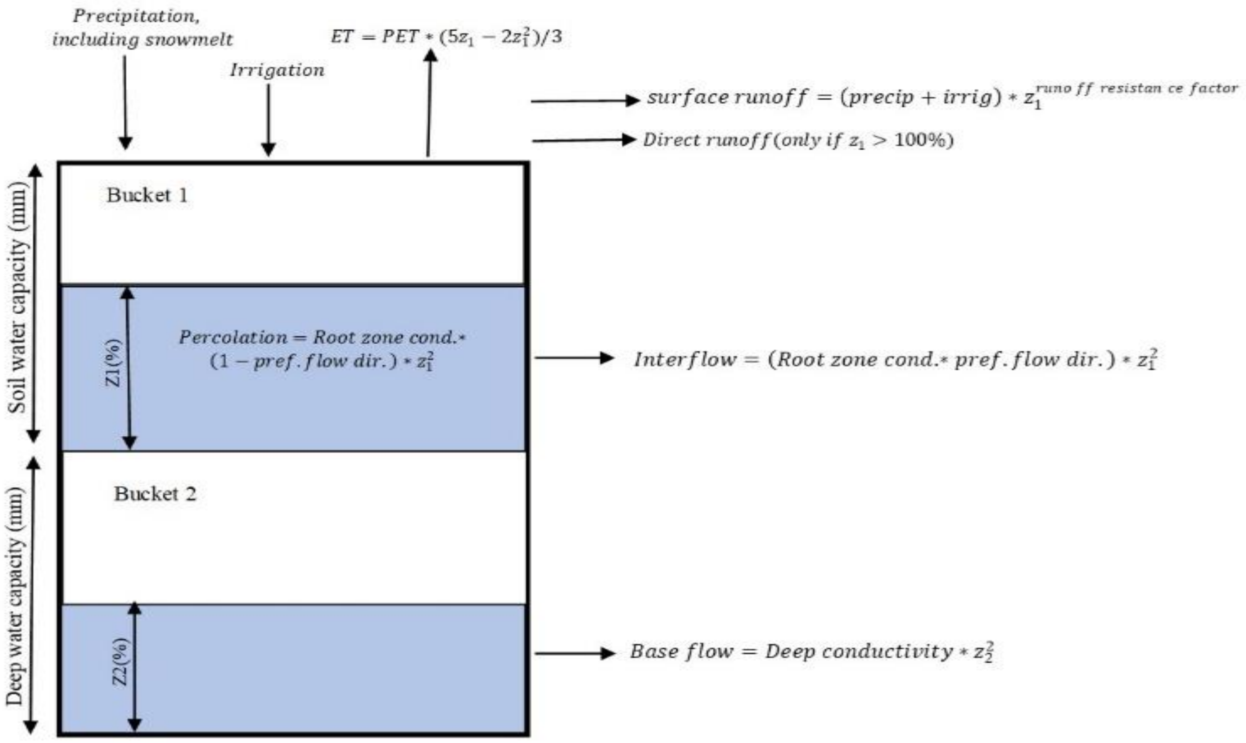


Fig. 2 Conceptual diagram and equations incorporated in the Soil Moisture model (Source: SEI, 2015)

Assuming uniform climate in each subbasin unit, the water balance for each fraction j of the basin, of N fractions are written as follows: $Rd_j \frac{dz_{1,j}}{dt} = P_e(t) - PET(t)k_{c,j}(t)\left(\frac{5z_{1,j}-2z_{1,j}^2}{3}\right) - P_e(t)z_{1,j}^{RRFj} - f_j k_{s,j} z_{1,j}^2 - \left(1 - f_j\right)k_{s,j} z_{1,j}^2$ (1)

Where $z_{1,j}$= [1] is the relative storage given as a fraction of the total effective root zone storage Rd_j (mm), for the land cover fraction, j. Effective precipitation P_e includes snowmelt from the accumulated snowpack in the sub-watershed. PET, is the potential evapotranspiration. The factor $k_{c,j}$ is the crop coefficient for each land cover fraction. The third term represents surface runoff, where RRF_j is the land cover runoff resistance factor. The fourth and fifth terms are the hypodermic flow and deep percolation terms, where respectively, the parameter, $k_{s,j}$ is an estimate of the conductivity (mm/time) of the saturated root zone, and f_j is a partition coefficient related to the soil, land cover type, and topography that divides the water both horizontally and vertically[4].

b) Methodology of the Groundwater Resources Assessment

Because the WEAP model does not support fractured aquifers, we will reduce the groundwater capacity to only the populated areas extended to a radius of 2 km. This distance represents twice the average distance traveled by women in rural areas in search of water for domestic use according to WHO[5]. This approach takes into account the fact that some parts of the watershed are not occupied[6]. Therefore, the groundwater resources potentially available in these areas are not accessible to different users due to their remoteness.

These populated areas are equated to a generalized aquifer in WEAP[7], with a specific yield of 3% relative to fissure aquifers. This specific yield is based on the work of[8] in India on the yields of different aquifer types. Thus, the groundwater capacity of each hydrogeological subbasin unit is formulated as follows[8]in Equation 2:

$$S = Vaq * Sy \tag{2}$$

Where S is the groundwater capacity of the aquifer, Vaq is the volume of the aquifer and Sy is the specific yield of the aquifer.

$$Vaq = Ar * \Delta h \tag{3}$$

Where ***Ar*** represents the area of the inhabited and extended zone of 2 km radius;

andΔ***h*** is the average thickness of the aquifer, which will be assumed to be equal to the depth of the boreholes in this area, given the lack of data.

c) Calibration, Validation, and Performance Criteria

The WEAP_LOBO model was calibrated and validated over the period 1980 - to 2011 for this study. To establish the degree of correspondence between observed and modeled values, the performance criteria used in the calibration of the hydrologic model are: the Nash-Sutcliffe efficiency index (NSE), the percentage bias (PBIAIS), the coefficient of determination R^2, the root mean square error (RMSE), and the standard deviation of root mean square errors (RSR)shown in Table 2[9],[10]. The $O_i$quantities are the observed precipitation (or flow) values and the $P_i$quantities are the model simulated values.

d) Estimation of the water demand of the Lobo River basin

The water demand is the sum of the demands of all lower-level branches of the demand sites (Figure 3). Thus, the annual demand of a demand site (DS) is derived from Equation 3:

$$Annualdemand_{DS} = \sum_{Br}(totalActivityLevel_{Br} * WaterUseRate_{Br}) \quad (4)$$

The total activity level of a demand site is the product of the activity levels of all branches related to that demand site.

Table 2. Equations, scales, optimal values of the statistical performance criterion. (Moriasi et al., 2015)

Statistics	Equation	Scale		Optimal values
NSE	$1 - \frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n}(O_i - \bar{O}_i)}$	From$-\infty to$ 1.0		1.0
RMSE	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}$	From0.0 $to\ \infty$		0.0
RSR	$\frac{\sqrt{\sum_{i=1}^{n}(O_i - P_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{P}_i)^2}}$	From0.0 $to\ \infty$		0.0
PBIAS	$\frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n}O_i}$	From$-\infty to + \infty$		0.0
R^2	$\left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}}\right]$	From0.0 to 1.0		1.0

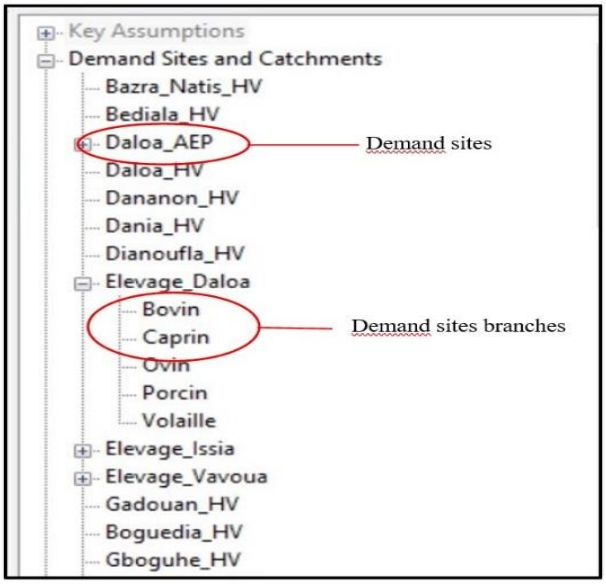


Fig. 3 Demand sites and their related branches

The annual water consumption of a branch is the amount of water consumed per activity per year at that branch. The level of activity in either the population size in the case of estimating water demand related to domestic activities, the land area for calculating agricultural demand, or the livestock size for a livestock sector demand. in this casestudy, the following four types of water demand will be evaluated:

1) Domestic demand

This demand includes both rural and urban demands. Drinking water is produced from drinking water treatment plants and distributed through a drinking water supply system (WSS). in this case study, only Daloa, Vavoua and Issia have such a drinking water supply system in the basin, which is managed by the Société de Distribution d'Eau de Côte d'Ivoire (SODECI)). Table 3 summarizes the annual water production of these four cities and other cities under the jurisdiction of the Central West Regional Directorate of SODECI (Daloa).

2) Agricultural demand

This demand is determined by the area, the annual specific consumption of the irrigated crop, which in our case is rice, and the monthly variation in the water requirements of the crop. The model only integrates the water demand of irrigated crops. in this basin, irrigated rice is generally grown on small plots (1 to 2 ha). The lack of total water control leads to a single annual crop cycle in most cases (June to November). The water demand for the rice-growing sector of the basin is estimated on average at 9,605 m^3/ha/yr, or 960.5 mm of water per year. This specific consumption is corroborated by[11]. Table 6 shows the area under rice cultivation in the basin.

3) Livestock demand

For the livestock sector, the unit water demands for each type of livestock according to the Water Resources Management Master Plan[12] are presented as shown in Table 5. Livestock sizes by species and department were obtained from the Planning and Programming Directorate of the Ministry of Animal Production and Fishery Resources (MIPARH/DPP), for the period 2001 to 2014.

4) Industrial demand

The industries in the cities of the basin are generally low consumers of water. They have generally related to the wood sector and the storage of agricultural products. The share of industrial consumption was about 12% of total urban water consumption in 1998[12], a relatively low rate compared to domestic consumption. For this purpose, we will adopt the assumption of the national rate of 12% of domestic demand as the industrial water demand to assess the industrial demand of each urban area.

Table 3. Annual water production (m^3) of some centers of the regional director of Daloa from 2004 to 2016. (Source: SODECI, 2018)

Years	Daloa	Issia	Saioua	Zoukougbeu	Gadouan	Vavoua	Bonon	Seguela
2004	2 320 796	332 474	56 736	na	na	107 493	63348	682 246
2005	2 332 587	323 931	62 582	na	na	163 057	69706	668 893
2006	2 322 844	349 002	71 124	na	na	143 671	45419	513 390
2007	2 382 113	382 785	116 577	32 862	na	130 586	55414	669 625
2008	2 349 539	396 026	126 392	43 337	na	145 117	39290	682 505
2014	2 206 754	420 433	121 152	31 397	40 217	193 026	84 343	na
2015	3 132 667	606 451	202 906	58 312	63 278	211 588	132 628	na
2016	3 225 320	593 979	209 581	79 304	79 256	248 128	235 361	na
The average growth rate of water production (%)								
Taux	3.88%	7.30%	15.32%	14.69%	25.59%	9.84%	9.45%	-1.77%

na: data not available

Table 4. Distribution of developed and cultivated areas in the Lobo River basin (ONDR, 2018)

Rice lowlands	Areas (ha)	Water development system	Hydraulic equipment	Villages	Longitude	Latitude
Drouple	163	Irrigated	Barrage	Brakaguhe	-6.56	6.81
Babadou	72	Irrigated	Barrage	Niouboua	-6.46	6.70
Boto	143	Irrigated	Barrage	Krizabouo	-6.36	6.39
Kpokpo	108	Irrigated	Barrage	Gazibouo	-6.48	6.36
Daloa acacia	30	Irrigated	Barrage	Daloa	-6.45	6.88
Daloamonastere	184	Irrigated	Barrage	Daloa	-6.20	6.89
Bata 1 à 9	100	Irrigated	Run-of-river catch	Daloa	-6.88	6.48
Kibouo	70	Irrigated	Barrage	Kibouo	-6.50	6.82
Zoukougbeu	70	Irrigated	Barrage	Zoukougbeu	-6.56	6.81

Table 5. Unit water demands of each livestock type

Livestock	Specific consumption
Cattle	30 liters/cattle/day
Sheep et goats	5 liters/sheep/day
Pigs	7.25/pig/day
Poultry	0.1 liter/poultry/day

5) Demand Priority Levels

WEAP uses a priority system to allocate the water resource to different demand sites according to their priority level in the water allocation system. Thus, the highest priority is 1 and the lowest is 99. Also for each type of demand, Table 6 summarizes the priorities[2].

Table 6. Priority Level of Water Demand by Sector of Activity

Demands	**Prioritylevels**
Domestic	1
Agricultural	3
Livestock	2
Industrial	4

6) Steps of scenarios Creation

i) The current account

The base or current account scenario is the basic structure of the water resources system as it exists in the current account year, and is the basis for the analysis of all other scenarios. To perform this, the data and assumptions must accurately reflect the system as it operates in that base year. For the Lobo Basin study, 2005 is the base year for the current account because of the greater amount of data available for that period.

ii) The baseline scenario (BSc)

The reference scenario or baseline scenario is based on the current account. It is a projection of the current account structured according to a variety of economic, demographic, hydrological, and technical policies. It is the scenario where the status quo is preserved. That is, demographic, agropastoral, industrial, climatic, and hydrological growth rates are maintained as they are. in the case of WEAP-Lobo, the baseline scenario is based on 2014 census population growth rates, agropastoral data (2002 to 2015), climate (1980 to 2011), and streamflow (1980 to 2011) records. It is executed over the period 2006 to 2050.

iii) High Population Growth Scenario (HPGS)

The high population growth scenario (HPGS) is based on the assumption that the Upper-Sassandra region is a region of high immigration. This region has a strong agricultural potential that draws people from various origins. in addition, the latest UN report on demographic prospects forecasts a doubling of the Ivorian population by 2050. All of these aforementioned reasons imply the need to implement a high population growth scenario with an average rate of 5% from 2020 to 2050, given that growth rates in the region ranged from 1.48 to 3.35% in 2014[13-16].

iv) Rice Development Project Scenario (RDPS

This scenario is based on the implementation of the Upper-Sassandra Rice Field Development Project (Projetd'Amenagement Hydro-Agricole du Haut-Sassandraet du Fromager (PAHAHSF)). Here, only the developments in the Upper-Sassandra region will be taken into account in the Rice Development Project Scenario. These additional rice-growing areas developed (Table 7I) were used to simulate future agricultural demand under the implementation of the two phases of the PAHAHSF project starting in 2015 in the departments of Issia, Daloa, and Vavoua.

Table 7. Upper Sassandra Rice Field Development Project (ONDR, 2018)

Counties	**Localities**	**Areas (ha)**
	Phase I	
Issia	Gazibouo	111
	Krizabahio	143
	Phase II	
Daloa	Niouboua	172
	Brakaguhé	163
Vavoua	Yuala	97

IV. RESULTS

A. WEAP model in the Lobo basin

The development of the WEAP model in the Lobo watershed led to the subdivision of the watershed into two subbasins (North-Lobo in blue and South-Lobo in red) and the development of a resource distribution scheme into supply sites (green) and water demand sites (red). Thus, the water resource is supplied by two watershed sites (green circle), and 24 groundwater sites (green square), and is distributed by transmission links (37 links). The demand sites (38 sites in red circles) are divided into domestic, agricultural, livestock, and industrial sites (Figure 4).

B. Calibration and validation

The WEAP_Lobo model was calibrated and validated over the period 1980 to 2011 for the North Lobo sub-basin and 1988 to 2011 for the South Lobo basin according to the availability of hydrometric data. The accuracy of the model was evaluated through different statistical performance criteria that are: the Nash-Sutcliffe efficiency index (NSE), the percentage bias (PBIAS), the ratio of the root mean square error to the standard deviation (RSR), the root mean square error (RMSE) and the coefficient of determination R^2. Table 8 summarizes the performance of the model according to the values obtained for each optimization criterion.

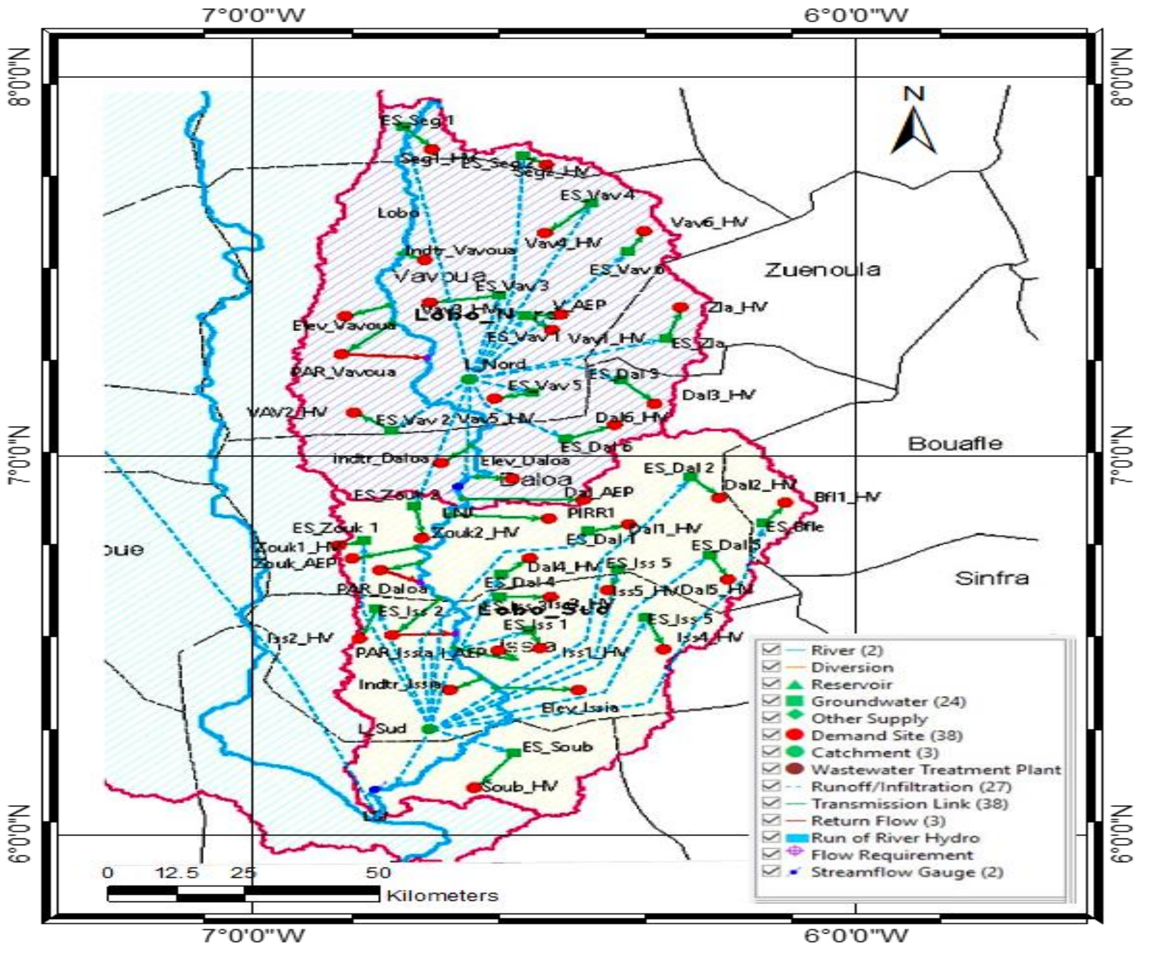


Fig. 4 Water resource allocation in the Lobo River basin according to the WEAP model.

Table 8. Characterization of the performance of the WEAP-LOBO model using the calibration curve (observed flows in blue and simulated flows in red), regression curve, and performance criteria

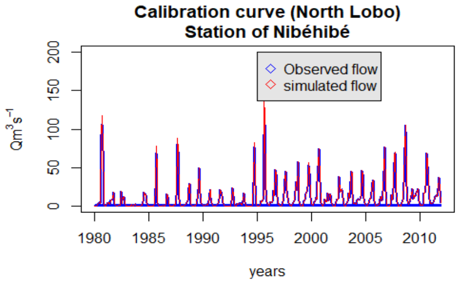
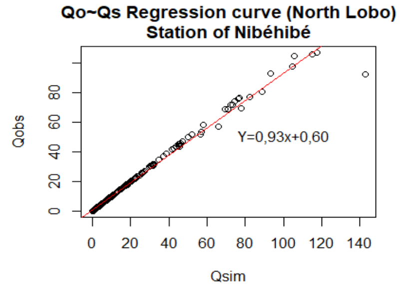
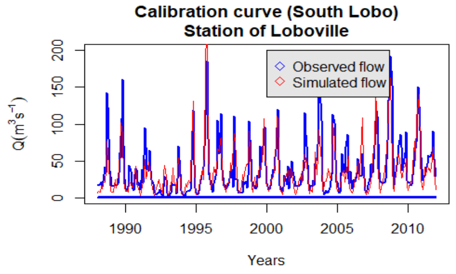
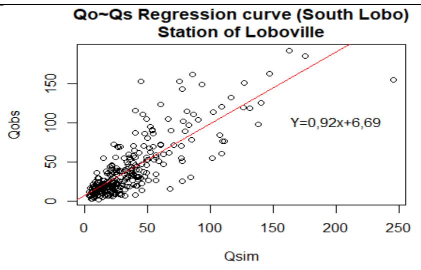
Calibration curve	Regressioncurve	Peformancecriteria	
		NSE (%)	97.82
		PBIAS (%)	-2.68
		RSR	0.15
		RMSE	2.81
		R^2	0.98
		NSE (%)	65.10
		PBIAS(%)	9.33
		RSR	0.59
		RMSE	21.49
		R^2	0.67

Table 8 presents the results of the calibration and validation of the WEAP-Lobo model. The results simulated by the WEAP-Lobo model are estimated to be very good for criteria such as NSE, PBIAS, RSR, RMSE respectively estimated at 97.82%; -2.68% (the negative values of PBIAS, close to 0, mean that predicted values are slightly bigger than those observed); 0.15 and 2.81 for the North-Lobo subbasin. For the South-Lobo subbasin, the performance criteria obtained are 65.10%; 9.33%; 0.59, and 21.49 respectively for NSE, PBIAS, RSR, and RMSE. The accuracy of the model is good for the coefficient of determination R^2 for both subbasins; that is to say 0.98 and 0.67 for the North-Lobo and South-Lobo respectively.

The calibration curves in Table 8 clearly show that the temporal distribution of flows is well executed by the model. However, the extreme flows of the river at the Lobo hydrometric station in Loboville are sometimes not well reproduced by the model, since the flow chronicle is relatively short. Thus, this does not allow the model to integrate all the fluctuations of the stream.

The regression curves show that the model simulates very well the flows observed in the river at the Nibehibe station. On the other hand, at the Loboville station, the flows are partially well simulated with respective slopes of 0.93 and 0.92 for the regression curves of the observed flows versus the simulated flows close to 1.

C. Water Resource Estimation Results

a) Water balance

The water balance determined using the WEAP model estimates hydrological parameters such as deficit in soil moisture, increase in soil moisture, evapotranspiration, flow to groundwater, interflow, precipitation, and surface runoff.

The WEAP model emphasizes the inputs (precipitation, deficit in soil moisture) to the watershed system as positive quantities. While the other hydrological parameters (evapotranspiration, flow to groundwater, increase in soil moisture, interflow, and surface runoff) assumed to be outflows from the system, are negative values. Thus, the multiannual mean of precipitation between 1980 and 2011 is estimated at 1,155 mm (Table 9) for the North Lobo sub-basin and 1,350 mm (Table 9) for the South Lobo; that is to say, an average precipitation volume of 7,495,000,000 and 8,448,000,000 m^3/year, respectively. Both basins have a high evapotranspiration potential representing 95% of the annual precipitated volumes. This could be explained, on the one hand, by the importance of the vegetation cover (88%). and on the other hand, by the fact that the Penman-Montieth method on which the calculation of evapotranspiration in the model is based, tends to overestimate it. This implies that the share of precipitation reserved for the other parameters of the water balance remains low to the benefit of evapotranspiration. Consequently, surface runoff is equivalent to only 0.1 and 0.6% of precipitation in the North and South Lobo respectively. Infiltration to groundwater reservoirs is greater in the North (364 million cubic meters) than in the South (170 million cubic meters).

Table 9. Multiannual means water balance of both sub-basins of Lobo basin. The amount of water is esteemed in millions of cubic meters (MCM) and the depth of water in millimeters (mm)

Hydrological parameters	**North Lobo**		**South Lobo**	
	Water amount (MCM)	Water depth (mm)	Water amount (MCM)	Water depth (mm)
Decrease in soil moisture	1971	304	1941	310
Evapotranspiration	-7127	-1099	-7536	-1204
Flow to groundwater	-364	-56	-170	-27
Increase in soil moisture	-1964	-303	-1992	-318
Interflow	-0.17	-0.026	-168	-26.91
Precipitations	7495	1155	8448	1350
Surface runoff	-10.28	-1.59	-523	-84

b) Surface water

The mobilized quantity of surface water in the South Lobo fluctuates between 0.570 billion cubic meters (BCM) and 1.920 BCM with a multiannual mean volume of 1.140 BCM. Similarly, for North Lobo, the average multiannual volume of surface water is estimated at 0.389 BCM. For an annual volume between 0.026 BCM and 0.968 BCM.

c) Groundwater

The Höllermann method was used to determine the groundwater resources available in the inhabited areas of the basin with a buffer zone of 2 km corresponding to twice the average distance traveled by women in rural areas in search of water. This method yielded an available resource of 4.8 BCM of water as shown in Table 10 for the entire watershed and an estimated aquifer capacity of 41 BCM.

Table 10. Groundwater resources in the Lobo watershed

Subbasins	Maximum monthly withdrawal from the aquifer (m^3)	Inhabitedlocalities areas (km^2)	Aquiferscapacity	Number of boreholes or wells
Lobo Nord	1,999,753,920	336	18,650,628,390	336
Lobo Sud	2,833,807;680	819	22,281,062,952	446
Total	**4,833,561,600**	**1155**	**40,931,691,342**	**782**

d) Estimated Water Demand in the Basin from 2020 to 2050

Water demand in the basin is divided into four main types of demand. These are domestic demand (made up of urban demand or AEP and rural demand or HV), agricultural demand, livestock sector demand, and industrial demand.

Figure 5 shows that the overall demand for water in the two basins fluctuates from 26.02 million cubic meters per year (MCM/yr) to 39.50 MCM/yr in the baseline scenario (BSc). This demand is relatively higher in the other two scenarios, that is to say, 28.92 MCM/yr and 32.68 MCM/yr in 2020 in the Rice Development Project Scenario (RDPS) and the High Population Growth Scenario (HPGS) respectively. in 2050, demand reaches 46.15 MCM and 92.2 MCM for these two scenarios respectively.

In the RDPS scenario, implementation of the Rice Development Project will lead to a substantial increase in rice-growing areas and thus in agricultural water demand of 6.5 MCM/yr over the entire RDPS simulation period. Apart from climate change that reduces water resources and therefore increases demand, the rapid growth of population in the city of Daloa is the main cause of the high water demand in the HPGS scenario, with a water requirement of 40 MCM in 2050 at the end of the scenario, as illustrated in Figure 6. It is followed to a lesser extent by the water demand of the city of Vavoua, which is estimated at 18 MCM at the end of the HPGS scenario.

e) Assessment of unmet demand (UD) and efficiency of water coverage

This demand is defined as the water required to be covered to fully meet the water demand.

According to Figure 7, in the BSc scenario, the UD grows from 12.56 MCM to 17.95 MCM over the entire simulation period. in the RDPS scenario, the UD is higher between 2020 and 2030, reaching 22.34 MCM (in 2030), compared to the UD in the HPGS scenario, which is 18.95 MCM. From 2040 to 2050, the UD in the HPGS scenario increases sharply to 33.8 MCM.

Water coverage efficiency is the percentage of time steps at which demand meets water requirements for a given site. For example, a six-month shortage in each decade corresponds to a water efficiency of 95%.

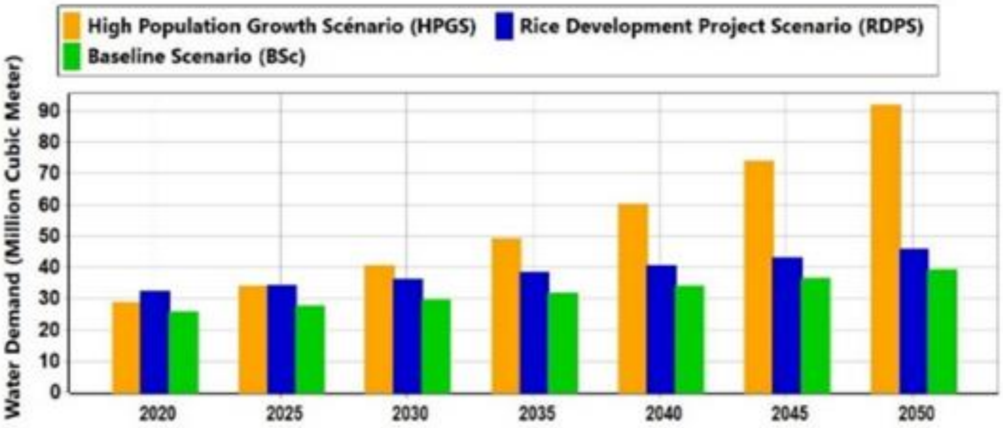


Fig. 5 Comparative evolution of the water demand in the Lobo river basin in the different scenarios

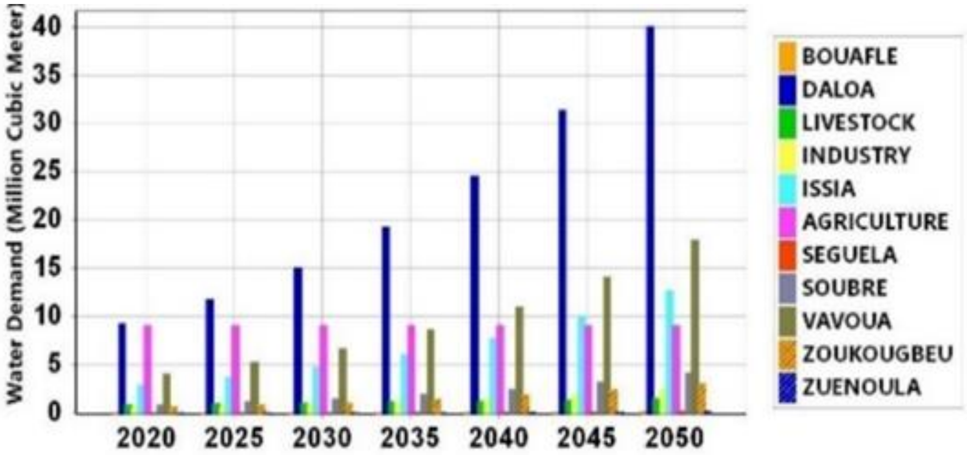


Fig. 6 Water demand evolution in the High Population Growth scenario (HPGS) in millions of cubic meters per year

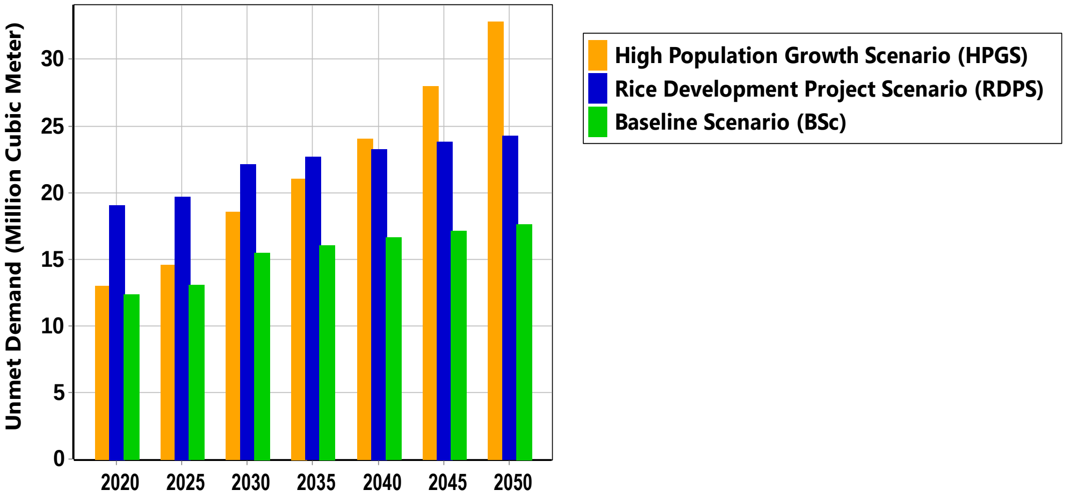


Fig. 7 Comparative evolution of the unmet demand (in Millions m^3) in the scenarios BSc, RDPS, and HPGS from 2020 to 2050

This index implies the following findings:

- All rural sites are 100% satisfied. But in fact, the lack of data on the fluctuation of the piezometric level of the water tables of groundwater collected in rural areas does not allow the model to capture the seasonal variations of resources in rural localities. in fact, in the dry season, the water table level in boreholes and wells drops and people have to resort to a water source for their needs.
- Urban sites remain very vulnerable to water shortages with a water efficiency of 26% for large cities such as Daloa, Issia, and Zoukougbeu which are only satisfied with drinking water for 26% of the time between 2020 and 2050 in all scenarios. in Vavoua, we observe a 100% satisfaction coverage according to figure 8. This result does not take into account the recurrent breakdowns of the functional pumps and the drying of the water table.
- Agricultural and industrial sites have coverage that fluctuates according to the scenario. For example, in agricultural sites, according to Figure 9, the coverage is 71% for the rice-growing perimeter in all scenarios. in the RDPS scenario, rice projects are covered at 69%.
- For livestock and industry, the coverage is from 19 to 25% in all scenarios.

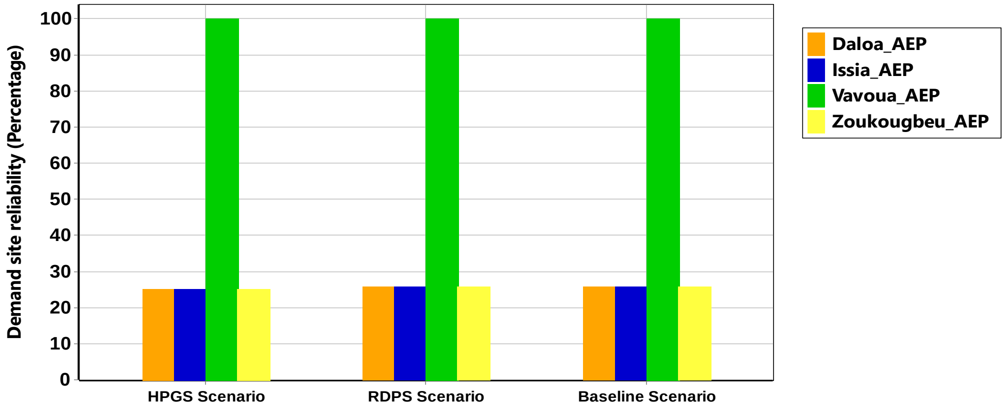


Fig 8. Urban water demand sites reliability (%) in all scenarios

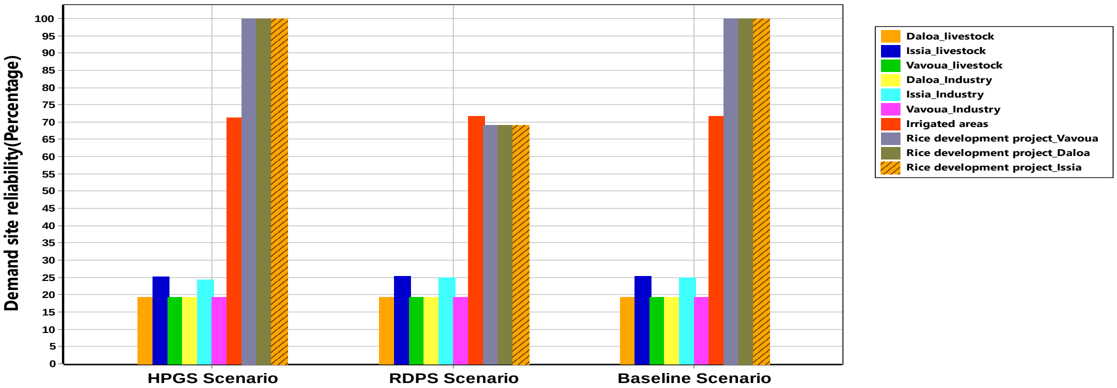


Fig. 9 Agricultural, livestock, and industrial water demand sites reliability (%) in all scenarios

V. DISCUSSION

A. Quality of the data used

The use of the WEAP hydrological model requires a considerable amount of data to conduct all studies related to water resources management and planning. in addition, these data can be subject to uncertainties at several levels and thus be primary sources of errors that affect the model results[17]. However, the hydrological data collected from the Hydrological Branch are the only data available for the study of this watershed. They have gaps that despite being filled affect the quality of the results. The Loboville station was opened in 1988, hence the short chronicle available for the station at the outlet of Loboville.

B. Results of the WEAP_LOBO model

The level of accuracy of the results obtained with WEAP over the Lobo River basin is similar to those of[18]. The calibration and validation of the WEAP model achieved a Nash Index (NSE) of 97.82% and 65.10% at Nibehibe and Loboville respectively. This is relatively close, to those obtained by[18], which are respectively invalidation 73.3 % at Nibehibe and 62.10% at Loboville. However, the infiltrated and runoff volumes are different even in absolute values. Indeed, the WEAP calibration parameters are more numerous than those of GR2M and each parameter has a non-linear action on the surface runoff, base runoff, infiltration, and all the other parameters of the water balance in WEAP. These parameters are generally derived from the literature rather than from physical terrain parameters[3].

In addition, while the modelsimulates almost perfectly the flows of the North Lobo at Nibehibe, with an NSE index of 97.82%, it reproduces with difficulty the extreme values at the South Lobo. The values are still respectively very good and satisfactory at the monthly time step according to the studies of[10] on hydrological models. in addition, these extreme values are produced in the same frequency but with a smaller amplitude.

The assessment of the groundwater resource is subject to many simplifications given the lack of data in general on this type of resource. The ref[6]in his method assimilates a fissure aquifer to an alluvial aquifer, that is to say generalized, even if it is at the local scale; this leads in our case to an overestimation of the groundwater resource, although the encounter of large fissures could produce very important water arrivals. in any case, this approach only gives us an index of the water potential of the basin. The major uncertainty lies in the accuracy and quality of the borehole data. Is the borehole flow rate constant? Is the depth of drilling accurate? Field observations have revealed that some pumps fail due to groundwater depletion.

The assessment of water demand is also hampered by the acquisition of water withdrawal data. Although the consumption of drinking water produced by SODECI exists, it is very difficult to access. Thus, while water demand in urban areas may be well assessed, this is not the case in rural areas where the withdrawal of the resource is not always known. in this case, the WHO water consumption data are the reference.

In addition to the physical unavailability of water, the deterioration of water pipes and water treatment plants,recurrent pump breakdowns, and the pollution of waterways all contribute to the depletion of water resources.

VI. CONCLUSION AND RECOMMENDATIONS

The Lobo River is a watershed of capital importance because it contains the second-largest economic region in Côte d'Ivoire. This research with the WEAP model, widely used by planning experts, showed that this basin has a potential surface water of 369 MCM/yr at the Nibehibe station and 1,440 MCM/yr at the Loboville station, as a multiannual mean. Groundwater is estimated at 1.9 BCM/yr and 2.8 BCM/yr for the North Lobo and South Lobo respectively. The water requirements of the basin are estimated at 39.5 MCM/yr, 46.15 MCM/yr, and 92.10 MCM/yr for the BSc, RDPS, and HPGS scenarios. Despite the relative abundance of the resource, many demand sites are subject to water shortages. To address this, the following suggestions are necessary: the establishment, monitoring, and management of a public database on water resources, production, and consumption in both rural and urban areas; Mapping of the exact geometry of groundwater aquifers in Côte d'Ivoire; the implementation of prospective research on water resources and potential demand for the whole territory for better planning; the update and effective implementation of IWRM in Côte d'Ivoire as recommended by JICA. With regard specifically to the Lobo basin, the Daloa water treatment plants are at their maximum capacity, but they do not meet the demand, so it will be necessary to rehabilitate these plants, increase their pumping capacity and install other pumping stations. With the resource dwindling due to the galloping population, decision-makers are considering inter-basin water transfers to mitigate unmet demand.

The water from the Zoukougbeu station is abandoned by the population because of its organoleptic quality, which is not appreciated by the population. They resort to other sources of water to satisfy their water demands. in this case, it is necessary to raise the awareness of the population and to treat the resource appropriately, taking into account the financial resources available.

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