National Water Security in the First Half of the Twenty-First Century

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1 INTRODUCTION

Since the UN Conference on water held was in Mar del Plata in 1977, water resources issues have remained firmly rooted on the international agenda. In the last ten years, the Earth Summit, the first and second World Water Fora have sought to rally international cooperation for holistic and sustainable use of water resources.

On its part, the Gambia, like other countries in the West African sub-region was painfully awoken to the devastating impacts of climate change and in the early 1970ies. In the same logic of interventions aimed at ensuring greater access to freshwater supplies to the Gambian population and productive sectors of the economy in the last quarter century, the formulation of a water management strategy is one of the top items on the country's water resources development agenda. When completed, the strategy is expected to provide the basic framework for orderly and integrated planning and implementation of water-related programmes and projects, hitherto missing from the policy landscape.

In conformity with the author's terms of reference as Water Resources Planner under the United Nations Rural Water Supply and sanitation Project (GAM/93/003 – GAM/92/CO1), this paper seeks to assess long-term water security in the Gambia – one of the fundamental pre-requisites for social well-being and sustainable economic growth.

2 METHODOLOGY

Water security is assessed by carrying out detailed analysis of factors affecting current and future water resources availability and demand, such as, climate change, population and economic growth.

A national water budget which matches projected demand for water against expected water resources availability under various growth scenarios leads to an objective measure of national water security that stakeholder could rely upon when contemplating investments in water-related projects.

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3 WATER RESOURCES STATUS

3.1 Definitions

Water Resources is defined as naturally occurring surface and groundwater, whose chemical, physical, and microbiological quality does not deter, in view of technological constraints, from its exploitation for human benefit [1]. The reader's attention is drawn to the fact that such a definition excludes rainfall, which is sometimes counted as part of the water resources pool [2]. Notice that the definition given by [1] and adopted in this paper is consistent with water resources development, concerned with the capture, treatment and distribution of water to users/consumers. It goes without saying that river flows, and water stored in natural depressions and aquifers, all derive from rainfall.

Flow characteristics in the River Gambia, and aquifer potential and hydraulic behaviour have been described in detail in various reports [3, 4, 5, 6, 7]. On the other hand, the potential of hill depression storage has not been established. Accordingly, water resources status is described by flow rates in the River Gambia, and groundwater storage in the system of aquifers that underlie the country.

3.2 Renewal processes and rates

Rain falling at the surface of the soil is partitioned into several component of the hydrological cycle [8, 9], including runoff and groundwater recharge.

Diffuse runoff from various points in the Gambia River Basin converge to well defined flow channels, and eventually into the River Gambia. Average annual flow of the River Gambia as it enters the country is 164 m^3/s. Owing to lack of flow measurements along the river, the contribution of local tributaries, and groundwater is not known with a high degree of accuracy. Preliminary assessments of groundwater inflows [10] suggest a contribution of 8 m^3/s. Modelling studies show little sensitivity of flows from the upper Gambia River Basin to global warming [10].

Infiltration is reported as the primary recharge mechanism [4, 7] for the shallow sand aquifer that provides the quasi-totality of the country's groundwater supplies. Note that local infiltration varies from place to place due to differences in rainfall, surface geology, land use, and other factors [5, 8]. Estimated recharge of the shallow sandstone aquifer, averaged over the eight year period (1993 – 2000), amounts to 564 hm^3/yr [10], compared to 630 hm^3/yr m over the period 1981 to 1985 [4].

3.3 Climate change and variability and their impacts

The Geophysical Fluid Dynamics Laboratory (GFDL) and Hadley Centre (HCGS) General Circulation Models used in climate vulnerability studies [10] do not indicate significant changes in rainfall, relative to the post-1970 situation. Expected changes in climate are transcribed therefore by global warming of 2 K/Century, and sea level rise of 100 cm/Century.

3.3.1 Impacts on River Gambia flows

A global warming trend is found to have marginal impacts on river flow in the upper Gambia River Basin, where hardshield rocks, and accidental topography largely determine the catchment's water balance [4, 6, 10]. Evaporation losses from the retention dam planned to be constructed at Sambangalou, in the order of 11 m^3/s [11], are expected to increase to by 10% under the projected warming trend. These losses, attributable to both climate change and human intervention, are to be considered as a net reduction of average annual flow entering the Gambia.

As a direct consequence of sea level rise, annual flow hydrographs of the river Gambia would be subject to reservoir routing effects [12]. Specifically, peak flows are expected to decrease in magnitude and occur later than under present sea level.

3.3.2 Impact on saline intrusion in the estuary of the River Gambia

Under projected sea level rise, the saline front (salt concentration = 1g/l) is expected to migrate landward/upstream of its present upper limit around Kuntaur (river km 254). Owing to current unavailability of software to conduct salinity intrusion modelling, the exact distance of this translocation is fraught with uncertainty. The best estimate, based on the tidal range at Banjul and semi-diurnal excursions of the saline front, is 4 km. Evaporation losses from the river in the order of 0.3 m^3/s are expected to add another 170 metres to the above intrusion length. Modification of the annual flow hydrograph previously highlighted is expected to result in changes in the salinity regime at different locations along the River Gambia. Oceanwards, the duration of salt water transgression will be increased, but the perennial nature of the freshwater flow regime will be enhanced the further one moves upstream.

3.3.3 Impact on groundwater resources

Considering that groundwater is replenished by local infiltration, and significant deviations of rainfall from current levels has not been demonstrated [10], a warming global trend is expected to have limited impacts on groundwater recharge. The scope of this impact however has not been successfully quantified because of poor partial correlation between recharge and temperature [10]. But, using information on the maximum expected increase in open water evaporation, in conjunction with the mean ratio of actual to potential evapotranspiration at Sambangalou and Gouloumbo, one may deduce a 2% reduction in groundwater recharge, by the year 2050. We point out however that expansion of agricultural land, at the expense of forests, is likely to cut this figure down [5].

3.4 Population growth and its impacts

Population projections extracted from [10] are shown in figure 1 and Table 1. Excluding Expo_I which includes net migration of 0.7 %, population forecasts from various growth models range from 3.6 to 7.5 million by the year 2050. Note that Cohort_II projections, which assume no changes in fertility rates from now against 2050, is indistinguishable from an exponential growth model assuming a natural population growth rate of 3.5%.

Along with [15], we point out that future spatial distribution of population is hard to predict, but concentration of population in some geographical locations is bound to occur. Associated with such concentration, one may expect a reduction in groundwater recharge and increased risk of groundwater pollution from on-site sanitation systems and inefficient waste disposal methods. To fix some ideas, a 60% decrease in recharge expected by 2050, in the Kombo Peninsula. Concurrently, a hydraulic loading of 5 litres/person/day, from on-site sanitation systems, assuming time-invariant distribution of population, would result in sewage effluent accounting for 25% of groundwater recharge by 2050 (see figure 2). The risk of pollution of groundwater resources by nitrates and coliform bacteria is self-evident.

A 13% decrease in recharge, lower population densities and water use in rural areas, are mitigating factors against groundwater pollution risks. Waste disposal in disused wells could however substantially alter this situation in some limited geographical areas.

On a national basis, we estimate, a linear decrease of 13% in recharge by the year 2050, when working with Cohort_II population projections, and a 6% decrease using the logistic population growth model.

3.5 Economic and social development impacts

Land Use and Land Use Changes (LULUC) are expected to alter the partition of rainfall among the different components of the hydrological cycle [8], possibly causing modification to figures in Table 2. In § 3.4 above, it was also pointed out that

Table 1: *Population projections with different mathematical growth models and the cohort survival method* (*using different assumptions of total fertility*) [10]

	Growth Models				
Year	Expo_I	Expo_II	Logistic	Cohort_I	Cohort_II
1993	1,038,145	1,038,145	1,038,145	1,038,145	1,038,145
2000	1,384,625	1,239,508	1,225,833	1,326,259	1,336,459
2010	2,089,341	1,596,751	1,546,519	1,814,573	1,879,330
2020	3,152,727	2,056,955	1,937,294	2,430,088	2,636,187
2030	4,757,334	2,649,797	2,406,068	3,200,588	3,727,520
2040	7,178,617	3,413,503	2,957,944	4,110,901	5,287,951
2050	10,832,233	4,397,320	3,593,466	5,148,150	7,531,265

Notes: Exponential growth models, Expo_I and Expo_II: $P_t = P_0(1 + r)^t$ extrapolates population on the basis of past growth. The model assumes constant growth rates, *r*, for the period under consideration. Expo_I uses the 1983-1993 inter-censal growth rate $r = 0.042$. Expo_II uses the 1901-1993 nonadecadal growth rate $r = 0.026$. P_0 is the population count during the 1993 census.

In the logistic (S- shaped) model, $P_t = \left[\frac{b}{a}\left(1 - e^{-at}\right)P_0 + e^{-at}\right]^{-1} P_0$. Parameters *a* and *b* characterise and constrain growth rates. Insofar as growth rates are dependent on population level, the logistic model transcribes population growth better than the exponential model. Similar to the exponential model however, demographic factors and population dynamics are not considered in the logistic model. These omissions are particularly important if one considers that *a* and *b* are calibrated using a relatively short record, but fix the upper limit of population. Indeed, as $t \rightarrow \infty$, $P_t \rightarrow P_\infty = a/b$.

The cohort survival technique which explicitly accounts for demographic factors and interactions between population sub-groups (i.e. cohorts), computes population growth as the net number of births for child-bearing age groups, and the fraction of population that survives to become part of the next older cohort [17]. For an *n*-year interval, $P_n = \mathbf{C}^n P_0$, in which $\mathbf{C} = \mathbf{B} + \mathbf{S}$, **B** being the matrix of net number of births by age group, and **S** the survival matrix incorporating aging and mortality). For the Gambia, the age-specific fertility rate (ASFR) that fits the general form of **B** corresponds to the UN Arab system. Crude death rate (CDR=11.27/1000) and infant mortality rate (IMR=84/1000) that fit the general form of **S** is the *Coale-Demeny* South model. DEMPROJ, a software package held by the Central Statistics department is used to make projections with the cohort survival method. Cohort_I assumes a decline in Total Fertility rate (TFR=6.04 in the 1993 census) by 5% in 2003, 10% in 2013, decreasing linearly thereafter to 33% of TFR recorded in 1993, by 2050. Cohort_II assumes unchanging fertility rates (i.e., TFR constant at 1993 level) throughout the study period. Under both scenarios, net migration is assumed to be negligible.

Sources: 1901 to 1993 data used in calibrating Expo_II and the logistic models were obtained from [13].
Cohort_I and Cohort_II projections provided by Mr. Alieu Saho of Central Statistics Department.

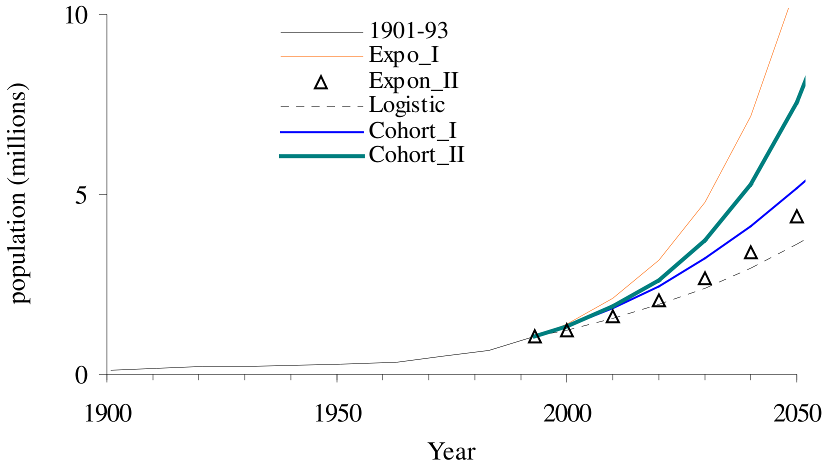

Figure 1: *Population projections using different mathematical growth models and cohort survival method* [10].

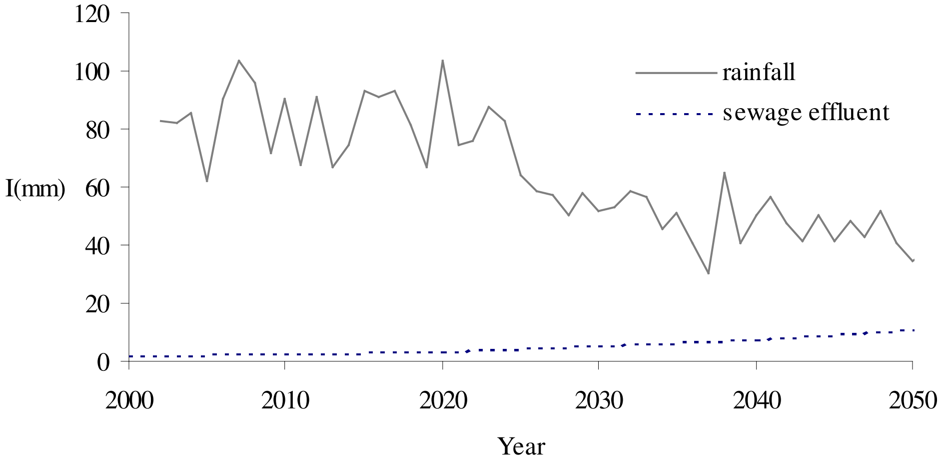

Figure 2: *Contribution to recharge in Kombo Peninsula from stochastically generated rainfall and sewage effluent under* Cohort_II *population projections* [10].

Table 2: *Contribution of River Gambia flows and groundwater recharge to renewable water resources base* (hm^3/yr) . *Moduli of River Gambia flows decreased by* 11m^3/s *(being evaporation from Sambangalou reservoir) from* 2020 *onwards.*

Year	Gouloumbo flows [a]	Cohort_II recharge [b]	Logistic recharge [c]	Minimum water resources [a]+[b]	Maximum water resources [a]+[c]
2000	5,172	563	564	5,735	5,736
2010	5,172	553	558	5,725	5,730
2020	4,825	541	552	5,368	5,378
2030	4,825	530	547	5,355	5,372
2040	4,825	519	541	5,344	5,366
2050	4,825	508	536	5,333	5,361

Note: values in columns 2 through 6 may not add up exactly because of truncation errors

urbanisation could have negative impacts on groundwater quality.

Whilst the expansion of cropland area, at the expense of forests, is expected to reduce evapotranspiration losses [8], nitrate leaching may become a problematic issue especially under inefficient management of agro-chemicals at farm level. In the same vein, nitrates, pesticides, and their break-down products in return flows could initiate limited changes in the chemistry of surface waters in the River Gambia. On one hand, nutrient loading may be beneficial to fish, but toxic effects from pesticides are likely to accumulate over time.

Pollution of surface water by sediments from unpaved surfaces in semi-urban area, and soil erosion may be expected to become a bigger problem if counter-measures are not put in place.

4 WATER DEMAND PROJECTIONS

In carrying out water demand projections, the very first step constitutes that of identification of components that make up aggregate demand. In any case, these are well documented in a number of reports [7, 15, 16]. Per capita water use/consumption by units associated with demand components [7, 15, 17], derived from water use surveys [7] or controlled experiments, are then used in conjunction with population size, cropland area, livestock population, etc., to compute volumetric water demand. One important assumption we make is that water supplied to users/consumers conforms to national and international quality norms. The influence of water pricing on demand, and legal restrictions in suppressing water use [15, 17] whilst acknowledged, are not taken into account when specifying per capita demand.

4.1 Sectoral demand

Water demand from the domestic and other sectors of the economy are evaluated in the next few sections. We point out that no strict guidelines exist on the allocation of water resources. Accordingly demand in any sector is not constrained by demands in another, the exception being industrial water demand, which is considered a fixed percentage of aggregate demand.

4.1.1 Domestic sector

Domestic water demand is directly linked to population size and people's lifestyles. GITEC [7], the only consumption survey available reports average per capita consumption of 18 litres/day in rural areas. Under the Japanese Integrated Water Use project, JICA uses the design per capita of 35 litres/day. Per capita consumption in the Kombos is estimated at 70 litres/day [10]. Water demand using these indicative values is tabulated in Table 3 for Cohort_II and logistic population growth projections. As would be expected the differences reflect more or less the ratio of population projections at specific dates.

Table 3: *domestic sector water demand* (m^3/d) *according to the Cohort-II and Logistic population growth models*

Year	Logistic	Cohort_II
2000	61,370	66,908
2010	77,424	94,086
2020	96,988	131,977
2030	120,456	186,613
2040	148,085	264,734
2050	179,902	377,042

4.4.2 Tourism sector

Similar to the domestic water sector, personal life styles, bathroom fittings (shower caps, bath tubs, water closets), and amenities available at various resorts play an important role in shaping demand.

Competitive strengths and weaknesses of the Gambia tourist industry are well documented [18], but projections in tourist arrivals are not available in official reports. This may be quite understandable given the potential for disruption of the tourist market by global politics. To circumvent difficulties in making long-term projections of tourist arrivals, the number of beds available within the hospitality and catering industry is used to derive sectoral water demand [10]. Such an approach however tends to overestimate demand due to its implicit assumption of a 100% occupancy rate all year round.

Assuming conditions for investments are favourable, and that (1) current capacity increases at a rate of 160 beds/year between 2005 and 2030, (2) construction of smaller units providing an average 50 beds/year take place between 2030 and 2050, the number of beds in the hotel and catering industry and corresponding water demand are shown in Table 4.

Table 4: *tourism sector expansion and water demand* (m^3/d)*, based on* 130 litres/day/bed *per capita*

Year	# beds	Demand
2000	6,000	760
2010	7,333	953
2020	8,667	1,127
2030	10,000	1,300
2040	10,500	1,365
2050	11,000	1,430

Compared with demand values in Table 2, it is seen that demand from the tourism sector constitutes 1% or less of domestic demand.

4.4.3 Agricultural sector

For detail and clarity, demand from the agricultural sector is disaggregated into irrigation and livestock sub-sector water requirements.

4.4.3.1 *Irrigation sub-sector*

Existing and planned irrigation schemes in the country consist of relatively large rice irrigation perimeters in the Central River Division (CRD) flood plains, and export-oriented horticultural gardening in the Kombos and parts of Western Division. Family gardens of much smaller size, on which vegetables are grown in the dry season, are present throughout the rural areas.

Water requirements for irrigated rice are estimated at 3,000 mm-equivalent of water per year [10]. Corresponding demand for locally-grown horticultural crops [19] are pegged at 700 mm/year [20]. This amount is increased in this study by 20% to compensate for rainfall deficits during drought years, dry spells during rainy seasons, and increased evapotranspiration associated with global warming.

Pertaining to targets for expansion of rice irrigation schemes, we note that no firm targets have been set by government. The prospects for expansion before the completion of and operation of a retention dam Sambangalou however, are minimal. Between 2020 and 2050, we assume an ambitious target of 425 ha/yr, thus taking the present hecterage [19] from 2,800 ha to 15,600 ha by 2050. Projections and arguments related to expansion of commercial horticulture, expected to peak at 3,000 ha by 2050, are given in [10]. The total area under family gardening is computed from family plots of $25m^2$ each, and population characteristics of the Cohort_II and logistic model projections.

Depending on population size, and whether or not rice irrigation is considered, Tables 5 and 6 show that demand from the irrigation increases by 4 – 480%, with respect to conditions in the year 2000. In table 5, notice also that the large area under rice irrigation and higher water consumption of rice is one reason why rice irrigation accounts for 80 to 90% of irrigation water demand.

4.4.3.2 *Livestock sub-sector*

Subject to slight modifications linked to heat stress and water content of feed material, water demand by different livestock species is readily obtained from a number of sources [7, 15, 17], reducing the task of water demand projections to that of livestock population projections. The complexity of this task, related to imponderables such as disease and drought, government economic and agricultural policies, environmental issues, and livestock population dynamics, is highlighted by [10].

Estimates of maximum and minimum herd sizes, at specific dates, together with their corresponding water demands are shown in Table 7. In this table, maximum herd size is obtained from an exponential growth model using a growth rate of 0.75% derived from [19]. Minimum herd size is based on the concept of carrying capacity of monotonously contracting rangelands, and the assumption that no commercial cattle ranching schemes are in place.

Tables 8 and 9 give the estimated upper and lower bounds of water demand from small ruminants and equine species found in rural areas. Estimates of stock populations are derived using human population projections, current human:stock head ratios, and average daily water consumption of individual species [7]. The possibility of making projections of small ruminant populations using and exponential growth model was contemplated, but eschewed, because of unconfirmed negative growth rates documented in [19].

Table 5: *Cultivated area (ha) irrigation water demand* (m^3/d) *and sources of irrigation water. Demand values for rice irrigation are* based on *conversion of flow rates under* Scenario 3 *of the* Gambia River Basin Hydraulic Master Plan [21] . *Total area of family gardens is based on rural population under* Cohort_II *population projections divided by mean family size of* 8.04. *Note that no expansion in irrigated rice takes place before* 2020

			GROUNDWATER			SURFACE WATER	
	Cultivated area (ha)		water demand (m^3/d)				
Year	Family Gardens	Commercial Horticulture	Family Gardening [a]	Commercial Horticulture [b]	Demand [a]+[b]	Irrigated Rice (ha)	water demand (m^3/d)
2000	249	740	5,741	34,060	39,802	2,800	230,137
2010	336	1,229	7,727	56,583	64,310	2,800	230,137
2020	450	1,719	10,353	79,106	89,459	2,800	230,137
2030	606	2,208	13,952	101,628	115,581	7,067	580,222
2040	818	2,604	18,819	119,855	138,674	11,333	931,507
2050	1,104	3,000	25,413	138,082	163,496	15,600	1,282,192

Note: values in columns 4 through 6 may not add up exactly because of truncation errors

Table 6: *Cultivated area (ha) irrigation water demand* (m^3/d) *and sources of irrigation water. Rice irrigation constrained by unregulated flows in the River Gambia . Total area of family gardens is based on rural population under* Logistic growth *population projections divided by mean family size of* 8.04. *Note that rice irrigation takes place under unregulated flow conditions in the River Gambia.*

			GROUNDWATER			SURFACE WATER	
	Cultivated area (ha)		water demand (m^3/d)				
Year	Family Gardens	Commercial Horticulture	Family Gardening [a]	Commercial Horticulture [b]	Demand [a]+[b]	Irrigated Rice (ha)	water demand (m^3/d)
2000	229	740	5,266	34,060	39,326	2,800	230,137
2010	276	1,229	6,359	56,583	62,942	2,800	230,137
2020	331	1,719	7,609	79,106	86,714	2,800	230,137
2030	391	2,208	9,006	101,628	110,635	2,800	230,137
2040	457	2,604	10,527	119,855	130,382	2,800	230,137
2050	527	3,000	12,126	138,082	150,208	2,800	230,137

Note: values in columns 4 through 6 may not add up exactly because of truncation errors

Table 7: *Projected maximum and minimum cattle herd sizes and corresponding water demand (m^3/d)*

Year	Minimum Herd size	Maximum Herd size	Minimum water demand (m^3/d)	Maximum water demand (m^3/d)
2000	263,454	364,114	5,269	7,282
2010	386,630	469,832	7,733	9,397
2020	422,547	659,047	8,451	13,181
2030	421,998	931,880	8,451	18,638
2040	421,481	1,321,988	8,440	26,440
2050	420,901	1,882,816	8,430	37,656

Table 8: *Maximum projected water demand* (m^3/d) *of small ruminants and equine species. Demand is computed from number of animals and per capita demand of* 8 litres/day *for small ruminants*, 25 litres/day *for donkeys*, and 30 *litres/day for horses*

Year	sheep [a]	goats [b]	horses [c]	donkeys [d]	all species [a]+[b]+[c]+[d]
2000	1,155	2,131	650	1,043	4,979
2010	1,555	2,868	875	1,404	6,702
2020	2,083	3,843	1,172	1,881	8,979
2030	2,808	5,179	1,579	2,535	12,100
2040	3,784	6,985	2,130	3,419	16,320
2050	5,114	9,432	2,877	4,617	22,040

Note: values in columns 2 through 6 may not add up exactly because of truncation errors.
Swine have been omitted because of large uncertainties and relatively small numbers.

Table 9: *Minimum projected water demand* (m^3/d) *of small ruminants and equine species. Demand is computed from number of animals and per capita demand of* 8 litres/day *for small ruminants*, 25 litres/day *for donkeys*, and 30 *litres/day for horses*

Year	sheep [a]	goats [b]	horses [c]	donkeys [d]	all species [a]+[b]+[c]+[d]
2000	1,060	1,955	596	957	4,567
2010	1,280	2,360	720	1,155	5,515
2020	1,531	2,824	861	1,382	6,598
2030	1,812	3,343	1,019	1,636	7,810
2040	2,118	3,907	1,192	1,912	9,129
2050	2,440	4,501	1,373	2,496	10,516

Note: values in columns 2 through 6 may not add up exactly because of truncation errors.
Swine have been omitted because of large uncertainties and relatively small numbers.

Table 10: *Maximum and minimum water demand* (m^3/d) *from the industrial sector*

Year	Minimum demand	Maximum demand
2000	10,360	10,821
2010	11,889	12,544
2020	13,268	68,130
2030	14,776	81,744
2040	16,284	96,094
2050	17,926	111,707

4.4.4 Environmental sector

Environmental water demand is the minimum river flow required to maintain the integrity of aquatic ecosystems. In the Gambian context, minimum flows have the corollary function of protecting investments in rice irrigation from the effects of saline intrusion.

According to [14], a constant flow of 20m^3/s in the dry season is required to limit saline intrusion in the estuary to 195 km upstream of which 15,000 ha have been marked for irrigation development. Attention is drawn to the similarity between this value and total area expected to be under irrigation by 2050, that is indicated in Table 5.

Assuming that downstream irrigation sites will be developed last, i.e., the best water management option, a minimum flow of 20 m^3/s equivalent to 631 hm^3/yr would be required, by the year 2050, to offset degradation of soils in the inter-tidal zone in areas upstream of Kaur.

4.4.5 Industrial sector

Demand for water in the industrial sector is driven by requirements for food processing, product packaging, cleaning, and as a raw material in some industrial processes. Vision 2020 Inc. [22] foresees an increase in the number of industrial units and diversification in the sector but goes no further than that. The caution displayed and general absence of projections is perhaps understandable in light of uncertainties in the evolution of world stock markets and commodity prices, and sensitivity of local industry to external market forces.

Owing to the lack of information on industrial water demand, an estimated proportionality between domestic and industrial water demand in the Kombos is transformed to 3% of the national demand [10], an upward revision of the 2% reported in [16]. Minimum and maximum demand, reflecting socio-economic developments as well as population growth from the industrial sector is shown in Table 10.

4.2 Aggregate demand

Aggregate volumetric demand from the major water use sectors under conditions of high socio-economic development and a constant population growth rate of 3.5% up to the year 2050, is presented in Tables 11. A cursory glance at the table shows that water demand from the irrigation sub-sector and environmental sector constitute the bulk of aggregate demand. This fact is visualised in figure 3 which shows that irrigation and environmental demand constitute more than 80% of aggregate demand.

Table 11: *Synoptic table of maximum sectoral and aggregate demand (m^3/d) corresponding to a scenario of high population growth and socio-economic development*

Year	Sectoral water demand (m^3/d)						Aggregate demand	
	Domestic	Tourism	Agricultural Livestock	 Irrigation	Industrial	Environment	(m^3/d)	(hm^3/yr)
2000	66,908	780	12,261	269,939	10,821	0	360,709	132
2010	94,086	953	16,098	294,447	12,544	0	418,129	153
2020	131,977	1,127	22,160	319,596	68,130	1,728,000	2,270,989	829
2030	186,613	1,300	30,738	696,403	81,744	1,728,000	2,724,798	995
2040	264,734	1,365	42,760	1,070,181	96,094	1,728,000	3,203,134	1,169
2050	377,042	1,430	59,696	1,445,687	111,707	1,728,000	3,723,563	1,359

Note: values in columns 2 through 8 may not add up exactly because of truncation errors

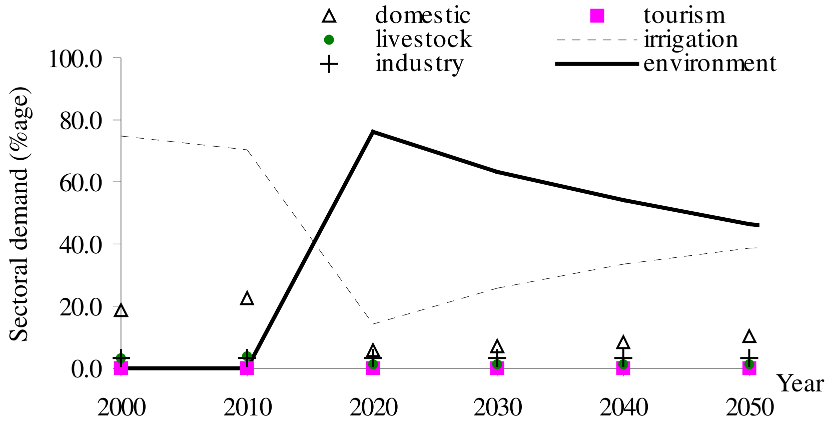

Figure 3: *Sectoral demand expressed as percentage of aggregate demand under conditions high population and economic growth*

Table 12: *Synoptic table of minimum sectoral and aggregate demand (m^3/d) corresponding to a scenario of low population growth and socio-economic development. Environmental demand is nil because no minimum flows are maintained in the River Gambia.*

	Sectoral water demand (m^3/d)						Aggregate demand	
Year	Domestic	Tourism	Agricultural		Industrial	Environment		
			Livestock	Irrigation			(m^3/d)	(hm^3/yr)
2000	61,370	780	9,836	269,463	10,560	0	352,009	128
2010	77,424	953	12,961	293,079	11,889	0	396,306	145
2020	96,988	1,127	14,037	316,851	13,268	0	442,271	161
2030	120,456	1,300	15,242	340,772	14,776	0	492,546	180
2040	148,085	1,365	16,553	360,519	16,284	0	542,807	198
2050	179,902	1,430	17,932	380,345	17,926	0	597,635	218

Note: values in columns 2 through 8 may not add up exactly because of truncation errors

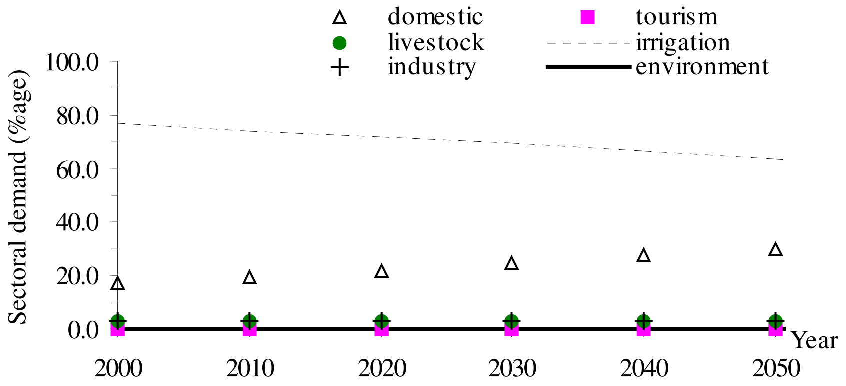

Figure 4: *Sectoral demand expressed as percentage of aggregate demand under conditions low population and economic growth*

Table 12 and figure 4 similarly illustrate results of aggregate demand computations, but under conditions of decreasing population growth rate and the absence of large-scale rice irrigation. Here, irrigation water demand make up the bulk of aggregate demand, whilst the share of the domestic sector increases from 17 to 30%, between 2000 and 2050. Notice that environmental demand is reduced to zero per cent because minimum flows are not maintained (i.e. unregulated flow conditions prevail).

5 NATIONAL WATER BUDGET

The national water budget compares renewable water resources with aggregate demand.

For the period under consideration, Table 13 shows a large surplus of water resources even under the most demanding scenario, viz., high population growth, high socio-economic growth, and decreasing groundwater recharge rates. Even though water resources surpluses gradually decrease over time, this does not obscure the fact that surpluses are at least 300% of maximum water demand in the year 2050 (i.e., the highest in the time series), offering significant latitude of action to water resources managers.

Table 13: *water budget under most demanding projections. Minimum resources are taken from* Table 2, *and maximum aggregate demand from* Table 11

Year	Minimum Resources (hm^3/yr)	Maximum Demand (hm^3/yr)	Balance (hm^3/yr)
2000	5,735	132	+ 5 ,603
2010	5,725	153	+ 5,572
2020	5,368	829	+ 4,539
2030	5,355	995	+ 4,360
2040	5,344	1,169	+ 4,175
2050	5,333	1,359	+ 3,974

5.1 Water Security

Another way of looking at national water budget surpluses is the sustainability of prevailing and expected usage of water resources. Comparison of overall per capita demand and water resources availability under high and low population growth scenarios (see Table 14) shows that the Gambia is not at risk of suffering from water scarcity [23] in the first half of this century. In table 14, we introduce a measure of water security (i.e., alternative view of water scarcity), different from [23], but indeed more appropriate. We hold the opinion that considering a per capita availability of 1,000 m^3/person/yr as the threshold for water scarcity [23], is erroneous, given the fact that such a threshold ignores overall per capita demand which translates the socio-economic realities of any particular country, at any particular time. The arbitrariness inherent in using a fixed threshold is revealed in figure 5, which suggests water scarcity under high population and economic growth by 2040, despite the fact that demand is lower than availability. This demonstrates that water security/scarcity can only be established therefore only if availability and demand are considered simultaneously.[1]

Under conditions of decreasing population growth rate and the absence of large scale rice irrigation, attention is drawn to Table 12 which shows that aggregate water demand, between 128 and 218 hm^3/yr, could be comfortably met from groundwater sources. A note of caution should be sounded however concerning the need to develop adequate infrastructure to meet demand in high population density areas. Anything less would lead to scarcity in the midst of plenty.

5.2 Uncertainties

Stemming from the fact that future developments and events cannot be forecast with certitude, we have deliberately used contrasting, yet plausible scenarios, to assess national water security. Nonetheless, climate change and its impacts remain an important source of uncertainty.

Whilst statistical analysis of annual rainfall data show no trend in rainfall after 1970, and climate change projections of rainfall are not as reliable as temperature or sea level projections [24], the negative step trend in sub-continental rainfall occurring around 1970 for which there is no universally accepted explanation [23], provides food for thought with respect to future climate. Whatever the cause(s) happen to be, it is clear that climate change stemming from natural processes are difficult to forecast or counter.

Assuming a negative step trend of 400 mm occurs between now and 2050, annual flow in the River Gambia is expected to drop to approximately 2,500 hm^3/yr. Under unregulated flow conditions, whereby 80 – 90 % of the annual flood volume takes place in the rainy seas, this would leave 200 – 250 hm^3 to cater for rice irrigation and environmental water demand – a truly tightrope walking scenario.

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[1] a water security index could be described by any suitable transformation of the ratio demand: availability ($W = D / A$). In this paper we use,

$$\xi = 1 - W \ , \quad -\infty < \xi \leq 1$$

in which D = demand, A= availability, ξ and W are water security indices.

Table 14: *Comparison of overall per capita water demand* (m^3/person/yr) *with per capita availability. Per capita demand is obtained by dividing maximum demand* in Table 11 *with projected population. Per capita availability is derived from renewable resources and population*

	Cohort_II population growth				Logistic population growth			
Year	Total Population	per capita demand [a]	per capita availability [b]	water security index 1 – [a]/[b]	Total Population	per capita demand [d]	per capita availability [e]	water security index 1 – [d]/[e]
2000	1,336,459	99	4,292	0.98	1,225,883	107	4,679	0.98
2010	1,879,330	81	3,046	0.97	1,546,519	99	3,705	0.97
2020	2,636,187	314	2,036	0.85	1,937,294	428	2,776	0.85
2030	3,727,520	267	1,437	0.81	2,406,068	413	2,233	0.81
2040	5,287,951	221	1,011	0.78	2,957,944	295	1,814	0.78
2050	7,531,265	180	708	0.75	3,593,466	378	1,492	0.75

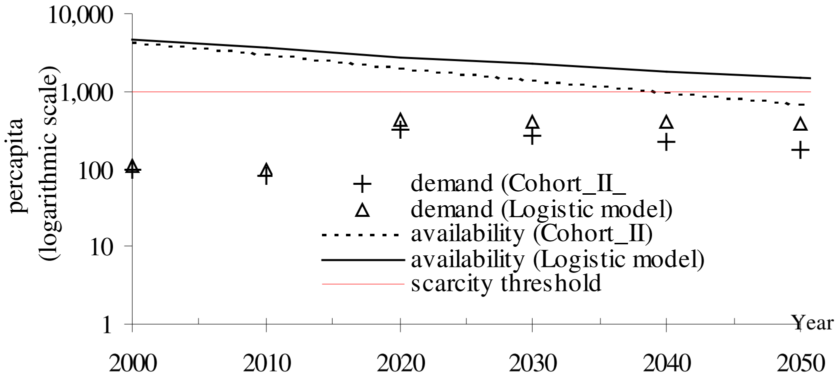

Figure 5: *Overall per capita water demand and availability in relation to water scarcity threshold [23]*

In a situation where Sambangalou dam is in operation,, live storage is expected to decrease by 50%, to 1,750 hm^3. Under these circumstances, national water security will be eroded, but water still available in sufficient quantities to meet maximum irrigation and environmental water demand in the order of 1,100 hm^3/yr.

If one is looking however at water security on a local scale, future population distribution and concentration of demand locations; and other sources of uncertainty, would play decisive roles in water security, even if the national water budget shows important surpluses.

6 CONCLUSIONS

Our examination of water security reveals a picture of plenitude. However, it is important to highlight the fact that real water security depends on development of supply and conveyance infrastructure to meet demand from the domestic and major sectors of the economy.

Except under circumstances of a dramatic decline in rainfall in the Gambia River Basin and in the Gambia, the major issues in water resources management in the Gambia are set to revolve around protection of water resources, and development of water resources infrastructure to spur and sustain economic growth, and promote social well being.

At the risk of incurring higher costs in treating water supplies resulting in higher water prices, water quality management needs to be accorded maximum priority.

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Appendix 1

Author’s Terms of Reference

WRMS Study Team
Terms of References (TORs)

National Water Resources Planner – Team Leader

Duties: Under the guidance of the Project Coordinator and in consultation with UNDESA's Interregional Adviser and International Consultant in Water Resources Planning and Management, the National Water Resources Planner will organise and implement the activities related to the preparation of a National Water Sector Strategy. In particular, the Planner is expected to:

1. Assist the International Consultant in Water Resources Planning and Management in planning and execution of the Strategy preparation, in particular, in defining the needs of National professionals' contributions (water resources assessment; urban and industrial water supply; rural water supply; environmental, institutional and legal aspects, etc.), and plan their interventions.

2. Spearhead the development of the Sector Strategy in his/her capacity as a team Leader for national professionals and review their terms of reference and ensure their contributions in time.

3. Identify stakeholders and establish consultations with them seeking participation of their professionals in the formulation process as resources persons (or national consultants).

4. To determine the impact of future development (population growth, economic and social development) on water demand (potable water supply; industrial and agricultural supply; environmental requirements) and on the status of water resources.

5. To draft a substantive contribution to the Water Sector Strategy as indicated in the Outline Water Sector Review Preliminary Table of Contents, covering past studies, overall management approach, stakeholders institutions, and riparian issues. potential developments and impact on resources, integrated river basin management. work plan and technical issues.

6. To draft a Water Sector Strategy (based on inputs from specialised national professionals/consultants as specified by the Outline Water Sector Review)