Assessment of freshwater scarcity using a model based on supply and demand law

B. Escribano

Càtedra UNESCO de Sostenibilitat, Universitat Politècnica de Catalunya, c. Colom 1, E-08222 Terrassa (Spain).

J. Sellarès

Dept. de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya, c. Colom 1, E-08222 Terrassa (Spain).

J. Xercavins

Escola Universitària d'Enginyeria Tècnica Industrial de Barcelona, Universitat Politècnica de Catalunya, c. Comte d'Urgell 187, E-08036 Barcelona (Spain).

Abstract

The main goal of this work is to provide an analysis methodology for assessment of water scarcity problems based on supply and demand. To this end, we must first determine what can be considered as supply and demand in the water scarcity problem. Although some variables involved are physical, economical or demographical, in our approach social factors are also included. This leads us to objectify water demand standards in relation to acceptable welfare levels. Within this approach, water scarcity will appear when demand reaches a higher value than supply. Two supply levels are defined based on other works. Demand is calculated within several scenarios. These scenarios represent the outcome of political or management decisions taken to reach a welfare standard. A special scenario will represent, simply, the continuation of the current state of affairs. The variables needed to calculate demand are obtained through a multilevel model where the lowest level is formed by disciplinary models and the highest level takes into account social and political factors. The methodology is applied to the countries of the gulf of Guinea. Its application to Côte d'Ivoire is described in detail and results are given for the other eight countries of the area. To summarize the results, two indexes are suggested. With this methodology, it is possible to divide the region of the gulf of Guinea in three areas of different freshwater capacity, giving new insight with regards previous studies that did not state differences between the countries of the region.

1. Introduction

Freshwater is a renewable resource that is not scarce at a global scale in spite of being limited [*Rijsberman*, 2006] but water availability varies by country and region and, therefore, situations can be very different [*Graffy*, 2006]. Anyway, many people suffer from freshwater scarcity due to physical availability and, especially, economic reasons [*IWMI*, 2007; *Barbier*, 2004; *Biwas*, 2005]. Demographic growth, pollution and poor management are among the causes that contribute to freshwater scarcity [*UNDP*, 2006].

At present, the prospects on freshwater scarcity are not promising. UNO is on the way to fall short on its goal to reduce in a half the people without access to drinking water or basic sanitation services in the period from 1990 to 2015 [*UNO*, 2011]. Nevertheless, there has never been so much information and tools to address this issue. For this reason it is of the greatest importance to find methods to assess water scarcity and to predict its appearance, as a first step to find a solution to the

problem itself and adopt the most appropriate decisions under the sustainability framework.

Generally, scarcity problems can be stated in terms of non-equilibrium function between supply (availability) and demand [UNDP, 2006; *Feitelson and Chenoweth, 2002*; *Bernholz,* 2005]. This principle states that there is an equilibrium price-quantity point where consumers will buy all the produced goods and the producers will make all the demanded goods. Strictly speaking this is a microeconomic principle but it has found its way in macroeconomic theory and beyond. Although it is considered more a conceptual tool than an accurate law it is useful when supply is independent from demand and there is a constraint on supply.

Therefore, it can be assumed that water scarcity appears when demand grows beyond the equilibrium price-quantity point. It is needless to say that the critical point of this approach is to identify the quantities that assume the role of supply and demand and to make sure that they comply with the assumptions necessary for the validity of the supply and demand law.

In this work we will argue that supply is related with the magnitude of renewable freshwater resources while the quantity that represents demand better is freshwater withdrawal [*Shiklomanov*, 1999; *Fraiture et al*., 2003]. In fact, supply will also be related to the acceptable environmental impact so it will be taken into account that, for environmental reasons, not all of the renewable freshwater resources will be exploitable. On its turn, the demand (water withdrawal) will be accounted by sectors [*FAO*, 2011]. Anyway, defined in this way, supply and demand comply with the aforementioned validity assumptions of the supply and demand law.

Since there is a lack of data [*Biswas,* 2005], either actual data or calculated data, we will use a multilevel model [*Xercavins*, 1999] to obtain some of the data needed to assess supply and demand for a given country in the foreseeable future. This means that in our case the lower level models are represented by disciplinary models (renewable water resources, water withdrawal, population, gross domestic product, …). The medium level is identified with aggregation of disciplinary models. The highest level works the politic options that consists on application of the goal standards of freshwater dynamic demand in the future scenario.

The highest level will adopt the goal seeking paradigm. This is, we will suppose that the system does not evolve in a deterministic way but, rather, tends to fulfill a goal. Each goal will be studied within a scenario [*Xercavins*, 1999]. Of course, there is always the possibility that nothing is done to modify the present evolution of the system. We will call this scenario "business as usual" (BaU). It will be important, aside from its likeliness, because it will be a reference to compare with other scenarios.

More accordingly to the goal seeking paradigm, we will also suppose that the system evolves towards attaining similar water withdrawal per capita than developed countries, either by political decisions or demand management. Therefore, we will define welfare standards inspired by the current water demand at developed countries [*FAO*, 2011]. The system will tend to attain these welfare standards in a plausible, but arbitrarily given, period of time.

It should be stressed that the method that has been developed is dynamic because it is based on the evolution of the country.

The assessment of water scarcity for each scenario depends mainly on the time remaining to reach the equilibrium price-quantity point and the surplus relative to the supply levels. To summarize these results an index will be suggested.

Once we have settled the methodology, we will apply it to a case study of the countries of the gulf of Guinea [*FAO*, 2005]. Our results reveal differences between countries that do not appear in other studies and that are likely according to geographical and economical data available [*IWMI*, 2007].

2. Methodology

2.1. Supply and demand

As mentioned earlier, we will take as supply the freshwater resources that are potentially available for withdrawal.

We have reviewed several criteria among scientists about the limit in freshwater withdrawal that take into account the renovation tax. From these criteria we have deduced two different supply levels. One criterion follows from the definition of exploitable water according to FAO-AQUASTAT [*FAO*, 2011] and the concepts from IWMI [*IWMI*, 2007]. The other criterion is inspired by several works [*Szöllösi-Nagy et al*., 1998; *Engelman and LeRoy.,* 1993; *Postel*, 2000] that postulate a more environmental exigent approach.

Since the first criterion leads to a greater withdrawal than the second, we will name the supply deduced from these criteria high level supply (*HLS*) and low level supply (*LLS*), respectively.

HLS turns out to be 60% of total renewable freshwater resources (R_T). In fact 60% is an average value of all the values that appear in FAO-AQUASTAT data. This average value turns out to be the same as employed by IWMI.

Overlap *(OL)* between surface (*SW*) and underground water (*GW*) should be taken into account. All in all, the formulae that have been employed are [*FAO*, 2011]:

$$R_T = SW + GW - OL \quad (1)$$

$$HLS = 0.6 \, R_T \quad (2)$$

Instead, we will take LLS as 40% of superficial freshwater resources plus 30% of underground water resources.

$$LLS = 0.4 \, SW + 0.3 \, GW - 0.35 \, OL \quad (3)$$

We will not consider the time evolution of these values since there are not reliable statistics about change of total renewable freshwater resources FAO-AQUASTAT uses to give constant values through time. Nevertheless, its values are likely to change on the long run due to climate change, albeit in a hardly predictable way [*IPCC*, 2007; *Meigh et al.*, 1999].

On its turn we will consider that demand is, simply, freshwater withdrawal. Strictly speaking, demand would be the freshwater required for satisfying all the socio-economical needs of human activities along a given period of time [*Wolfe and Brooks*, 2003]. Practically, this results in the withdrawal of a certain quantity of freshwater.

If we had reliable statistics of water withdrawal the determination of this variable would be really easy. Unfortunately this is not always the case. Moreover, unlike supply, demand is a truly dynamic variable and therefore we will need a model to extend the few values typically available.

It follows from the previous lines that the main modeling effort will be dedicated to obtain a useful description of demand and, to less extent, of consumption, that is an interesting variable related to demand. Consumption will be the part of extracted water that does not return immediately to the water sources. It is the water evaporated, becomes contaminated or incorporated into final products or crops [*Kholi et al*, 2010].

While the same definition of supply is used in all the scenarios, demand is calculated differently according to the scenario, or even within the same scenario, as we will explain in detail in the next sections.

2.2 Modeling of default scenario

The default scenario, "business as usual" (BaU), will consist in an analysis of current trends as if no political decisions are taken. Therefore, the outcome depends only on past values of relevant variables.

From a practical point of view, we should begin with historical demand data. If there are not enough records of water withdrawal, a medium level model can be employed to extend the few withdrawal data points available using other variables. This medium level model consists in the aggregation of models for water withdrawal (W) for activity sectors: agricultural (W_A), municipal (W_M) and industrial (W_I). Each one of these models will depend on variables such as population (P), irrigated surface (S_I), gross domestic product (GDP) and industrial GDP (GDP_I). These variables are much more easily available in databases than freshwater withdrawal.

So, the model begins with demand (D) being equal to water withdrawal [*FAO*, 2011]

$$D = W = W_A + W_M + W_I \quad (4)$$

For many countries, especially in the developing countries, data about withdrawal is so scarce that it may be limited to a single year. This is the case for some countries discussed in the next section. For agriculture withdrawal we will suppose that it is proportional to the surface of irrigated land because there are more data for this magnitude [*FAO, 2006*].

$$W_A(t) = S_I(t)\, W_A(t_0) / S_I(t_0) \quad (5)$$

We make a similar supposition for municipal withdrawal, but assuming proportionality to population. Population data is obtained from UNPD [*UNPD*, 2010].

$$W_M(t) = P(t)\, W_M(t_0) / P(t_0) \quad (6)$$

Finally, industrial withdrawal is assumed to be proportional to the industrial GDP.

$$W_I(t) = GPD_I(t)\, W_I(t_0) / GPD_I(t_0) \quad (7)$$

Once freshwater withdrawal data points are obtained, from this model or from databases, they are fitted. For past time values, the fit will give a smoother representation of historical records. In the case of future time values, the fit will represent the expected evolution of demand.

The BaU scenario is appealing if only because of the difficulty to change the behavior of demand, that makes it realistic. Moreover, it will be a useful reference to compare with other scenarios.

On the other hand, consumption is not really needed for the calculations but since it has some interest in itself it can be calculated simply using the withdrawal/consumption ratios given by Shiklomanov [*Shiklomanov*, 1999].

2.3. Modeling of goal seeking scenarios

Once we have set up the default scenario, we move on to the highest level of the multilevel model. Instead of assuming deterministic evolution, this level assumes that political or management options are adopted in order to reach a certain goal. The goal is defined by freshwater demand standards and the period within the system evolves to reach it.

We will take the freshwater demand standards from the present-day demand per capita of developed countries. The analysis of typical data from freshwater withdrawal in developed countries shows that presently it is fairly stable, so it is safe to suppose that this quantity represents the freshwater needed to satisfy a welfare that goes beyond mere subsistence, which is rated currently as 50 liters for person and day [*Howard,* 2003].

Even though demand per capita will be modeled within this highest level, population will continue to be obtained in the same way as before.

Of course, there are differences between demand among developed countries so two different scenarios are considered. In the EURO scenario the goal of the system is to reach the present-day freshwater withdrawal per capita of the European countries which is 560 m^3 for person and year [*FAO*, 2011; *UNPD*, 2010]. Instead, in the USACAN scenario the goal is to reach 1660 m^3 for person and year [*FAO*, 2011; *UNPD*, 2010], which is the present-day freshwater withdrawal per capita of United States and Canada. These withdrawal values will be referred as the EURO and the USACAN welfare standards.

To fully determine the scenario we also need to consider the period within the system reaches the welfare standards. At this point we have no other option than to make a reasonable guess of this length of time so we will consider that the period begins in 2010 and the goal is reached in 2050.

Therefore the goal seeking scenarios will be identical to BaU until 2010. From 2010, the freshwater withdrawal will rise exponentially, to reach the goal at 2050. We consider exponential rise as a likely path. The goal is calculated multiplying the standard per capita by the estimated population at 2050. From this time on, the freshwater withdrawal per capita will remain constant and, therefore, freshwater withdrawal will be just proportional to population.

2.4. Water capacity index

To assess the capacity of a country to satisfy a freshwater welfare standard we will consider the water withdrawal within the EURO standard (D_{EURO}) at year 2050 [*UNPD*, 2010]. In fact, this can be calculated according to

$$D_{EURO}(2050) = 560\, P(2050) \quad (8)$$

so if needed it can be calculated only with the estimated population for 2050. We can define the exhaustion of the supply levels as

$$LLE = 100\, D_{EURO}(2050) \,/\, LLS \quad (9)$$

$$HLE = 100\, D_{EURO}(2050) \,/\, HLS \quad (10)$$

where *LLE* stands for low level exhaustion and *HLE* stands for high level exhaustion.

We will distinguish between the following outcomes:

$$LLE < 100 \text{ (High capacity)} \quad (11)$$

$$HLE < 100 < LLE \text{ (Low capacity)} \quad (12)$$

$$100 < HLE \text{ (Null capacity)} \quad (13)$$

While only three possible values may seem too few to give a useful assessment, we will see that they are enough to give new insight in the current views on water scarcity.

We will call this index WCEI (Water capacity EURO-scenario index). We can define another index based on the USACAN scenario in a completely analogous way, substituting 560 m^3 for person and year by 1660 m^3 for person and year. We can call this index WCUI (Water capacity USACAN-scenario index).

3. Case study: the countries of the gulf of Guinea

In order to show the potentiality of this method, we will apply it to the countries of the gulf of Guinea. In some countries currently there is only one available demand data so the other points are calculated from equations 5, 6 and 7. In other countries there are enough demand data to make fits. This is the case for Côte d'Ivoire, that is the calculation that we will develop in this section. Results

for the other countries will be given and discussed.

HLS and *LLS* are calculated according to equations 1, 2 and 3, using the following values

$$SW = 78.3 \text{ km}^3/\text{y} \quad (14)$$

$$GW = 37.8 \text{ km}^3/\text{y} \quad (15)$$

$$OL = 35 \text{ km}^3/\text{y} \quad (16)$$

Demand data for Côte d'Ivoire is presented in table 1. Following equation 4, we identify the sum of these withdrawals as the demand.

In the BaU scenario the demand values are fitted through an exponential regression. The obtained regression formula for Côte d'Ivoire is

$$\ln(D) = 0.04195\, t - 83.53335 \quad (17)$$

The units of demand and time are km^3/y and y, respectively, in this regression formula and also in the following ones. This regression line is represented at Figure 1. Calculations show that this regression line intersects LLS and HLS well beyond year 2100.

The EURO scenario is also represented in Figure 1. Until 2010 the demand has the same values as in the BaU model. At 2010 it reaches a value of 2.20 km^3/y. From this year until 2050 the demand is given by

$$\ln(D) = 0.05844\, t - 116.66718 \quad (18)$$

Since none of the two supply levels is attained by EURO demand at 2050, the case of Côte d'Ivoire qualifies as "high capacity" according to the WCEI.

The USACAN scenario is also represented in figure 1. It is calculated in the same way as the EURO scenario but taking 1660 m^3 for person and year as a goal instead of 560 m^3 for person and year. The demand between 2010 and 2050 is given by

$$\ln(D) = 0.0856\, t - 171.26586 \quad (19)$$

In this case, LLS meets demand at 2041, even before the goal is reached. HLS meets demand shortly after reaching the goal, at 2046, so according to the WCUI Côte d'Ivoire is identified with "null capacity".

As a comparison, we introduce in figures 2 and 3 two cases with a lower and a higher stress, respectively. Figure 2 presents the results for Guinea where no water scarcity problems at all are in sight. Instead, figure 3 presents the results for Nigeria. In this country USACAN demand meets LLS at 2031 and HLS at 2035 while EURO demand meets LLS at 2038 and HLS at 2044. Using either scenario, serious water scarcity problems are foreseeable.

The Côte d'Ivoire outcome of the goal seeking scenarios for long periods of time is represented in figure 4. From 2050 onwards we use for the EURO scenario

$$D(t) = 560\, P(t) \quad (20)$$

Analogously, for the USACAN scenario

$$D(t) = 1660\, P(t) \quad (21)$$

The results of these equations for 2050 and 2100 are given in table 2, together with the population values employed.

For Côte d'Ivoire, in the EURO scenario, *LLS* meets demand at 2093 and *HLS* meets demand well beyond 2100. Anyway, the goal of 560 m^3/y per person is reached before any kind of water scarcity appears.

In other countries, the calculation of demand can be difficult because of the lack of data. To illustrate the procedure that we have followed in these cases, we outline in table 3 the calculation of demand for Nigeria. Equations 4, 5, 6 and 7 are used to extend the only withdrawal data point available.

The results for LLS and HLS for the countries of the gulf of Guinea are given in table 4. They are calculated in the same way as in the case of Côte d'Ivoire.

The exhaustion of the supply levels for the countries of the gulf of Guinea in the year 2050 is given in table 5. They are calculated from equations 20 and 21 and the data of table 4.

The data of table 5 gives rise to the index values presented in table 6 that are also represented graphically in figure 5. In spite of the simplicity of the method, the WCEI is able to distinguish between countries that are considered more or less equivalent in previous studies of water scarcity [*IWMI*, 2007]. The WCUI gives more uniform results. This indicates that the EURO scenario is more helpful to distinguish between different situations than the USACAN scenario.

4. Conclusions

The methodology that has been presented in this work is able to assess dynamically freshwater scarcity according to two supply levels and the dynamic demand.

From a practical point of view, the methodology is simple enough so it can be adapted to different available data and the calculations can be performed quickly. Since we have conceived this methodology as an assessment and decision support tool, it can be useful to anybody who works in water scarcity problems in the framework of human sustainable development. It can be particularly helpful to issue early warnings about the lack of capacity of a country to fulfill its freshwater needs in the future.

Since most of our interest is in developing countries, especially those with severe shortages, we have tried to make our methodology as simple and robust as possible. In this sense, it can be applied in cases where not much data is available, such as usually happens with most developing countries.

In order to assess the methodology, we have applied it to a case study of nine countries of the gulf of Guinea.

Our study begins with an analysis of the "business as usual" scenario. In the case study, the results of these scenarios coincide with the current views expressed in other works [*FAO*, 2011; *UNPD*, 2010; *FAO*, 2006; *IWMI*, 2007; *World Bank*, 2008].

The goal seeking scenarios represent the outcome of alternative politics. These politics should not only take into account the present reality but should also set future objectives that can be reached in a sustainable way. These scenarios go a step beyond other studies that only take into account environmental factors, leading to physical scarcity, and economical factors, leading to economical scarcity due to the lack of resources to withdraw and distribute freshwater [*IWMI*, 2007].

It should be stressed that one of the key points of our methodology is to take also into account social and political factors. This is done through the definition of two standards (EURO and USACAN), that are not based on the current withdrawal, that depending on the country can be very low, but rather on what we believe are acceptable welfare standards. It is this way of setting up the problem that gives us new insight on water scarcity.

We define the WCEI and the WCUI indexes, that summarize the capacity of a given country according to our methodology. In the case study, it has revealed some differences between the countries of the region. While according to the IWMI all the countries suffer water scarcity, our study is able to detect differences between them.

To sum up, we pretend to assess the chances for developing countries to reach the freshwater welfare standards that are enjoyed currently in developed countries. The supply and demand

approach, among other contributions of this work, can be useful in the study of the scarcity of any other natural resource. Finally, we have tried to contribute new tools that allow stakeholders to act preventively in front of eventual problematic situations.

References

Barbier, E.B. (2004). *Water and Economic Growth.* The Economic Record. Vol.80 N0 248. pp 1-16. Departament of Economics and Finance.University of Wyoming. Laramie, Wyoming.USA.

Bernholz, C.H. (2005). *Population and Development Report: Water Scarcity in the Arab World.* Governement Information Quartely. Volume 22, Issue 1, pp.134-136.Doi:10.1016/j.gip.2004.09.007.

Biswas, A.K. (2005). An assessment of Future Global Water Issues. *Journal of water resources development*, 21(2), pp. 229-237, doi:10.1080/07900620500098885.

Engelman, R. and LeRoy, P. (1993). *Sustaining water: Population and the future of renewable water supplies.* Population and Environment Program, Population Action International. Washington, DC.

Feitelson, E., and J. Chenoweth (2002). Water poverty: towards a meaningful indicator. *Water policy*, 4(3), pp. 263-281. doi**:** 10.1016/S1366-7017(02)00029-6.

Fraiture, De C., X. Cal, M. Rosegrant, D. Molden and U. Amarasinghe (2003) Addressing the unanswered questions in global water policy: A methodology framework. Irrigation and Drainage 52. pp.21-30.Wiley InterScience. doi:10.1002/ind.76.

FAO (Food and Agricultural Organization of the United Nations), (2011). AQUASTAT. Information System on Water and Agriculture. Food and Agricultural Organization of the United Nations. Available from the FAO-AQUASTAT **(**http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en)

FAO (Food and Agricultural Organization of the United Nations), (2005). Land and Water Development Division, Frenken, K. (dir.). *Irrigation in Africa in figures. AQUASTAT survey, 2005*. Food an Agricultural Organization of the United Nations, Roma.

Graffy, E. A. (2006). Expert forecasts and the emergence of water scarcity on public agendas. *Society and natural resources: An international journal*, 19(5), pp. 465-472. doi: 10.1080/08941920600561173.

Howard, G. (2003). *Domestic water quantity, service level and health*. Programme Manager, Water Engineering and Development Centre. Loughborough University ,UK.. Jamie Bartram Co-ordinator Water, Sanitation and Health Programme, World Health Organization. Geneva, Switzerland.

IPCC (Intergovernmental Panel on Climate Change) and Bates, B., Kundzewicz, Z.W., Wu, S. y Palutikof, J. (eds.). (2008). *Climate Change and Water* . Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat. Geneva, Switzerland

IWMI (International Water Management Institute). (2007). Trends in water and agricultural developme*nt*. Molden, D. (et al.) (eds.). *Water for food, water for life* [en línea]*: A comprehensive assessment of water management in agriculture*. Londres: Earthscan, y Colombo: International Water Management Institute, pp. 57-89.

Kohli, A., K Frenken and C. Spottorno (2010). *Disambiguation of water use statistics*. Food and Agricultural Organization of the United Nations, Roma.

Meigh, J.R.. A.A. McKenzie and K.J. Sene (1999). A grid-based approach to water scarcity for eastern and southern Africa. *Water Resources Management*. Vol.13, nº2, pp.85-105. doi: 10.1023/A:1008025703712

Postel, S. L. (2000). Entering an era of water scarcity: The challenges ahead. *Ecological applications,* 10(4), pp. 941-948, doi: 10.1890/1051-0761(2000)010[0941:EAEOWS]2.0.CO;2

Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? *Agricultural w*a*ter management,* 80(1/3), 5-22, doi:10.1016/j.agwat.2005.07.001.

Shiklomanov, I. A. (1999). World water resources and their use: a joint State Hydrological Institute

St Petersburg/UNESCO product. *UNESCO Water Portal.* International Hydrological Programme: UNESCO's intergovermmental scientific in water resources. Paris.

Szöllösi-Nagy, A., P. Najilis and G. Bjöklund (1998). Evaluación de los recursos mundiales de agua dulce. *Naturaleza y Recursos*, 34(1). Barcelona.

UNPD (United Nations Population Division). (2010). Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat *World population prospects: The 2008 revision: Population database, United Nations*. Available from the UNPD (http://esa.un.org/unpd/wpp/unpp/panel_population.htm)

UNO (United Nations organization). (2011). *The Millenium Development Goals Report 2011*. United Nations Organization. New York, New York, EUA.

UNDP (United Nations Development Programme). (2006). Human Development Report 2006: Beyond scarcity: Power, poverty and the global water crisis. New York, New York, EUA.

Wolfe, S. and D.B.Brooks (2003). Water Scarcity: An alternative view and its implication for policy and capacity building. *Natural Resources Forum*. 27(2), pp. 99-107. United Nations. Published by Blakwell Pubblishing. Oxford UK and Malden USA.

World Bank (2008). *World Development Indicators 2008* [CD-ROM]. The World Bank Group. Washington, DC.

Xercavins, J. (1999). Carrying capacity in East Sub-Saharan Africa: a multilevel integrated assessment and a sustainable development approach, Ph.D. thesis, Dep. of Mineral and Natural Resources, Universitat Politècnica de Catalunya. Barcelona.

Table 1. Water demand in Côte d'Ivoire

	1987	1990	1994	2000	2005
Agricultural water withdrawal (km^3/year)	0.475		0.8	0.6	0.762*
Municipal water withdrawal (km^3/year)	0.156		0.162	0.5392	0.6359
Industrial water withdrawal (km^3/year)	0.078		0.27	0.2696	0.318
Water demand (km^3/year)	0.709	1.1	1.232	1.409	1.7159

Source: FAO, 2011. *Modeled exponential data

Table 2. Population**,** water EURO and water USACAN demand in Côte d'Ivoire

	2050	2100
Population* (thousands)	40674	56412
EURO (km^3/year)	22.78	31.59
USACAN (km^3/year)	67.52	93.64

*source: UNPD, 2010

Table 3. Water demand in Nigeria

	1980	1990	2000	2002	2003
Irrigated surface** (1000 ha)	200	221	245	270	282
Agricultural water withdrawal (km³/year)	4.50	5.00	5.51*	6.03	6.32
Population*** (thousands)	75543	97552	123689	129832	133067
Municipal water withdrawal (km³/year)	1.980	2.557	3.242*	3.403	3.488
Gross domestic product **** (cte 2000 US$ *10^12)	1,433	1,447	2,424	2,109	2,631
Industrial water withdrawal (km³/year)	0.919	0,928	1,554*	1,352	1,687
Water demand (km³/year)	7,40	8,49	10,31*	10,79	11,50

Source: *FAO, 2011;** FAO, 2005; ** *UNPD, 2010; *** *World Bank, 2008.

Table 4. Low level supply and high level supply in the countries of the gulf of Guinea

Country	Low level supply (km^3)	High level supply (km^3)
Guinea-Bissau	11.50	18.60
Guinea	88.50	135.60
Sierra Leone	62.25	96.00
Liberia	90.55	139.20
Côte d'Ivoire	30.41	48.66
Ghana	19.90	31.92
Togo	5.56	8.82
Benin	10.16	15.84
Nigeria	90.55	139.20

Table 5. Low level exhaustion and high level exhaustion EURO and USACAN in the year 2050 in the countries of the gulf of Guinea

Country	EURO exhaustion (%)		USACAN exhaustion (%)	
	Low level	High level	Low level	High level
Guinea-Bissau	15.51	9.59	45.97	28.43
Guinea	14.56	9.50	43.15	28.16
Sierra Leone	9.97	6.47	29.57	19.17
Liberia	5.97	3.89	17.71	11.52
Côte d'Ivoire	74.90	46.81	222.03	138.76
Ghana	138.19	86.15	409.64	255.38
Togo	112.10	70.67	332.30	209.48
Benin	119.79	76.84	355.10	227.77
Nigeria	240.95	156.74	714.26	464.63

Table 6. Water capacity according to WCEI and WCUI in the countries of the gulf of Guinea for 2050.

Country	Water capacity EURO-standard index	water capacity USACAN-standard index
Guinea-Bissau	High capacity	High capacity
Guinea	High capacity	High capacity
Sierra Leone	High capacity	High capacity
Liberia	High capacity	High capacity
Côte d'Ivoire	High capacity	Null capacity
Ghana	Low capacity	Null capacity
Togo	Low capacity	Null capacity
Benin	Low capacity	Null capacity
Nigeria	Null capacity	Null capacity
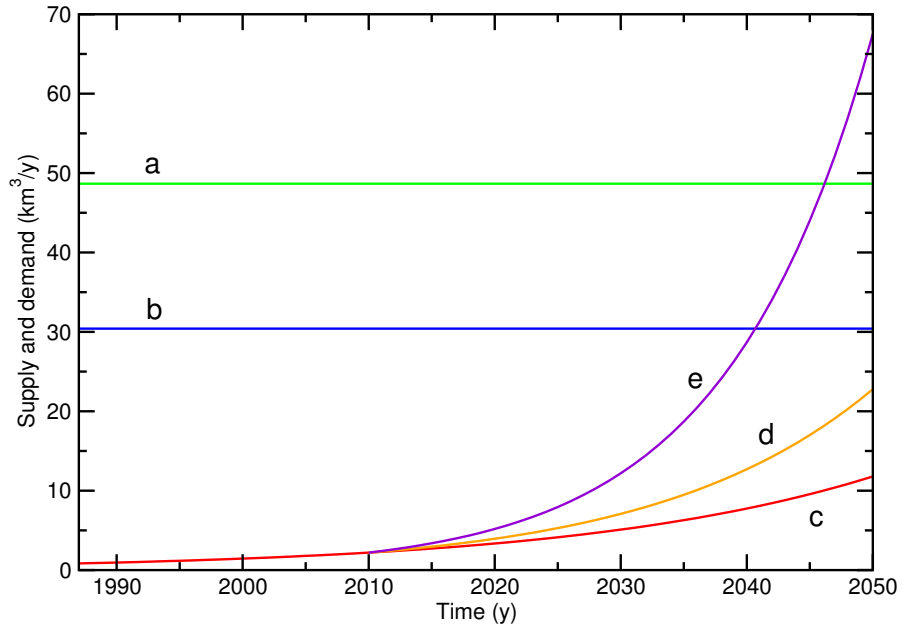
Figure 1: Supply and demand for Côte d'Ivoire between 1987 and 2050. a) HLS. b) LLS. c) BaU demand d) EURO demand e) USACAN demand.
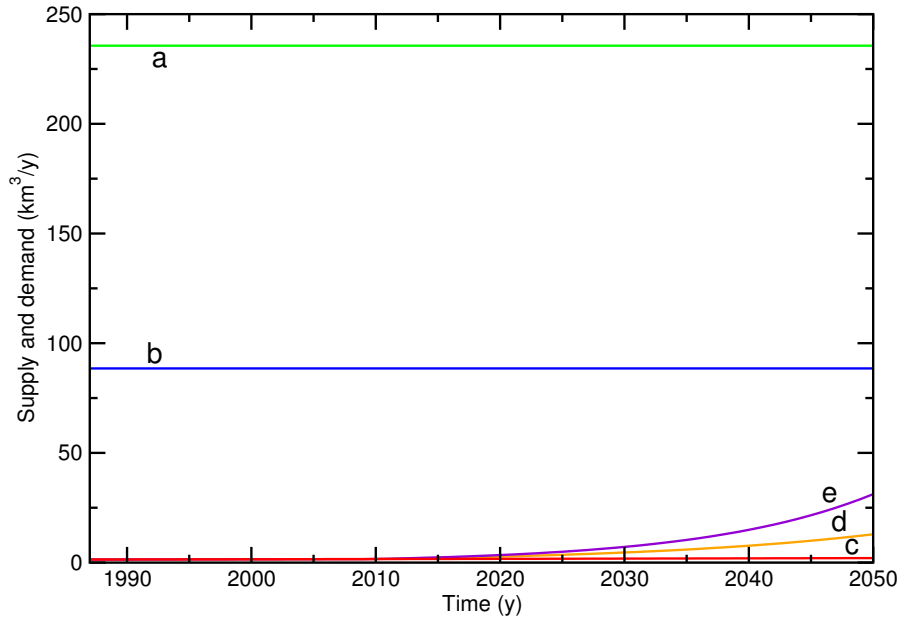
Figure 2: Supply and demand for Guinea between 1987 and 2050. a) HLS. b) LLS. c) BaU demand d) EURO demand e) USACAN demand.
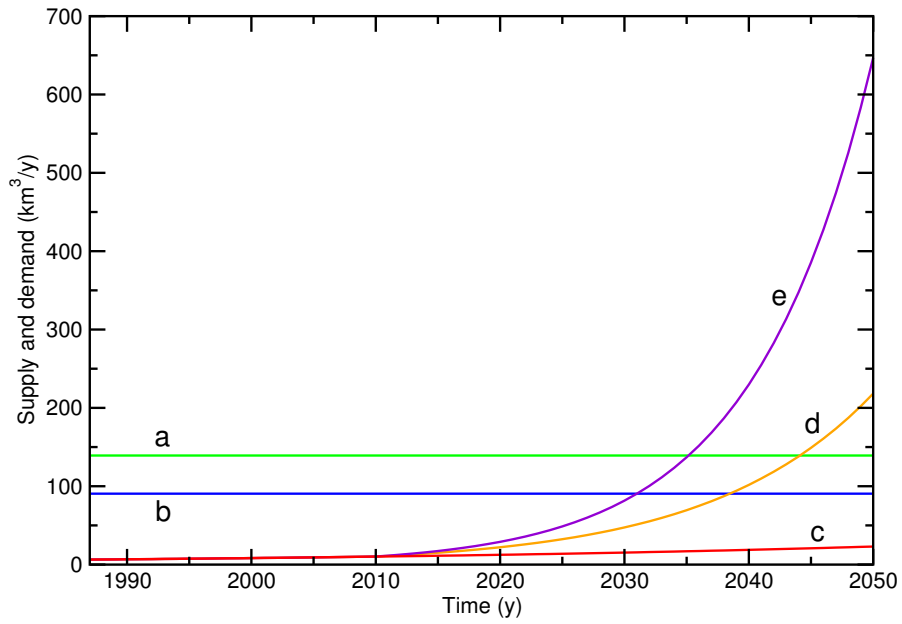
Figure 3: Supply and demand for Nigeria between 1987 and 2050. a) HLS. b) LLS. c) BaU demand d) EURO demand e) USACAN demand.
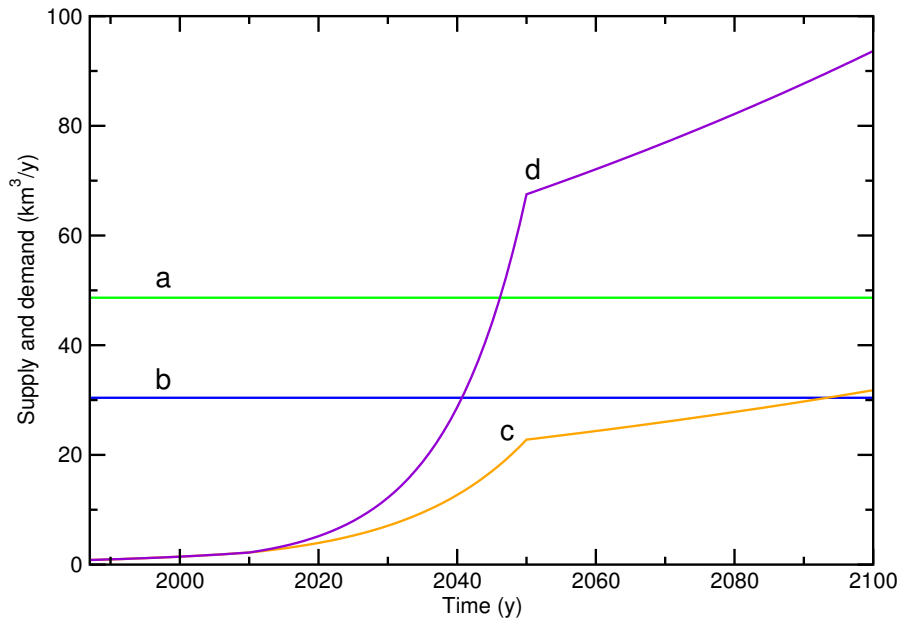
Figure 4: Supply and demand for Côte d'Ivoire between 1987 and 2100. a) HLS. b) LLS. c) EURO demand d) USACAN demand.
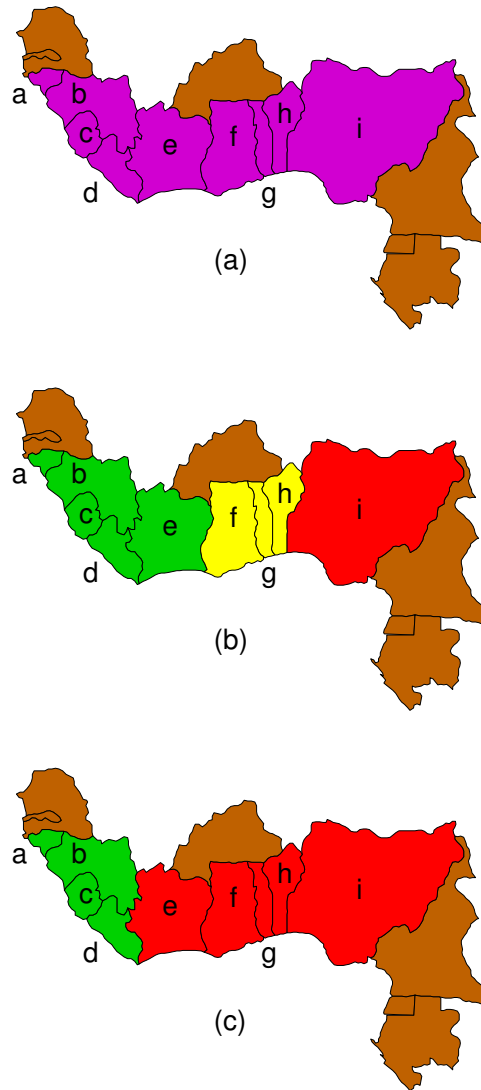
Figure 5: Water scarcity at the countries of the gulf of Guinea. a) Previous results [IWMI, 2007]. Economic water scarcity: a) Guinea-Bissau, b) Guinea, c) Sierra Leone, d) Liberia, e) Côte d'Ivoire, f) Ghana, g) Togo, h) Benin, i) Nigeria. b) Water scarcity according to WCEI. High capacity: a) Guinea-Bissau, b) Guinea, c) Sierra Leone, d) Liberia, e) Côte d'Ivoire. Low capacity: f) Ghana, g) Togo, h) Benin. Null capacity: i) Nigeria. c) Water scarcity according to WCUI. High capacity: a) Guinea-Bissau, b) Guinea, c) Sierra Leone, d) Liberia. Null capacity: e) Côte d'Ivoire, f) Ghana, g) Togo, h) Benin, i) Nigeria.