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Modelling Future Water Demand With WEAP Model: The Case Study of Marahoué Basin in Côte d'Ivoire

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ABSTRACT
The Marahoué basin in west-central Côte d'Ivoire is a transitional zone between the Sudanese climate and the attenuated equatorial one. This duality favors agricultural and pastoral activities in relation to a population growth requiring a high water demand. Faced to this problematic, we proposed to experiment the WEAP (Water Evaluation And Planning system) model on the Marahoué basin. The objective of this study is, modelling water demand on the horizon 2040. To achieve this, several types of data were injected into the WEAP21 in this case: precipitation, runoff, groundwater, growing, breeding, industrial and demographic data. They were compiled to estimate the five-year water demands for 2010 to 2040. Base on the priorities assigned to each request, growing and breeding needs are the most important with 25.2 million cubic meters due to a high growth rate of livestock. This sector is followed by the demand for urban and rural populations' water supply, estimated at 39.5 million cubic meters in a growth scenario. Industrial demand is low because of the weak development of this sector in the basin. It remains constant with a need of 1.4 million cubic meters. According to the forecast results of the model, all trends in the different sectors will exceed their double by 2040.

***Keywords* :** WEAP, Modelling water demand, Marahoué basin, Côte d'Ivoire

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I. INTRODUCTION

West Africa has suffered a particularly severe drought over the last forty years. Calculated in relation to the 1950-1970 period, the rainfall deficit during the period 1970-1990 was about 30% in the Sahel (Senegal, Mali, Burkina Faso and Niger) and slightly less pronounced for the countries bordering the Gulf of Guinea [1]; [2]; [3]. However, the current trend of this drought is moderate especially in the oldest countries marked as Niger and Burkina Faso [4]. This decrease in precipitation has resulted in a significant decrease in flows in major rivers. Indeed, the Senegal River lost 60% of its runoff for a 30% rainfall deficit while the Ouémé in Benin lost 40% of its flow for a rainfall deficit of 15 to 20% [5]. Côte d'Ivoire, like these countries, suffered this drop in rainfall at the end of the 1960s [6]. Thus, the variability of the climate between 1954 and 2008 was characterized by a major rupture of the rainfall at the end of the 1960s. Indeed, during the great drought of 1983, the rainfall deficits caused the drying of the traditional wells and natural reservoirs [7]. The Marahoué basin in west-central Côte d'Ivoire is a transitional zone between the Sudanese climate and the attenuated equatorial climate. This duality favors both agricultural and pastoral activities in relation to a population growth requiring a high demand for water. Unfortunately, most anthropogenic activities depend on surface waters that are dependent on rainfall, subject to the climatic variability mentioned above. In addition, the only source of rural water supply remains groundwater, the accessibility of which is hampered by granitic subsoil [8]. Faced with this issue whose stake is part of the SDG (Sustainable Development Goal), we proposed to test the WEAP model (Water Evaluation and Planning System) to reach a resource management plan in a context of high climatic variability and population growth. To do this, this article aims to assess the future water demand of the basin for domestic, industrial and agro-pastoral needs by 2040.

II. PRESENTATION OF THE STUDY AREA

The Marahoué basin is located in west-central Côte d'Ivoire between longitudes 5 ° 30 'and 7 ° 00' W and latitudes 6 ° 45 'and 9 ° 28' N. It drains an area of 24 300 km^2 (Fig. 1).

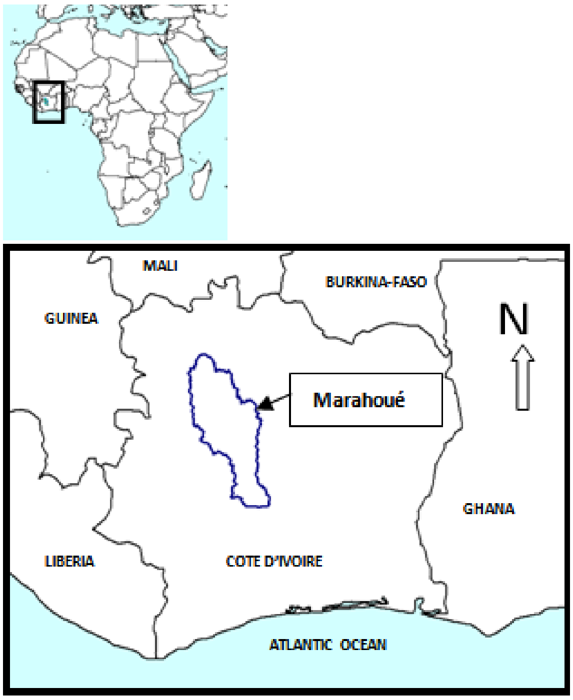

Figure 1: Geographic situation of Marahoué basin

This basin is influenced by two rainfall regimes. The equatorial transitional regime in the southern is characterized by four seasons, two rainy seasons (April-June and September-October) and two dry seasons. The tropical transition regime (Sudanese) in the North is characterized by two seasons including a wet (July-October). The hydrological regime is closely related to rainfall. Indeed, the period of low waters is observed from January to April. During this period, the flow is supported by alluvial layers. The geological formations belong mainly to the Precambrian basement. Through the work of [9] and [10], two types of aquifers are observed in the basin. Superficial aquifers of alterites are the first level of groundwater reservoirs. They constitute large reservoirs directly fed by precipitation infiltration, so that the groundwater level is significantly lower in the dry season and rises in the rainy season. The drop in water level is due to drainage of groundwater in rivers, but also to domestic use. The water supply in these reservoirs depends on the permeability and the thickness of the alterations. The deep aquifers underlying the superficial ones are immune to seasonal fluctuations and most of the different types of pollution [11].

The population of the Marahoué basin is estimated at about 7 million people in 2010 according to the general census of population and housing (RGPH) in 1998. Agriculture mainly rainfed, is the first income generating activity. Subsistence crops occupy 178 033 ha or 45% of the cultivated area, and make more and more place for cash crops (220 156 ha) even if they engage the largest mass of rural populations [12]. In this basin, the main irrigated crop is rice. It is essentially traditional at low level of input and extensive [13]. Two types of rice growing are practiced on this basin. Irrigated rice cultivation is generally practiced on summarily landscaped floodplains. The control of the water is partial in general with the installation of drains allowing the catch in the course of the water for a fair distribution of this one between the parcels of the operators or by the installation of dam. The industrial fabric is very little developed in this region. However, some agribusiness units that are very greedy for water such as SUCRIVOIRE in Zuénoula and SOLIBRA in Bouaflé contribute to the development of this region.

III. DATA AND METHODS

III. 3.1 DATA

III. 3.1.1 Rainfall and runoff data

The climatic data used come from Airports, Aviation and Meteorology Company (SODEXAM) database. These are precipitation, evapotranspiration and temperature data collected through precipitation stations in the basin and nearby synoptic stations. The runoff data were obtained from the hydrometrical stations of the national management of human hydraulic direction (DHH) (Fig. 2).

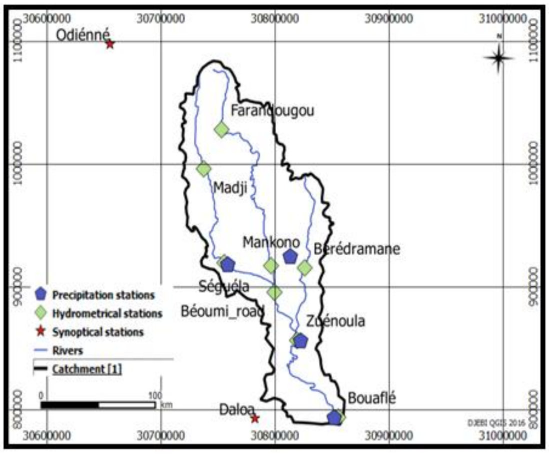

Figure 2: Presentation of precipitation and hydrometrical data measurement network

III.3.1.2 Groundwater data

Data on groundwater exploitation rates were obtained from DTH (Territorial Direction of Hydraulics) and SODECI (Water Supply Company in Côte d'Ivoire). These values are the annual production of drinking water in large urban centers (Table 1). In Côte d'Ivoire, the annual rural unit of water demand is estimated at 5.475 m3 / inhabitant [14].

Locality	Boua-flé	Zuénoula	Ségué-la	Manko-no	Bénou-fla
Dischar-ge (m^3/s)	3.7	1.9	1.9	3.7	2.0
Locality	Bén-oufla	Boundiali	Kani	Madina-ni	Bédia-la
Dischar-ge (m^3/s)	2.0	1.2	2.9	2.2	1.8

Table 1: Groundwater operating average discharge values by locality en 2010

III.3.1.3 Demographic data

The basin population estimates for 2010 are based on the 1998 General Population and Housing Census (RGPH) rate. Population data are presented by localities (Table 2).

Table 2: Populations and annual croissance rates by locality

Locality	Population in 1998	Croissance rates for 2010 (%)
Bouaflé	234326	2.98
Zuénoula	146012	2.98
Mankono	136095	1.20
Séguéla	113518	1.20
Kani	49485	1.20
Madinani	8726	2.50
TOTAL	688162	Average 2.01

III.3.1.4 Growing data

These data were obtained from the National Office for Rice Development (ONDR). Its agricultural sites are generally cultivated with partial or total control of water over small areas (1 to 2 hectares). Table 3 shows the irrigated areas of exploitation for each locality. The water requirements of rice cultivation are presented in the agrarian calendar of Table 3.

Table 3: Irrigated rice areas in the basin

Locality	Irrigated area (ha)
Bouaflé	45
Zuénoula	465
Bénoufla	50
Bédiala	105
Séguéla	206
Total	871

III.3.1.5 Breeding data

The livestock is: cattle, sheep, goats, pigs and poultry. According to [15], water unit requirements for each type of livestock, are: 30 l / head / day for cattle, 5 l / head / day for sheep and goats; 7.25 l / head / day for pigs and 0.1 l / head / day for poultry.

III.3.1.6 Industrial data

These are monthly pumping discharge from Marahoué River by the factory of lemonade and bracerie in Africa (SOLIBRA) and the yearly pumping volume collected by SUCRIVOIRE's factory from its own dam for irrigating sugarcane plantations. The yearly pumping discharge is about 102 m3/h.

IV. METHODS

According to [16], WEAP uses the principle of equilibrium of water resources (rivers, reservoirs and groundwater) with the requirements of the user. Thus, the user specifies the allocation rules in the allocation of priorities and supply preferences for each type of request, taking into account other constraints (maximum operating speeds, network load loss, and balance of the resource). These are mutable in time and space. The model uses an optimization algorithm based on priorities and the concept of equity in water allocation groups in the event of a shortage. Scenarios can cover issues such as: population growth; evolutionary economic development model; increased ecosystem needs; change in irrigation and cultivation techniques [17].

III.3.2.1 Creating project

The project is created by importing first in the schematic view of the model, the outline of the basin and river system in ArcView Shape files format. Then, demand sites, reservoirs, groundwater, basin and transmission links and back are scanned (Fig. 3). The project includes the following items:

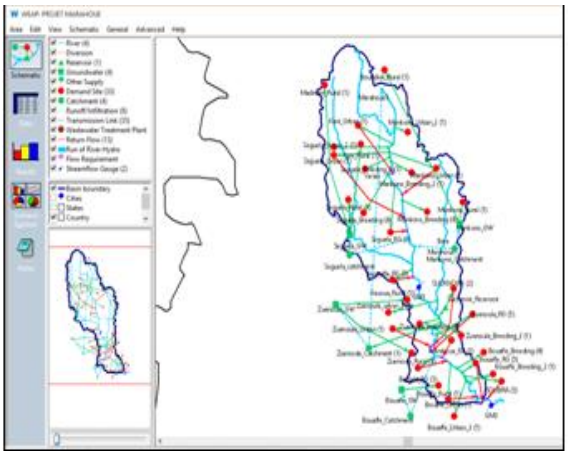

Figure 3: Marahoué managment project in WEAP area

III.3.2.2 Setting model general parameters

III.3.2.2.1 Setting time

The development of the current account allows the calibration of the model. The basic year for this study is 2010, with an annual time.

III.3.2.2.2 Creating hypotheses and scenarios

In this study, the Marahoué basin has only one dam, SUCRIVOIRE's. All groundwater data are affected to groundwater operating discharge. The rivers of the basin are reduced to Bouaflé streamflow Gauge (GM2), located at the outlet of the basin. The water demand modeling is based on the distribution of priorities whose allocation is oriented in Table 4.

The scenarios are based on data in Tables 1-3. Future trends are projected following two scenarios consist of a reference scenario (RS) and a croissance scenario (CS). The RS is based on historical data prior to 2010. In the CS, croissance rates are based on forecasts of the Plan for integrated water resources management of Côte d'Ivoire directed by JICA (2001) and other structures such as the WFP

- Demand sites (33): urban and rural localities, rural growing sites (RG), breeding sites and industries;
- Rivers (4) whose flow is simulated by the WEAP model;
- Catchment (4) which entered the climatic data (rainfall, ETP, temperature), the area and the coefficient of Culture;
- Reservoir (1);
- Transmission links (35) for the transit of water sources;
- Return flow (13) for sites whose water consumption is not full and a part returns to rivers;
- Streamflow gauging (2) allowing the historical flows observed in the model. This allows a comparison with the simulated discharges.

(World Food Program), INS (national statistics Institute), ONDR (National rice office).

Table 4: Water distribution priorities

Demand sites	Priorities
Urban (drinking water)	1
Rural (drinking water)	1
Industrial (irrigating sugarcane)	2
Growing (irrigating rice)	3
Industrial (operating water)	3
Breeding (livestock)	4

III.3.2.2.3 Calculating water demand

Water demand per branch (Db) expressed in cubic meter, is calculated by the formula

$$Db = L \times R \quad \text{(Eq.1)}$$

With: L= branch activity level,
R = Ratio of water use.

The branch activity level (L) corresponds to: the area expressed in m^2, ha, km^2 or percentage of agricultural land; specific proportions of populations (human or livestock). The ratio of water use (R) is the water use rate for application site.

Water demand per site (Ds) is expressed as:

$$Ds = \sum Db \quad \text{(Eq.2)}$$

Global water demand (Dg) of the project is given by:

$$Dg = \sum Ds \quad \text{(Eq.3)}$$

All these formulas are in use in the WEAP21 model.

V. RESULTS

IV.4.1 Urban demand

The modeling results show that the urban water demand estimated at 200 000 m3 in 2010 will tend to double by 2040 for the cities: Zuénoula and Mankono in the Reference Scenario. The needs of cities Bouaflé, Séguéla, more populated, initially approximately 600 000 m3 will be quadrupled. This trend in the Reference Scenario (RS) appears to follow a linear increasing (Fig. 4A). In Croissance

Scenario (CS), the same trend observed earlier, switches to exponential evolution after a break observed in 2019. Thus, the demand estimated at about 4 million m3 for the cities of Mankono, Séguéla and Zuénoula and 8 million m3 for the city of Bouaflé, change from single to quadruple (Fig. 4B). Under these conditions, the trend of urban water demand generally remains the same for both scenarios despite different rates over the period 2010-2040.

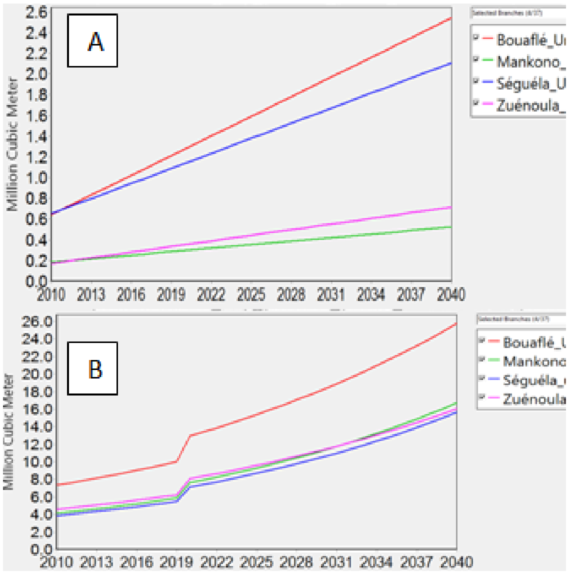

Figure 4: Urban water demand models for reference (A) and croissance (B) scenarios

IV.4.2 Rural demand

In rural areas the trend is almost the same for both scenarios. Indeed, the demand varies between 400 000 m^3 and 800 000 m^3 for all villages except the villages of Kani and Madinani whose needs, like their populations are very low. This application will undergo a sharp increase in 2019 which will pass from simple to triple by 2040 (Fig. 5).

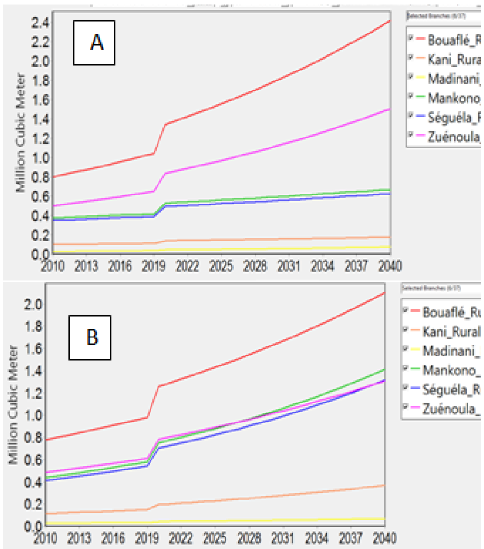

Figure 5: Rural water demand models for reference (A) and croissance (B) scenarios

IV.4.3 Growing demand

The growing water demand follows an exponential trend in 2040 like the two previous applications (Fig. 6).

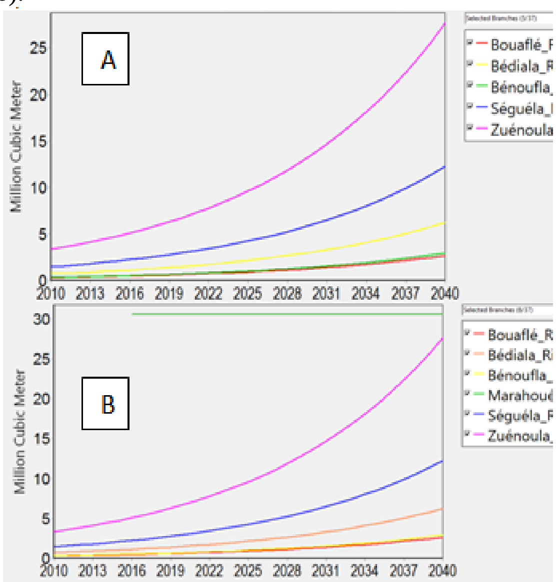

Figure 6: Rice growing water demand models for reference (A) and croissance (B) scenarios

It is more accentuated in Bouaflé, considered as a strong rice growing area. Indeed, demand for Zuénoula estimated less than 500 000 m^3 in 2010, is likely to exceed five times in 2040.

IV.4.4 Breeding demand

Pastoral request follows a linear trend in Reference Scenario with values around 500 000 m^3 in 2010 and three million m^3 in 2040. In Croissance scenario, an exponential trend is well marked for applications in

Séguéla and Mankono with values around 800 000 m^3 in 2010, will be tripled by 2040 (Fig. 7).

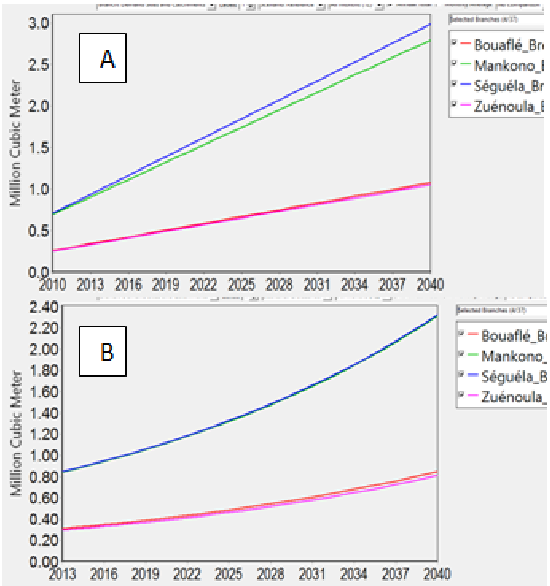

Figure 7: Breeding water demand models for reference (A) and croissance (B) scenarios

IV.4.5 Industrial demand

In this sector, the industrial water requirement is calibrated and the needs for operating are identical year by year. Thus, SOLIBRA and SURIVOIRE factories water demand estimated respectively at about 700 000 m^3 and 800 000 m^3 in 2010, will be constant until 2040 (Fig.8).

IV.4.6 Global water demand in Marahoué basin

The compilation of all data provides the overall water demand of Marahoué basin whose five-year results are presented in Table 5. The growing and breeding needs are most important from 2015. This is related to the national agricultural investment plan (PNIA) that envisages promoting the rice sector irrigation which requires lots of water. However, industrial demand remains the lowest due to the low industrialization of the basin (only two agribusinesses whose needs are limited to 1.4 million cubic meters). During the five-year period 2015-2020, the total needs estimated at 42.6 million cubic meters in 2015, will be doubled before slowing in 2040 according to croissance scenario.

Figure 8: Industrial water demand models for reference (A) and croissance (B) scenarios

Table 5: Five-year water demand for 2010 to 2040 (x 10^6 m^3)

Type of Demand	Scénario	2010	2015	2020	2025	2030	2035	2040
Urban and rural	R	3.8	4.7	6.4	7.5	8.7	10.0	11.3
	C	22.1	26.4	39.5	47.2	56.4	67.5	80.7
Growing and Breeding	R	8.6	12.3	17.4	23.8	32.6	44.6	61.2
	C	8.6	14.8	50.8	57.9	67.4	80.2	97.8
Industrial	R				1.4			
	C							
TOTAL	R	13.8	18.4	25.2	32.7	42.7	56.0	73.9
	C	32.1	42.6	91.7	106.5	125.3	149.1	179.9

R = Reference, C = Croissance

VI. DISCUSSION

Modeling water demand by 2040 has shown that the overall needs of the Marahoué basin will increase regardless of the scenarios. In 2020, they are estimated at 25.2 million cubic meters and 91.7 million cubic meters respectively in the reference and growth scenarios. These values will tend to exceed their double, 20 years later. This could raise the problem of water supply, especially in a context of rapid population growth and climate variability [17]. [18] also showed in a similar study in the Olifant Basin (South Africa) that, taking into account the different needs of users (rural, urban, mining, agricultural, forestry, industrial and electrical), this would exacerbate the complexity management of water resources. This same observation is made by [19] on the management of water resources in the Morondava basin.

VII. CONCLUSION

The model WEAP, although its intensive data, appears very suitable for assessing the demand for water uses. Thus, it allowed us to estimate until 2040, five-year needs of Marahoué basin by application sector. According to the order of priority assigned to each type of request, the agricultural sector ranks first with 25.2 million cubic meters and 91.7 million cubic meters in 2020, respectively in reference scenario and croissance scenario (very likely because of the agricultural activities increasing due to population croissance rates in the basin). This sector is followed by the urban and rural water demand estimated at 39.5 million cubic meter according to croissance scenario. Industrial demand is low due to the underdevelopment of this sector in the basin. It is kept constant in both scenarios with a value of 1.4 million cubic meters. All trends are likely to more than double in 2040.
Already, these results can be used as indicators for decision making. However, the implementation of water resources management plan for Marahoué basin is necessary in a context of high climate variability.

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