Table 3.5: Community forestry (mixed hardwood)						
Year	**Number of trees**	**Cumulative number of trees**	**Area (Ha)**	**Annual growth increment**	**Biomass (t)**	**Equivalent t CO_2 absorbed**
1	11,786	11,786	1,875	6.8	12,750	23,375
2	11,786	23,572	1,875	13.6	25,500	46,749
3	11,786	35,358	1,875	20.4	38,250	70,124
4	11,786	47,144	1,875	27.2	51,000	93,498
5	11,786	58,930	1,875	34.0	63,750	116,873
6	11,786	70,716	1,875	40.8	76,500	140,247
7	11,786	82,502	1,875	47.6	89,250	163,622

Table 3.6: Cost of carbon sequestration project		
		Cost (US$)
Component 1:	Farm boundary tree planting	5,888,124
Component 2:	Private land enrichment programme	327,469
Component 3:	Community forest management	1,212,916
Total		**7,428,509**

According to MHC, unless it receives revenue from the CER sales, the project would not be financially viable for the company. Accordingly, because MHC would invest in the project only if CER revenues could be generated under the Clean Development Mechanism (CDM), the project could be financially additional.

MHC will target approximately 144,000 Gambians, or about 11% of The Gambia's total population of 1.33 million. According to MHC estimates, it is technically feasible for MHC to import, distribute, and market approximately 8,000 t LPG per year in The Gambia. Based on current per capita consumption of LGP in The Gambia (55.5 kg LPG/yr./person), the project therefore could technically switch 144,000 Gambians away from using fuelwood to using LPG instead. But it would not be feasible for MHC to supply LPG to a larger consumer group.

GHG Emissions in Base Case: Fuelwood

788,400 t fuelwood would be consumed over a 30-yr period:

144,000 * 182.5 kg fuelwood * 1.9 kg CO_2/kg fuelwood * 30 year = <u>1,497,960 t CO_2</u>

GHG Emissions in the Alternative: Large Scale LPG Project

144,000 * 55.5 kg LPG/yr.	7,992 t LPG/yr.
7.992 10^3 t LPG * 47,31 Terra Joule/1000 t	378 Terra Joule
378 Terra Joule * 17,2 t C/Terra Joule	6,502 t C
Conversion C to CO_2: 6,502 t C * 3.67	23,863 t CO_2
30 year lifetime: 30 * 23,863 t CO_2	<u>715,890 t CO_2</u>

Carbon Dioxide Savings

Base case - Alternative: <u>782,070 t CO_2</u>

Revenue from CER Sales

If assuming a CERs world price of US$5, the revenue from CER sales would amount to about $5/t CO_2 * 782,070 t CO_2 = **<u>US$ 3,910,350</u>**

CHAPTER 4

4: VULNERABILITY OF THE MAJOR ECONOMIC SECTORS AND ECOSYSTEMS OF THE GAMBIA TO PROJECTED CLIMATE CHANGE

4.1: Introduction

Stabilization of the concentrations of greenhouse gases in the atmosphere at all levels will eventually entail substantial reductions in CO_2 emissions. Long term stabilization of atmospheric CO_2 concentrations requires that net anthropogenic CO_2 emissions ultimately (over centuries) decline to the level of persistent natural sinks, which are expected to be less than 0.2 PgC/yr (IPCC WG I TAR, 2001). IPCC (2001) concludes that temperatures will continue to warm decades after the CO_2 concentrations have stabilized due largely to thermal inertia. As temperatures are projected to increase decades after stabilization of concentrations of CO_2, climate change will not be obviated and, therefore, adaptation will be necessary to minimize damages and to maximize opportunities.

4.2: Climate and Socio-economic Scenarios

4.2.1: Baseline climate scenarios

Forty years (1951-1990) of current climate data are used to develop the baseline climate scenarios (Table 4.2.1 and Figure 4.2.1) for The Gambia. The data was extracted from a window that included some meteorological stations in Senegal and its Casamance region, and hence values are slightly different from those containing only stations within The Gambia. During the 1951-1990 period, the behaviour of the climate of The Gambia and the Sahel in general, shows almost equal distribution of wet/cool and dry/warm years.

Table 4.2.1: Baseline climate scenarios of The Gambia

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann. Avg.
Mean Temperature (^{O}C)													
1951 - 1990	24.8	26.6	28.4	29.6	29.6	29.3	27.7	27.1	27.2	28	26.8	24.8	27.5
Minimum Temperature (^{O}C)													
1951 - 1990	16.3	17.6	19.6	20.9	22.6	23.9	23.7	23.4	23.1	22.8	19.8	16.7	20.9
Maximum Temperature (^{O}C)													
1951 - 1990	33.1	35.4	36.4	36.8	36.4	34.5	32.3	31.4	31.9	33.5	34.5	32.8	34.1
Rainfall (mm)													
1951-1990	0.2	0.4	0.0	1.2	12.1	87.4	202.0	281.0	215.0	73.8	6.3	0.4	878.7
Solar Radiation (w/m^2)													
1970 - 1985	232	272	289	295	286	263	235	233	244	256	241	218	255
Relative Humidity (%)													
1951 - 1990	43	42	44	48	55	67	78	82	82	76	61	50	61
Wind (knots)													
1951 - 1990	4	4	5	5	5	5	4	4	3	3	3	4	4
Potential Evapotranspiration (mm)													
1951 - 1990	165.6	175.2	231.6	226.8	210.0	174.0	160.8	151.2	141.6	148.8	141.6	145.2	2072.4

Source: Climatology and Agrometeorology Units, Department of Water Resources

As shown in Figures 4.2.1 and 4.2.2, the 1951-1980 period was wetter and relatively warmer while the 1961-1990 period was drier and cooler. Figure 4.2.1 clearly shows that between the two periods, the rainfall for the months of July and September have significantly decreased. It is for this reason that the 40-years period has been used instead of the 30-year (1961-1990) period. Selection of this period is expected to minimize bias.

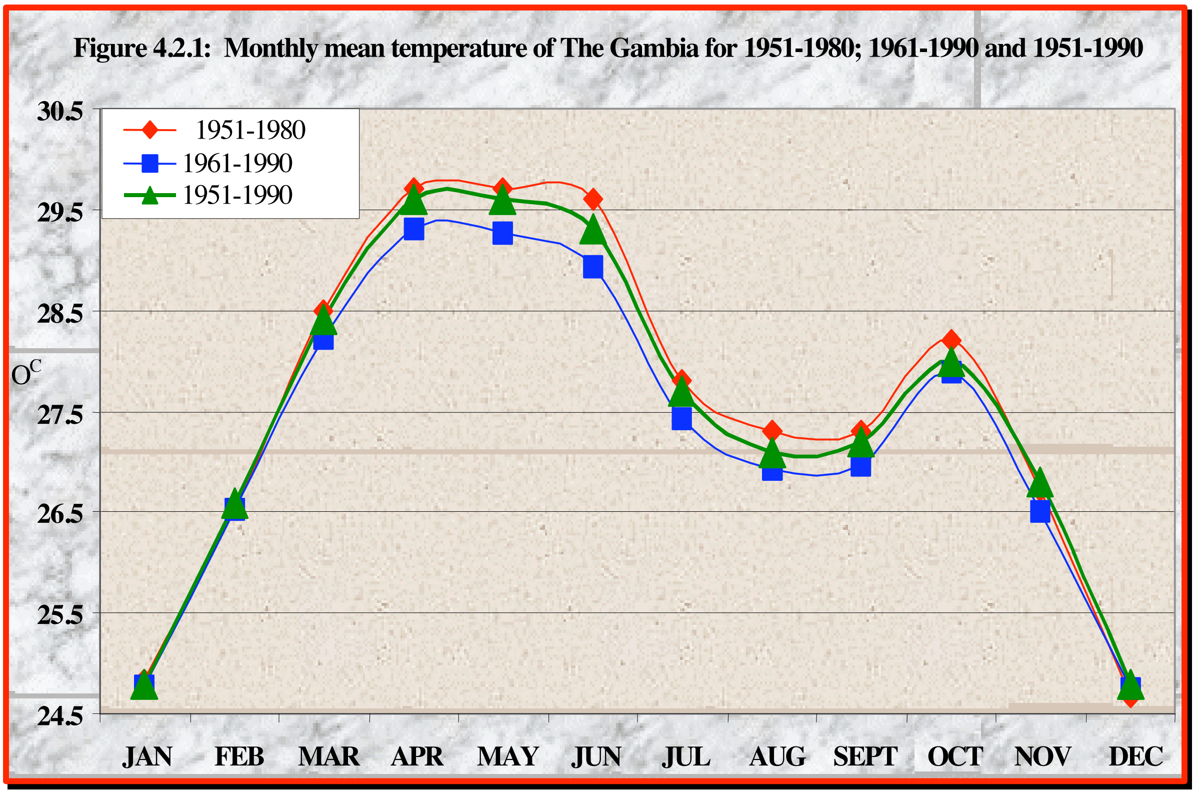


Figure 4.2.1: Monthly mean temperature of The Gambia for 1951-1980; 1961-1990 and 1951-1990

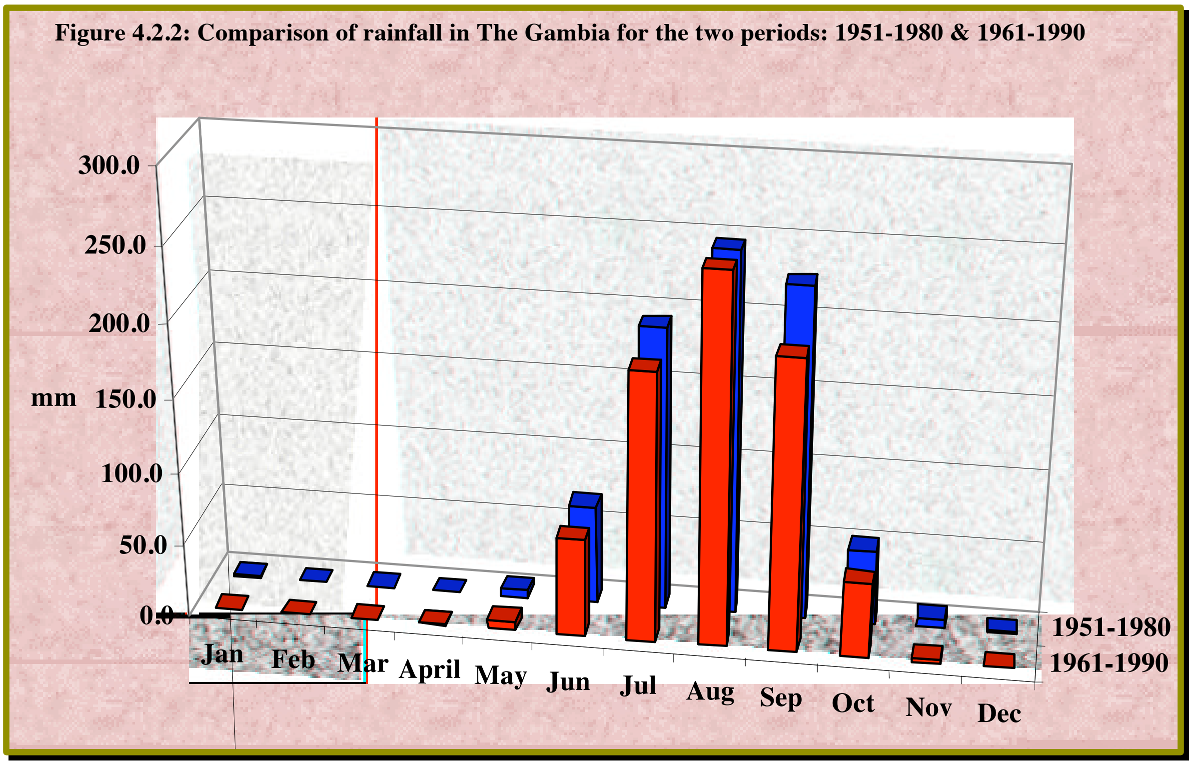


Figure 4.2.2: Comparison of rainfall in The Gambia for the two periods: 1951-1980 & 1961-1990

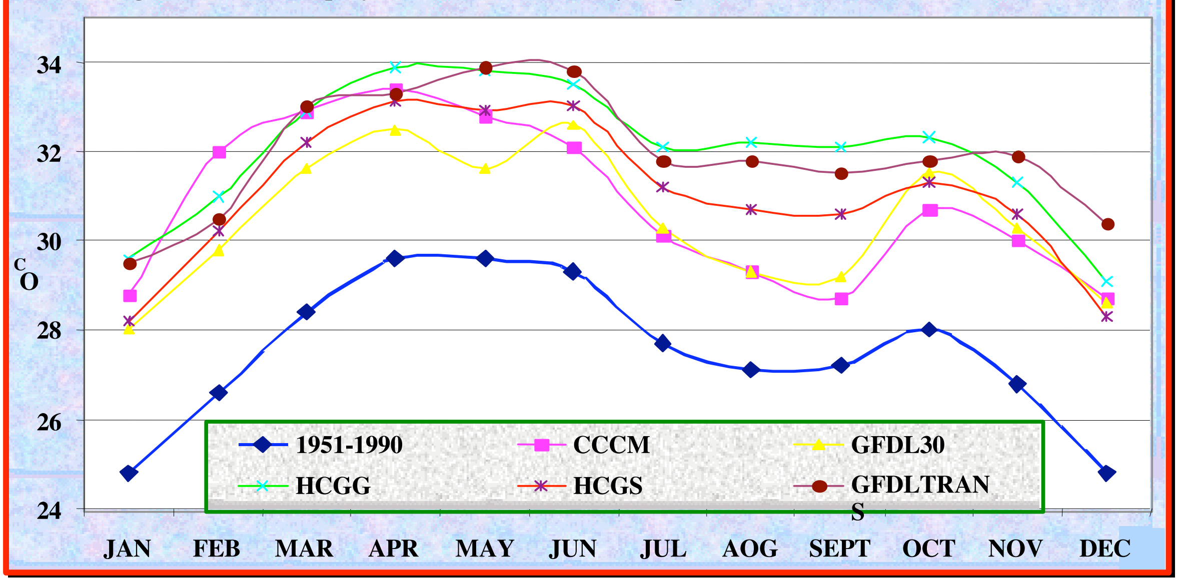
4.2.2: Climate change scenarios

In this study, the GRADS software was used to develop climate change scenarios. Only the equilibrium General Circulation Model (GCM) outputs are used to create the climate change scenarios. Outputs from five GCMs were run to obtain 1*CO_2 and 2*CO_2 outputs for temperature (and the difference 2*CO_2-1*CO_2), rainfall rates and solar radiation (and the ratio 2*CO_2/1*CO_2) for creating 2*CO_2 equilibrium scenarios. The models ran are the Canadian Climate Centre Model (CCCM, Boer et al., 1992), Goddard Institute for Space Studies (GISS, Hansen et al., 1983), United Kingdom Meteorological Office (UKMO, Wilson and Mitchell, 1987), the Geophysical Fluid Dynamics Laboratory (GFDL) equilibrium run (GFD3, Mitchell et al., 1990), and the Hadley Centre General Circulation Models with greenhouse gases alone (HCGG, Hagler Bailly Services, Inc, 1997), and with sulphate aerosols (HCGS, Hagler Bailly Services, Inc, 1997). The GFDL 1% transient model (GF01, Gates et al., 1992) was also ran just to visualize the transient behavior.

To choose the models that best estimated the climate of The Gambia, the 1*CO_2 temperature output from all the seven models was compared with the 1951-1990 temperature data (Table 4.2.1). The GFDL (equilibrium, GFDL30 and transient, GFDL01), CCCM, HCGG, and the HCGS models were the five models (Figure 4.2.3) that best approximated the climatology of The Gambia. Statistical analysis shows correlation coefficients of 0.84 for CCCM, 0.92 for GFDL30, 0.85 for GFDL01, 0.83 for HCGG and 0.81 for HCGS models. Only four GCM models (GFDL, CCCM, HCGG, and HCGS)[1] were recommended for use in the vulnerability study in The Gambia.

On the average, by 2075, mean temperature of The Gambia is projected to increase by 3°C to 4.5°C depending on the GCM used. By 2100 a decrease of 59% (HCGG), 17% (HCGS) and 15% (GFDL equilibrium model), and an increase of about 15% (GFDL01) and 29% (CCCM) about the 1951-1990 average rainfall amount are projected in The Gambia (Figure 4.2.4). Little change is estimated in solar radiation (-0.4% (GISS), -5% (GFDL-equilibrium), and 6% (UKMO)) and PET (+1% CCCM and GFDL-equilibrium, -5% HCGG and -3% HCGS).

Figure 4.2.3: Model projections of mean monthly temperature of The Gambia to 2100



[1] (GCM = General Circulation Model, GFDL = Geophysical Fluid Dynamic Laboratory, CCCM = Canadian Climate Change Model, HCGG = Hadley Centre with Greenhouse Gases, HCGS = Hadley Centre with Greenhouse gases and Sulphate aerosol.

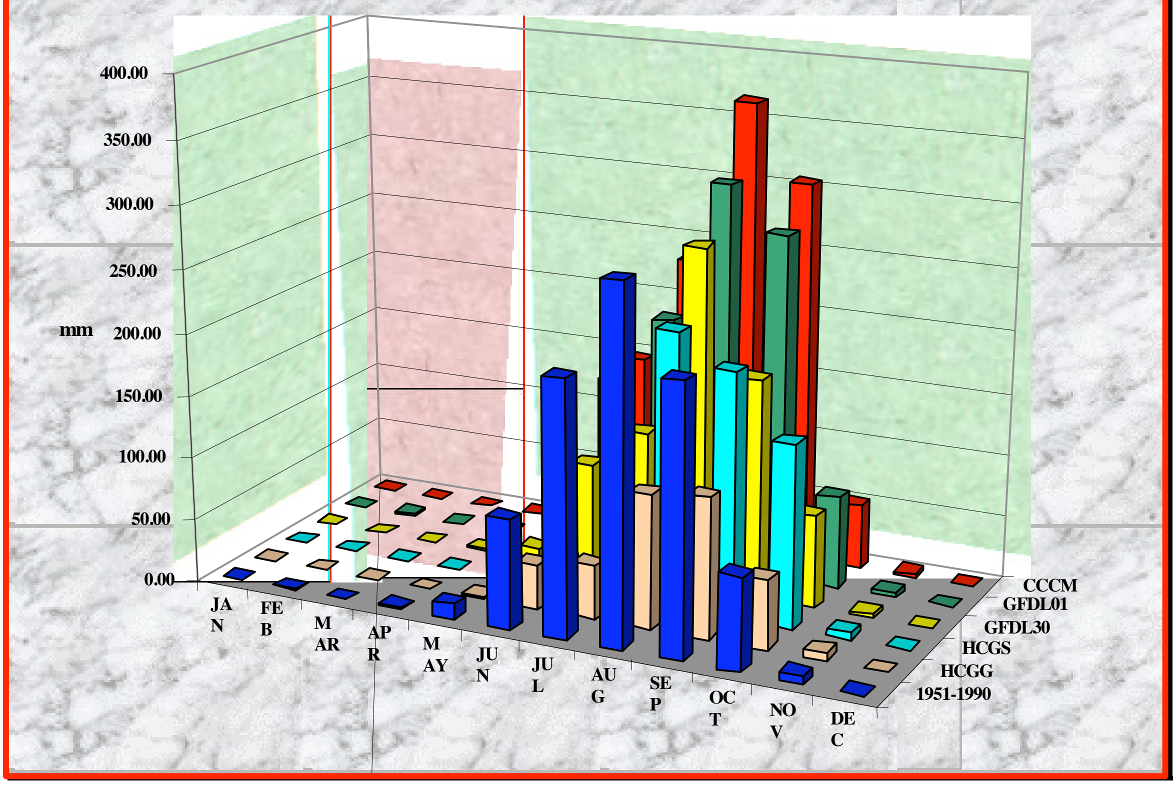


Figure 4.2.4: Projections of monthly rainfall of The Gambia under various models

CO_2 levels and Sea Level Rise Scenarios: A CO_2 concentration of about 330 parts per million (ppm) is assumed for the 1970s. Double CO_2 concentration levels of 540 - 580 ppm are likely to be achieved by 2075 and about 650 ppm by 2100. Sea level rise (SLR) scenarios adopted in this study are 0.2 m as baseline, and 0.5 m, 1.0 m, and 2.0 m by 2100 (IPCC, 1990).

Table 4.2.2: Atmospheric CO_2 concentrations and sea level rise scenarios

Year	CO_2 Concentrations (ppm)	Sea level rise	
1990	355		
1991-2000	376		
2001-2025	429	**Baseline**	0.2 m by 2100
2026-2050	502	**ASLR1**	0.5 m by 2100
2051-2075	580	**ASLR2**	1.0 m by 2100
2076-2100	646	**ASLR3**	2.0 m by 2100
ASLR is Accelerated Sea Level Rise			

4.2.3: Socio-economic scenarios

Assuming that population growth rate will remain at 4.0% for the first decade of the analysis period, 1.4% by 2075 and 0.8% by 2100, a population of about 8 million is estimated by 2075 and about 10 million by 2100 (Table 4.2.3). The GNP value of 2.87 million Dalasis for 1993 is projected to increase to 27.64 million Gambian Dalasis (US $ 3.037 million) in 2075 and 55.12 million Dalasis (US $ 6.058) by 2100. The GDP value of 2.95 billion Dalasis in 1993 grows to 14.27 billion Dalasi in 2075 and 18.3 billion Dalasi by the end of the century.

Table 4.2.3 Population and economic assumptions for The Gambia					
Year	**Population Assumptions (millions)**	**GNP Assumptions (10^6 Dalasi)**	**GNP per Capita (10^3 Dalasi)**	**GDP Assumptions (10^9 Dalasi)**	**GDP per Capita (10^3 Dalasi)**
1993	1.03	2.87	2.8	2.95	3.20
1994 - 2000	1.35	3.68	2.7	3.24	3.44
2001 - 2025	3.11	10.71	3.4	6.00	6.37
2026 - 2050	5.63	13.86	2.5	11.13	11.11
2051 - 2075	7.98	27.64	3.5	14.27	14.25
2076 - 2100	9.73	55.12	5.7	18.30	18.27

4.3: Impacts of Climate Change on Economic Sectors and Ecosystems

4.3.1: Agricultural crop production

4.3.1.1: Background to agricultural production

The Gambian economy is predominantly agrarian. The agriculture sector alone provides employment for about 75% of the labour-force, and an estimated two-thirds of total household income. These attributes make the sector a prime area for investments, if the nation's socio-economic development policy objectives of poverty alleviation and household food security are to be realized.

The sector is characterized by subsistence rain-fed, cash and food crops production and horticulture. Agro-industrial activity is mainly limited to groundnut milling, cereal processing, cotton ginning and sesame oil extraction. Gambian agriculture is dominated by food and cash crop production (contributing 60% of agricultural GDP and 14% of national GDP). Cereal crops, mainly millet (*Pennisetum spp.)*, sorghum (*Sorghum bicolor*), maize (*Zea mays*) and rice (*Oryza sativa)* account for 56 % of the cultivated land. Rice is the staple food and accounts for 25-35% of total cereal production. Groundnut is the main cash crop for the farming communities, and the prime export item, comprising 74% of the agricultural export items and 38% of the Agricultural GDP (AGDP). Other cash crops are cotton (*Gossypium*), sesame (*Sesamum indicum*) and horticultural crops (which hold the greatest potential for on-farm income and export earning augmentation). The short wet season limits production to one crop per year.

Environmental degradation is a serious problem arising from a combination of factors including: inappropriate land use practices, over-grazing of pasture lands, deforestation from over-felling of trees and bush fires, increased sediment flow and salinity in the lowlands and erosion in the uplands and along the coastline. Soil erosion on the upland and severe sedimentation in the lowland are grave. Fertile top soils are removed as runoff finds its way down the slope to the valley where the sediment load is deposited. No statistics are available on the annual rate of soil loss through water erosion but it is estimated that about 12.5 tons/ha/year are eroded from frequently cultivated soils with 2% slope (FAO Fertilizer Project, 1993). Wind erosion is a major problem in North Bank Division (NBD) where desertification is apparent.

4.3.1.2: Study methodology

The vulnerability and adaptation assessment started with a training workshop, which was followed by data and information collection on crops and crop management practices. To have location specific soils' data, soil specialists of the Soil and Water Management Unit (SWMU) of the Department of Agricultural Services (DAS) were contracted to conduct a study on soils in the study sites. Data on rainfall, solar radiation, temperature and sunshine hours were collected from the DWR.

Sites identified and used in a previous assessment (Jaiteh, 1997) were maintained for this study and they are Bakendik, Kuntaur, Giroba Kunda and Somita. These sites represented an area where one of the crops was predominantly cultivated. The climate change impact analysis of the crop production sub-sector of Agriculture made use of the GCM scenarios from the CCCM, GFDL30, HCGG and HCGS models. These scenarios, socio-economic data and crop production data were input into the DSSAT3 biophysical model to run the simulation of impacts of climate change.

4.3.1.3: Potential impacts of climate change on crop production

Maize

In Table 4.3.1.1a, the simulated water balance of the maize ecology shows that transpiration from the maize crop is estimated to decrease by a range of 8 to 76% of values under current climate conditions despite significant increases in rainfall under climate change scenarios. Also, runoff and drainage are estimated to increase, compared to the current climate values by amounts ranging from 58 – 98% and 48 – 84%, respectively.

Table 4.3.1.1a: Estimates of water balance parameters of maize at Giroba Kunda under current climate and climate change scenarios

Parameter (mm/crop/crop cycle)	Baseline	Model Estimates			
		CCCM	**GFDL**	**HCGG**	**HCGS**
Transpiration	426	110.8	102.2	362.1	391.9
(%) above/below Baseline		*-74*	*-76*	*-15*	*-8*
Rainfall	868	812	1316	1513	1645
(%) above/below Baseline		*-6*	*52*	*74*	*90*
Runoff	169	153	267.5	307.1	333.9
(%) above/below Baseline		*-9*	*58*	*82*	*98*
Extractable Water	434	406	658	756.5	822.5
(%) above/below Baseline		*-6*	*52*	*74*	*90*
Drainage	212	202.4	312.7	359.5	390.9
(%) above/below Baseline		*-5*	*48*	*70*	*84*

NB: Negative sign indicates that the estimate is below the baseline value

As runoff and drainage are estimated to increase under climate change scenarios, results of the nitrogen utilisation scenarios in Table 4.3.1.1b equally show that the nitrogen leached in climate change scenarios is estimated to be 21% (CCCM), 58% (GFDL), 81% (HCGG) and 98% (HCGS) higher than values under current climate conditions. Similarly, nitrogen uptake, total nitrogen in stems and leaves, and soil nitrogen are also estimated to be significantly lower than values under current climate. It should be noted from Table 4.3.1.1a above that both runoff and drainage are projected by CCCM to decrease by 9% and 5%, respectively under the climate change scenarios.

Table 4.3.1.1c shows that all the crop growth parameters (kg dm/ha) for the maize crop would undergo significant reductions under climate change, as demonstrated by the models used.

Table 4.3.1.1b: Estimates of nitrogen utilization parameters of maize at Giroba Kunda under current climate and climate change scenarios

Parameter (kg/ha)	Baseline	Model Estimates			
		CCCM	GFDL	HCGG	HCGS
Nitrogen Uptake	69	51	44	51	55
(%) above/below Baseline		*-26*	*-36*	*-26*	*-20*
Total Nitrogen (stem + leaf)	505	396	300	345	375
(%) above/below Baseline		*-22*	*-41*	*-32*	*-26*
Nitrogen Leached	43	52	68	78	85
(%) above/below Baseline		*21*	*58*	*81*	*98*
Soil Nitrogen	2432	2331	2188	2187	2734
(%) above/below Baseline		*-4*	*-10*	*-10*	*12*

NB: Negative sign indicates that the estimate is below the baseline value

Overall, grain weight is estimated to be 28% (CCCM), 31% (HCGG), 33% (HCGS) and 40% (GFDL) lower than current climate values. Leaf and stem weights are also expected to be lower than current climate values by amounts ranging from 18 – 35% and 17 – 34%, respectively. Though rainfall is estimated to increase under climate change scenarios, the total dry matter production of the maize crop would be lower than that under current climate conditions (Figure 4.3.1.1), as the crop (maize) is sensitive to fertilisation (nitrogen), and hence might be affected by the significant increases in the quantity of nitrogen leached, as well as the decrease in soil nitrogen, as climate changes. The nutritional value of the biomass products from maize will also be decreased due to the decrease in nitrogen content.

Table 4.3.1.1c: Estimates of growth parameters of maize at Giroba Kunda under current climate and climate change scenarios

Parameter (kg dm/ha)	Baseline	Model Estimates			
		CCCM	GFDL	HCGG	HCGS
Leaf Weight	578	472	376	432	470
(%) above/below Baseline		*-18*	*-35*	*-25*	*-19*
Stem Weight	1357	1057	900	1035	1125
(%) above/below Baseline		*-22*	*-34*	*-24*	*-17*
Root Weight	1048	741	765	880	956
(%) above/below Baseline		*-29*	*-27*	*-16*	*-9*
Grain Weight	2108	1520	1270	1461	1588
(%) above/below Baseline		*-28*	*-40*	*-31*	*-33*
Total Dry Matter Produced	5091	3790	3311	3808	4139
(%) above/below Baseline		*-26*	*-35*	*-25*	*-19*

NB: Negative sign indicates that the estimate is below the baseline value

Late Millet

A look at the water balance output on Table 4.3.1.2a below, will again reveal the significant difference in rainfall estimates between the GCM outputs and the biophysical models. Thus rainfall is estimated to be 28% (CCCM), 31% (GFDL), 47% (HCGG) and 69% (HCGS) higher than current climate estimates. From the above, it follows that runoff is estimated to be higher under climate change scenarios, than current climate by a range of 2 – 26%.

Drainage is also estimated to increase under climate change scenarios by a range of 3 – 31% over baseline conditions. Meanwhile extractable water is estimated to vary by a range of 9 – 36% higher in the climate change scenarios than over the baseline.

Figure 4.3.1.1: Estimates of total dry matter produced by the maize crop under current and climate change scenarios

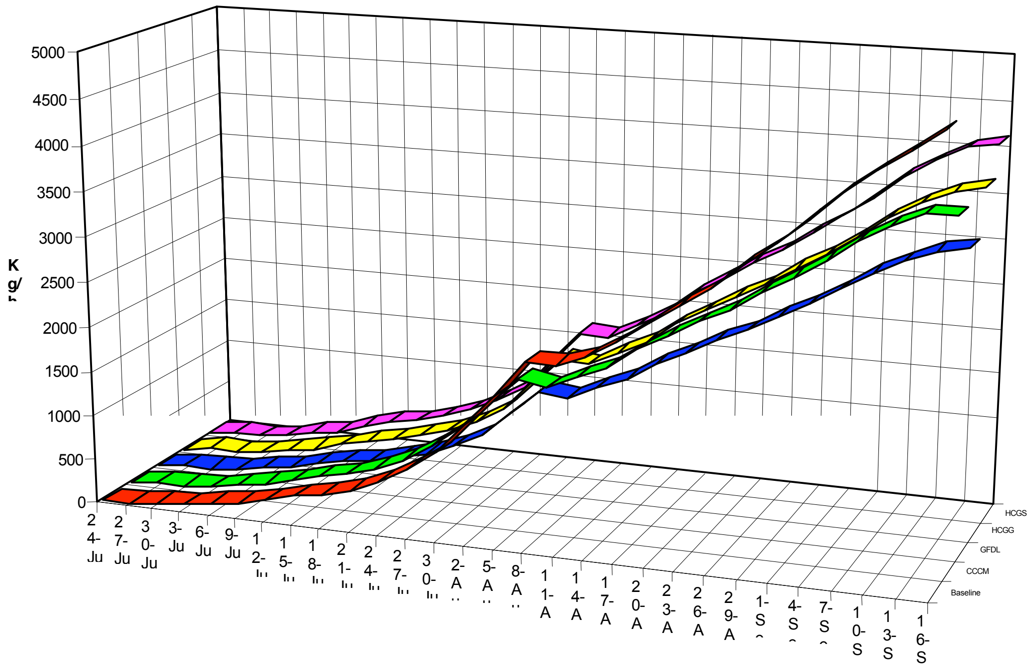


Table 4.3.1.2a: Estimates of water balance parameters of late millet at Somita under current and climate change scenarios					
Parameter (mm/crop/crop cycle)	**Baseline**	**Model Estimates**			
		CCCM	**GFDL**	**HCGG**	**HCGS**
Transpiration	398	294	322	412	430
(%) above/below Baseline		*-26*	*-19*	*4*	*8*
Rainfall	770	988	1009	1128	1302
(%) above/below Baseline		*28*	*31*	*47*	*69*
Runoff	186	191	194.8	209	234
(%) above/below Baseline		*2*	*5*	*12*	*26*
Extractable Water	459	501	515	546	625
(%) above/below Baseline		*9*	*12*	*19*	*36*
Drainage	218	225	230	249	285
(%) above/below Baseline		*3*	*5*	*14*	*31*
NB: Negative sign indicates that the estimate is below the baseline value					

Meanwhile, the results of soil fertilization in Table 4.3.1.2b show that both nitrogen uptake by the late millet crop and the total nitrogen content of the above-ground biomass are estimated to be significantly lower under climate change scenarios than the baseline conditions. Nitrogen uptake is estimated to decrease by a range of 26 – 41%, whilst aboveground nitrogen content is also estimated to decrease from 23 – 39%. Though soil nitrogen is not expected to vary much from current estimates, the amount of nitrogen leached is estimated to be 65% (CCCM), 72% (GFDL), 115% (HCGS) and 126% (HCGG) higher in climate change conditions than under current climate.

Table 4.3.1.2c and Figure 4.3.1.2, show that all the climate change scenarios project significant reductions in the growth parameters of late millet compared to the current climate.

Table 4.3.1.2b: Estimates of nitrogen utilization parameters of late millet at Somita under current and climate change scenarios

Parameter (kg/ha)	Baseline	Model Estimates			
		CCCM	GFDL	HCGG	HCGS
Nitrogen Uptake	111	78	66	73	82
(%) above/below Baseline		*-30*	*-41*	*-34*	*-26*
Total Nitrogen (stem + leaf)	92	66	56	68	70
(%) above/below Baseline		*-29*	*-39*	*-26*	*-23*
Nitrogen Leached	33	54	56	74	70
(%) above/below Baseline		*65*	*72*	*126*	*115*
Soil Nitrogen	67	71	73	67	85
(%) above/below Baseline		*6*	*9*	*-1*	*21*

NB: Negative sign indicates that the estimate is below the baseline value

Whilst total dry matter (leaf, stem, root and grain) produced is estimated to decrease by 25 - 44% under all the model scenarios, grain weight will be particularly affected as it is estimated to decrease by 29% (HCGG), 32% (HCGS), 35% (CCCM) and 46% (GFDL) below current climate estimates.

Table 4.3.1.2c: Estimates of growth parameters of late millet at Somita under current and climate change scenarios

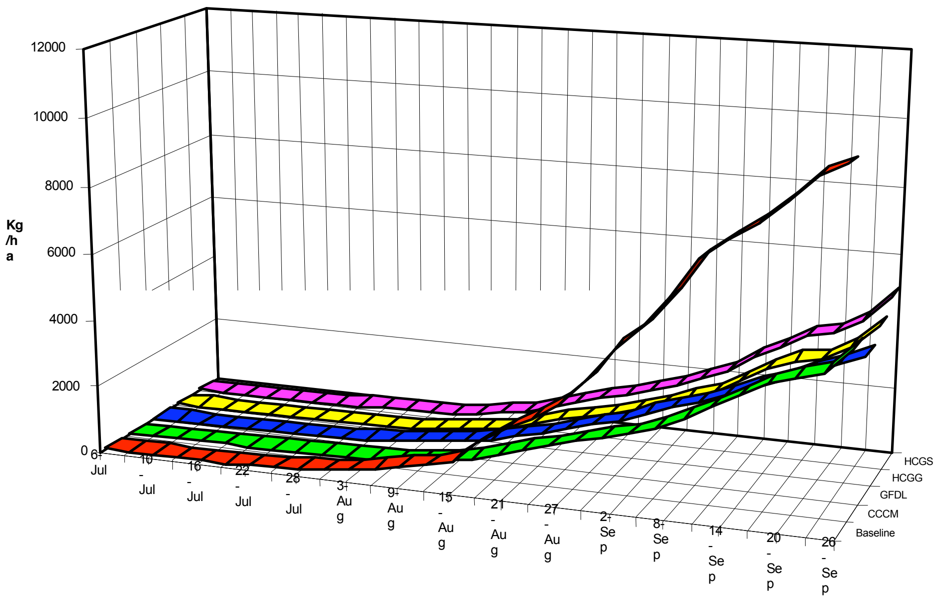
Parameter (kg dm/ha)	Baseline	Model Estimates			
		CCCM	GFDL	HCGG	HCGS
Leaf Weight	4402	2823	2092	3763	2615
(%) above/below Baseline		*-36*	*-53*	*-15*	*-41*
Stem Weight	8395	6385	5114	5877	6393
(%) above/below Baseline		*-24*	*-39*	*-30*	*-24*
Root Weight	744	536	424	567	530
(%) above/below Baseline		*-28*	*-43*	*-24*	*-29*
Grain Weight	2021	1318	1095	1444	1369
(%) above/below Baseline		*-35*	*-46*	*-29*	*-32*
Total Dry Matter Produced	15562	11062	8725	11629	10881
(%) above/below Baseline		*-29*	*-44*	*-25*	*-30*

NB: Negative sign indicates that the estimate is below the baseline value

Early Millet

In Table 4.3.1.3a below, the biophysical models project more rainfall and reduced transpiration (-17% under HCGG, -21% under GFDL, -22% under CCCM and -38% under HCGS) for early millet at Kuntaur under the climate change scenarios. Both runoff and drainage, however, are estimated to increase under climate change scenarios, by 8 - 56% and, 4 - 57% respectively, over current climate conditions. Thus extractable water available to the roots of the plants increases by 4 - 30%. The water balance results in Table 4.3.1.3a seem to corroborate the increase in water loss from the crop, through runoff and drainage.

Figure 4.3.1.2: Estimates of total dry matter produced by late millet under current and climate change scenarios



From Table 4.3.1.3b, nitrogen leached from the root zone is estimated to be 25% (HCGS), 85% (CCCM), 190% (GFDL) and 229% (HCGG) higher in climate change scenarios than under current climate. Hence nitrogen uptake and total nitrogen content of the plants are reduced below current climate estimates by 7 - 32% and 14 - 33% respectively.

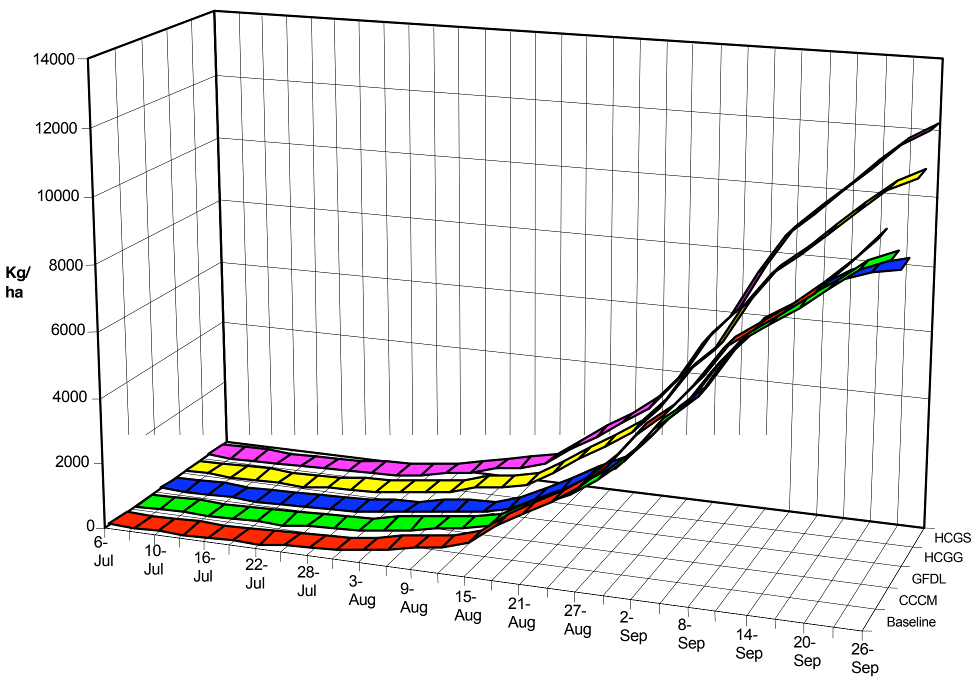
Table 4.3.1.3a: Estimates of water balance parameters of early millet at Kuntaur under current climate and climate change scenarios

Parameter (mm/crop/crop cycle)	Baseline	Model Estimates			
		CCCM	GFDL	HCGG	HCGS
Transpiration	322	252	255	268	200
(%) above/below Baseline		*-22*	*-21*	*-17*	*-38*
Rainfall	770	807	981	1164	1226
(%) above/below Baseline		*5*	*27*	*51*	*59*
Runoff	1561	169	191	241	244
(%) above/below Baseline		*8*	*22*	*54*	*56*
Extractable Water	385	400	471	488	502
(%) above/below Baseline		*4*	*22*	*27*	*30*
Drainage	183	190	236	270	288
(%) above/below Baseline		*4*	*28*	*47*	*57*
NB: Negative sign indicates that the estimate is below the baseline value					

Results of the growth parameters of the early millet crop in Table 4.3.1.3c below, suggest that total dry matter produced is estimated to be 1% (HCGS), 18% (CCCM), 19% (HCGG) and 21% (GFDL) lower under climate change scenarios than the baseline. Of these parameters, grain weight is estimated to be most affected with deviations from current climate conditions, ranging from 3 - 30%.

Table 4.3.1.3b: Estimates of nitrogen utilization parameters of early millet at Kuntaur under current and climate change scenarios					
Parameter (kg/ha)	**Baseline**	**Model Estimates**			
		CCCM	**GFDL**	**HCGG**	**HCGS**
Nitrogen Uptake	111	95	85	76	103
(%) above/below Baseline		*-14*	*-23*	*-32*	*-7*
Total Nitrogen (stem + leaf)	96	83	73	65	74
(%) above/below Baseline		*-14*	*-24*	*-33*	*-23*
Nitrogen Leached	16	29	46	52	20
(%) above/below Baseline		*85*	*190*	*229*	*25*
Soil Nitrogen	58	60	59	98	72
(%) above/below Baseline		*4*	*1*	*69*	*25*
NB: Negative sign indicates that the estimate is below the baseline value					

Figure 4.3.1.3: Estimates of total dry matter produced by early millet under current and climate change scenarios



Groundnut (peanut)

The results of the simulations of water balance in the groundnut ecology shown in Table 4.3.1.4a suggest increasing transpiration under climate change scenarios over the current climate, by amounts ranging from 5 - 25%. Runoff and drainage are also projected to increase. However, the increase in precipitation projected under all model simulations has meant that there is sufficient water available at the root zone to be extracted by the roots of the plants.

Table 4.3.1.3c: Estimates of growth parameters of early millet at Kuntaur under current and climate change scenarios					
Parameter (kg dm/ha)	**Baseline**	**Model Estimates**			
		CCCM	**GFDL**	**HCGG**	**HCGS**
Leaf Weight	4141	3272	3145	2406	4090
(%) above/below Baseline		*-21*	*-24*	*-42*	*-1*
Stem Weight	5940	5110	5001	5881	6387
(%) above/below Baseline		*-14*	*-16*	*-1*	*8*
Root Weight	635	493	481	487.6	616
(%) above/below Baseline		*-22*	*-24*	*-23*	*-3*
Grain Weight	1610	1256	1123	1259	1570
(%) above/below Baseline		*-22*	*-30*	*-22*	*-3*
Total Dry Matter Produced	12326	10131	9750	10034	12164
(%) above/below Baseline		*-18*	*-21*	*-19*	*-1*
NB: Negative sign indicates that the estimate is below the baseline value					

Table 4.3.1.4a: Estimates of water balance parameters of groundnut at Bakendik under current climate and climate change scenarios					
Parameter (mm/crop/crop cycle)	**Baseline**	**Model Estimates**			
		CCCM	**GFDL**	**HCGG**	**HCGS**
Transpiration	400	420	456	460	500
(%) above/below Baseline		*5*	*14*	*15*	*25*
Rainfall	672	787	848	773	840
(%) above/below Baseline		*17*	*26*	*13*	*25*
Runoff	114	124	134	131	141
(%) above/below Baseline		*8*	*17*	*15*	*23*
Drainage	177	201	214	194	202
(%) above/below Baseline		*13*	*21*	*9*	*14*
Extractable Water	336	390	417	390	414
(%) above/below Baseline		*16*	*24*	*16*	*23*
NB: Negative sign indicates that the estimate is below the baseline value					

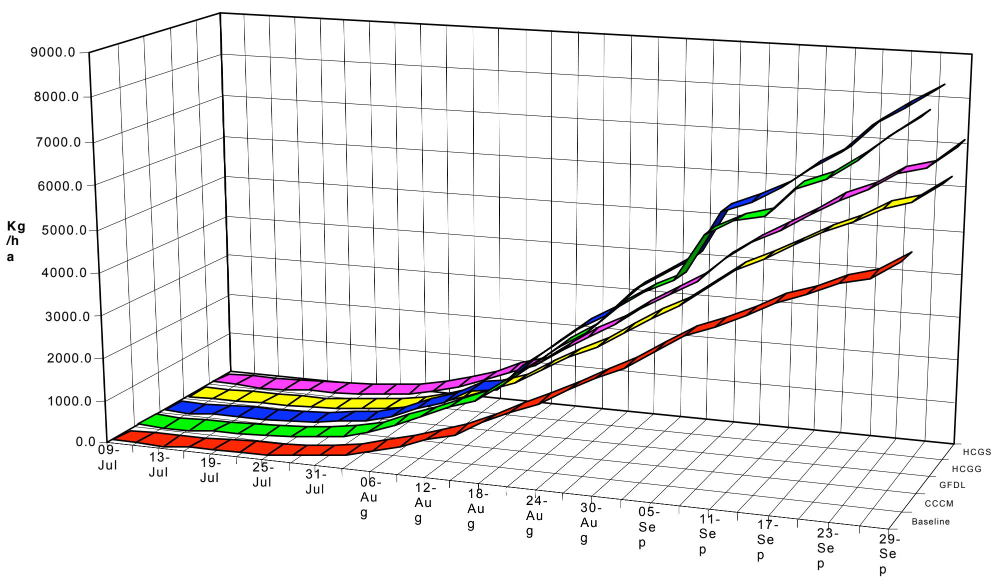
With regard to nitrogen utilization, Table 4.3.1.4b shows that nitrogen uptake is estimated to be 3% (CCCM), 7% (GFDL), 14% (HCGG) and 25% (HCGS) higher under climate change scenarios than under the current climate conditions. Although the quantity of nitrogen fixed is estimated to increase significantly under climate change scenarios, soil nitrogen is estimated to decrease slightly under projected climate change conditions than under current conditions. This could be attributed to the fact that the amount of nitrogen leached under climate change conditions as compared to the baseline is quite significant.

Simulation of growth of groundnut (Table 4.3.1.4c) suggests that groundnut production would be more favourable with climate change than under current climate scenarios. All growth parameters are estimated to be significantly higher under climate change scenarios, with grain weight (Table 4.3.1.4c) estimated to increase by 9% to 25% above the current climate's production. Total dry matter production increases by 15 to 47% under climate change over current climate scenarios.

Table 4.3.1.4b: Estimates of nitrogen utilization parameters of groundnut at Bakendik under current and climate change scenarios					
Parameter	**Baseline**	**Model Estimates**			
		CCCM	**GFDL**	**HCGG**	**HCGS**
Nitrogen Uptake	91	94	98	105	114
(%) above/below Baseline		*3*	*7*	*14*	*25*
Total Nitrogen (stem + leaf)	119	178	183	136	146
(%) above/below Baseline		*50*	*55*	*15*	*23*
Nitrogen Leached	22	21	24	25	28
(%) above/below Baseline		*-3*	*9*	*15*	*25*
Soil Nitrogen	56	53	55	50	55
(%) above/below Baseline		*-5*	*2*	*-11*	*-3*
Nitrogen Fixed (Cumulative)	142	227	241	163	177
(%) above/below Baseline		*60*	*70*	*15*	*25*
NB: Negative sign indicates that the estimate is below the baseline value					

Table 4.3.1.4c: Estimates of growth parameters of groundnut at Bakendik under current and climate change scenarios					
Parameter (kg dm/ha)	**Baseline**	**Model Estimates**			
		CCCM	**GFDL**	**HCGG**	**HCGS**
Leaf Weight	1867	2735	2845	2147	2334
(%) above/below Baseline		*46*	*52*	*15*	*25*
Stem Weight	3857	5829	6000	4442	4829
(%) above/below Baseline		*51*	*56*	*15*	*25*
Root Weight	474	661	697	545	592
(%) above/below Baseline		*39*	*47*	*15*	*25*
Grain Weight	1752	1911	2146	2015	2190
(%) above/below Baseline		*9*	*22*	*15*	*25*
Total Dry Matter Produced	7950	11136	11688	9149	9945
(%) above/below Baseline		*40*	*47*	*15*	*25*
NB: Negative sign indicates that the estimate is below the baseline value					

Figure 4.3.1.4: Estimates of total dry matter produced by the groundnut crop under current and climate change scenarios



4.3.1.4: Potential adaptation measures

1. Select drought, pest and disease, weed, salinity resistant and high yielding crop varieties for the local conditions. For this purpose the genetic potential of local crop species must be investigated and specimens stored in seed banks,

2. Enhance and maintain soil fertility, to improve the economic water consumption for agriculture,

3. Change planting dates and replace long duration upland & lowland crop varieties for short duration varieties,

4. Restructure present irrigation system through the use of sprinkler and drip irrigation system with the objective of reducing water consumption and wastage;

5. Introduce and promote integrated agricultural management system, which will provide the improvement and application of innovative agricultural technologies that will increase the efficiency of agriculture,

6. Develop early warning system to inform farmers and other stakeholders on possible climate change and its impact on agriculture and to sensitise them in order to be ready to implement the adaptation measures,

7. Introduce, promote and encourage the adoption and diffusion of improved post harvest technologies that will reduce post-harvest losses in the field and in storage. This will have the long-term effect of reducing extensive cultivation of marginal lands.

4.3.2: Biodiversity and wildlife

4.3.2.1: Background on biodiversity and wildlife

The small size of The Gambia (~11,000 km^2) makes it very difficult to get an adequate home range of many faunal species, especially the big game, and as a result they cannot be found in the wild. Many parts of the country have already been devoid of forests. Only 42% of the country is covered with forest and this includes the seven Protected Areas (PAs) of the country.

The study is located in the first protected area to be established in The Gambia, Abuko Nature Reserve, which was gazzetted in 1968. Due to growing awareness about the importance of conserving what remained of the country’s flora and fauna, the Government created a Wildlife Conservation Unit under the DOF. This Unit was upgraded into a government department (Department of Wildlife Conservation) in 1977 and re-designated in 1994 to the Department of Parks & Wildlife Management (DPWM) to reflect its widening role into wildlife management as well as conservation. As well as being accountable for the management, administration and development of The Gambia’s seven PAs, the department also handles all matters relating to wildlife conservation and management. This includes the enforcement of the 1977 Wildlife Act, which prohibits the sale of wildlife products and the keeping of wild animals in captivity. The department also controls and monitors hunting activities in the country.

The current checklist of animals in The Gambia, compiled by Barnett and Emms (2000) indicates that there are 104 mammal species. However, certain species such as the African Lion, Wild Cat, Red River Hog, Roan Antelope and Red-fronted Gazelle have become extinct. The checklist further indicates that there are 549 bird species, 59 reptile species (with 32 snake species) and finally 27 amphibian species.

To date, PAs comprise more than 4% of the total area of The Gambia (Table 4.3.2.1). The latest wildlife policy aims at increasing this to 5% with a proportional regional distribution. The parks and reserves of The Gambia have been specially chosen for the endangered nature of the habitat type and/or species found within them. The intention is to provide a safe haven for flora and fauna to flourish without undue interference from human beings. A limited range of resource utilisation by local communities is permitted, provided this is compatible with the aims and objectives of the PA concerned.

4.3.2.2: Impacts of climate change on habitat and species

The methodology used involves the application of the Habitat Suitability Index (HSI) model developed by the United States Fisheries and Wildlife Department (USFWD). HSI is a software package that combines cover-types and sub-area cover-types with their respective lexicon variables. Cover-type refers to the surface cover (water, vegetation, sand, rocks, etc.) of the study site and the parameters are in-built in the software. Initially, 10 animal species (fauna and avi-fauna) were entered as model inputs covering an associated 20 cover-types (with sub-area cover-types).

The type of fauna species used in the study include Bushbuck, Dwarf Crocodile and Green Sea Turtle while the avi-fauna include Bateleur, African Spoonbill, Turaco, Crowned Crane, Great White Egret, Sacred Ibis and Osprey. These species were selected based on their similarity (phenotypically) with some of the 120 animal species used to develop the HSI model. Most of the values entered for the variable lexicons as input are default values primarily due to lack of required data. However, successful parameterization and results under the current temperatures were obtained for only 5 species namely: Dwarf Crocodile, Great white Egret, Osprey, Bushbuck and Turaco (Table 4.3.2.2).

Table 4.3.2.1: Protected areas of The Gambia under DPWM

Protected Areas	Area (ha)	Location
Abuko Nature Reserve	134	Western Division
Tanji River (Karinti) Bird Reserve	612	Western Division
Bao-Bolong Wetland Reserve	22,000	North Bank Division
Kiang West National Park	11,526	Lower River Division
River Gambia National Park	589	Central River Division
Nuimi National Park	4,940	North Bank Division
Tanbi Wetland Complex	6,000	Western /Kombo St. Mary's Divisions

Source: DPWM, 2001

Analysis shows that the HSI values for the species studied range from 0.029 to 1.0. For this study, a HSI score of more than 0.5 is regarded as a conducive habitat for the species studied, while HSI values less than 0.5 are regarded as unfavourable. From the results obtained, it can be said that the status of habitats under the projected climate change are highly favourable for *Bushbuck,* especially within the PAs (Table 4.3.2.2). This is followed by habitats for *Great White Egret*, and *Turaco*.

The suitability of the habitats for the *Dwarf Crocodile* and *Osprey* species will be highly reduced under the projected climate change scenarios. Migratory species such as the Osprey may be especially vulnerable because they require separate breeding, wintering, and migration habitats. In many cases, one or more of these habitats could be at risk because of climate change and other reasons.

Table 4.3.2.2: List of species, annual average current and model projected temperatures and HSI

Species	Annual average temperature (°C)				Habitat Suitability Index			
	Current	GFDL	HCGG	HCGS	Current	GFDL	HCGG	HCGS
Dwarf Crocodile	27.0	28.5	29.5	31.0	0.326	0.326	0.581	0.326
Great White Egret	27.0	28.5	29.5	31.0	0.845	0.845	0.845	0.845
Osprey (riverine)	27.0	28.5	29.5	31.0	0.029	0.029	0.144	0.029
Bushbuck	27.0	28.5	29.5	31.0	1.000	1.000	1.000	1.000
Turaco	27.0	28.5	29.5	31.0	0.734	0.734	0.545	0.734

4.3.2.3: Potential adaptation options

Various strategies are available to help conserve wildlife and biodiversity. These include the establishment and maintenance of PAs (in situ conservation), active management of wild populations outside PAs (inter situ), and maintenance of captive populations (ex situ methods) (IPCC, 1996). Of these, the highest priority should be placed on in-situ and inter-situ conservation.

The adaptation strategy should be developed within the context of global, regional and national biodiversity conservation priorities. A large number of habitat management and intervention techniques can be used as part of an overall adaptation strategy. Many habitat management and intervention techniques are already in use in PAs managed by DPWM and the techniques themselves can be adopted for use under a new set of climatic conditions. The following adaptation measures are recommended:

1. Develop strategies that seek to maintain ecological structure and processes, maximise evolutionary and ecological potential in species and ecosystems, and increase ecological resilience;
2. Maximise reserve connectivity, size, and number; discourage fragmentation and encourage corridors that will serve as habitat migration lanes; and
3. Adopt flexible zoning of reserve boundaries and develop more effective buffer zone management.

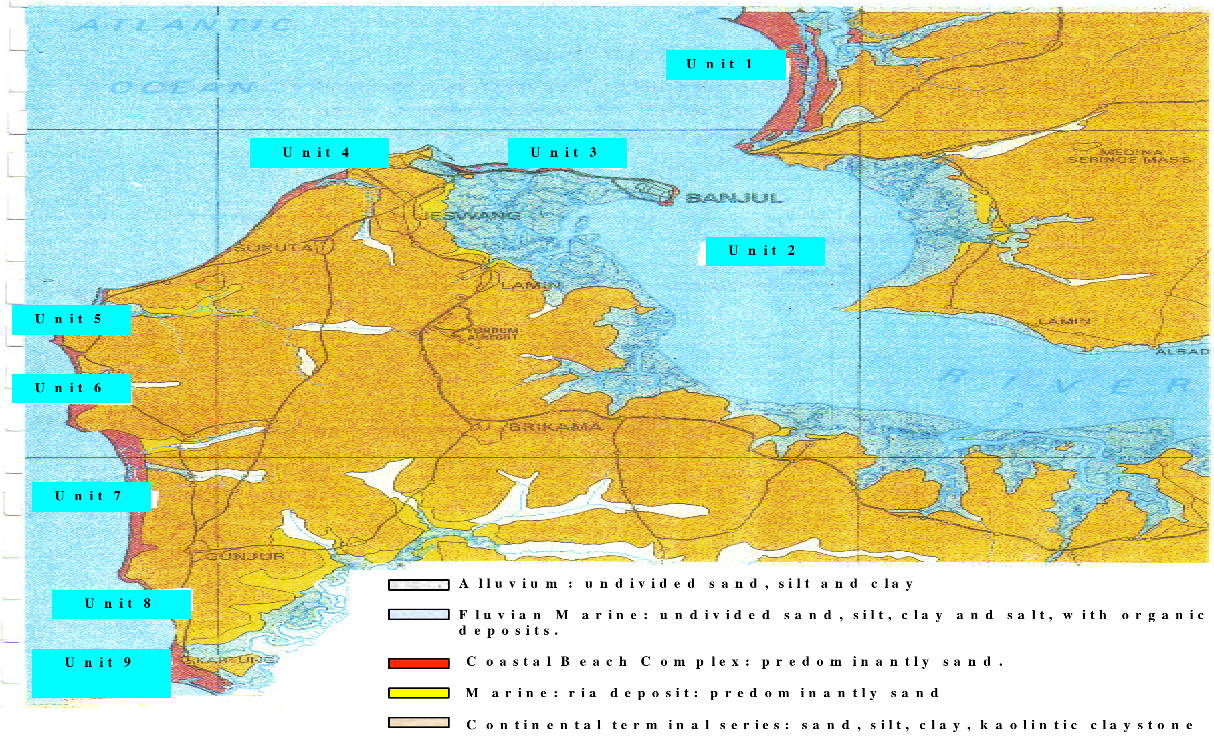
4.3.3: Coastal zone and resources

4.3.3.1: Background on the coastal zone

The coastal one of The Gambia extends 80 km from Buniadu Point and the Karenti Bolong in the north, to the mouth of the Allahein River in the south (Figure 4.3.3.1, Whyte and Russel, 1988). It has 70 km of open ocean coast and about 200 km of sheltered coast along The Gambia River. The sheltered coast is dominated by extensive mangrove systems (66,900 ha), and mud flats. Only about 20 km of the coastline is significantly developed and this includes

Banjul (the capital city), Bakau and Cape St. Mary, Fajara and the Tourism Development Area (TDA).

Figure 4.3.3.1: Geological Map of the Coastal Zone of The Gambia (The Coastal Zone is divided into Units)



Thirteen hotels and tourist resorts have been built on this stretch of the coastline. Elsewhere, the coastline is largely underdeveloped except for some fish landing sites and cold storage infrastructure used to process and store fish and shrimps. The coastal zone contributes significantly to the economy of The Gambia. During the period of October to May, The Gambia receives more than 100,000 tourists, all beach resorts and hotels are operational, and the industry is estimated to employ about 100,000 people either directly or indirectly.

4.3.3.2: Impacts of climate change on the coastal zone

As shown in Table 4.3.3.1, it is projected that about 92 km^2 of land in the coastal zone of The Gambia will be inundated as a result of 1-metre sea level rise. About 50% (47 km^2) of the total land loss due to inundation will be on the sheltered coast. It is evident that with a 1-metre sea level rise, the whole of the capital city of Banjul will be lost due to the fact that the greater part of the city is below 1 m (Figure 4.3.3.2). The mangrove systems on St. Mary's Island, Kombo St. Mary and on the strand plains in the north bank from Barra to Buniadu Point will be lost. About D1,950 billion (217 million US Dollars) worth of land will be lost.

Inundation will be followed by shoreline retreat which would vary along the coast from 102 m in the harder cliffted zone between Cape Point and Fajara, to 839 m in the gently sloping, sandy strand plain near Sanyang Point (Table 4.3.3.2).

Table 4.3.3.1: Potential area (km²) of land to be inundated in the coastal zone of The Gambia in response to various sea level rise scenarios				
Coastal Unit	**Sea level rise scenarios (m/century)**			
	0.2	**0.5**	**1.0**	**2.0**
Unit 1	0.56	14.06	28.12	56.25
Unit 2	0.94	23.40	46.87	93.75
Unit 3	1.56	3.90	7.80	17.63
Unit 4	**Cliff Zone**			
Unit 5	0.01	0.03	0.05	0.20
Unit 6	0.41	1.01	2.03	2.89
Unit 7	0.27	0.67	1.34	1.81
Unit 8	0.03	0.08	0.17	0.17
Unit 9	1.19	2.69	5.93	8.85
Total	4.96	45.89	92.32	181.55

Note: Unit 1 = Senegal Border to Barra Point, Unit 2 = the Gambia River Basin, Unit 3 = Banjul Point to Cape St. Mary, Unit 4 = Cape St Mary to Fajara, Unit 5 = Fajara to Bald Cape, Unit 6 = Bald Cape to Solifor Point, Unit 7 = Solifor Point to Benchmark KM125, Unit 8 = Benchmark KM125 to Kartong Point and Unit 9 = Kartong Point to Allehein River

Table 4.3.3.2: Application of the Bruun Rule to project land retreat and rate of beach erosion on the open coasts of The Gambia in response to 1 m sea level rise							
Coastal Unit	**d* (m)**	**G**	**L**		**B (m)**	**S**	**Retreat (m)**
			Map (cm)	**Actual (m)**			
Unit 1	5.9	1	3.5	2610.5	2.0	1	330.4
Unit 2	**No estimation because this is in the sheltered coast**						
Unit 3	5.9	1	3.0	2284.2	2.7	1	275.6
Unit 4	5.9	1	1.6	1232.5	6.1	1	102.2
Unit 5	5.9	1	2.8	2080.8	2.7	1	264.1
Unit 6	5.9	1	8.6	6475.5	1.8	1	839.2
Unit 7	5.9	1	6.8	5098.3	3.0	1	597.2
Unit 8	**No estimation due to lack of data**						
Unit 9	**No estimation due to lack of data**						

Note: d* = depth of closure; G = overfill ratio; L = active profile width; B = dune or cliff height; S = scenario R = retreat of land. Unit specification are as in Table 1

Plates 1 to 8 below indicate the physical damage on structures on the coast. All the damages shown are located between Toll Point at Sarro and the city of Banjul. This is also the area on the coast where erosion is most worrying. Figure 4.3.3.3 attempts to explain the critical erosion phenomenon in this part of the coast. The development of a lagoon and a Sand Spit has meant that the Cemetery and the city of Banjul are sand-starved. Sand is trapped by the sand spit and does not flow to the areas east of the spit and the lagoon. This means that the massive loss of sand at the cemetery due to erosion is not replaced. The sand eroded from the Cemetery finds its way to the Gambia Ports Authority (GPA) and the Ferry Terminal, thus causing navigational problems.

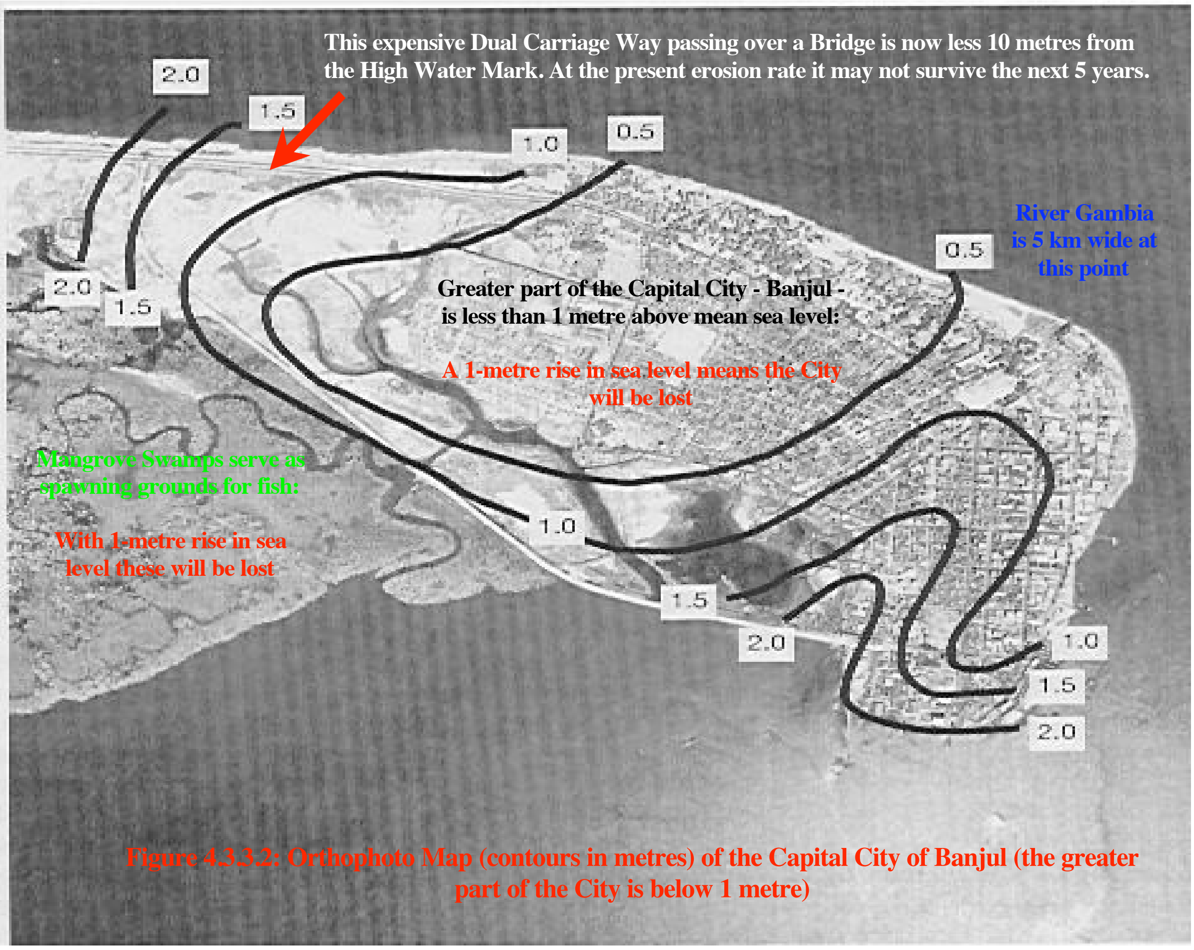
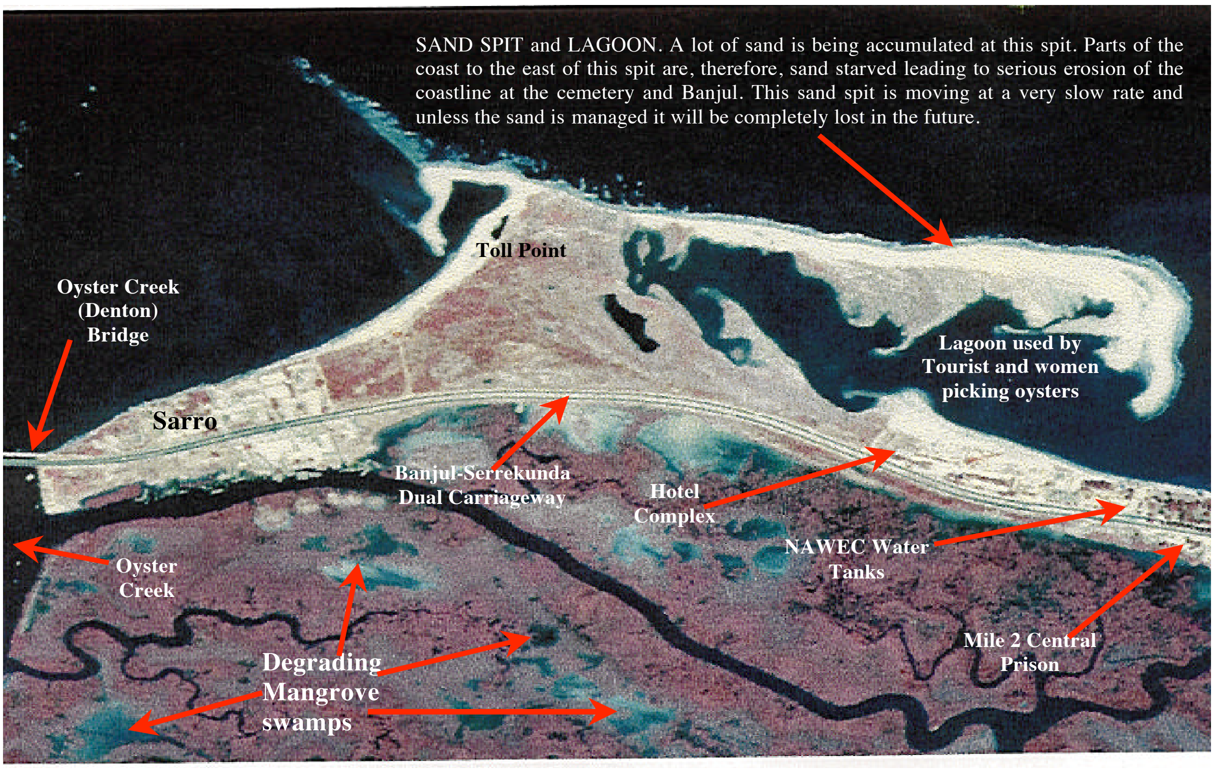


Figure 4.3.3.2: Orthophoto Map (contours in metres) of the Capital City of Banjul (the greater part of the City is below 1 metre)

Figure 4.3.3.3: Sand Spit and Lagoon



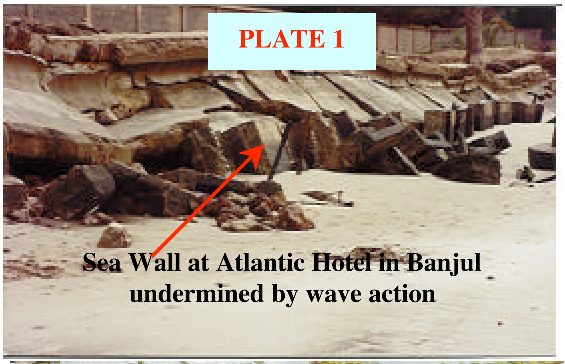


PLATE 1

Sea Wall at Atlantic Hotel in Banjul undermined by wave action

PLATE 2

The Banjul-Serrekunda Dual Carriage Way is now less than 10 metres from the high-water mark. Motorists have experienced running over water from the sea during high tide.

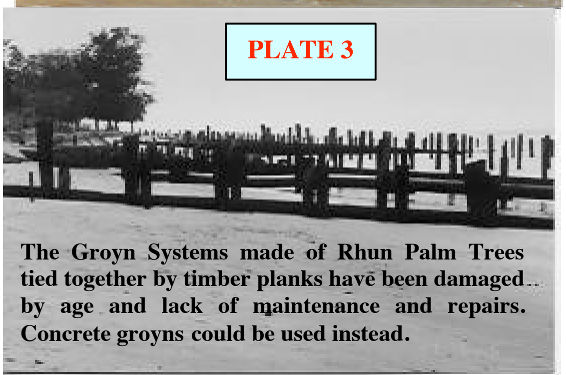


PLATE 3

The Groyn Systems made of Rhun Palm Trees tied together by timber planks have been damaged by age and lack of maintenance and repairs. Concrete groyns could be used instead.

PLATE 4

The Banjul Community headed by the Imam, used community participation to try some sea defense technology. This was not enough to salvage the graves.

PLATE 5

Another Sea Defense technology tried but poorly constructed with ineffective material. Engineering design may not have considered wave statistics.

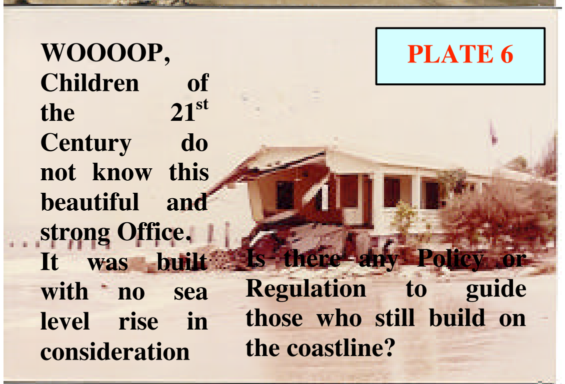


PLATE 6

WOOOOP, Children of the 21st Century do not know this beautiful and strong Office. It was built with no sea level rise in consideration

Is there any Policy or Regulation to guide those who still build on the coastline?

PLATE 7

WOW, Suicide or Desparation!!!!!!!!!!!!!!!! This looks very much like RADIO SYD, going at 909 kilocycles per second

PLATE 8

Erosion is changing the sandy beaches to rocky beaches. This will affect Tourism in The Gambia as Tourists love sandy beaches

Figure 4.3.3.4 shows a closer view of the small channel that has developed between the Sand Spit (Figure 4.3.3.3 above) and the mainland. The lagoon fills and empties through this channel. The existence of this channel causes the sand spit to be continuously disconnected from the mainland. The result is that the sand spit continuous to move eastward but at a very slow rate and so erosion to the east of it always remains severe.

Figure 4.3.3.4: Close view of sand spit, channel and main land close to the NAWEC water tanks and Mile 2 Central Prison

4.3.3.3: Response strategies and adaptation options

Response strategies

In the coastal zone of The Gambia, the suggested response to sea level rise and particularly to coastal erosion is to protect only the important areas between Banjul and Cape Point and areas around the Hotel Complex from Kairaba to Kololi Beach Hotel. The following shoreline hardening and stabilization techniques could be used to protect these areas.

i) <u>Rehabilitation of the groyne system</u>

Groynes are a major technique of beach stabilization in Africa, whereby trunks of rhun palm trees are jetted into the beach and tied together with timber. They are also constructed from re-enforced concrete, as on the Maputo shoreline in Mozambique. They are easy to build, fairly cost effective and locally hold the beach or capture more sand in the longshore sediment transport (LST) system. They do not "create" new sand but merely redistribute the sand along the beach. Groynes have been found to be very effective in stabilizing eroded beaches particularly in the Republic of Togo, West Africa (Blivi, 1993). In The Gambia, the existing groynes in the area between Laguna Beach/Palm Grove Hotels and Banjul Point (Figure 4.3.3.5 below) need to be rehabilitated. To reduce the flow of sand to the Port and Ferry Terminal, a long and high terminal groyne must be constructed at Banjul Point between State House and Albert Market. This terminal groyne must not be filled with sand so that the LST is halted or reduced for some period of time.

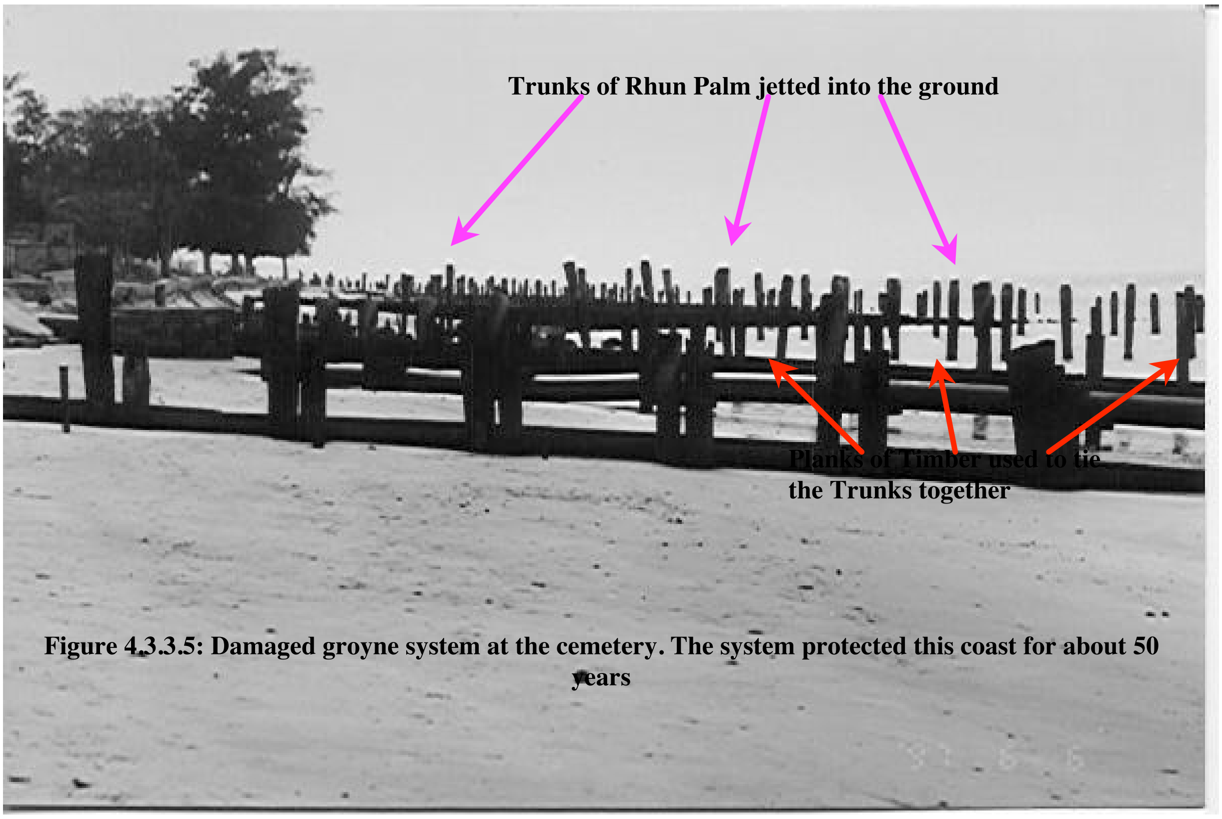


Figure 4.3.3.5: Damaged groyne system at the cemetery. The system protected this coast for about 50 years

ii) <u>Construction of breakwater system</u>

Another shoreline stabilization technique that could be useful in the protection of the sandy beaches of The Gambia is the **Breakwater System** (Figure 3.3.3.6). Breakwater Systems have the ability to reduce the strength of breaking waves coming onshore, reduce their impact on the shoreline and thus reduce the quantity of sand eroded.

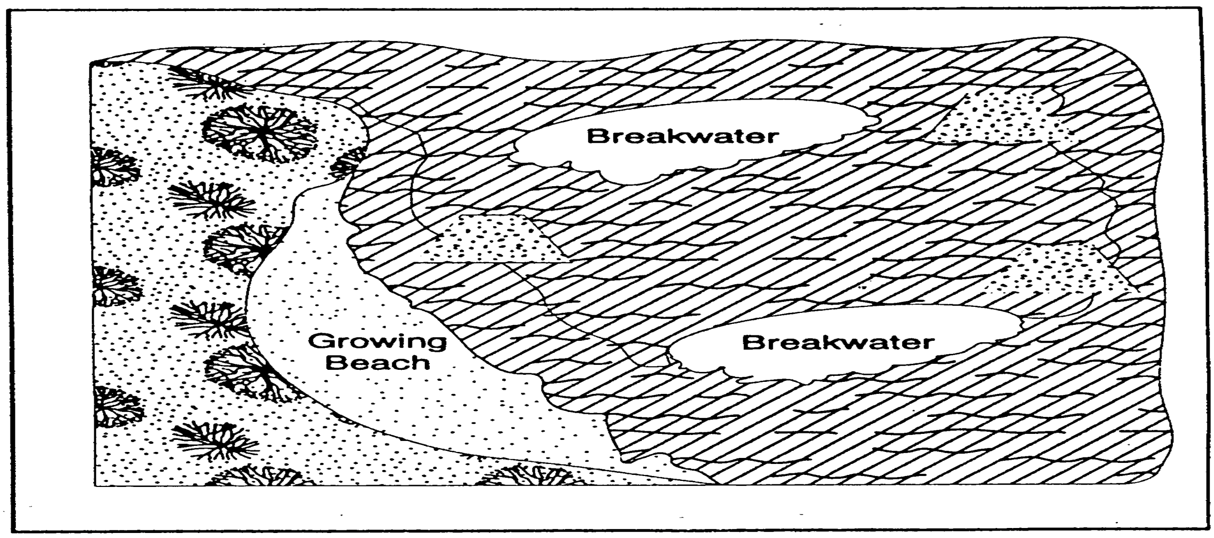


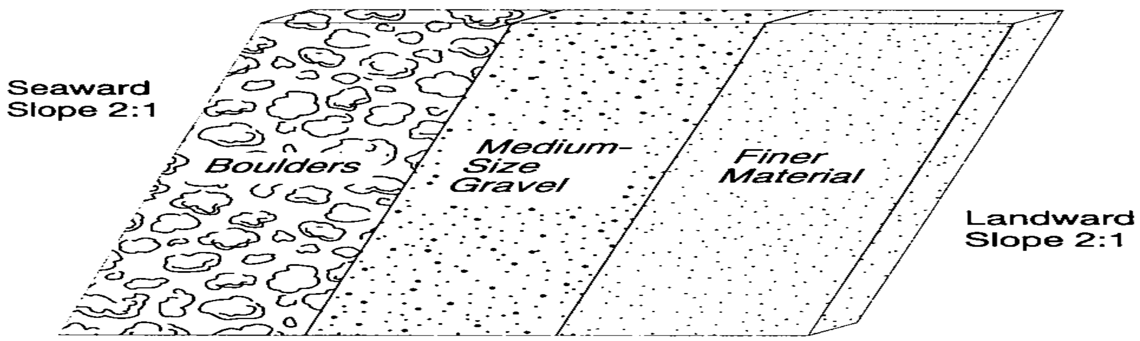
Figure 4.3.3.6: Breakwater system for reduction of erosive wave energy

iii) Construction of revetment system
Revetments are also useful in reducing erosion but need proper construction to be effective. They are expensive and in most cases the beach is lost. Revetments consist of a layer of large boulders on the seaward side and layer of filter screening material on the landward side. Another layer of medium size gravel that is used to protect the screening material (Figure 4.3.3.7) separates these two layers. The void structure of the outer layer on the seaward side is used to dissipate wave energy; the filter screening material of the landward layer allows water to pass through.

iv) Construction of seawalls or bulkhead
It may be sufficient to build only a low cost **seawall or a bulkhead**. The seawall has a 1:2 slope, a 2-metre berm and a height above water of 1.2 times sea level rise scenario (Figure 4.3.3.8).

Particularly for The Gambia, it may be necessary to employ an innovative sand management approach to solve the large erosion problem between the National Water and Electricity Corporation (NAWEC) water tanks and Banjul Point. This could be achieved by tying the end of the sand spit off the Palm Grove-Laguna Beach Hotel Complex (Figure 4.3.3.9) to the mainland so that it becomes a sand-feed to the area in the east and city of Banjul. This will, however, result to the flow of large unwanted quantity of sand to the Banjul-Barra Ferry Terminal and the GPA facilities. The flow of unwanted sand can be solved as suggested in the preceding section, i.e., the construction of a long terminal groyne at Banjul Point.

Figure 4.3.3.7: Cross-section of a Revetment



Also to protect the areas between the Cold Storage Plants east of the Public Works Complex (National Partnership Enterprise and Pelican) and the Gambia Senior Secondary School, and areas bordering the mangrove systems, it is sufficient to use dikes made up of about 1.5 to 2 m of sand on which is planted some vegetation.

Adaptation Options
Long term adaptation options that are identified are:

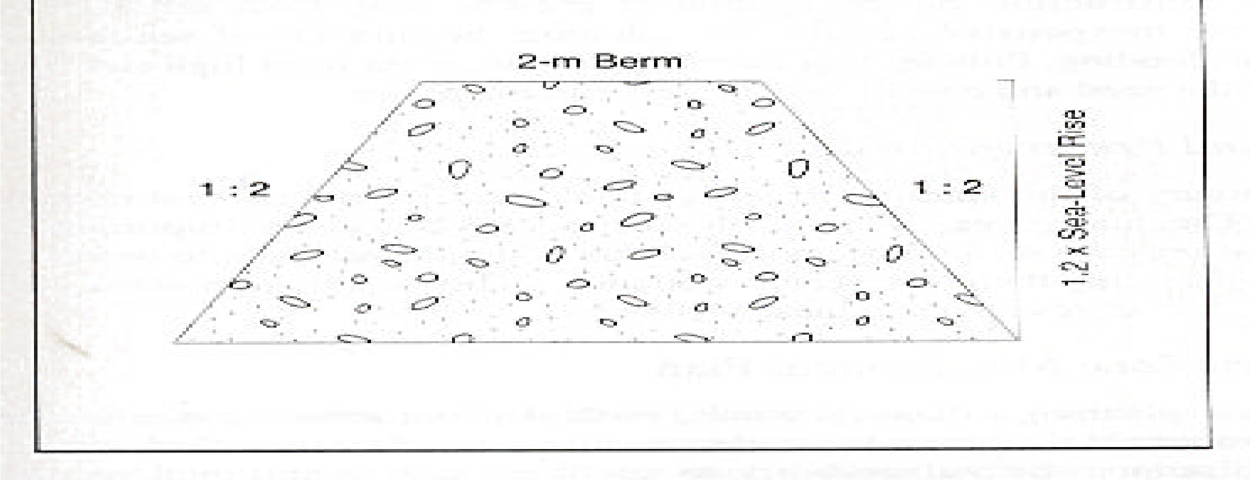


Figure 4.3.3.8: Cross-section of a Sea Wall or Bulkhead

i) **Public awareness and outreach activities** through which the public is informed of the danger of living in coastal lowlands that are at risk of being affected by SLR. Timely public education about SLR impacts and risks could be a cost-effective means of reducing future expenditures.

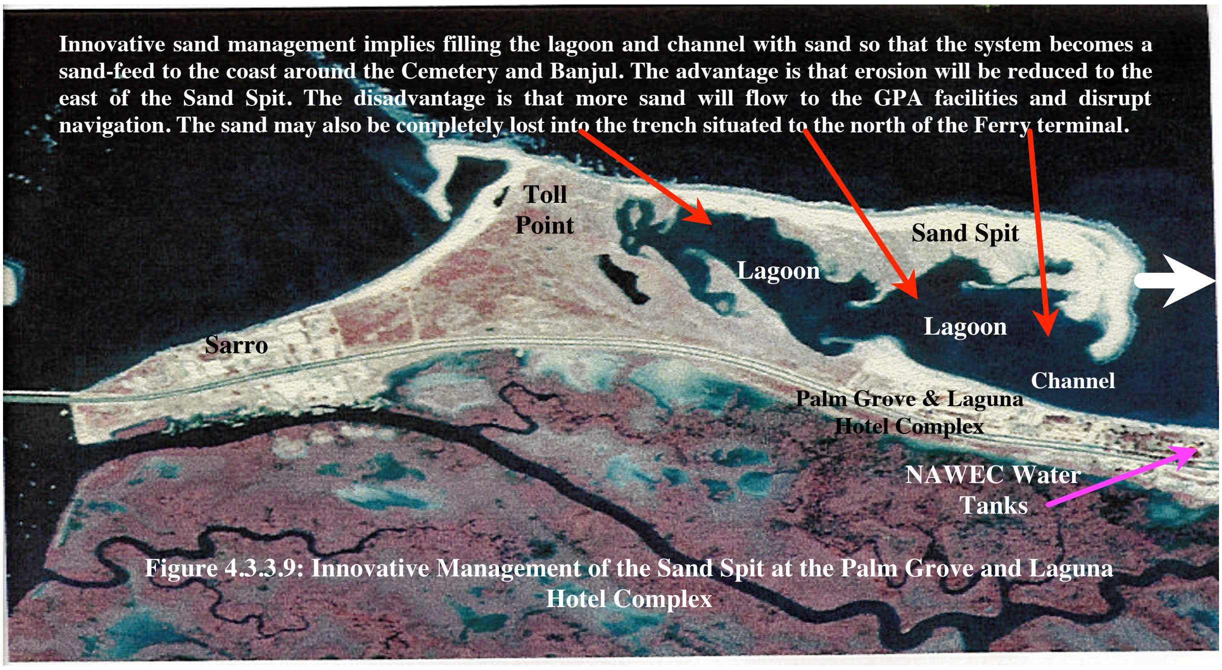


Figure 4.3.3.9: Innovative Management of the Sand Spit at the Palm Grove and Laguna Hotel Complex

ii) **Increase in height of coastal infrastructure and urban growth planning:** Physical planning and building control measures and regulations should be instituted and implemented. The Lands, Physical Planning and Building Control institutions of The Gambia should avoid allocation of land that is likely to be flooded such as in the dried-up streams on the Kombo Peninsular, that have recently witnessed flooding during the rainy seasons of the late eighties.

Where the building of coastal infrastructure such as roads, fish landing and curing plants are approved and must be put in place, the authorities and owners of these infrastructures should make sure that marginal increase in the height of the structures are included to account for SLR and any other related phenomena. Siting of large capital facilities or those that pose significant hazards when flooded should not be allowed in sensitive lands and must be directed towards less vulnerable areas. People located in high-risk areas should be offered incentives to relocate out of these areas. Policies should be instituted that allow the use of high-risk areas as natural preserves or for low-value use.

Marginal increases in the height of the infrastructures during construction phase and redirecting growth away from sensitive lands are relatively inexpensive options for reducing the impacts of SLR and risks of flooding. Policies that may lead to relocation from high-risk areas will reduce the need and cost of disaster relief in the future.

iii) Wetland preservation and mitigation: The estuary of the Gambia River contains economically important wetlands and mangrove systems. The mangrove systems on the Kombo St. Mary Island and Kombo Peninsular are important breeding grounds for various aquatic species. Efforts should be made to protect these areas by declaring them as protected wetlands. This would discourage exploitation of the resources in these wetlands. The possible impacts of upstream dams on the Gambia River in terms of reduced sediment supply should be investigated.

iv) Coastal zone management plan: Land-use planning in coastal zones, such as the use of building setbacks or allocating low-lying vulnerable lands to lower value uses (e.g., parks rather than housing), will help reduce the overall vulnerability to SLR. Other land use planning mechanisms, such as construction standards, reduce the risks of living in coastal areas. Additional risk-reduction measures can be encouraged through appropriate financial mechanisms. Each of these policies reduces the risks from current climatic variability and protects against potential sea-level rise impacts. When put together in the form of a programme, they constitute a Coastal Zone Management Plan.

4.3.4: Fisheries and fish resources

4.3.4.1: Background on the fisheries sector

The Fisheries Sector is comprised of the industrial and artisanal fisheries sub-sectors and contributes about 12% to GDP. The sector produces food-fish (which is the major source of animal protein for the majority of Gambians) for local consumption and for export to earn foreign exchange. The average annual per capita fish consumption is estimated at 23 kg. Fish consumption is higher than other sources of protein (livestock & poultry). As the population continues to expand in The Gambia, fish demand is going to increase.

The artisanal fisheries sub-sector is the major employer and supplier of almost all the supplement animal protein needed in the diets of the Gambian people. The fishing and fisheries related activities provide direct and indirect employment for over 36,000 people. It provides employment for about 6,000 people in the harvesting side and about 30,000 on boat building, fish handling, processing, transportation and marketing activities. If fishermen and people working on the ancillary activities as well as their dependants are added, it is estimated that not less than 140,000 people in The Gambia depend on the fisheries sector for their livelihood.

About 80% of artisanal catches are bonga (*Ethmalosa fimbriata*). The riverine artisanal fishery is considered non-industrial operation, employs traditional methods, and is under-exploited due to low levels of fisheries technologies. Some of the marine fish species caught in the river include shad (*Ethmalosa fimbriata*), threadfins (*Polynemidae sp*.), marine catfish (*Arius sp*.) and solefish (*Cynoglossidae sp*.) The lower reach of the river has a brackish water regime and attracts certain marine species, which use the river for feeding and spawning purposes (e.g. threadfins, solefish, catfish and shrimps). These fish migrate up the river during the dry season. The upper reach of the river has a freshwater regime where *Tilapia nilotica* and *Clarias luzerra* are important fish species. The most important crustaceans in the river fishery are shrimps caught by artisanal fishermen in the estuary (Mendy, 1996). These species are caught and sold to industrial companies which usually provide nets, engines and ice to these fishermen as an agreement for them to sell their products to these companies.

The industrial fisheries sub-sector comprises of local fishing companies and licensed local and foreign industrial fishing vessels of various capacities and fishing techniques. The fishing methods employed are trawling, purse seining and long lining. This sub-sector also targets species in all four stock categories (pelagic, demersal, cephalopods and crustaceans). It is this aspect of multi-species fisheries that creates problems in the management of fishery resources due to the fact that both artisanal and industrial fisheries target the same species especially the most valuable categories of fish stocks namely, demersal, cephalopods and crustaceans. Over 95% of industrial fisheries production is processed and exported. In view of the reported resource potential and the current rate of exploitation of marine resources, demersal fish resources are believed to be fully exploited, whilst the pelagic resources are under exploited.

The major aquatic habitats present in The Gambia are the main river, its tributaries and floodplain systems, coastal habitats such as estuaries, mangrove swamps and the delta. In addition to this diversity of habitats, an even greater variety of ecologically and economically important species occupy these habitats and will have to be considered with regard to the impacts of potential climate change.

4.3.4.2: Impacts of climate change on fisheries

The vulnerability assessment for evaluating potential climate change impacts on fisheries resources follows a weight of evidence approach. This is as a result of the diversity of fisheries resources and aquatic habitats that are to be addressed, and the inability of any single approach to evaluate potential impacts on all the fisheries resources and habitats. The weight of evidence approach uses multiple lines of evidence to identify potential impacts and evaluate the significance of any projected impacts.

The assessment methods use the relationship between the outputs from GCM and biophysical factors to project fish productivity under climate change. The methods address riverine and coastal marine habitats and evaluate potential impacts of fisheries resources of climate induced changes in water temperature, stream flow and SLR. The methods also focus primarily on estimation of yield or catch (species-specific) for the entire fishery resources, species-specific habitat suitability and habitat vulnerability. In general, the methods focus on three climate-related variables: temperature, precipitation and SLR to evaluate its potential effects at the total fishery level in relation to the life history of the fish, growth rate, habitat suitability, and yield.

Climate change and fish productivity

The effects of temperature on annual productivity of riverine fisheries resources are evaluated on the basis of average stream width, the biogenic capacity of the stream, average annual water temperature, the alkalinity/acidity of the water, and the type of fish population present in the river. The productivity is calculated using the formula:

Productivity $K = B * W * (k_1 * k_2 * k_3)$ **(Equation 4.1)**

Where K = annual productivity (kg/km of river)

W = average width of the river (m)

B = the Biogenic capacity

(B = 1 – 3 for waters with little food for fish;
B = 4 - 6 waters with average levels of fish food; and
B = 7 – 10 for waters that are rich in fish food).

k_1 = annual average water temperature of selected sites across the country (see Table 4.3.4.1)

k_2 = salinity of the water

k_3 = type of fish population present in river. The value for k_3 can be approximated on the basis of the percentage of fish found in rheophilic (fast flowing waters, such as rivers) and limnophilic (slow moving waters, e.g. streams) using the equation $k_3 = (2L + R)/100$, where L = the percentage of the fish comprised of limnophilic species and R = the percentage of fish comprised of rheophilic species. Values of L = 5% and R = 95% as assumed by Jallow (1997) are used in this study. Most rivers are fast flowing waters hence it is reasonable to assume R to be 95%.

The fish catch potential of the Gambia river fishery is not known because no research work to estimate fish stock biomass has been undertaken in and along the river. Hence, in this formula, default data are used to estimate the value of k_3 (type of fish population). The water temperature data used for this model were for the period of 1985 – 1995 and were compiled from the hydrology database of the DWR. Mean stream width was estimated from the bathymetric map of the River Gambia. Data on salinity levels were collected from the Water Quality Laboratory of the DWR and data on fish species were collected from the Department of Fisheries (Dfish). Default data presented in the models were also used where local data were lacking.

Fish productivity is projected to increase over the current climate productivity of $12.9 * 10^6$ kg/km of the river by 10% under GFDL30 equilibrium model scenarios, 11% under the CCCM and the HCGS, and 14% under HCGG and the Transient GFDL01 models (Table 4.3.4.1).

Climate change and habitat suitability
Another approach used to assess climate change effects on fisheries resources is the assessment of the effects of precipitation, temperature and dissolved oxygen on habitat suitability using a HSI model. This species-specific approach includes the development of HSI for the individual species of concern. The model incorporates environmental variables such as water temperature, current velocity, floodplain inundation duration, dissolved oxygen concentrations, and substrate composition, and produces an index of habitat suitability between 0 (unsuitability habitat) and 1 (optimally suitable habitat).

Data used includes species-specific habitat and physiology data, habitat characteristic including but not limited to temperature, dissolved oxygen, substrate stage and flow and predicted water temperature data. Except for water temperature, all data used in this assessment are default data presented in the models. Habitat suitability indices are estimated for specific habitats using baseline or current climate, hydrological and ecological data. Suitability indices are then calculated for the projected climatic and hydrological conditions associated with each climate change scenario. By comparing baseline and climate change projected HSI values it was possible to assess vulnerability of shrimp yield to climate change.

The HSI Model was run on Shad, Catfish, Ladyfish, Shrimps and Grouper. All these species tolerate water temperatures above 20^oC and relatively low dissolved oxygen levels of 20% in the waters. The projected climate change scenarios from the output of the GCM shows that potential warming of 3^oC to 5^oC over the next century has little or no effect on the suitability of the present habitat for the pelagic species of shad and catfish (Table 4.3.4.2). This could be attributed to the fact that shad has an optimum tolerance temperature of 25^oC and a maximum temperature of 30%.

Table 4.3.4.1: Estimates of the impacts on productivity (kg/km) due to increase in water temperature on riverine fisheries in The Gambia

Model	B	W (m)	L (%)	R (%)	K_1 (^oC)	K_2 (pH)	K_3 = (2L + R)/100	$K=B*W*(K_1*K_2*K_3)$ (kg/km of river)	Percent Variation
Current	6	5500	95	5	27.5	7.25	1.95	12.9	
CCCM	6	5500	95	5	30.8	7.25	1.95	14.4	11
HCGG	6	5500	95	5	32.0	7.25	1.95	14.9	14
GFDL01	6	5500	95	5	31.9	7.25	1.95	14.9	14
GFDL30	6	5500	95	5	30.5	7.25	1.95	14.2	10
HCGS	6	5500	95	5	31.0	7.25	1.95	14.5	11

Catfish can tolerate high temperatures and can adapt in waters of low dissolved oxygen. Hence a temperature rise of more than 3^oC in their habitat will have little or no impacts on their survival and productivity. Shrimps, Grouper, and Ladyfish are found in depths of less than 100m, and might be sensitive to oxygen and cannot tolerate low oxygen in waters of below 20% oxygen saturation with maximum temperature of 35^oC. Warming of more than 3^oC to 5^oC will have negative impact on their productivity. It is worth mentioning that species that are negatively impacted on by increase in temperature are classified as high valued species that are mainly consumed locally (which brings better returns to the fishermen or are mainly exported (which also brings foreign exchange to the country). Therefore, there is need to effect adaptation measures in order to obtain and maintain a healthy fishery stock.

Climate change and shrimp yield
Assessing the effects of temperature changes on shrimp yield is based on regression analysis of empirical data to develop exponential relationships of the Arrhenius form relating ecological rates to absolute temperature.

The Arrhenius form of an exponential relationship is given as:

$$Log\ K = a - b(1/T) \quad \textbf{(Equation 4.2)}$$

where, K = rate constant
T = absolute temperature (degrees K)
a (y-intercept) and b (slope) are coefficients estimated by regression analysis

Since no historic shrimp yield data were available for this study, the model used to estimate shrimp yield under different temperature scenarios is that developed by Regier et al. (1990) in the form:

$$Log_e\ SCSY = 52.0 - 144312\ (1/T)\ (r = 0.58) \quad \textbf{(Equation 4.3)}$$

where $SCSY$ = Stabilized Commercial Shrimp Yield (kg/ha of intertidal vegetation)
T = Annual air temperature (K)

Table 4.3.4.2: Habitat Suitability Index for fish and shrimp based on water temperature variation

Species	Annual Average Water Temperature					Habitat Suitability Index			
	Current	GFDL	HCGG	HCGS		Current	GFDL	HCGG	HCGS
Shad	24.0	27.0	32.0	31.0		1.000	1.000	1.000	1.000
Catfish	24.0	27.0	32.0	31.0		0.921	0.918	0.918	0.918
Ladyfish	24.0	27.0	32.0	31.0		0.435	0.432	0.432	0.413
Shrimps	24.0	27.0	32.0	31.0		0.642	0.596	0.596	0.596
Grouper	24.0	27.0	32.0	31.0		0.632	0.894	0.819	0.819

Data used include historic mean annual air and water temperatures collected from the Hydrology and Meteorology Divisions of DWR and projected mean annual air and water temperatures calculated using GCM outputs. In the analysis, GCM projected temperatures are input into the models to project shrimp yield under different temperature scenarios. Vulnerability is assessed by comparing projected yields under baseline and climate change scenarios.

Table 4.3.4.3 and Figure 4.3.4.1 below show that under temperature scenarios projected by the various GCMs, shrimp yield will increase. By the end of the next century, yield increases over the baseline scenario values are projected to vary from 38% under the GFDL30 equilibrium model scenario, 40% under the CCCM model, 42% for the HCGS model to 50% under the GFDL01 and the HCGG models.

4.3.4.3: Adaptation measures

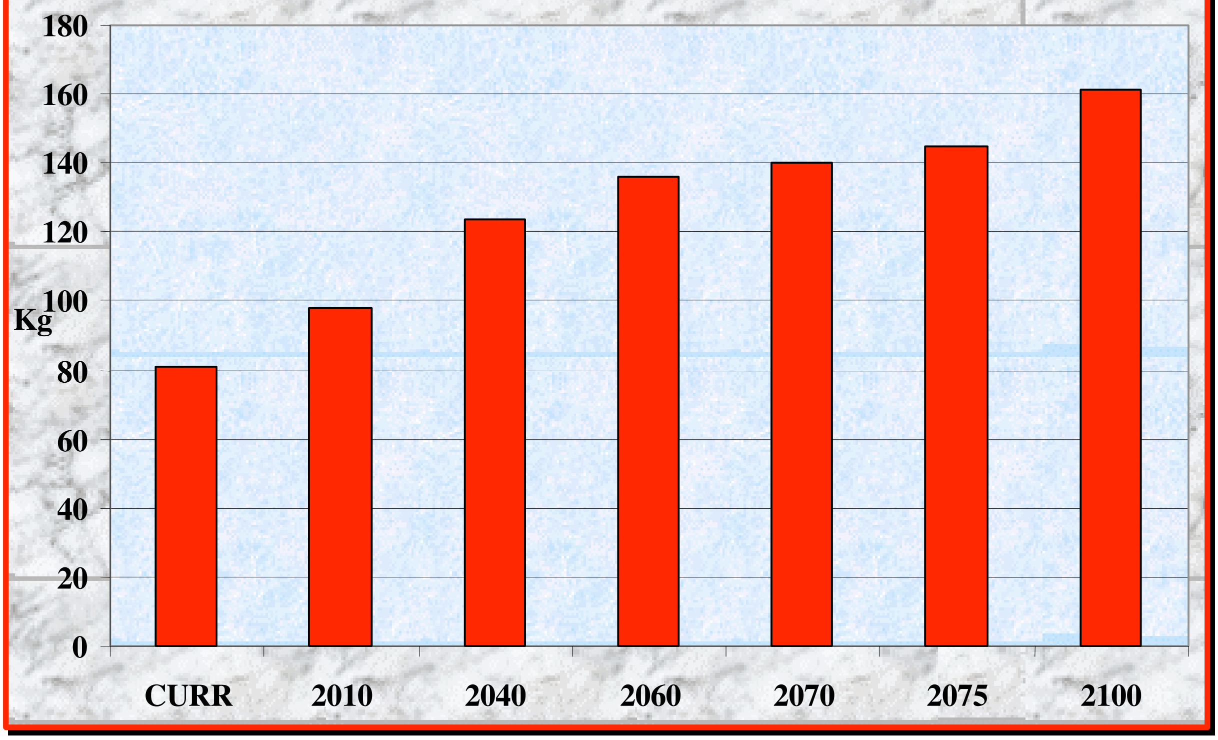
Given that demersal fish resources are over-exploited, the fisheries strategic and management plan calls for stricter control of the exploitation of resources. This will require a reduction in the number of fishing licenses issued to foreign vessels, improved surveillance of the fisheries

Table 4.3.4.3: Estimates of shrimp yield from temperature changes due to climate change

Model Scenario	Mean Annual Air Temperature		Natural log of SCSY	SCSY	Percent Increase
	Degrees Celsius	Degrees Kelvin			
Current	27.5	300.7	4.4	81.2	0
GFDL01 2010	28.7	301.9	4.6	98.1	17
GFDL01 2040	30.2	303.4	4.8	124.0	35
GFDL30	30.5	303.7	4.9	129.9	38
CCCM	30.8	304.0	4.9	136.1	40
GFDL01 2060	30.8	304.0	4.9	136.1	40
GFDL01 2070	31.0	304.2	4.9	140.4	42
HCGS	31.0	304.2	4.9	140.4	42
GFDL01 2075	31.2	304.4	5.0	144.8	44
GFDL01 2100	31.9	305.1	5.1	161.3	50
HCGG	32.0	305.2	5.1	163.8	50

Stabilized Commercial Shrimp Yield = SCSY in units of kg/ha of intertidal vegetation; Degrees K = C + 273.15

Figure 4.3.4.1: Simulation of Stabilized Commercial Shrimp Yield using the GFDL Transient Model



waters, and an increase in licensing fees for demersal trawlers. Closed seasons during spawning and areas such as the nursery grounds for fish species could also be implemented. With these measures, the fisheries sector could obtain and maintain healthy fish stocks for sustainable utilisation.

Ponds and other inland water bodies for spawning are indispensable components of a balanced aquatic environment. During the drought years, many of these ponds and inland waters dry out, leading to reductions in fish populations. Those that survive the drought are threatened with pollution (pesticide run-offs and plant discharges). In view of the importance of these ponds and water bodies in enhancing fish population, measures should be taken to safeguard the spawning sites, and stop the destruction of mangroves (fish nursery areas), and pollution along the coastline and the riverbanks. A study of the state of the mangroves will help facilitate these measures. Raising public awareness on the importance of the mangroves is also important.

Sound knowledge of the state of the fish resources is a pre-requisite for effective planning, development and management of the fish resources. Therefore, it is important to increase research activities on the fisheries resources by studying the abundance and distribution of fish. There is also need to study plankton as a source of food for fish, and the feasibility of the development of the fishery resources of the freshwater zone of the River Gambia. It will also be necessary for the Dfish to carryout research to further assess the feasibility and scope of fish farming in the Gambia. There is no data on cultured fish as this is still in its experimental stages in Central River Division (CRD) as part of the poverty alleviation programme. However, there is great potential in subsistence and commercial fish culture in some parts of the river.
In order to reduce the possibility of decline in fishery productivity, strict biological monitoring of fish stocks is essential. Monitoring of fish stocks can ascertain the extent of the resource base, and establish optimum margins for sustainable exploitation. This strategy can help develop the commercial potential of high valued fish species such as shrimps and lobsters.

The rational utilisation of the fish resources is essential. To achieve the measures outlined above will require the collective effort of the government, fish producers as well as other stakeholders. All stakeholders should be invited to take part in public educational and awareness programmes relative to the conservation of fisheries resources.

With the realisation of the economic potential of fisheries, the sector has witnessed a heavy influx of new entrants with modern fishing technologies in recent years and thus increase in fish landings. Since sufficient scientific knowledge necessary for the sustainable management of the fish stocks is lacking, the need to generate appropriate information regarding the fish stocks has become critical. However, capacity to adapt to adverse effects of climate change especially in fisheries is low in The Gambia due to scarce financial resources, and limited institutional and technological capability.

It is important to have a set of proposed adaptation measures that will assist the country in achieving national adaptation goals in meeting commitments to the UNFCCC. It is hoped that the measures put forward will form a basis for conservation and the monitoring of stock levels and their sustainable utilisation in the face of physical stress caused by climate change and other environmental phenomena, while still meeting the growing demand for food fish.

4.3.5: Forestry and forest resources

4.3.5.1: Background on the forestry sector

The Gambia lies along the boundary between two vegetation zones known as "South Guinea Savanna" and "Sudan Savanna". South Guinea Savanna is open woodland with tall grasses up to 5 m high; the trees and shrubs, including broad-leaved species, form a two-storeyed broken canopy, giving light shade. Sudan Savanna, which occupies the drier areas in the eastern and northern parts of the country, has shorter grasses and trees not exceeding 15 m, most of which are small-leafed and thorn-bearing (Percival, 1968). Areas of salt-water mangroves also characterize the lower half of the River Gambia and fresh water swamps characterize the upper half of the river and its creeks.

Up to the turn of the century, The Gambia was covered with dense forest. Forest destruction began by mid 1960 through shifting cultivation, bush-fires and wood exploitation. A decrease of the Gambian forests area from 333,200 ha in 1972 to 68,500 ha in 1988 (Ridder, 1991) has been registered. According to some estimates the rate of deforestation in the Gambia is about 6 percent per annum. This has however, changed during recent years due to the annual tree planting campaign adopted by Government.

The Gambia is endowed with about 140 tree and shrub species from about 12 families. The forest cover is estimated at 43% of the total land area and are classified as closed forest (26,800 ha), open forest (62,600 ha), tree and shrub (34,700 ha) and mangroves (66,900 ha) (Foster, 1983).

The forest still remains as the basic provider of domestic energy supply (85%) in the form of fuel wood and also provides 17% of the domestic saw timber needs (Dunsmore, 1976). The value of timber is very high and the average price for local hardwood timber in the 1980s and 1990s is about D400 per cubic metre while for Gmelina it is D250.00 (Schindele and Bojang, 1988).

4.3.5.2: Impacts of climate change on the forest resources

Two biophysical models were used in the assessment of the impacts of climate change on the forestry sector of The Gambia.

The Holdridge Life Zone Classification Model (Holdridge, 1967 as cited in Beniof et al. (eds.), 1996) is a climate classification model that relates the distribution of major ecosystem complexes to the climatic variables of bio-temperature, mean annual precipitation and the ratio of potential evapotranspiration to precipitation (PET ratio). The PET ratio is the quotient of PET and average annual precipitation. Figure 4.3.5.1 illustrates the Holdridge Life Zone Classification scheme.

The life zones are depicted by a series of hexagons in a triangular coordinate system. Identical logarithmic axes for average annual precipitation form two sides of an equilateral triangle. The PET ratio forms the third side, and an axis for mean annual bio-temperature is oriented perpendicular to its base. The two variables, bio-temperature and annual precipitation, determine classification. By striking equal intervals on these logarithmic axes, hexagons are formed that designate the Holdridge Life Zones (Smith, 1994).

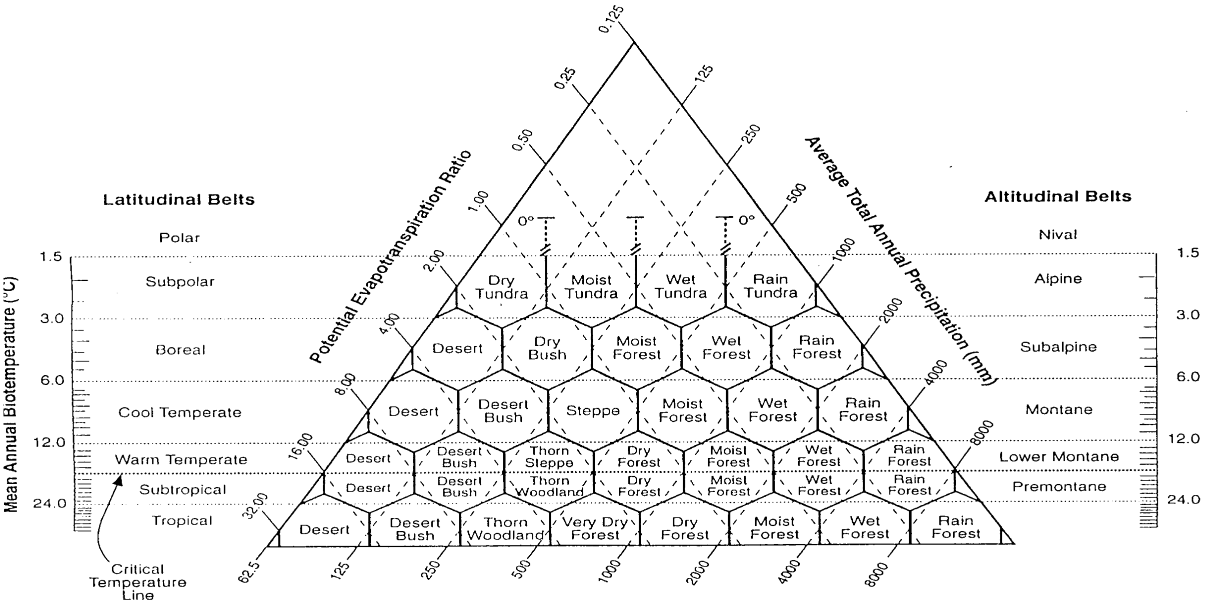


Figure 4.3.5.1: Holdridge Life Zone Classification Scheme

Application of the Holdridge Life Zone Classification to a site requires only data on annual bio-temperature and precipitation. The spatial resolution of the data should be as high as possible, since the resolution at which the land cover is defined is dependent on the spatial resolution of the climate data from which it is defined (Smith, 1994). Once the climate database has been established and the primary variables have been calculated each land cell (i.e., area described by a single observation of bio-temperature and annual precipitation) can be classified using Holdridge classification and the results can be mapped.

Classification based maps for baseline (current) climate and GCM scenario driven climate are produced. A direct comparison of the output land cover databases under current and climate change scenarios provides a summary of the change in land cover projected to occur under the GCM scenarios.

The Forest Gap Model simulates the demographics of plant populations. Individual plant species are modeled as a unique entity with respect to the processes of establishment, growth and mortality. The model structure includes two features that are important to the dynamic description of vegetation:

1. the response of the plant species to the prevailing environmental conditions, and
2. how the individual modifies those environmental conditions (i.e., the feedback between vegetation structure/composition and the environment, Smith, 1994)

The model approach is high resolution in that it can predict species composition, vegetation structure and associated productivity and standing biomes through time. It tracks the temporal response of vegetation to changing environment conditions. The model is limited in that the information (species composition and productivity) required to parameterize the model relate to site specific features such as topographic position, soil characteristics, land use history, disturbance, and present vegetation structure, all of which may vary over short distances. The current climate and climate change scenarios have been applied to the forest gap model as a step function (i.e., changes in temperature and precipitation are assumed to occur within a single year).

Data availability is critical in the applications of the Forest Gap Model. For the assessment of impacts of climate change on forest resources historical rainfall and temperature records were used to calculate total rainfall, which was then used as input to the Forest Gap Model. Tree species and site data are required to parameterize the forest gap model for a given site. Data for 29 species were used as input and also simulated, but only five of the most economically important species are discussed in this report. The parameters from which the optimal growth function (D-CURVE) is derived are maximum age, maximum diameter and maximum height of the tree species. The result is a species specific optimal growth curve for some of the most economically important timber and fuelwood species simulated. These optimal curves are input into the gap model in which this potential optimal growth is modified by the environmental conditions on the plot. Growth is defined as diameter as a function of time, and diameter increment as a function of current diameter. The environmental response to light is described by the parameter L, where L = 1 classifies the species as shade intolerant. All the scenarios have been applied to the Gap Model as step functions with simulation beginning in 1971 and full climate change is expected by 2075, which is extrapolated to 2100.
As indicated above only 5 of the 29 species used in the simulations are discussed in the report. These are:

Borassus aeithiopum/flabellifer is a tall palm tree that attains a height of about 30 m. It is highly gregarious with a stem that is thicker in the upper than in the lower part of the trunk. The stem and leaves are very important for construction of houses; the stem is used, whole or sliced, for construction of jetties, bridges, groynes and as poles for fencing. The leaves and leaf stalks are used for roofing and fencing.

Chlorophora regia is a large forest tree with a tall bole, buttressed at the foot. It is more or less extinct in The Gambia because of several years of intensive exploitation of the forest but specimens can be found in and around villages. It is an important timber tree.

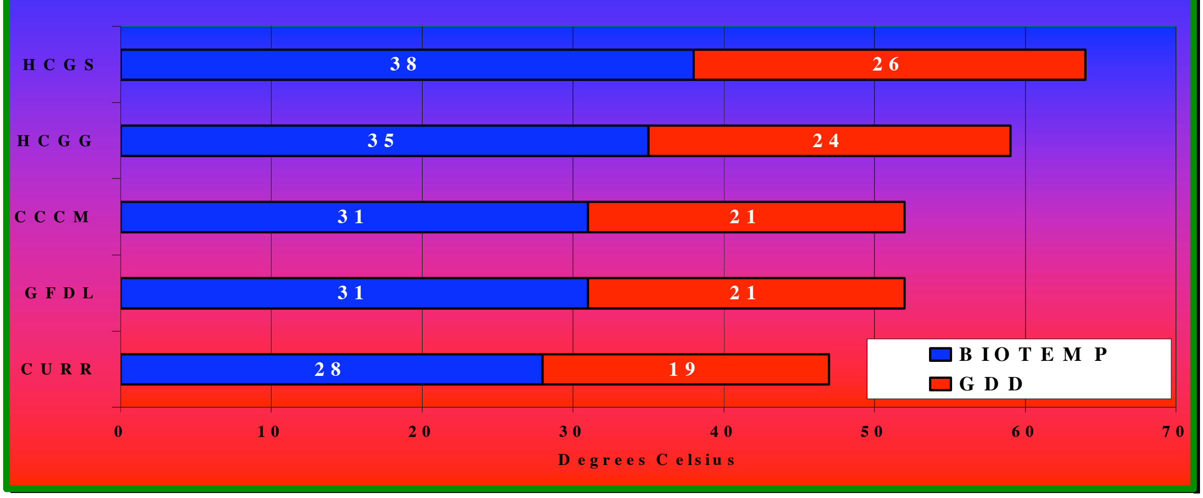
Pterocarpus is the "African Rosewood" with dark bole, often streaked and sometimes divided. The timber is very hard and durable and used in building and construction of utensils. It is also used in the construction of local bridges. The leaves are useful fodder and when the bark and leaves are infused a medicinal stuff is produced.

Rhizophora racemosa is a mangrove tree that grows into tall tress up to 50 m high along the river. It has a large per hectare biomass. It is a valuable timber, especially for piling and roofing since termites never attack it. The mangrove swamps are important areas of fish spawning.

Adansonia digitata has peculiar swollen trunk and short thick branches, holding water-storage tissues. The fruit is a hanging velvety structure that breaks, when old and scatters white flossy seeds embedded in a dry acid pulp. The tree has many uses. The bark is stripped as fiber; the leaves, when young, are boiled and eaten as a vegetable and, when mature, are dried, ground and used as flavouring. The fruit pulp is edible and has earned the name "monkey bread".

From Figure 4.3.5.2, the Growing-Degree-Days (GDD) varied from 19°C under current climate to 26°C under the HCGS model scenarios. Mean annual bio-temperature (GDD at base temperature of 0°C) at current climate (baseline scenario) is estimated as 27.6°C. Increases in bio-temperature are estimated as 11% (GFDL-equilibrium and CCCM), 28% (HCGG) and 39% (HCGS) over the baseline scenario.

Figure 4.3.5.2: Estimates of Biotemperature and Growing Degree Days under various scenarios



4.3.5.3: Simulation results from the Holdridge Model

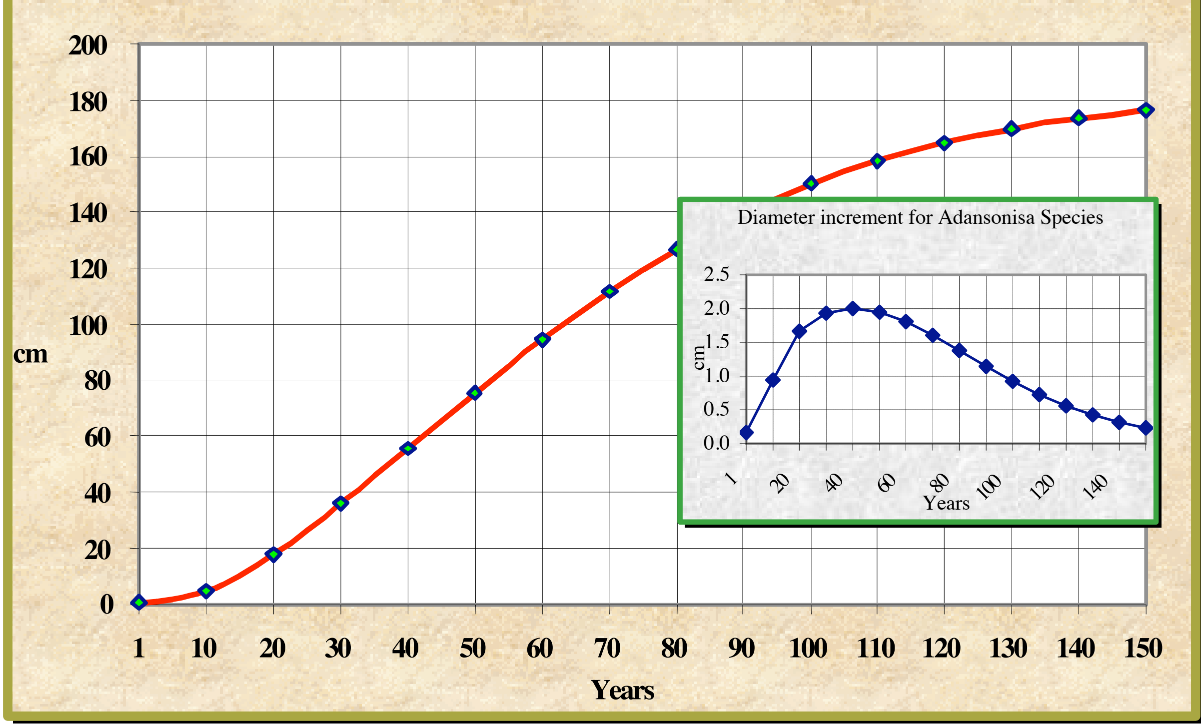
Scenarios of bio-temperature (Figure 4.3.5.2 above) and total rainfall are used to drive the Holdridge Model. Overall indications are that, under an equilibrium climate the potential land cover of The Gambia will tend to the ***tropical dry forest*** category as a result of the projected increase in precipitation, temperature and CO_2. The projections indicate that by 2075, 40% of the country will be under ***tropical very dry forest*** and 60% under ***tropical dry forest***. This is the reverse of current situation and indicates a northward shift in the vegetation categories i.e., from ***very dry forest*** to ***dry forest***.

4.3.5.4: Simulation results from the Forest Gap Model

Species specific growth in diameter

Data on diameter size and diameter increment were input into the D_CURVE component of the Gap Model to determine the growth characteristics of individual tree species. Figure 4.3.5.3 shows species-specific optimal growth curve for Adansonia, one of the most economically important multi-purpose species simulated. Growth is defined as diameter as a function of time, and diameter increment as a function of current diameter. These optimal curves serve as input into the Gap Model in which this potential optimal growth is modified by the environmental conditions on the plot.

Figure 4.3.5.3: Projections of diameter and diameter growth for Adansonia Species



Diameter size class distribution
Simulation results suggest that all species do not attain their current maximum diameter for all climate change scenarios. The reader is referred to the detailed Vulnerability Study (Jallow, 2002).

Borassus species: Diameter expansion is faster under the climate change scenarios than under current climate, but trees have a shorter survival period of 60 years as opposed to 120 years of survival under current climate simulation. The number of trees within any of the size classes is less under the climate change scenarios than under current climate scenarios.

Chlorophora species: Simulation results are similar to Borassus species except that under this species, the number of trees within any size class is greater under HCGS and HCGG scenarios.

Pterocarpus species: Simulation results are similar to Borassus species. Expansion rate is slower under current climate scenarios but the trees survive longer than any of the climate change scenarios. Under current climate, the trees survive after 130 years while under all the climate change scenarios, the trees do not survive beyond 80 years.

Rhizophora species: For these species more trees per hectare are simulated under climate change scenarios than under current climate scenarios. However, the diameter of the trees is not simulated to expand greater than 20 cm. Under current climate scenarios, number of trees per hectare is small but the trees attain a diameter of between 20 - 30 cm. Trees survive longer than 130 years under all scenarios.

Adansonia digitata: This tree specie can attain a diameter of 100 cm. Under current climate scenarios, trees are simulated to attain a size greater than 60 cm but under all climate change scenarios the trees have not attained this size. The rate of expansion of diameter is simulated to be faster under climate change scenarios and slower under current climate. The number of trees per hectare is higher under the HCGG and HCGS climate change scenarios.

Simulated biomass production

Stand Level Basal Area
Under current climate, basal area was negligible in the fist year, but increases to 5.45 m^2/ha by 2075 and 6.31 m^2/ha in 2100 (Figure 4.3.5.4). Simulations with climate change scenarios give basal area as negligible during the first year of simulation. Projected values show an increase to 47.67 m^2/ha (GFDL), 47.53 m^2/ha (CCCM), 54.82 m^2/ha (HCGG) and 59.59 m^2/ha (HCGG) by 2075, and 47.06 m^2/ha (GFDL), 46.92 m^2/ha (CCCM), 54.12 m^2/ha (HCGG) and 58.82 m^2/ha (HCGS) by 2100.

Stand Level Biomass Produced
Stand biomass is the total biomass produced through the simulation of 29 tree species. Average stand biomass is estimated for current climate and climate change scenarios. Under current climate, stand biomass is estimated to increase from 2.15 tons per hectare (t/ha) in the first year of simulation to 49.66 t/ha by 2075 and 59.15 t/ha by 2100. Simulations with climate change give biomass production as 2.76 t/ha (GFDL), 2.75 t/ha (CCCM), 3.17 t/ha (HCGG) and 3.45 t/ha (HCGG) under current climate projections for the first year of simulation. Stand biomass under climate change scenarios increased to 207.32 t/ha (GFDL), 206.70 t/ha (CCCM), 238.42 t/ha (HCGG) and 259.15 t/ha by 2075, and 211.84 t/ha (GFDL), 211.20 t/ha (CCCM), 243.62 t/ha (HCGG and 264.80 t/ha (HCGS) by 2100.

4.3.5.5: Potential adaptation options

About 86% of the energy supply for domestic use in The Gambia comes from forest resources (NCC, 1994). Results of the vulnerability analysis suggest that, at the broader scale, the forest resources will tend to the **dry forest category** but some tree species may not be able to survive the climate change projected by some model scenarios. The Gambian population will have to develop potential adaptation options and measures to enable them have continuous access to the benefits provided by the forest resources. Adaptation options and measures that may be adopted in The Gambia include:

- ***Development of seed banks***

Most of the forest tree species in the Sahel region of Africa, including The Gambia, have adapted to droughts but may not be able to survive the projected climate change. Development and maintenance of forest seed banks, especially indigenous forest species, will allow access to seedlings in times of crisis. This could also ensure that benefits derived from forest are not lost forever.

- ***Promotion of effective management practices and flexible criteria for intervention***

The Community Forestry Management Concept introduced in The Gambia, with assistance from the German Government has proved to be very effective in improving the vegetation cover. The concept involves the management of the natural forest by the community through effective planning, forest fire control strategies, sustainable exploitation of the forest, and reforestation. Such forest management practices should be replicated in different parts, to eventually cover the whole country. With the development of seed banks and, effective and flexible management strategies put in place, the forest cover could be able to survive the projected climate and environmental change.

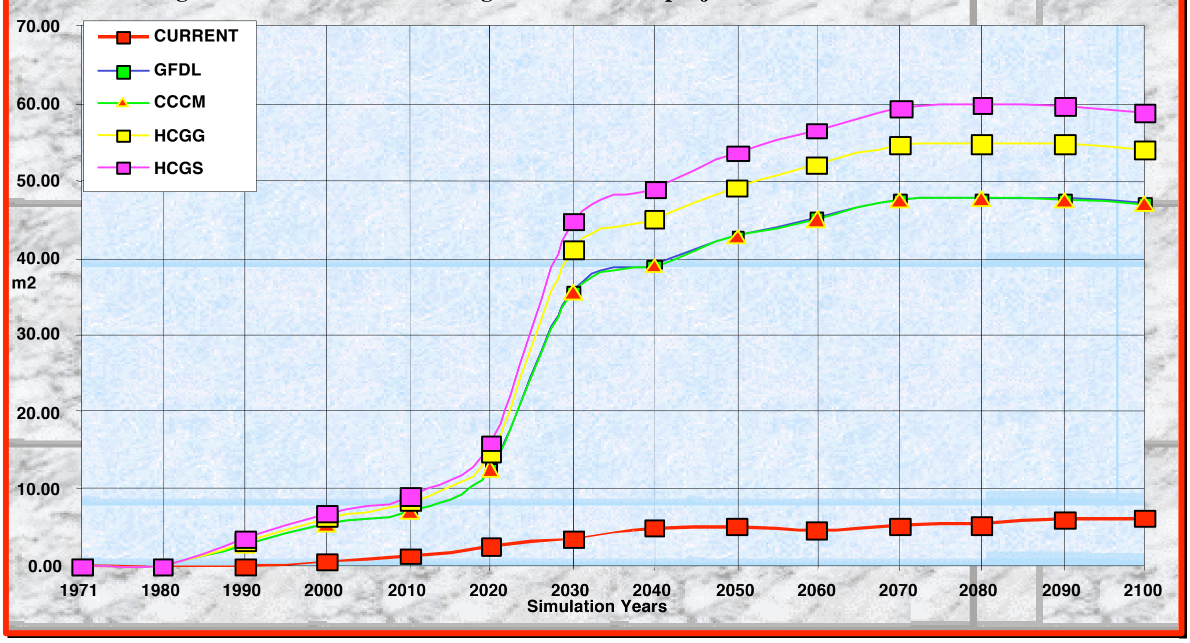
4.3.6: Rangelands and livestock

4.3.6.1: Background on the rangelands and livestock resources

Rangelands are agricultural systems with relatively low productivity that make up about 40% of the earth's surface. The system provides food and habitat for domestic livestock and many species of wildlife. High rainfall variability, fire regime and grazing patterns are some of the forces responsible for degradation of these ecosystems.

In The Gambia the rangeland system consists of natural vegetation cover (grasses, shrubs and woody plants) and agricultural lands. Crops are cultivated on the agricultural lands during the wet season and animals graze on the crop residue left behind after harvesting. The natural vegetation cover is used for grazing throughout the year.

Figure 4.3.5.4: Basal area of vegetation stand as projected under the various scenarios



4.3.6.2: Impacts of climate change on rangelands and livestock - Assessment methodology

In this study, the approach used to assess impacts of climate change to rangelands and livestock in The Gambia consists of a simulation technique using the second generation Simulation of Production and Utilization of Rangelands (SPUR2) Model (Hanson et al, 1992). SPUR2 was developed by the USDA-ARS Great Plain Systems Research Unit and Colorado State University as a general rangeland ecosystem model that simulates the cycling of carbon and nitrogen through several compartments, including standing green, standing dead, live roots, dead roots, seeds, litter, and soil organic matter. It also simulates competition between plant species and the impact of grazing on vegetation. The model also simulates the direct effects of CO_2 on plant production.

The SPUR2 model consists of five basic components: hydrology, plant growth, animals (domestic and wildlife) and economics. The hydrology/soils component calculates upland surface runoff volumes, peak flow, snow melt, upland sediment yield, and channel stream flow and sediment yield. Soil water tensions, use to control various aspects of plant growth, are generated using a soil water balance equation. The soil conservation service curve number procedure computes surface run off, and soil loss is computed by the modified Universal Soil Loss Equation (USLE). The plant component of the model is a deterministic set of equations and relationships that can simulate the dynamics of both cool-season (C_3) and warm-season (C_4) plants. With small exceptions for computational efficiency, the model processes each plant species in the simulation in exactly the same manner. All species growth, death, and physiological dynamics are calculated the same way, no matter whether the species is C_3 or C_4. The species' responses to temperature, moisture, nutrients, etc., are simulated by supplying a set of parameters and critical values for each plant species to be simulated. These parameters and critical values are used to distinguish the physiological and ecological differences between plants, and are in effect for the entire simulation.

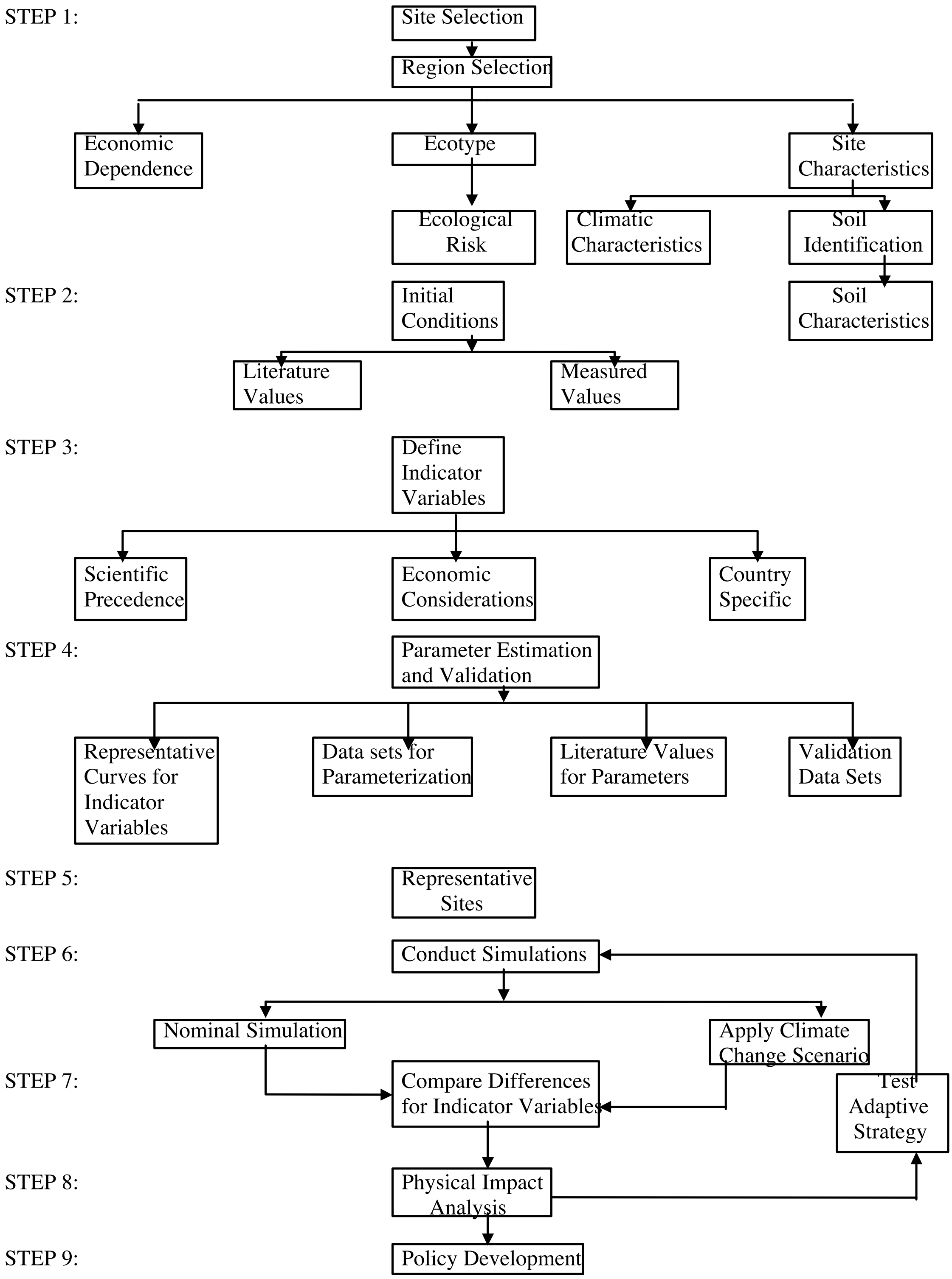
The SPUR2 model has the capability to simulate the effects of grazing by wild as well as domestic animals. In this study, only the wildlife component is used as all domestic animals are grazed in the open. The model uses wildlife as a sink for the removal of vegetation and only standing green and standing dead biomass are considered to be forage available for harvest by wildlife.

The methodology for implementing the assessment of climate change impacts on rangelands/livestock is divided into the following nine steps as shown in Figure 4.3.6.1 below.

Step 1 determines the areas of the country in which the simulation sites will be located. Location of sites is determined in part by the availability and completeness of data for the simulations. These data include weather elements, soil and vegetation data. Four sites were located in this study but only one site has been analyzed and discussed in this report.

Step 2 determines the initial conditions for the simulations using the plant, soil and livestock models.

Figure 4.3.6.1: Flow Diagram for Country Study Program Rangeland/Livestock Impact Assessment Methodology (from *Beniof et al, 1996)*



Step 3 defines indicator variables, which include peak standing crop, water use efficiency, soil organic matter, forage intake, etc.

Step 4 is parameter estimation and model validation. Types of curves needed include monthly standing crop, forage crude protein or nitrogen, and yearly peak standing crop.

Step 5 selects representative simulation sites. Four sites were selected but only the results of one site are analyzed in this reported.

Step 6 conducts the simulation experiment. The number of simulations includes a normal simulation, which uses an unaltered version of the historical weather file, and simulations using climate change scenarios.

Step 7 compares the difference between the "normal" and climate change scenario runs.

Step 8 tests adaptive strategies, which depend on the current and accepted management strategies within a country and the type of livestock being studied.

Step 9 develops policies to mitigate the negative impacts or to take advantage of possible positive impacts of climatic change.

Economic analysis can be conducted to examine the effects of climatic change on the local or producer level, at a more aggregated level to examine the effects of secondary supply and demand within a region or country. However, economic analysis was not conducted in this study due to limited knowledge in econometrics.

Forty years of historical weather data are used for each simulation site. The data includes daily maximum and minimum temperature (^oC), rainfall (mm), wind run (km/day), and solar radiation (Langleys). Data for the hydrology model includes soil name, type, and texture; slope; percentage of sand, clay, and silt; organic matter; parameters for USLE; soil evaporation; bulk density; and water holding capacity at 15 bar. Plant model initial conditions include biomass estimates for green shoots, live roots, propagules, standing dead, dead roots, litter, and soil organic matter as well as an estimate of the amount of nitrogen (g/m^2) in green shoots, live roots, propagules, standing dead, dead roots, litter, soil organic nitrogen, and soil inorganic nitrogen. In this simulation, domesticated animals in The Gambia are classified as wildlife because of their feeding characteristics over an extensive and unmanaged area. Data for the wildlife component included animal weight, forage intake, preferred grazing sites, etc. Where climatological data are missing, interpolation is used to fill the gaps. In some cases abiotic and biotic data to be used in the simulation are unavailable and in such situations the default data provided in the model are used.

4.3.6.3: Results and discussion

Results for the indicator variables are output on daily, weekly or monthly but in this study, data are analyzed on a yearly basis. Data analyzed includes annual averages for peak standing crop (g/m^2), rainfall (cm), PET (mm), transpiration (mm), soil moisture conditions, nitrogen mineralized and nitrogen fixed.

Annual averages of water balance parameters
Simulation results suggest that PET is projected to increase over the current climate value of about 1,890 mm by 5% under GFDL and CCCM models and about 21% and 31%, respectively, under HCGG and HCGS models. Increases in soil evaporation over the current climate value of 17.2 mm are significant, varying from 93% under the GFDL and CCCM models to 122% and 142%, respectively, for the HCGG and HCGS models. The annual average quantity of water available to the plants decreases under CCCM and GFDL model scenarios by about 13% over the current climate value of 281 mm. There is little variation in the projected value under current climate and HCGG scenarios but projections from the HCGS are 9% higher than current climate estimates (Table 4.3.6.1).

Average biomass and dry matter production

Total biomass
The average monthly live biomass produced for the simulation period (1951-1990) is 2,487 kg/ha under current climate scenarios. When this period is projected for double CO_2 induced climate (2051-2090), average monthly total live biomass simulated under the various climate change scenarios shows a reduction of 43% under CCCM and GFDL model scenarios, 34% under HCGG and 29% under HCGS climate change scenarios. Estimates of the average monthly total biomass produced for the whole simulation period (Figure 4.3.6.2) clearly show this reduction for all the months.

Table 4.3.6.1: Water balance parameters for the Bakendik Flats

	Current Climate (mm)	GFDL (mm)	%of Current Climate	CCCM (mm)	% of Current Climate	HCGG (mm)	% of Current Climate	HCGS (mm)	% of Current Climate
Precipitation	2552.6	2067.6	-19	2061.36	-19	2377.7	-7	2584.4	1
Infiltration	916.6	778.76	-15	776.42	-15	895.57	-2	973.45	6
PET	1889.6	1986.0	5	1980.07	5	2283.9	21	2482.5	31
Soil Evaporation	17.2	33.27	93	33.17	93	38.26	122	41.59	142
Plant Transpiration	604.1	558.04	-8	556.37	-8	641.75	6	697.55	15
Deep Percolation	296.9	189.74	-36	189.17	-36	218.20	-27	237.18	-20
Plant Available Water	281.4	244.86	-13	244.13	-13	281.59	0	306.08	9

Plant Available Water is quantity of water that is extractable by plants and within the root zone

However, average monthly biomass production per species shows some differences. For warm season grasses (Table 4.3.6.3 and Figure 4.3.6.3), estimates under current climate are lower than estimates under all climate change scenarios. Estimates under GFDL and CCCM scenarios are 14% higher than current climate scenarios and HCGG and HCGS model scenario estimates are 31% and 43% higher than current climate estimates respectively.

Total site leaf area
The average leaf area (LA) simulated for Bakendik Flats is 7.1 grams per metre squared (g/m^2). The average LA under various climate change scenarios is lower than current climate scenarios by 45% for CCCM, 44% for GFDL, 36% for HCGG and 31% for HCGS scenarios.

Table 4.3.6.2: Estimates of average annual biomass (kg/ha) produced under various scenarios

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average	% Variation
Current	1450	1350	1215	997	885	1377	3688	4598	5185	4550	3000	1550	2487	0
CCCM	824	767	690	567	503	783	2096	2613	2947	2586	1705	881	1413	-43
GFDL	827	770	693	568	504	785	2102	2621	2955	2594	1710	884	1418	-43
HCGG	950	885	796	654	580	903	2417	3014	3399	2983	1967	1016	1630	-34
HCGS	1033	962	866	710	631	981	2628	3276	3694	3242	2138	1104	1772	-29

Figure 4.3.6.2: Estimates of average monthly biomass produced under various climate scenarios

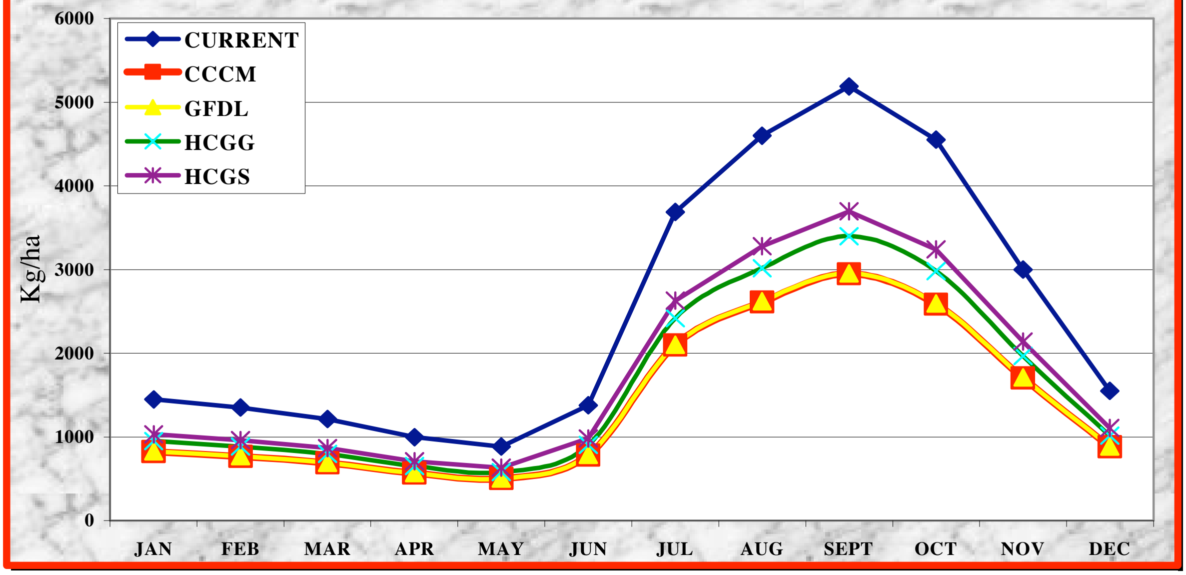


Figure 4.3.6.3: Estimates of average monthly live biomass for warm season grass under various climate scenarios

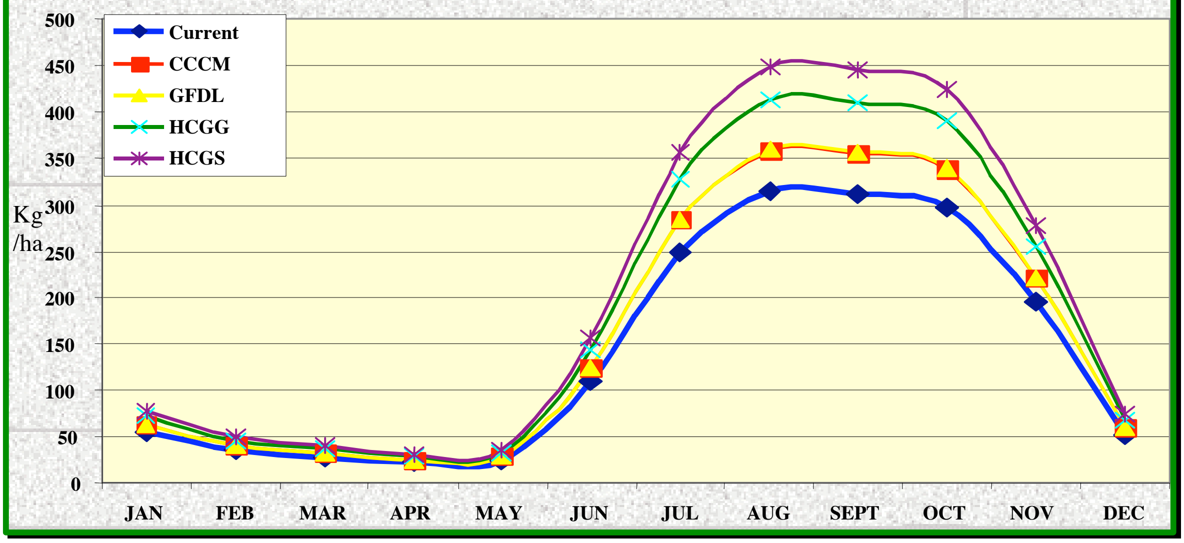
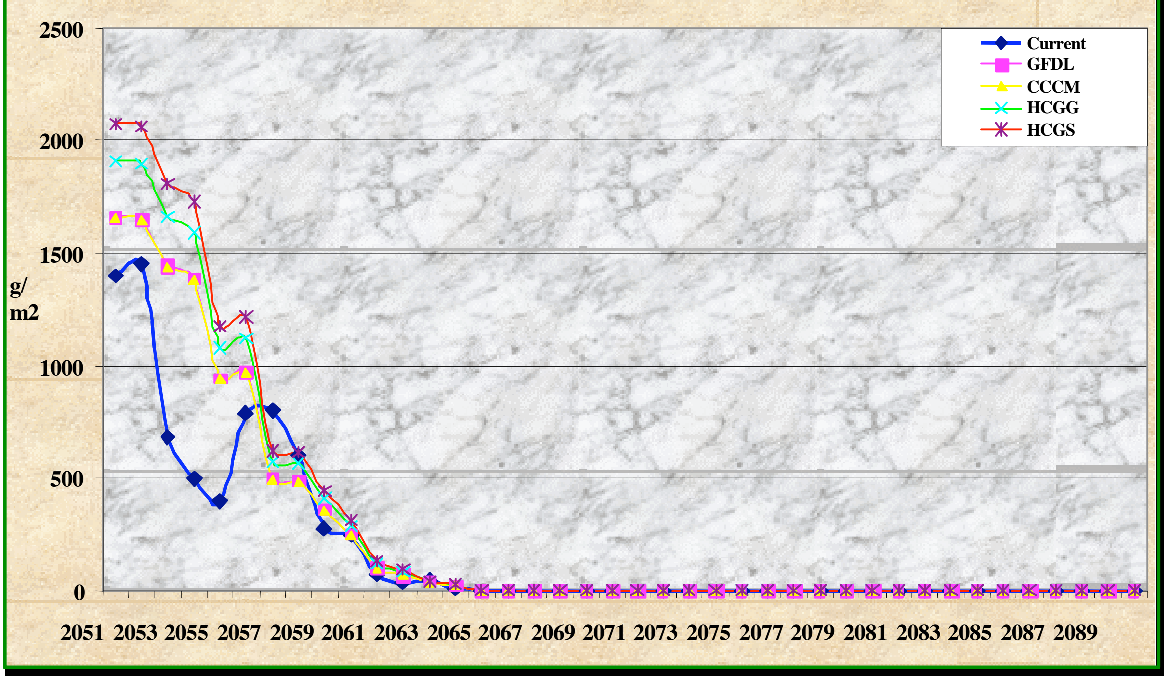


Figure 4.3.6.4: Estimates of dry matter production for warm season grass under various climate scenarios



Peak standing crop for warm season grass

Average Peak Standing Crop for warm season grasses under current climate is estimated as 88 g/m^2. This value increases by 8% to 95 g/m^2 under the CCCM and GFDL climate change scenarios. The HCGG and HCGS show increases of 24% (109 g/m^2) and 35% (119 g/m^2) respectively. For this grass species, standing crop is realized only during the first 14 years of the simulation period. After the 15th year of the simulation period, the climate will not be able to support warm season grasses under all model scenarios.

Dry matter production

From Figure 4.3.6.4, average aboveground dry matter production for warm season grass is simulated to be 523 g/m^2 under current climate scenarios. This productivity is estimated to increase by 35% to 706 g/m^2 under GDFL scenarios and 704 g/m^2 under CCCM, by 55% to 812 g/m^2 under the HCGG and by 69% to 883 g/m^2 under the HCGS scenarios. All scenarios project that dry matter production will not be sustained after 2065.

Soil moisture tension

From Table 4.3.6.4 average soil moisture tension increases above the current climate value of -34 bars by 4% to -36 bars under CCCM and GDFL model scenarios, by 20% to -41bars under HCGG and by 30% to –45 bars under HCGS model scenarios. Values of moisture tension at 15 cm and within the wettest soil layer (or the root zone) are equal under current climate scenario but increases towards the wettest layer by -1 bar for all climate change scenarios (Table 4.3.6.4).

Table 4.3.6.3: Estimates of average monthly biomass (kg/ha) for warm season grasses under various scenarios

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Avg.	% Variation
Current	55	35	28	22	25	110	250	315	312	298	195	52	141	0
CCCM	62.5	39.8	31.8	25.0	28.4	125.0	284.1	358.0	354.6	338.7	221.6	59.1	161	14
GFDL	62.7	39.9	31.92	25.08	28.5	125.4	285	359.1	355.7	339.7	222.3	59.28	161	14
HCGG	72.1	45.9	36.7	28.8	32.8	144.2	327.8	413.0	409.0	390.7	255.6	68.2	185	31
HCGS	78.4	49.9	39.9	31.4	35.6	156.8	356.3	448.9	444.6	424.7	277.9	74.1	202	43

Table 4.3.6.4: Simulated average moisture tension and 10-day temperature at Bakendik Flats

	Soil moisture tension (bars)	
	15 cm Layer	**Wettest Layer**
Current	-34	-34
CCCM	-36	-35
GFDL	-36	-35
HCGG	-41	-40
HCGS	-45	-44

Effects of Temperature on Nitrogen Uptake (ETNU)

ETNU is a multiplier. An ETNU value of unity means there is no temperature effect on nitrogen uptake. Model simulations suggest that for the Bakendik Flats ETNU values lie between 0.93 to 0.99 for warm season grasses for all scenarios. Thus temperature will not affect nitrogen uptake.

Effects of moisture on nitrogen uptake

Results of simulation of effects of moisture on nitrogen uptake for warm season grasses show that under the CCCM and GFDL climate change scenarios effectiveness of moisture on nitrogen uptake is higher than current climate scenarios by 10% but lower by 3% under HCGG and by 12% under HCGS scenarios. For the 40-year period simulated, the effect of moisture varies from 0.47 - 0.20 under current climate simulations, 0.43 - 0.09 under GFDL and CCCM scenarios, 0.49 - 0.10 under HCGG and 0.53 - 0.11 under HCGS climate change scenarios. Thus, as climate warms, moisture becomes more effective on nitrogen uptake. Results are similar for other simulated species.

Effects of moisture on de-nitrification

Inorganic nitrogen is lost from the soil through de-nitrification, which is dependent on the soil water potential of the top 15 cm of the soil layer. Similar to simulations of effects of moisture on nitrogen uptake, the effects of moisture on de-nitrification increases as the climate warms. The effect varies between 0.58 - 0.39 under current climate scenarios, but as the climate warms the effect varies between 0.55 - 0.33 under GFDL and CCCM, 0.63 - 0.38 under HCGG and 0.69 - 0.41 under HCGS climate change scenarios.

Mineralized and mixed nitrogen
The average amount of nitrogen mineralized for warm season grasses during the period of simulation varies from 20.84 g/m^2 under current climate scenarios to 12.11 g/m^2 under GFDL, 12.08 g/m^2 under CCCM, 13.93 g/m^2 under HCGG and 15.14 g/m^2 under HCGS climate change scenarios. Nitrogen fixed varies from 0.35 - 6.90 g/m^2 under current climate to 0.35 - 6.46 g/m^2 under GFDL and CCCM, 0.40 - 7.43 g/m^2 under HCGG and 0.44 - 8.08 g/m^2 under HCGS climate change scenarios.

4.3.6.4: Potential adaptation measures

It can be concluded that the rangelands at the Bakendik Flats may degrade under warmer climate due to the projected decrease in precipitation and increase in evaporation, especially soil evaporation. Less water will be available to the plants. It is also projected that reduced moisture will affect nitrogen up-take by plants. Hence, the grasses will be less palatable to the animals grazing on them leading to reduction in their weight and milk production. The consequence of this is that human population is affected as they depend on these animals for meat and milk consumption.

Potential adaptation measures can be spontaneous and human assisted. It will be necessary to utilize a combination of efforts to reduce land degradation and foster sustainable management of the natural resources. Suggested adaptation options include:

1. **Development and implementation of effective policies on integrated natural resources management**
   The negative impacts of climate change on rangelands can be mitigated by the development and implementation of effective policies that seek to improve production and also take into consideration the needs of other sub-sectors of the natural resources base of the country.
2. **Restoration of rangeland landscape**
   This adaptation option includes the monitoring and manipulation of animal stocking, institutionalization of strict grazing controls and management of the vegetation and soils.

4.3.7: Water resources

4.3.7.1: Background on the water resources of The Gambia

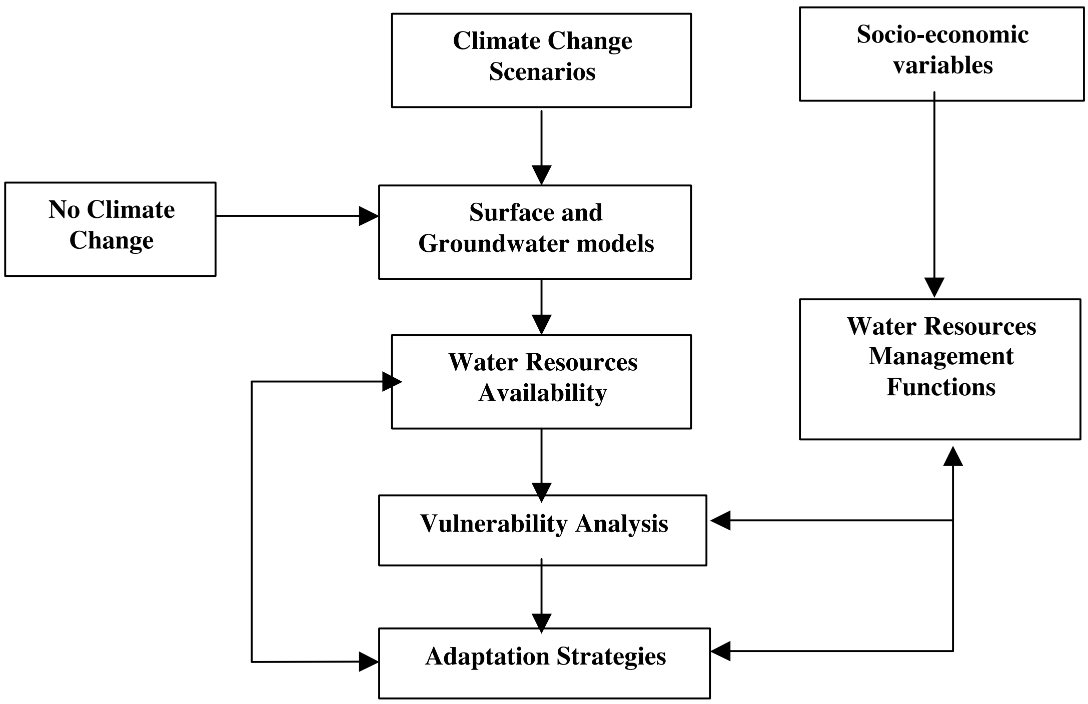
Detailed description of the country's surface and groundwater systems can be found in a number of reports (Howard Humphreys and Sons Ltd., 1974a; Ceesay and Sons, et al., 1987; GITEC, 1992; DWR, 1983, 2001; Lamagat et al., 1990), and has therefore not been treated in similar depth in this study. Briefly, the River Gambia is subject to the intrusion of seawater in its estuarine part. Variable intrusion length, a complex function of freshwater flow (DWR, 2001), roughly divides the estuary into perennially saline, seasonally fresh, and perennially fresh reaches. Groundwater resources are represented by exploitable storage in the aquifer systems underlying the country (Ceesay and Sons et. al, 1987). Infiltration is reported as the primary recharge mechanism (DWR, 1983; Ceesay and Sons et. al, 1987) for the shallow sand aquifer that provides the quasi-totality of the country's groundwater supplies.

The current assessment of water resources vulnerability – seeks to (i) verify and update the findings reported by Manneh (1997), (ii) undertake relevant analyses absent from Manneh (1997), and (iii) carry out the assessment in a more systematic and holistic way than was previously the case.

4.3.7.2: Data acquisition and procedural aspects

The general approach to the study is shown in the flowchart (Figure 4.3.7.1) below. The study area concerned by this assessment is The Gambia. However, one has to look beyond the Gambia's borders given the country's relationship within the Gambia River Basin (GRB, Figure 4.3.7.2). Suffice to say that more than 90% of the Gambia's territory lies within the GRB and over 80% of the country's surface water resources have an external origin (IPCC, 1998). As in Manneh (1997), it was imperative therefore to conduct an assessment of the flow entering the country from the upper GRB.

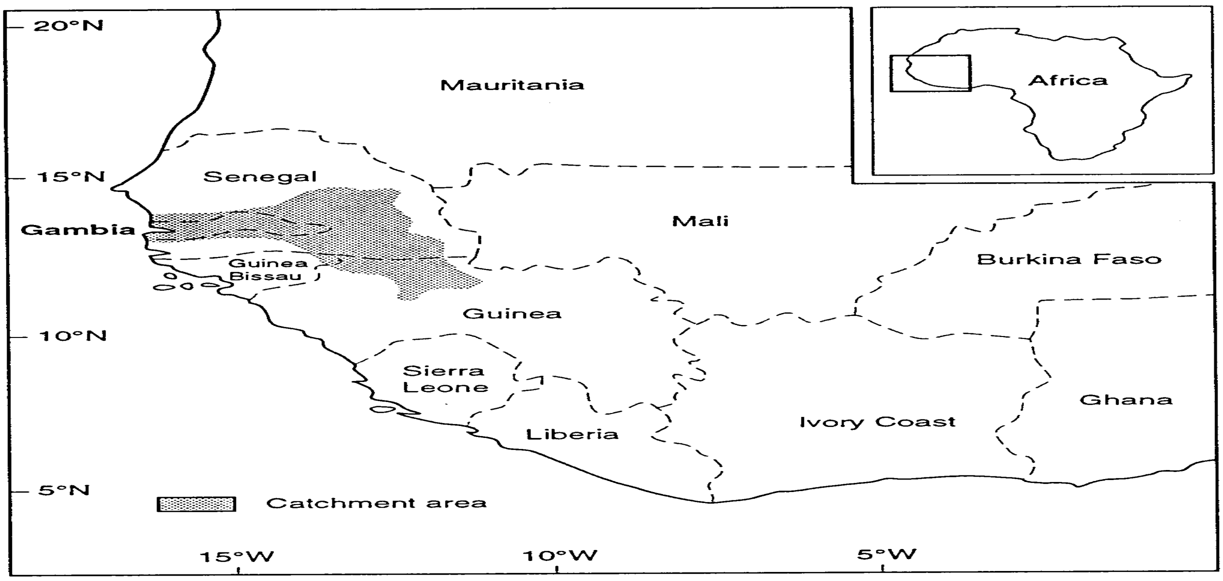
Figure 4.3.7.1: Framework for vulnerability assessment and adaptation study



Pertaining to internal water resources, these are mostly found in extensive aquifer systems. It is estimated that only 8% of groundwater recharge come from lateral inflow (Ceesay and Sons, and Howard Humphreys, 1987). As the principal mechanism for the replenishment of groundwater resources, local infiltration varies from place to place due to differences in precipitation, surface geology, land use, and other factors (DWR, 1983; Ceesay and Sons, et al., 1987). For this reason, and to better grasp the regional aspects of vulnerability, the country is divided into nine 'Analysis Units (AU)', in the majority bounded by the Atlantic Ocean, the River Gambia and its major tributaries. One drawback in the use of AUs is the absence of basic socio-economic data at the tertiary administrative level.

Table 4.3.7.1: Areal Extent of Analysis Units (excluding swamps)	
Analysis Unit	**size (km^2)**
1	547
2	802
3	691
4	1,451
5	1,352
6	1,322
7	1,054
8	840
9	861
The Gambia	**8,920**
source: G. Corr	

Figure 4.3.7.2: Situation map of the Gambia River Basin (Amara, 1993)



Data requirements for the study

For the type of analysis attempted, socio-economic data and planning information are as important as physical data reflecting water resources status. Owing to the fact that some of the data used in the study is not originally presented in the requisite format, level of detail, and/or acceptable quality standards, pre-processing is carried out using standard techniques of water resources planning. In-depth analyses rely on statistical mathematics, hydrological analysis and modelling techniques (Linsley et. al., 1982; Shaw, 1983, Hall, 1996).

The DWR provided hydro-climatic data. OMVG[1] reports were also secondary sources of hydrological data, in particular monthly flow series of the River Gambia. Data on cultivable and

[1] OMVG the acronym for *Organisation pour la mise en valeur du bassin de fleuve Gambie*, which is the French equivalent of Gambia River Basin Development Organisation.

cropland area, and livestock population were gleaned from various sources (Hasan, 1996; GOTG, 1997, NEA, 1997; DOP, 2001). Relevant data on water supply infrastructure were downloaded from the EDF/DWR database. NAWEC also provided invaluable data on its urban and provincial water supply infrastructure. Water production and aggregate water demand by different sectors is computed using maximum yield and per capita values, respectively (GITEC, 1992).

Climate change scenarios

From the set of quantifiable attributes describing climate, special emphasis is placed in climate change studies, on precipitation and mean air temperature. Indeed, these are primary outputs of GCM. The GFDL and Hadley Centre GCMs calibrated over the period 1950 – 1990 (Jallow, 2002) are used to generate precipitation projections for the period 2002 – 2078, under the assumptions of a doubling of CO_2 emissions over the same period (Jallow, 2002). Projections given in Table 4.3.7.2 point strongly to (i) statistical equivalence of the GFDL and HCGS model projections, and (ii) fundamental differences between HCGG and the other GCM projections. The GFDL and HCGS projections are, therefore, retained for further analyses of impacts of climate change on water resources.

Table 4.3.7.2: GCM projections of rainfall (mm) for the Gambia for the period 2002 – 2078 (Jallow, 2002)

	GFDL	HCCG	HCGS
Jan	0.2	0.1	0.2
Feb	0.2	0.1	0.1
Mar	0.0	0.0	0.0
Apr	1.2	0.2	0.4
May	9.7	1.8	6.8
June	87.4	35.0	24.5
July	119.3	42.5	133.5
Aug	272.3	106.7	218.9
Sept	175.5	111.3	194.7
Oct	73.8	55.4	145.4
Nov	3.2	6.7	5.7
Dec	0.4	0.4	0.5
Year	743.1	360.1	730.7

Related to the projected rise in mean global temperature, mean sea level rise is expected to increase as a direct consequence of glacier and continental ice sheet melt and thermal expansion of the oceans (Oerlemans, 1993; Bird, 1993). Additionally, changes in ocean temperature and salinity are expected to make further contributions to sea level rise (Oerlemans, 1993). Figure 4.3.7.3 shows the probability distribution of future sea level rise (Titus and Narayanan, 1992). Consistent with the Coastal Zone Vulnerability Assessment, a high rise scenario of 100 cm/ Century is adopted in this study.

The projected change in temperature of 2 K/century is adopted without further enquiry. One must not lose sight however of the fact that natural variability of monthly temperatures, in the order of 0.6 to 1.2 °C, makes it difficult to isolate temperature change impacts on water resources in the first 40 years covered by the assessment. Nonetheless, potential evapotranspiration (PET) is expected to steadily rise by 10% in summer months, by the year 2075 as shown in Table 4.3.7.3 below).

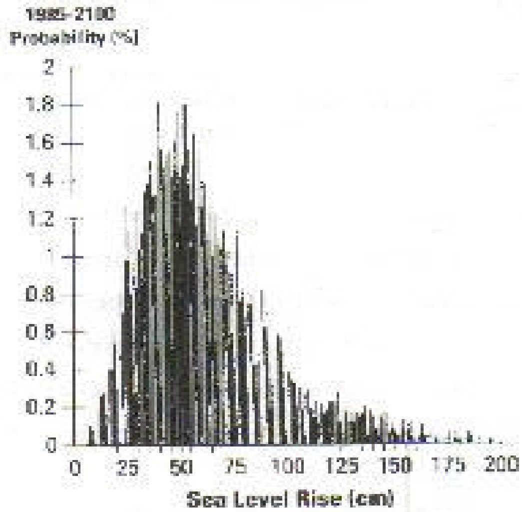


Figure 4.3.7.3: Probability distribution of sea level rise (Titus and Narayanan, 1992)

Table 4.3.7.3: Percentage increase in PET under temperature trend of 2°K/Century. PET due to global warming is assessed by Euler's method using the differential d(PET)/dT of Hargreaves equation (Benioff, 1992)

		Year		
		2002	2040	2075
Jan.	0.0	4.1	7.9	
Feb	0.0	3.9	7.5	
Mar	0.0	3.8	7.4	
Apr	0.0	3.8	7.3	
May	0.0	3.9	7.3	
June	0.0	4.4	8.4	
July	0.0	4.9	9.5	
Aug	0.0	5.1	9.7	
Sept	0.0	4.9	9.5	
Oct	0.0	4.6	8.8	
Nov	0.0	4.1	7.9	
Dec	0.0	4.2	8.0	

Having failed to demonstrate significant differences between GFDL and HCGS and post-1970 historic annual rainfall depths, climate change trends in this study are transcribed therefore by global warming of 2 K/Century, and sea level rise of 100 cm/Century. Annual rainfall is treated as a random variable conforming to the normal probability distribution, with a mean of 796.2 mm and standard deviation of 146.7mm. Time series of monthly rainfall are derived from annual rainfall series generated from a normal distribution, and seasonal distribution factors of historic time series, computed over the period 1971 – 2000. Generation of monthly rainfall time series from appropriate probability distributions (Njie, 1987) was considered as an alternative approach, but was dropped due to its failure to preserve annual rainfall statistics.

4.3.7.3: Results of climate change impacts assessment on surface and ground water resources

In this study, surface and groundwater resources are evaluated under an integrated modeling framework in which a desegregation model converts country rainfall to point estimates that serve as time series inputs in hydrological models used in this study.

Surface water resources

The catchment water balance model (*Manneh*, 1997)

$$S_{\max}\frac{dz}{dt} = P(t) - R_s(z,P,t) - R_g(z,t) - E(z,PET,t)\,, \qquad \textbf{Equation (4.4)}$$

in which $S_{\max}$ is the maximum moisture holding capacity (mm) of the catchment,
$P(t)$ is rainfall rate (mm/d).
R_s is direct runoff (mm/d),
R_g is subsurface flow (mm/d),
$z(t)$ is relative moisture storage of the catchment,

is calibrated against Gouloumbo (1986 – 1991) and Sambangalou (1973 – 1975) flow data, the calibration period being determined by concurrent availability of input (i.e., temperature and rainfall) and output (i.e., flow) data. Unlike Manneh (1997), R_g in Eqn. (4.4) regroups both baseflow and inter-flow (Linsley et al., 1982). Hargreaves' formula (Benioff, 1996;) for PET computation is also selected in preference to the Priestly-Taylor formulation (Linsley et al., 1982; Manneh, 1997) whose data requirements cannot be met under the climate change scenarios. Model parameters, $S_{\max}$, ε, and α, in Table 4.3.7.4 are obtained through a combination of heuristic and automatic calibration procedures, with due care given to physical correlates of parameters (Howard Humphreys and Sons Ltd., 1974a; Ambroise, 1978; Hall, 1996).

Table 4.3.7.4: Hydraulic characteristics of the GRB at Gouloumbo and Sambangalou. ε is a runoff production factor, whilst α is the groundwater discharge rate of over-spilling aquifer(s)

	Sambangalou	Gouloumbo
ε	0.281	0.137
α (mm/d)	0.610	0.206
$S_{\max}$ (mm)	800	900
Area (km^2)	7,080	42,000

To evaluate the impact of global warming, the runoff model,

$$Q(t) = P(t) - E(z,PET,t) - S_{\max}\frac{dz}{dt}\,, \qquad \textbf{Equation (4.5)}$$

is used to generate 100 monthly flow sequences (2002 – 2078) assuming (i) no rise in global temperature, *dT/dt* = 0, and (ii) a warming trend *dT/dt* = 2 K/Century. Sensitivity of catchment response to a warming trend is measured by changes in flow frequencies and average catchment yield.

Results of simulations under both conditions shown in Tables 5.3.7.5 and 5.3.7.6, indicate very minor changes in flow frequency, and the long-term mean flow. Insensitivity to surface flows may be explained by the fact that (i) actual evapotranspiration is close to the potential value in the rainy season and (ii) baseflow contributes only 5% of total runoff in the middle and upper GRB. In this part of the basin the hydrologic response to rainfall is practically determined by surface geology and topography (Howard Humphreys and Sons Ltd., 1974a, Lamagat et al.,1990).

Demonstrated insensitivity of runoff to global warming alone should however, not obscure the fact that open water evaporation (see Table 4.3.7.3) downstream of Gouloumbo and from a future reservoir at Sambangalou, may have significant impacts on surface water resources and its management.

Table 4.3.7.5: Flow frequencies at Gouloumbo, and Sambangalou under warming and no warming scenarios. Frequencies are given as occurrences out of a maximum possible of 900 (i.e. 75 years monthly flow simulations). Differences are underlined.

	Driest Scenario				Wettest Scenario			
Flow	Sambangalou		Gouloumbo		Sambangalou		Gouloumbo	
Range (dT/dt)	= 0	≠0	= 0	≠ 0	= 0	≠ 0	= 0	≠ 0
[0, 20]	529	529	480	480	526	526	458	460
[20, 50]	104	104	44	44	71	71	65	63
[50, 100]	82	82	8	8	94	94	3	3
[100, 150]	100	100	29	29	85	85	13	13
[150, 200]	67	67	60	60	78	78	41	42
[200, 300]	18	18	58	59	44	44	66	67
[300, 400]	1	1	52	52	3	3	43	41
[400, 500]	0	0	52	52	0	0	50	50
[500, 600]	0	0	27	27	0	0	34	34
[600, 700]	0	0	64	63	0	0	67	67
[800, 1000]	0	0	21	21	0	0	38	38
[1000, 1200]	0	0	2	2	0	0	13	13
[1200, 1400]	0	0	1	1	0	0	7	7
[1400, 1600]	0	0	2	2	0	0	0	1
[1600, 1800]	0	0	0	0	0	0	2	1
[1800, 2000]	0	0	0	0	0	0	1	1
[2000, 2500]	0	0	1	1	0	0	0	0
[2500, 3000]	0	0	0	0	0	0	0	0

In evaluating future flow conditions (Hall, 1996), it is assumed that S_{max}, ε, and α remain unchanged for the duration of the assessment. Low population densities, migration trends, limited agricultural potential and remoteness (Sogreah et. al., 1999) make it difficult to contemplate significant changes in the hydrological response of the upper GRB. Additionally, the replication of land and water management programmes, instituted under the *Projet Régional d'Aménagement du Massif du Fouta Djallon* (The Fouta Djallon Highlands Regional Development Project), with emphasis on restoration of degraded watershed areas is expected to curtail large-scale land-use changes.

Table 4.3.7.6: Long-term flow (m^3/s) at Gouloumbo and Sambangalou with and without global warming for the driest and wettest flow sequences

		Flow Sequence		
	Driest		**Wettest**	
dT/dt	=0	≠0	=0	≠0
Sambangalou	42.8	42.8	49.7	49.7
Gouloumbo	177	178	214	215

A total of 100 simulations of equally likely runoff sequences at Gouloumbo and Sambangalou are generated under a warming trend using Equation 3.2. A subset of these, illustrated in Figure 4.3.7.4, shows very clearly that variability is highest during the rainy season months.

The driest flow sequence, identified as having the highest number of months, at Gouloumbo, with flows below 1000 m^3/s, is assessed in terms of vulnerability to water shortages. On the other hand, flood risks are evaluated using the wettest flow sequence.

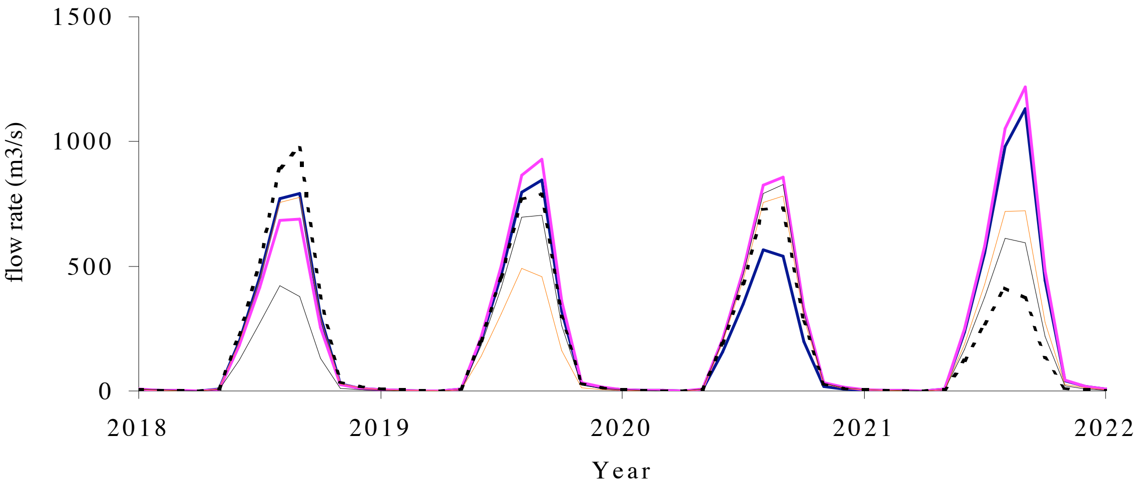


Figure 4.3.7.4: Subset of equally likely flow sequences at Gouloumbo

Reference to results obtained in the context of sensitivity tests (Table 4.3.7.5), the study draws attention to the fact that differences between long-term average flows under the wettest and driest sequences could be as high as 17%. Time constraints and an inappropriate computational environment, however, were decisive factors in limiting the number of simulations carried out. Ideally, a minimum of 1,000 simulations should be carried out to better guarantee the capture of extreme values, and stability of flow statistics. At locations downstream of Gouloumbo, generated flow sequences are corrected for rainfall and evaporation fluxes over relevant reaches of the River Gambia.

Figure 4.3.7.5 shows the net negative flux at Bansang (river km 316), and Sambang (river km 176) during low flow periods at Gouloumbo (river km 526). Observe that the monthly hydrograph at Gouloumbo is smoothed to the extent that there is hardly any difference between the hydrographs in the high flow season. Ultimately, the differences appearing during low flow periods can be linked to open water evaporation between these locations.

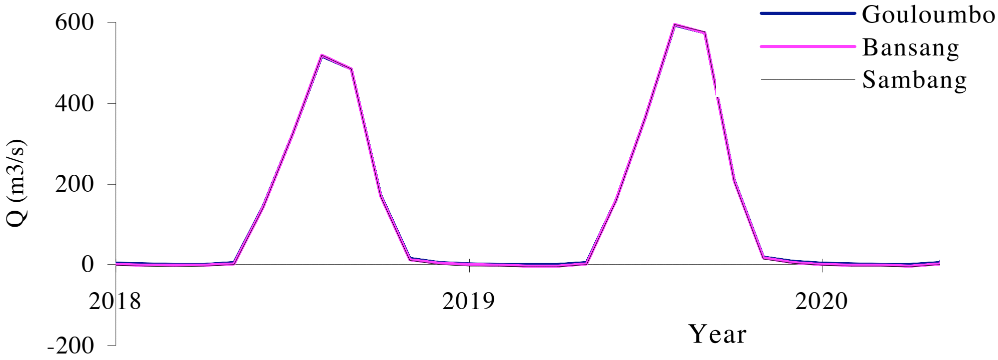


Figure 4.3.7.5 (a): 2-year window (2018 – 2020) from the driest flow sequence showing flow hydrographs at Gouloumbo, Bansang, and Sambang

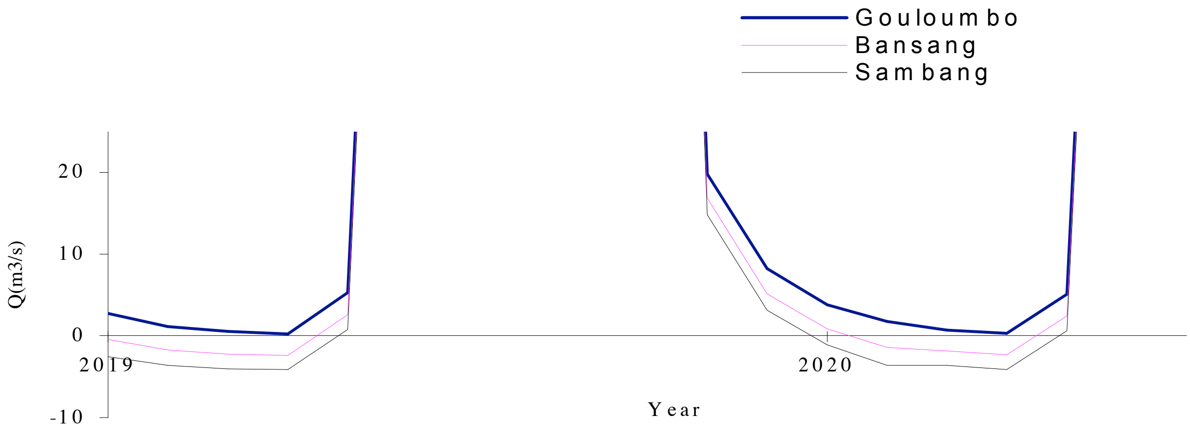


Figure 4.3.7.5(b): close-up view of low flow periods. Observe the negative flows (i.e. net upstream fluxes) at the last two stations

At the start of operations of the Sambangalou dam, a target hydrograph of 50 m^3/s at Gouloumbo is recommended by Sogreah et al. (1999). At low flow periods, this means that water is released from the dam at a rate $Q_0(t) \leq 50$ m^3/s, depending on flow forecast or observed in real-time, downstream of the dam. An approximate representation of the dam's release policy expressed as

$$Q_0(t) = \begin{cases} 50 \quad m3/s, \quad from \quad Dec \quad to \quad June \\ 0 \quad , \quad otherwise \end{cases} \qquad \textbf{Equation. (4.6)}$$

is applied to the driest flow sequence to illustrate the effect of regulation on flows.

In Figure 4.3.7.6, peak flows are reduced by 20 – 30%, and minimum flows augmented from less than 1 m^3/s to 50 m^3/s. Corollary to the regulatory effects of dam releases, the ratio of peak to minimum flows drop from 1000 to 20 or less.

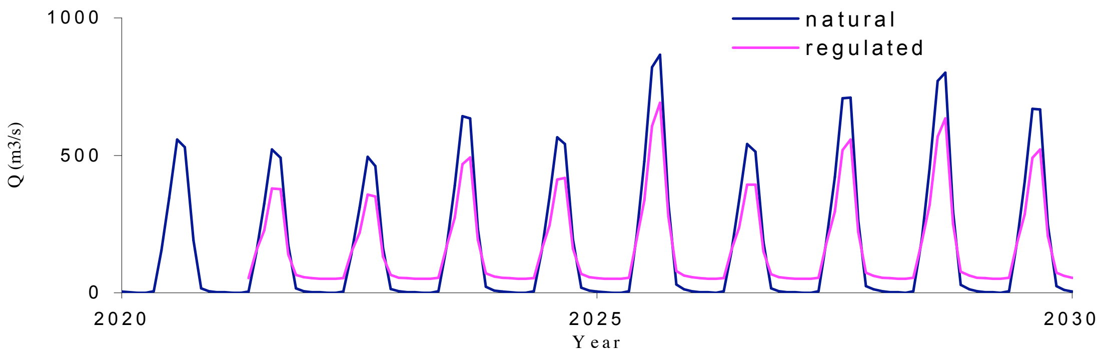


Figure 4.3.7.6: Regulated and unregulated flow hydrographs at Gouloumbo illustrating the impact of regulation on peak flow reduction, and low flow augmentation

The study draws attention to the fact that recent vulnerability assessment and planning studies (Manneh, 1997; Sogreah et al., 1999) have failed to incorporate a sea level rise scenario, its impacts on flow regulation and water resources management. Key questions related to sea level rise are: (i) what impacts (if any) sea level rise has on the flow regime; and (ii) how does it affect saline intrusion.

The projected rise in mean sea level, which closely resembles a surge of long duration, could set up an equilibrium water level profile along the estuary (Volker, 1987), and extend it's current tidal length by another 37 km (see distance-elevation data in Table 4.3.7.7).

Table 4.3.7.7: Distance and critical topographic variables at locations close to the limit of tidal influence on river water levels and discharge. Low water levels at River km 563 are obtained from average of forward and backward linear interpolations of Gouloumbo and Wassadou-Aval elevations.

Station	D	z	S
Gouloumbo	526	0	0.05
River km 563	563	1	0.07
Wassadou-Aval	623	5	0.09
Wassadou-Amont	625	5	0.09

D = distance (km) from estuary mouth, z = elevation (m) above mean sea level, S = slope (m/km) at station) (* = estimated)

During the peak flow season, when tidal effects are pushed oceanwards, unidirectional flow is only expected upstream of Fatoto (free of tidal effects for two or three weeks in September/October under current situation). Furthermore, one could expect the downgrading and retardation of flood peaks[2]. As a logical consequence of increasing tidal length, landward/upstream fluxes are also expected to become a more prominent feature of flow at locations along the estuary.

Using depth and surface area data from Howard Humphreys and Sons Ltd. (1974a), and DHI (1982), in conjunction with a 100 cm/Century sea level rise scenario (Titus and Narayanan, 1992; IPCC, 1996, Jallow and Barrow, 1997), this author computes an additional tidal influx of 2,700 m^3/s at the estuary entrance in Banjul by the year 2077. In this regard, maximum upstream

[2] These predictions derive directly from reservoir routing of flood hydrographs (*Linsley et al*., 1982; *Shaw*, 1983, *Hall*, 1996)

fluxes at Sambang (river km 176) are expected to increase by 0.3 to 0.5 m^3/s, i.e., 6% to 10% above current values.

On the question of saline intrusion, there is significant uncertainty regarding future migration of the saline front (concentration of dissolved solids = 1g/l). One estimate, based on the increase in tidal fluxes which agree with findings reported under (DWR, 2001), puts upstream migration of the upper limit of the saline front around 250 m, over the next 75 years. On the other hand, distance-elevation data in Table 4.3.7.7 suggest upstream migration by 37 km, approximately equal to 370 m/year. If the tidal range at the mouth of the River Gambia estuary does not change over the study period, one could expect a 100 cm increase in mean sea level, equivalent to the tidal amplitude at Banjul, to induce a translocation of the upper limit of the saline front 4 km upstream of Kuntaur (river km 254), the current upper limit of intrusion.

To demonstrate that dispersive, rather than advective transport[3] is the principal mechanism responsible for saline intrusion, and that 4 km is a more likely intrusion value than 37 km, one has to examine the one-dimensional approximation of the advection-dispersion equation (Savenije and Pagès, 1991; Jolánkai, 1992).

$$A\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x} \right) - Q\frac{\partial C}{\partial x}, \qquad \textbf{Equation. (4.7)}$$

together with salinity and discharge measurements made at specific locations along the estuary.

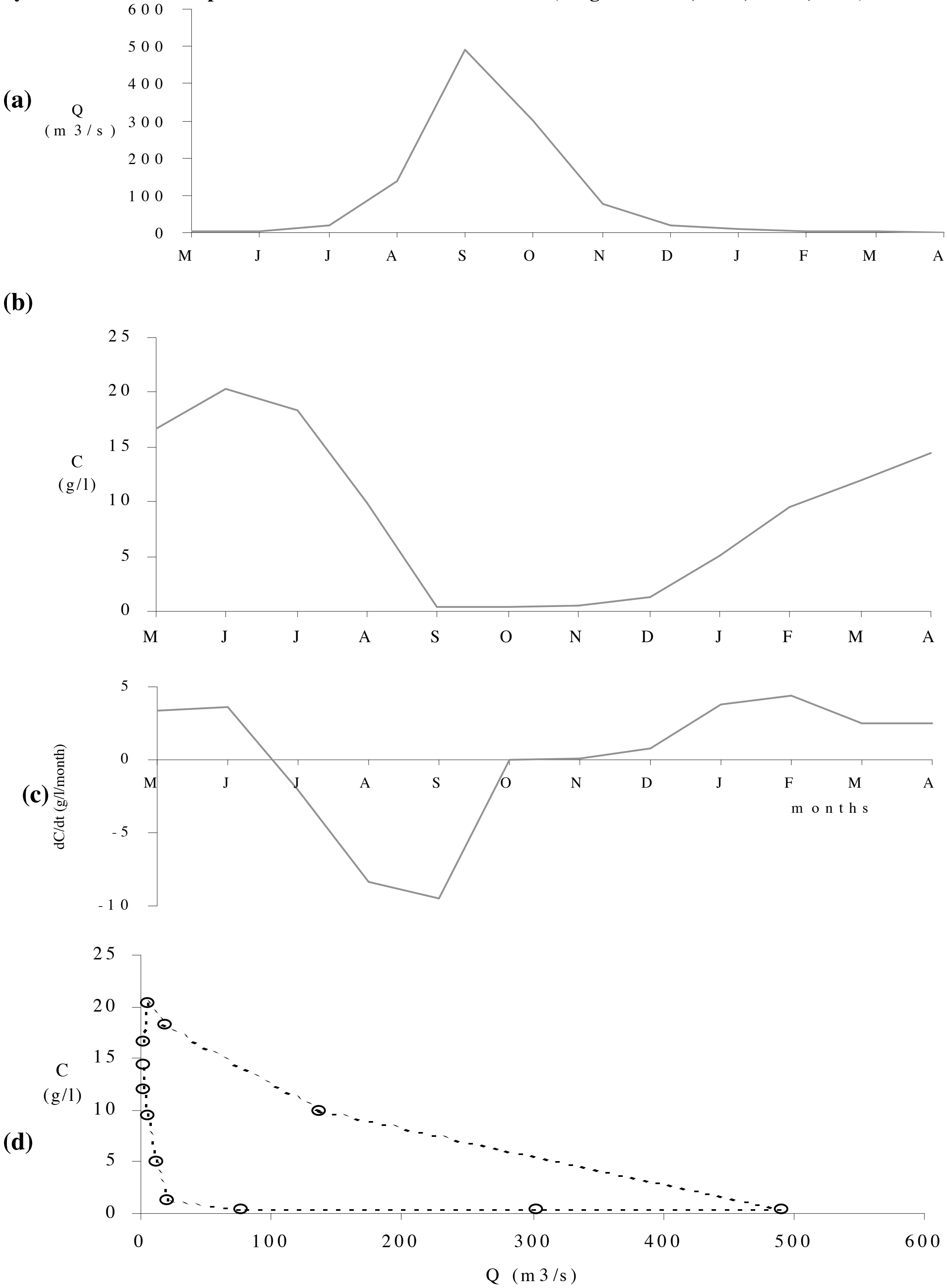
Table 4.3.7.8: Gouloumbo flows and corresponding concentration at Balingho during the 1977/8 hydrological year – one of the driest years on the instrumental record. Missing concentration values for the months of August, September, October and March are estimated from the long-term mean (1974-2000). ∂C/∂t is approximated by finite differences ΔC /Δt

	Q	C	*DC /Dt*
May	2.32	16.7	3.4
June	4.42	20.4	3.7
July	18.4	18.3	– 2 .1
Aug	137	10.0	– 8.3
Sept	490	0.4	– 9.6
Oct	303	0.4	0.0
Nov	75.9	0.5	0.1
Dec	19.4	1.3	0.8
Jan	11.0	5.1	3.8
Feb	4.4	9.5	4.4
Mar	2.05	12.0	2.5
Apr	1.14	14.5	2.5

Note: Q = distance (m^3/s) at Gouloumbo, C = concentration (g/l), $\Delta C/\Delta t$ = incremental rate of change of concentration (g/l/month)

[3] Dispersive transport is the movement of salt due to molecular and turbulent diffusion. Advective transport is the movement of salt due to bulk movement of water.

Figure 4.3.7.7: Variation of discharge and concentration during 1977/8 hydrological year (see Table 4.3.7.8). Observe the rapid flushing of salt from the estuary on the rising limb of the flow hydrograph. Notice also the hysteretical relationship between flow and salt concentration (Ferguson et al., 1994; DWR, 2001)



In the present study, the salinity regime at Balingho (river km 130) is shown for demonstration purposes because (1) the station features prominently in OMVG salinity control projects, and (2) DWR's monitoring protocol, is primarily targeted towards tracking the saline front, hence the unavailability of concentration data at Kuntaur (river km 254) for most of the year. Note that the river Gambia is a fully mixed estuary (Manneh, 1988; Sogreah et al., 1999), in which the most significant changes in salinity, both temporal and along the axis of flow, occur between river km 100 and river km 200.

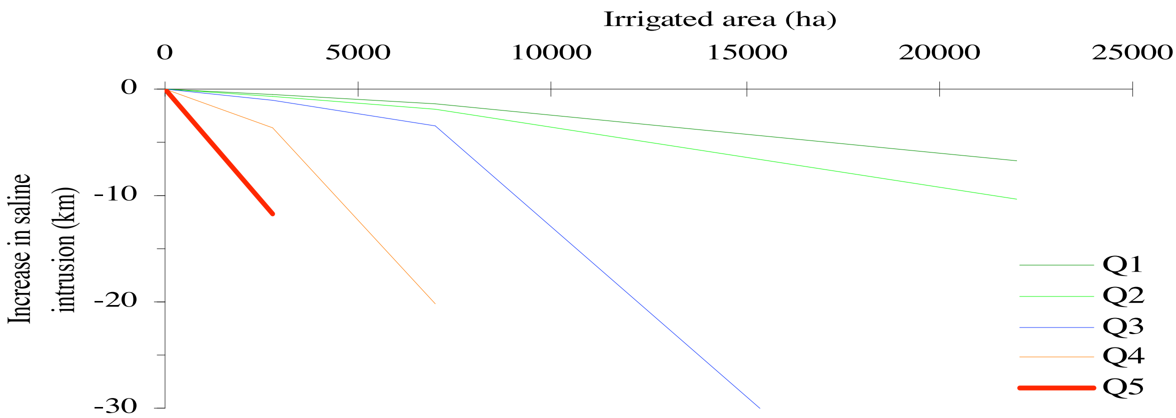
In Figure 4.3.7.7c, $\Delta C/\Delta t < 0$ occurs when the advective transport term $Q\frac{\partial C}{\partial x}$ is dominant. As the reader will appreciate from figures 5.3.7.7a and 5.3.7.7c, this situation corresponds to the period of high flows. Conversely, $\Delta C/\Delta t \geq 0$ when $\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right)$ is equal to or greater than the advective transport term, which typically occurs when Q and $\partial C/\partial x$ both tend to zero. Note in particular, that D_x is inversely proportional to Q (John, 1973; Jolánkai, 1992). The maximum value of $\Delta C/\Delta t$ in Table 4.3.7.8 and Figure 4.3.7.7c reflects the fact that net tidal fluxes on the ocean side of the saline front may be briefly significant, at specific locations, during the recession phase of the Gouloumbo flow hydrograph. Outside of these periods of significant tidal fluxes, dispersive transport, which is a relatively less efficient transport mechanism, prevails. To fix some ideas, compare the rapid flushing of saline water during floods (i.e. advective transport of freshwater) with the slow upstream migration of the saline front (resulting primarily from dispersive transport of saline seawater).

Table 4.3.7.9: Increase in saline intrusion, ΔX_s, under different irrigation scenarios. The negative sign indicates landward/upstream translocation of saline front. Current irrigation area of 2,800 ha is projected to increase to 7,000 ha, and 22,000 ha, by 2030 and 2075, respectively. dX_s/dQ is derived from the relationship between freshwater inflow, Q, and location of the saline front, X_s, during the dry season (DWR, 2001). Irrigation water demand/abstraction, Q_a, is computed on the basis of 3,000 mm/yr/ha.

	A = 2,800 ha $Q_a = 2.66$ (m^3/s)	A = 7,000 ha $Q_a = 6.66$ (m^3/s)	A = 22,000 ha $Q_a = 20.9$ (m^3/s)
Q (m^3/s)	ΔX_s (km)	ΔX_s (km)	ΔX_s (km)
50	– 0.5	– 1.4	– 6.6
40	– 0.7	– 1.8	– 10.3
25	– 1.1	– 3.4	– 51.1
10	– 3.5	– 20.2	
5	– 11.6		

From the preceding discussion concerning the relative importance of the dispersive and advective transport mechanism, the study concludes that upstream migration of the saline front based on distance-elevation relationships is extremely unlikely. The study also concludes that a drastic reduction of flows reported by Manneh (1997) is not a sufficient condition for significant changes in saline intrusion length. Whereas reduced freshwater flows lead to insufficient flushing of accumulated salts, and changes (over time) in chemistry of river water (Savenije and Pagès, 1991), relatively large volumes of freshwater abstraction on the upstream side of the saline front, is a necessary condition for saline intrusion upwards of 10 km. This deduction is based on (i) the principle of continuity, which requires compensatory landward/upstream fluxes in response to abstraction of freshwater, and (ii) the greater efficiency of advection as a transport mechanism of dissolved salts. Observe from Table 4.3.7.9 and Figure 4.3.7.8 how saline intrusion, reaches alarming proportions when freshwater inflow drops below 10 m^3/s, or the total area under irrigation exceeds 7,000 ha.

Figure 4.3.7.8: Increase in saline intrusion, ΔX_s as a function of freshwater inflow from the upper GRB (Q_1 = 50 m^3/s, Q_2 = 40 m^3/s, Q_3 = 25 m^3/s, Q_4 = 10 m^3/s, and Q_5 = 5 m^3/s) and irrigated area.



Groundwater resources

Ground water resources evaluation faces several problems. Amongst these are (i) a sub-optimal monitoring network, (ii) absence of detailed topographic maps, and (iii) inadequate knowledge of aquifer properties. Furthermore, information on abstraction projections and future location of boreholes is not currently available from NAWEC, which has just embarked on the preparatory phase of a 30-year groundwater development plan in partnership with the ADB.

In the current study, groundwater recharge is computed by the Rise Method,

$$i(t) = S_y \frac{dh}{dt}, \qquad \textbf{(Equation 4.8)}$$

in which $i(t)$ is recharge rate (m/d), S_y is the specific yield of the relevant aquifer, dh/dt is the rate of change (m/d) of groundwater levels. Equation (4.8) does have some limitations however. First, it underestimates recharge due to the non-consideration of groundwater abstractions and discharge. Secondly, the accuracy of the method is dependent on the density of the groundwater observation network, which in some places is woefully inadequate.

Analysing groundwater levels from a circumstantial network of 47 observation boreholes, average recharge for the nine-year period (1993-2001), mean annual recharge is found to be 565 cubic hectometres (hm^3) corresponding to 2.1% of maximum groundwater storage. Table

4.3.7.10 gives the breakdown of recharge by AUs. It is quite possible that an undesirably high level of bias has been introduced into the computations by the sparse network of groundwater level observations (see Figure 4.3.7.11).

Cognisant of the fact that surface geology and rainfall are key determinants of recharge, one may discern a degree of consistency in the spatial variation of computed recharge. Specifically, maximum recharge depth occurs in AU1, which combines the highest rainfall and sandy soils. On the other hand, lower recharge is registered in AUs with rainfall marginally above or below the national average. AU7 recharge looks suspicious considering the prevalence of ironstone crust in this spatial domain. Alternatively, the AU9 estimate could be in error, considering that the two spatial domains have similar surface geology and very little differences in rainfall.

Table 4.3.7.10: Estimates of groundwater recharge for the period 1993 to 2001 using the Rise Method. Volumes are computed as the product of recharge depth[4], and areas of corresponding AUs. NB: 1 $hm^3 = 10^6 m^3$

AU	I (mm)	Volume (hm^3)
1	90	49.2
2	74	59.1
3	55	38.2
4	53	77.6
5	56	75.4
6	60	79.3
7	76	80.6
8	63	53.1
9	60	52.1

source: G. Corr

Noting that only *a posteriori* recharge estimates could be obtained from the Rise Method, the study made an attempt to establish statistical relationships between recharge, rainfall, and temperature in all AUs, to ensure transfer of information from some stochastic variables whose probability distributions are reasonably well known (i.e. annual rainfall and monthly temperature) into another stochastic variable on which there is little information, and which defines groundwater resource status (i.e. recharge).

Whilst the link between recharge and rainfall is beyond question, temperatures averaged over 5-month period (July to October) are introduced as proxy variables for evapotranspiration. The author acknowledges the limitation of this approach in the sense that recharge is dependent on a host of other factors, including physiographic variables, land use, and temporal distribution of rainfall.

Table 4.3.7.11 shows simple and multiple regression parameters, and corresponding statistical measures of significance and optimality for AU7 and AU9. According to the Akaike Information Criterion (Delleur, 1991), improvements attributable to temperature in the multiple regressions are not statistically significant. On the other hand, regression coefficients established with rainfall as the only variable are far from being perfect. It is quite possible that variable

[4] recharge depth, $I = S_y \int_{h\,min}^{h\,max} dh$

transformations may lead to improved results and different conclusions, but a systematic search for suitable transformations was not carried out due to time constraints. As a fall-back option, recharge coefficients are computed as a fraction of rainfall during the period 1993 – 2001. Results are shown in Table 4.3.7.12.

Table 4.3.7.11: Regression models, parameters, and statistical measures of significance and optimality

			AU7				
Model	a_0	a_1	**n**	***df***	R^2	$R^2_{critical}$	**AIC**
$I=a_0P$	0.0701	-	8	7	0.2468	0.4441	83.730
$I=a_0P + a_1T$	0.0446	0.8569	8	6	0.3533	0.4994	84.351
			AU9				
Model	a_0	a_1	**n**	***df***	R^2	$R^2_{critical}$	**AIC**
$I=a_0P$	0.0686	-	8	7	0.7232	0.4441	69.892
$I=a_0P + a_1T$	0.0621	0.2164	8	6	0.7339	0.4994	73.096

P= rainfall (mm), T= 5-month temperature average (°C), n= sample size, *df*= degrees of freedom, R^2= coefficient of determination, $R^2_{criricatl}$ = critical value at 5% confidence level [10], AIC= Akaike Information criterion (*Delleur*, 1991).

Considering that groundwater is replenished by local infiltration, and significant deviations of rainfall from current levels has not been demonstrated, a global warming trend is expected to have limited impacts on groundwater recharge. The magnitude of the impact has not been successfully quantified in this study because of poor partial correlation between recharge and temperature. Making use of the mean ratio of actual to potential evapotranspiration at Sambangalou and Gouloumbo, one may however deduce an overall reduction in groundwater recharge of 3% by the year 2075, which may be expected to be even lower considering the expected expansion of agricultural land, at the expense of forests.

Against the background of population growth and concentration, economic growth, and land use changes, the study draws the reader's attention to expected changes in recharge coefficients in some of the AUs. In this connection, a (i) 90% decrease is forecast for AU1, and (ii) 20%, decrease in AU2, AU3, AU4, AU5, and AU8, by the year 2075. Given the apparent lack of encroachment of human settlements unto recharge areas in AU7 and AU9, and intense agro-sylvo-pastoral management activities in these areas, recharge coefficients in these AUs are assumed to remain constant over the same period of this study.

Assuming that projected changes are linear in time, updated recharge coefficients are used together with rainfall corresponding to the driest flow sequence (Run 61), to compute natural groundwater recharge in all AUs. Results of these computations are shown in Figure 4.3.7.13.

As expected, AU1 is most seriously affected by changes in its recharge coefficient. What Figure 4.3.7.9 does not reflect however are occult recharge from NAWEC's water distribution network (5% of system of production: personal communication from A. Jobe, Manager, Water and Sewerage Division), and on-site sanitation systems in the area. Whilst economic imperatives force NAWEC to curtail distribution losses (equivalent to a standing water column of 2 mm), seepage from sewage effluent is set to grow, in parallel with population size. Using a hydraulic loading of 5 litres/day/person from sanitation systems, recharge from sewage effluent could account for 50% of groundwater recharge by 2065 (see Figure 4.3.7.10). The increasing risk of pollution from nitrates (NO_3^-), and coliform bacteria is self-evident.

Table 4.3.7.12: Groundwater recharge coefficients for the different AUs.

AU	r
1	0.1044
2	0.0786
3	0.0686
4	0.0627
5	0.0682
6	0.0736
7	0.0617
8	0.0887
9	0.0686

In this study, a preliminary estimate of baseflow originating from AU7 and AU9, stands at 8.26 m^3/s, that is, roughly 4% of mean flow under the driest scenario (Run 61). Approximating variations in base flow by a triangular hydrograph starting in August and peaking in November, one observes from Table 4.3.7.14 that groundwater discharge into the estuary could play an equal or greater role than inflows from the upper GRB, in fending off saline intrusion between February and May. If, as the preliminary results suggest, baseflow is more significant than evaporation losses, serious effort should be made to quantify the base flow in the estuary reaches affected by saline intrusion.

Water resources management functions
In recognition of the finite nature of water resources and its vulnerability to pollution from numerous human activities, water resources management (WRM) is instituted to integrate all aspects, uses, and functions of water. Due to diverse stakeholder interests, changing social perspectives, situation factors, level of water resources development (WRD)[5], etc., there is no universal definition of what constitutes water resources management (Bardossy, 1991; Hall, 1998). Not-withstanding, conflicting stakeholder interests (Bardossy, 1991), and competing management objectives need to be reconciled using politically and socially acceptable criteria.

Viewed from an operational perspective, three vital functions, i.e., meeting water demands; flood control; and ecosystem management and pollution control, that concretise universal and time-invariant concerns of WRM are investigated by the study.

Meeting water demands
This aspect of WRM consists of striking a balance between consumer/user demand for water and installed capacity of water supply infrastructure. In general, demand is correlated with population size, and level of economic activity. On the other hand, supply capacity is dependent on the water resources availability, WRD infrastructure and investments. In the sections that immediately follow, demand trends and WRD prospects constitute the subject of discussions. Attention is drawn to the fact that water demand explicitly refers to volumetric demand.

[5] WRD – engineering works whose objective is the capture of water resources, its treatment (if necessary) and delivery to the user/consumer (Author's definition)

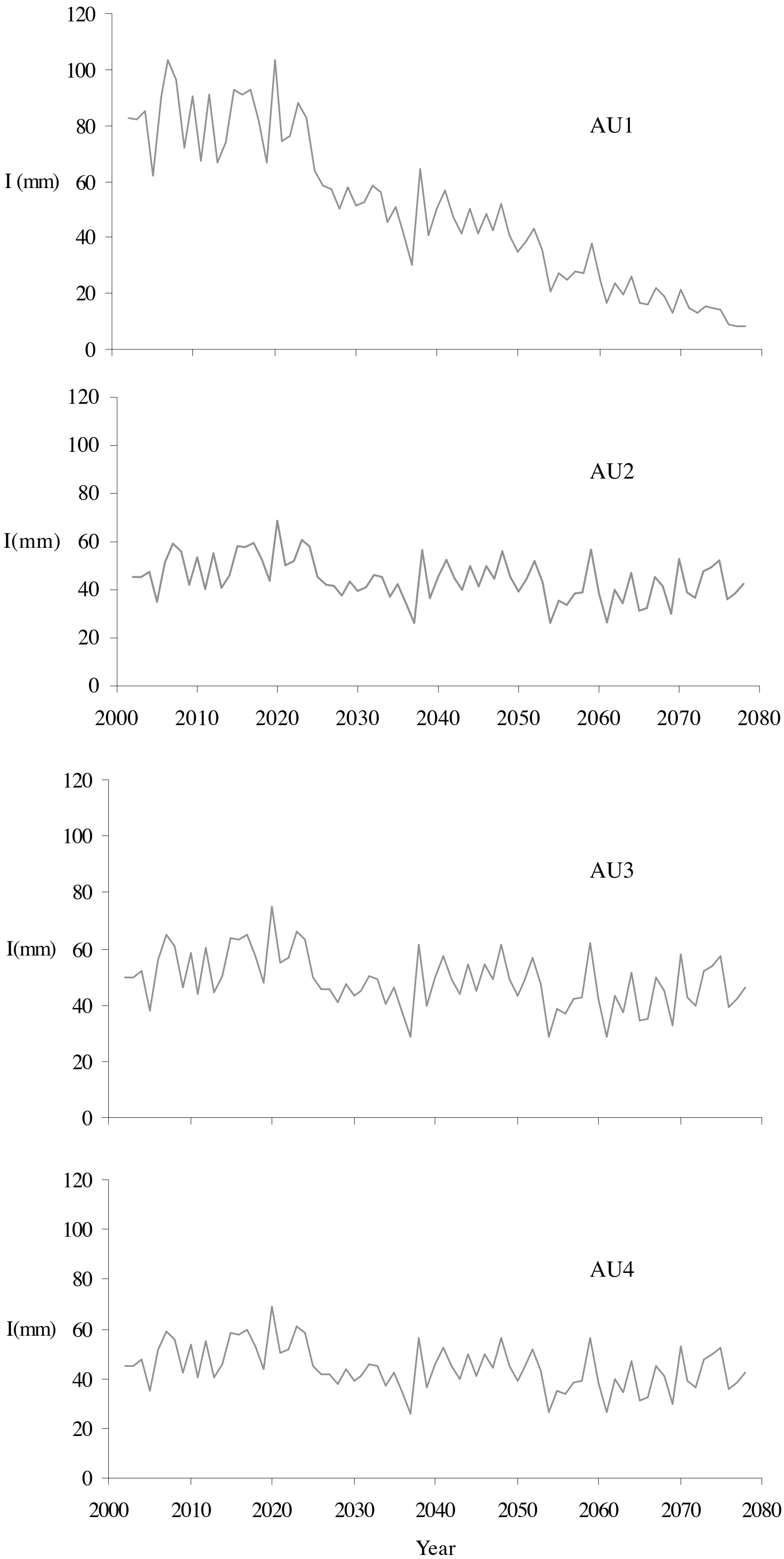


Figure 4.3.7.9: *Estimates of groundwater recharge under conditions drier than normal. The influence of land use changes on recharge has also been considered. Observe in particular the drastic reduction* in AU1 recharge *figures, arising mainly from urbanisation.*

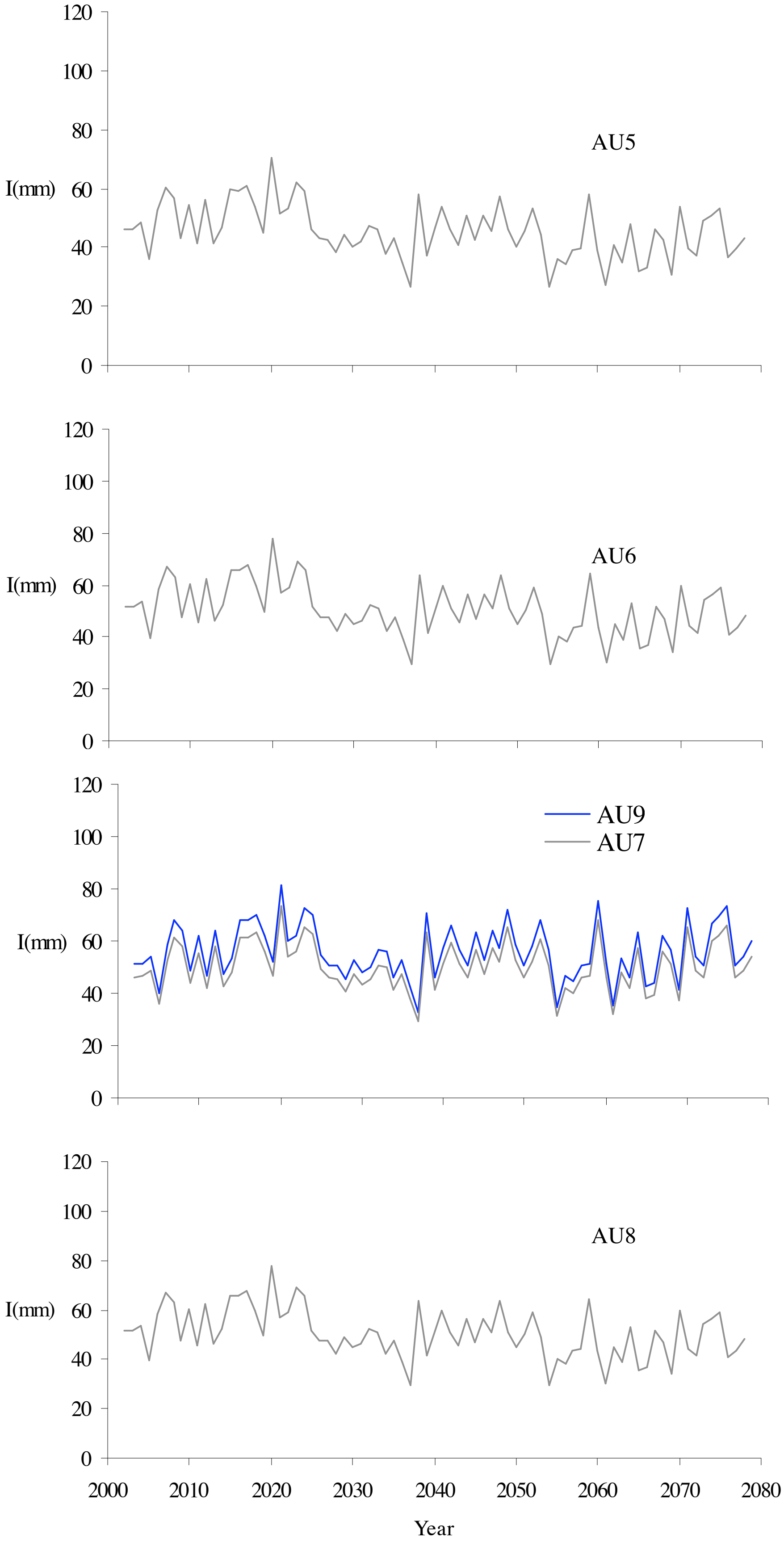


Figure 4.3.7.9: (cont'd) *Basse rainfall is used to compute both* AU7 *and* AU9 *recharge which have been grouped on the same graph to economise space*

Figure 4.3.7.10: Increasing risk of groundwater pollution in AU1 as a result of decreasing recharge from rainfall and increasing leakage of sewage effluent from on-site sanitation system

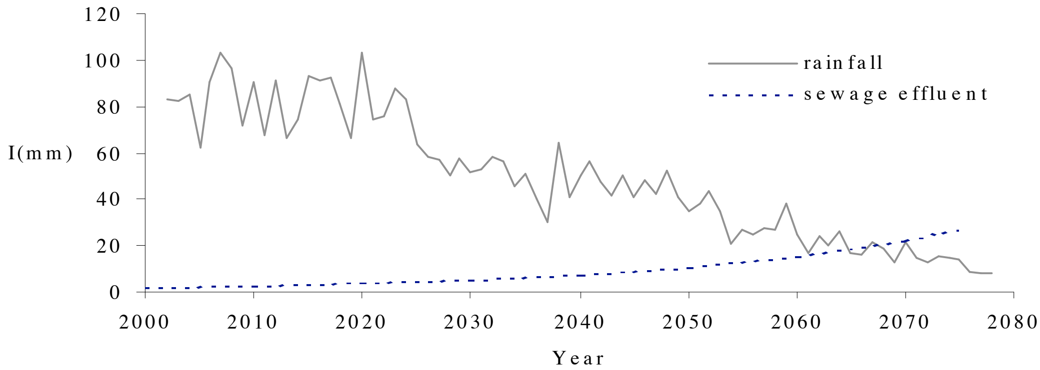


Table 4.3.7.13: Groundwater abstraction from the shallow sand aquifer. Comparison with results in Figure 4.3.7.12 show levels of abstraction between 4 – 10% of recharge in AUs falling outside the conurbation of the Greater Banjul Area. In AU1, which overlaps with the latter abstraction is close to 50% of recharge.

	Abstraction (m^3/d)			Abstractions	
	Wells	Boreholes	[a]+[b]	hm^3/year	mm equivalent
AU	[a]	[b]			
1	3,370	59,808	63,178	23.1	42
2	5,551	6,044	11,595	4.2	5
3	3,348	4,320	668	2.8	4
4	6,242	4,269	10,511	3.8	3
5	3,478	9,965	13,443	4.9	4
6	4,406	4,420	8,826	3.2	2
7	2,980	10,445	13,425	4.9	5
8	3,542	4,710	8,252	3.0	4
9	2,160	3,759	5,919	2.1	2

source: G. Corr

Table 4.3.7.14: Relative importance of Groundwater contribution to base flow. Gouloumbo flows are for year 1974/5 (modulus = 274 m^3/s) one of wettest on instrumental record since 1970

	Source		
Month	AU7 & 9 [a]	Gouloumbo [b]	[a]/[b]
Jan	12.8	21.1	0.61
Feb	11.2	12.7	0.87
Mar	9.2	7.8	1.18
Apr	7.3	5.9	1.22
May	5.5	2.2	2.50
June	3.6	18.8	0.19
July	1.8	264.0	0.00
Aug	0.0	832.0	0.00
Sept	5.5	1142.0	0.00
Oct	11.0	757.0	0.01
Nov	16.5	160.0	0.10
Dec	14.7	60.4	0.24

It is assumed that water undertakers will comply with quality standards prescribed under the law when providing water to users/consumers.

Demand projections
Njie (2002) contains a detailed description of demand projections for the various sectors of the economy. Aggregate volumetric demand from the major water use sectors under a changing climate is presented in Table 4.3.7.15 below. 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 4.3.7.11 which shows that, from 2015 onwards, irrigation and environmental demand constitute more than 80% of aggregate demand. Notice also that environmental demand is initially nil because minimum flows are not maintained (i.e. unregulated flow conditions prevail).

Water resources development
In order to put water resources to beneficial use, engineering works and facilities are required to transfer water from its sources to demand locations. In this regard, WRD is defined as the capture and distribution of water to users/consumers. Treatment of natural water quality, upstream and downstream of the point of its use, is also an integral part of WRD. To mitigate the impacts of seasonal variability on water demand, storage facilities often feature as a key element of surface water resources development infrastructure. Groundwater, on the other hand, occurs in natural reservoirs (i.e. aquifers).

Table 4.3.7.15: Synoptic table of sectoral and aggregate demand (m^3/d)

	Sectoral water demand (m^3/d)						Aggregate demand	
Year	**Domestic**	**Tourism**	**Agricultural Livestock**	**Agricultural Irrigation**	**Industrial**	**Environment**	**(m^3/d)**	**(hm^3/yr)**
2000	66,908	780	11.320	269,938	10,792	0	359,739	132
2030	186,613	1,300	23,903	696,403	81,533	1,728,000	2,717,751	992
2075	936,392	1,593	82,546	2,000,796	200,330	3,456,000	6,677,657	2,437

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

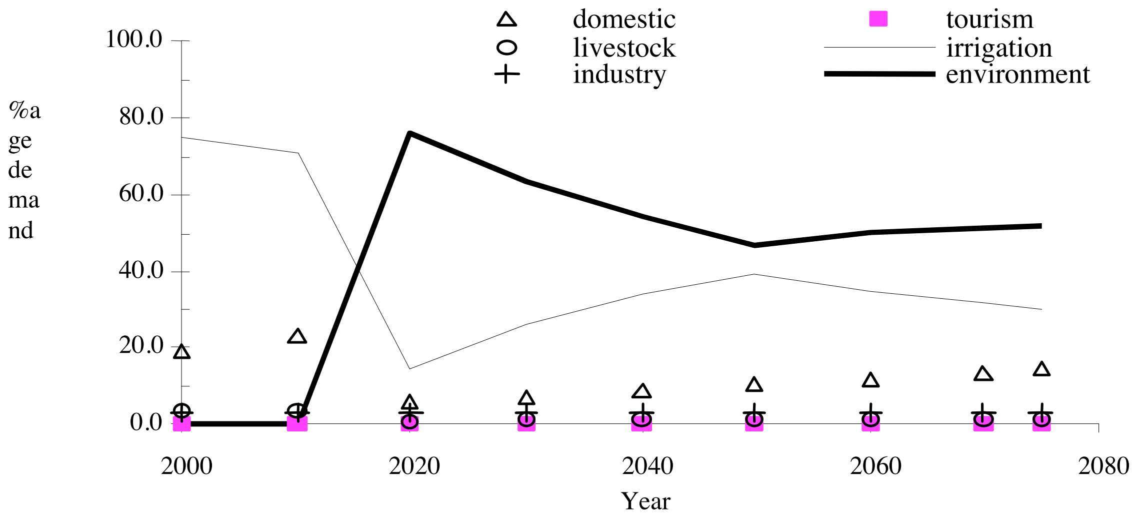


Figure 4.3.7.11: Sectoral demand expressed as percentage of aggregate demand

Except for minimum flow requirements and rice irrigation, water demand from other socio-economic sectors are met from groundwater resources, due to its relatively cheap development costs, and easy access throughout The Gambia. Except for slight acidity problem, and high iron content in some areas, groundwater quality is generally good (Ceesay and Son et al., 1987). River water, in contrast, being saline on long stretches of the river Gambia has no consumptive value. In the perennially fresh reaches of the river, its use as drinking water has practically been confined to history, as newer and safer water supply systems are developed in rural communities.

Water resources development takes place at different scales and under different ownership and management structures. Pertaining to the domestic sector water supplies, NAWEC and the DWR are the major service providers. Most industrial units get their water from the urban public water system operated by NAWEC[1].

NGOs, and charities to a lesser extent, are also involved in the provision of water supply to rural communities (Njie, 1994; Sonko, 2000). Self-supply is the rule when water supply is not available through any of the agencies already mentioned.

In the CRD flood plains, small-scale water control and irrigation projects funded through grants constitute intake works, embankments, drainage and irrigation channels. Irrigation water requirements in the uplands, whether on commercial, communal, or family gardens is provided mainly by self-supply. Most NGOs and charities working in the water sector focus their support on water development for agricultural production.

Groundwater abstraction closely follows population distribution in the country. Thirty-one high-capacity boreholes with coordinated pumping schedules constitute well-fields that supply the Greater Banjul Area. Elsewhere, small and medium size water distribution systems, and covered wells equipped with hand pumps, cater for water requirements of local communities (Njie, 1994; 1997a). Besides its technological appeal, and economic advantages (GITEC, 1992), the covered well equipped with hand pump is particularly suited to the dispersed settlement patterns that prevail in The Gambia.

Exact statistics of safe water supply coverage are difficult to obtain. Based on infrastructure statistics, Njie (1997a) estimates safe water supply coverage to lie between 58 and 78%. A recent survey conducted by the CSD however, gives coverage figures of 77 and 95% in the rural and urban areas, respectively (CSD, 2000). Accepting the latter to be a true reflection of the situation, one has to concede that achievements will still fall short of government's target of 100% coverage by 2003 (GOTG, 1998).

Figure 4.3.7.15 illustrates the heavy dependence of rural water supply development on external funding, and the link between grants-in-aid received to political developments inside and outside the country. Even with opportunities under the New Partnership for African Development (NEPAD) beckoning, The Gambia may still need to reflect on strategies for internal mobilisation of resources to face off future emergency situations.

[1] NAWEC is a paratstatal entity, whose operations are regulated by government, operates on a profit-making basis. In contrast, DWR is the technical and engineering arm of government that executes/supervises donor-funded rural water supply projects.

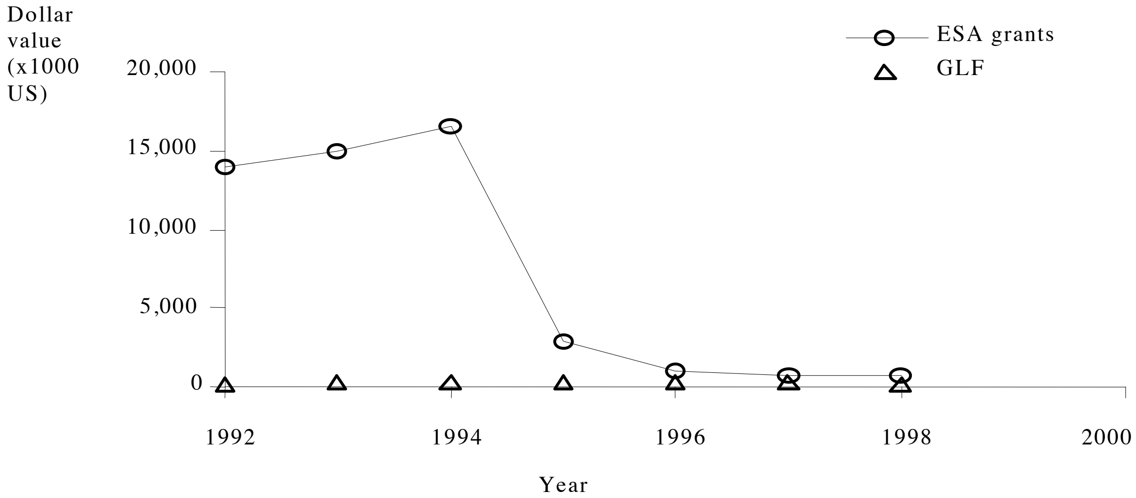


Figure 4.3.7.12: Expenditure on water resources development (data from Sonko (2000). Observe the clear dominance of External Support Agencies (ESA) grant funds over Gambia Local Funds (GLF) between 1992 and 1994, and exponential decrease after this date.

Flood control

Floods are naturally occurring events that closely follow the pattern of rainfall over a catchment. Surface conditions including geology, topography, forest cover, and soil moisture status are known to play decisive roles in the generation of floods (Linsley et al., 1982; Amara, 1993; Iorgulescu and Jordan, 1994; Hall, 1998). The 1999 floods in URD and CRD may be rare but not exceptional as shown by historical records maintained by the British colonial administration (Amara, 1993).

Flooding in The Gambia is caused by riverine floods, high tidal levels, and poor drainage, or in any combination. The geographical position of The Gambia, which flanks the River Gambia on its North and South banks, places the country squarely within the flood plains of the River Gambia. Except in the URD, where the riverbanks are relatively high, all areas below the 1-metre contour line are prone to tidal flooding. MANR (1999) designates/characterises 20% of the Gambia's land area as swamp and wetland areas prone to tidal flooding. Njie (2002) underscores the fact that areas prone to or currently experiencing tidal flooding are bound to expand, under the projected sea level rise scenario.

For a number of reasons, riverine floods pose a lesser hazard than sea level rise. Firstly, the drastic reduction in rainfall since independence (Amara, 1993) has led to a decrease in the frequency and magnitude of floods. Secondly, the annual flood wave of the River Gambia dissipates as it propagates downstream, where the main risk areas (i.e. low riverbanks) are located. Sogreah et al. (1999) note that the tidal component in river water levels dominates those associated with fluvial floods downstream of Kaur (river km 199). Flow regulation is also expected to further dampen the flood wave downstream of the Sambangalou reservoir. Table 4.3.7.16 shows the expected decrease in water levels that are consequent to flow regulation. For average and low exceedance frequencies, it can be observed that the decrease in maximum water levels at Basse and Fatoto, due to flow regulation, is larger than expected rise in mean sea level.

Future inundation of low-lying areas in the URD is expected therefore to be less severe during the high flow season.

Table 4.3.7.16: Reduction in annual maximum level caused by flow regulation at Sambangalou

Exceedance Frequency	Fatoto	Basse	Bansang	Janjanbureh	Kuntaur	Kaur	Balingho
0.1	234	109	15	10	4	8	2
0.2	220	100	13	9	4	8	2
0.5	160	67	10	7	3	6	2
0.8	96	32	6	4	2	4	1
0.9	81	28	5	4	2	4	1

Source: Sogreah et al. (1999). Note: values are averages obtained from three simulations

Due to its low elevation (Brown and Root Environmental, 1994; Jallow and Barrow, 1997), the capital city, Banjul, is also liable to flooding in the event of loss of structural integrity of the ring dyke, failure of pumps, or loss of tidal flaps at the polder station. A generally flat topography, non-adherence to physical planning regulations, and inadequate drainage infrastructure, are the main contributory factors to flooding in the urban and semi-urban areas of Kombo St. Mary and Western Divisions. Alteration of the hydrographic network and local topography, in particular, were reported by Corr (1996) as principal causes of flooding around the Kotu Stream, located within the Kanifing Municipality.

In conjunction with sea level rise, shallow water tables, water-logged soils, and coastal erosion are also adding to flood risk in settlements, such as Old Jeshwang, Eboe Town, and Fajikunda etc., that are steadily encroaching unto wetlands.

4.3.7.4: Vulnerability to Climate Change (Impacts and Adaptation)

According to Njie (1997b), vulnerability is the degree of loss or hardship society would suffer as a consequence of a specific hazard event, which, in the present context, is that of climate change in all its manifestations. Using Aysan's classification of factors influencing vulnerability (ICE, 1995; Njie, 1997b), one may retain:

ecological vulnerability (degradation of the environment), and
organisational vulnerability (lack of strong national and local institutions),

as the most pertinent themes for vulnerability assessment of water resources management functions in the light of projected climate change.

Vulnerability is assessed in qualitative terms, as adverse changes to water resources availability (spatially and temporally), ability of public institutions to reliably perform their management functions, and general society to face up to new challenges. Where projected climate change does not have a clear negative impact, only a description of resulting environmental conditions is provided. An opinion on overall impact is deferred until more detailed analyses have been conducted.

Due to the nature of projected impacts on water resources, Njie (2002) also points out that the literal meaning of "degradation of the environment" is eschewed in favour of its logical meaning which highlights loss of utility and damages arising from changes in water resources status and regimes. This shift of emphasis is deemed necessary because of unresolved valuation problems. For instance, risk of flooding may force costly land use changes, but paradoxically cut down irrigation pumping costs and open up new opportunities for aquaculture.

Ecological Vulnerability
In view of the preceding arguments, ecological vulnerability is assessed by looking at climate change impacts on future renewal rates of groundwater resources, flow and salinity regime of the River Gambia.

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 (Howard Humphreys and Sons, 1974; Lamagat et al, 1990). Evaporation losses from the retention dam planned to be constructed at Sambangalou, in the order of 11 m^3/s (Hydro-Quebec et al., 1996), are expected to gradually increase to 12 m^3/s by 2075. 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, flow hydrographs passing through the tidal reach of the River Gambia would be subject to further reservoir routing effects (Linsley et al, 1982; Shaw, 1983). Specifically, peak flows are expected to decrease in magnitude and occur later than under present sea level.

As previously mentioned, climate change scenarios were not considered in the development of the Gambia River Basin Hydraulic Master Plan (Sogreah et al., 1999). Lacking the resources of the latter, Njie (2002) could not provide straightforward answers as to whether or not changes in flow regime have an overall positive or negative effects. Impacts arising from a 10% increase in evaporation losses from Sambangalou reservoir could be easily offset by flow regulation.

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 at present, 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 m to the above intrusion length. Modification of the annual flow hydrograph is expected to cause 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 in the direction of the river's headwaters.

Pending substantiation of the projected saline intrusion length, it is estimated that riverine ecosystems can readily adapt to changing environmental conditions (Njie, 2002). Under the projected rise in mean sea level, it is observed that maximum saline intrusion length increases by a mere 40 m/year.

Flooding

Due to the arterial nature of the river Gambia, its low-lying and broad open valleys, 20% of the land area is currently covered by freshwater swamp and salt marshes (MANR, 1999). In spite of the availability of orthophotomaps, the principal investigator on climate change and water resources issues is not aware of the existence of hypsometric information downstream of Gouloumbo. One cannot therefore make an accurate assessment of the area liable to flooding from a 100-cm sea level rise. It is reasonable however, to assume that all or part of the current swamp area will be inundated.

If sea level rise projections turn out to be accurate, dry season water levels will increase throughout the estuarine part of the river Gambia, leading to permanent flooding of current inter-tidal areas. The fluvial component of water levels in the rainy season will however be reduced due to reservoir routing of the annual flood wave by higher river water levels.

Construction of embankments/bunds and dykes may be effective against flooding of real estate, paddy fields, and other amenities, but soil salinisation, in areas adjacent to the river, is still likely to ensue from evaporation of shallow groundwater (Njie, 1991).

Groundwater recharge

Considering that groundwater is replenished by local infiltration, and significant deviations of rainfall from current levels has not been demonstrated, 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. 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 3% reduction in groundwater recharge, by the year 2075. Expansion of agricultural land, at the expense of forests however, is likely to cut this figure down (Wheater et al., 1982; Hall, 1996).

Where hydraulic connectivity exists between the coastal aquifers and saline surface water bodies (DWR, 1983; Howard Humphreys and Partners, 1994), the likelihood of saline intrusion into aquifers is dependent on the location of well-fields, abstraction rates, and sea-level rise. Analysing data from geophysical surveys carried out under the project "Groundwater Survey of The Gambia - Phase 2", Scott Wilson Kirkpatrick (1993) were able to delineate areas where groundwater is at risk of saline intrusion. These areas are represented by a 3-km strip of land adjacent to the Atlantic Ocean and 1-km wide swathe of land along tidal streams and the River Gambia estuary. With retreating shorelines (Jallow and Barrow, 1997), some areas outside the current salinity risk areas would gradually fall within the evolving risk areas.

Organisational vulnerability

Arguably, organisational vulnerability is best measured by impacted countries/communities' response to sudden onset disasters. In the case of The Gambia, the best examples that come to mind are the 1999 floods, and negative step trend in rainfall at the start of the 1970ies. Conditions prevalent three decades ago may no longer be valid, but some conclusions drawn from that painful experience may still be valid today.

Doubtless, the critical factors of resiliency/vulnerability comprise the existence of technically competent front-line institutions with resources to undertake necessary planning and implement vulnerability reduction programmes, in concert with other stakeholders and communities at risk. Coordination structures therefore have an important role in overall response capacity.

National level
Judging form progress made in the Emergency Disaster Relief Programme instituted in the wake of the 1999 floods, response capacity is well below the required level. This may have to do with administrative bottlenecks, but the principal investigator on climate change and water resources issues is of the opinion that an *ad hoc* approach to disaster management, and emphasis on relief, are partly responsible for poor national response capacity (Njie, 2002). A comprehensive Strategy for Contingency and Disaster Preparedness Planning (Njie, 1997b), seeking to change the *status quo*, has largely been ignored by policy makers.

Flooding from a 100-cm sea level rise requires extensive surveying, land valuation, and massive engineering works that are out of the reach of government. Construction on a large scale would require the participation of the private sector. National capacity to deal with estuarine flooding compounded by poor drainage as happened in 1999 is practically dependent on water managers' ability to regulate flow in the River Gambia.

Pending construction of a retention dam at Sambangalou, flood risk from intense rainfall is unabated, whilst government and communities are powerless to prevent flooding. Similarly, adverse changes to riverine ecosystems, resulting from changes in the salinity regime along the River Gambia and some of its tributaries, may only be neutralised by flow regulation.

Ultimately, financial resources will be a key determinant of vulnerability, therefore government's divestiture and cuts in public spending related to vulnerability reduction can only lead to a clash between "logics of action " (Karpik, 1974; Hood, 1976).

Local level
The geographical scale and magnitude of projected climate change impacts on the natural environment are such that municipalities and other local government structures are bound to be out of their depth. Notice that the dearth of technical capacity at national level is reflected at local government level.

Regarding water resources development, the strong dependence on external grants is illustrated in Figure 4.3.7.12. Given current levels and trends of poverty in the country, the ability to develop self-supplies may be entirely limited to small groups of wealthy cattle owners. Local well diggers and registered well digging contractors have sufficient wealth of experience to construct, re-deepen, and rehabilitate concrete-lined wells used for water supply. If provided with sound technical advice, local government and communities may also avoid location of water points in unsuitable locations. On the contrary, nothing short of judicial enforcement may deter risk-taking behaviour where this concerns use of flood-prone areas for housing development.

The dispersed nature of settlements is a major disadvantage for optimal planning and use of resources. On the contrary, mobilisation of volunteers under the "*nyodema*" flag is much easier in small communities. Such mobilisation has indeed been instrumental in the successful construction of anti-salt dykes/bunds by the Soil and Water management Unit in the Baddibus and Niumis.

4.3.7.5: Adaptation (option/strategies)

Major climate change impacts on water resources status and management functions have been identified as:

- inundation of areas that are below the 1-metre contour line and contiguous to the River Gambia estuary and its tributaries;
- risk of saline intrusion into aquifers in hydraulic connection with the estuary and sea; and
- increased saline intrusion length in the River Gambia estuary.

To a somewhat lesser extent (i) changes in river salinity regime, and (ii) decrease in groundwater recharge, also crystallise impacts that may require adaptation measures on the part of affected communities/parties. Table 4.3.7.17 succinctly summarises expected climate change impacts and adaptation measures to countervail their potentially adverse consequences.

Table 4.3.7.17: Climate change impacts on water resources status and management functions and corresponding adaptation measures

Expected impacts	Adaptation measures
1. inundation of flood-plain areas	(a) construction of embankments/dykes
	(b) relocation of threatened activities
	(c) construction of flood-proof housing
	(d) Institutional Reforms
2. saline intrusion into aquifers	(e) relocation of abstraction points
	(f) changes in pumping policies of fully penetrating/deep wells/boreholes
3. increased saline intrusion length	(g) flow regulation
	(h) licensing and permits for withdrawal of river water for irrigation;
changes in river salinity regime	(i) flow regulation
4. decrease in groundwater recharge	(j) increase water column in wells

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CHAPTER 5

5: RESEARCH AND SYSTEMATIC OBSERVATIONS

5.1: Introduction

Under Article 4, paragraph 1(g) of the UNFCCC, Parties are committed to amongst others *"promote and cooperate in ………………… research, systematic observations and developments of data archives related to the climate system…………."* Article 5 of the Convention guides Parties on the mode of cooperation and support in fulfilling the commitments under Article 4.1(g). The Gambia continues to fulfill these requirements despite its constraints.

5.2: Research

There is no single body in the country responsible for directing research although, in the agriculture sector, the National Agriculture Research Board (NARB) directs research and the National Agricultural Research Institute (NARI) is responsible for conducting research. Line institutions such as the DWR are responsible for research in their specific fields.

5.2.1: Finalised climate change studies

The DWR in collaboration with the NCC has participated in national, regional, and global studies on climate change, biodiversity and desertification. In 1993 the NCC participated in the development of the Gambia's first published National Inventory of Greenhouse Gas emissions. Between 1993 and 1995 the NCC also collaborated with the USCSP to conduct the vulnerability study on some economic sectors of The Gambia. Some members of the Committee also participated in the development of the National Strategies and Action Plans of the Biodiversity and Desertification Conventions. The Committee also collaborated with the UNEP Collaborating Centre on Energy and Environment (UCCEE) at RISOE in Denmark to develop the capacity of members of the NCC in the analysis and evaluation of CDM activities and projects.

5.2.2: On-going and planned climate change studies

In the year 2001, the DWR set-up a Global Change Research Unit (GCRU) to conduct and coordinate research on global change issues, particularly climate change. The Unit is currently collaborating with the Energy and Development Research Centre (EDRC) of the University of Cape Town, South Africa and the UCCEE, on Capacity Building in Analytical Tools for Estimating and Comparing Costs and Benefits of Adaptation Projects in Africa. The key objective of this project is to help build and strengthen the institutional capacity within Africa to develop and implement analytical tools for estimating and comparing the costs and benefits of adaptation projects in key economic sectors.

Results from the study will contribute to the development of international climate change policies and programs, particularly with regard to adaptation activities in developing countries under the UNFCCC. The project will focus on developing and applying a framework for estimating and comparing adaptation costs in Southern and West Africa.

GCRU is also expected to participate in a regional project to study and establish regional emission factors for the West African Region. Most of the countries in West Africa developed their National Greenhouse Gas Inventories using default emission factors contained in the IPCC 1994 Revised Guidelines, which do not reflect national circumstances. Hence, uncertainties are introduced in the results of the inventories. The UNDP and the NCSP are executing the project.

5.2.3: Key research issues and constraints

Presently, one of the key issues of research is the policy implication of the implementation of the UNFCCC, particularly in the areas of economic and natural resources management to ensure sustainable economic and environmental development and management. Such a study should increase understanding of climate change issues and also help put in place policies that take account of climate variability and institutional reforms that may become necessary. The study will also serve to initiate the process mainstreaming climate change into national development programmes of The Gambia.

A major constraint is the limited capacity of the NCC in the economic analysis of GHG mitigation measures and climate change adaptation activities.

5.3: Systematic Observations

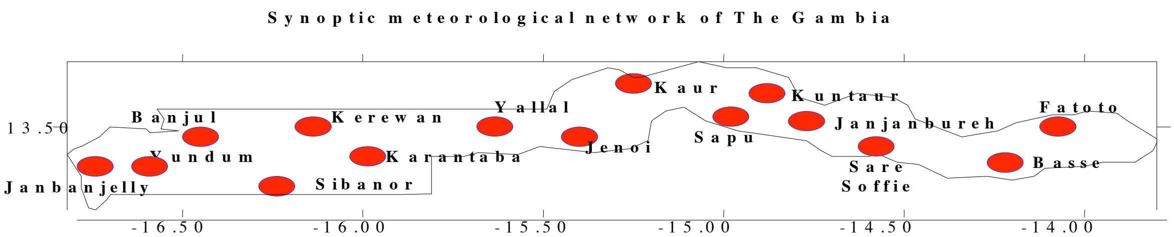
5.3.1: National hydrological and meteorological observing systems

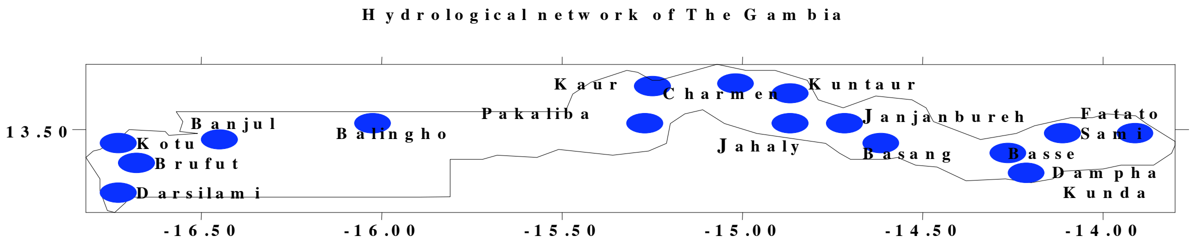
Meteorological phenomena have been observed in The Gambia since 1886 under the supervision of the Royal Air Force and later under British West African Meteorological Services. The Hydrological and Meteorological Services of The Gambia are housed within DWR. The Services are mandated to collect, process and disseminate data and information on hydrology and meteorology. The figure below shows the network of stations from which the raw data is collected. The meteorological network has 15 synoptic stations, two of which operate for 24 hours while the rest operate for 18 hours. In addition to these stations the meteorological service maintains 44 rainfall measuring stations and 18 crop-monitoring stations for observations of crop phenology.

Three satellite-based data receiving and processing stations (PDUS (Primary Data User Satellite), MDD (Meteorological Data Dissemination) and SADIS) are available at the meteorological station at the Banjul International Airport in Yundum. These stations are used to collect and process cloud pictures and meteorological data in digital, graphical and pictorial form. The data and information received are used in the preparation of weather forecasts for the general public and for specialized agencies such as the GPA. CLICOM, HYDROM and GIS data processing software are also available at the head office of DWR. The Main Meteorological Station at the Banjul International Airport is connected to the WMO Regional Telecommunications Hub in Dakar, Senegal by Very High Frequency (VHF) radio link and a

Landline. These are used to transmit national meteorological data to the world and receive global meteorological data.

Figure 5.1: Meteorological and Hydrological Networks of The Gambia





5.3.2: Water level and pollution monitoring network

The Water Quality and Rural Water Supply Divisions of the Department also maintain a network of 47 observation boreholes and about 200 wells for water quality and groundwater level monitoring throughout the country. Water points and the River are monitored regularly for any pollutants. The various sources of pollution to ground water have been described but monitoring and control must be organised in a comprehensive manner. Unfortunately, the DWR lacks the necessary means to monitor and control this potentially hazardous problem to the nation's ground water resources.

5.3.3: Regional and global observing networks

The Gambia participates in the AGRiculture, HYdrology and METeorology (AGRHYMET) observing and monitoring programme of the 9 CILSS members. This Programme was established in 1975 after the serious drought of 1968 and the early 1970s with the objective of monitoring agricultural, hydrological and meteorological phenomena within the CILSS member states. All hydrological and meteorological services were strengthened, expanded and capacitated in terms of human resources and infrastructure.

Since 1993, the support to DWR from the UNDP Country Cycle has not been forthcoming. The Government placed more emphasis on environment issues and did not consider the AGRHYMET Programme a priority. The stock of hydrological and meteorological equipment were exhausted and all the network of stations have experienced shortage of equipment for monitoring weather phenomena and climatological elements. This has resulted to breaks in the trends and series of data of the most important climatological elements of temperature, rainfall, solar radiation, etc.

5.3.4: Constraints related to systematic observations

Major constraints related to systematic observations are inadequate financing, technical support and limited human capacity. Inadequate financial support from Government and donor partners has resulted to depleted stocks of instruments and other equipment. These have proved to be very expensive for Government to replace. The inadequate financing also meant that the observation networks could not be expanded to cater for areas that are not well represented.

In terms of human resources the Government and donor partners have provided some fellowships to train technicians on electronics and instrumentation for the maintenance of the observations networks. However, most of the trained technicians leave government service for the private sector, where they earn higher wages and have better and conducive working conditions.

5.3.5: Priority activities related to systematic observations

Priority activities include:

1. Replacement and upgrading of the conventional equipment to digital equipment to minimize human interaction and also to provide continuous recording of the meteorological, hydrological and climatological elements and phenomena.
2. Rehabilitation and expansion of the existing station networks for more representative monitoring of weather, climate and other environmental issues.
3. Provision of better and bigger capacity data processing and storage equipment for the upgrading, networking and interconnectivity of the various data base systems of the DWR and other collaborating institutions.
4. Strengthening the human resources and capacity of the institutions involved in collection, processing and maintenance of data and information related to meteorology, hydrology and climatology.

CHAPTER 6

6: EDUCATION, TRAINING AND PUBLIC AWARENESS

6.1: Introduction

Education plays a critical role in the development process as it helps in the dissemination and assimilation of development information including information on climate change. Similarly, public awareness is another critical factor in implementing the UNFCCC. The understanding of the public of issues relating to climate change will help them play their role and influence policy and the decision making process.

6.2: Education

Generally speaking, climate and climate change issues are absent in the educational system of The Gambia. The subject of climatology is treated under geography. All environmental issues are treated under the Social and Environmental Studies (SES) component of the school curriculum. Weather and climate elements are not treated in the required depth. The following should be put into consideration in the educational system of The Gambia.

6.2.1: Formal education

The science, mitigation and adaptation measures as regards all the sectors of the national economy should be incorporated in the school curricula at lower and upper basic cycles. These should be incorporated in disciplines such as SES, General Science and other related subjects. At the tertiary level, both government and private educational institutions should be encouraged to develop and incorporate the relevant curricula on climate change. They should be assisted in building both the material and human resource capacities of the collaborating institutions to better handle climate change curriculum.

6.2.2: Informal education

The curricula used by the Non-Formal Education directorate should be expanded to cover climate change issues. Mass media techniques such as television/video, radio, print media, traditional communicators and extension agents could be used in well designed campaigns aimed at achieving the desired results in climate change, by changing attitudes and ushering in the right behaviour. Awards for media people, communities and any other bodies could be in the annual NEA awards competition to encourage participation in climate change activities. Celebrities, important public figures and opinion leaders should be called upon to vehicle messages, giving particular focus on women and youth who are key actors on the ground.

To ensure the full integration of climate change issues in the curriculum, the following activities will be required and should be implemented:

1. Assessment of what can be incorporated in the education curriculum;

2. Training of teachers at the various levels; and
3. Development of educational materials.

6.3: Training

A series of workshops were held to train the various technical teams involved in the implementation of the project. These include:

6.3.1: Training on National Greenhouse Gas Inventory Development

First week of the workshop on the development of the National Inventory of Greenhouse gas emissions was devoted to lectures and discussions on the 1996 Revised IPCC Guidelines (IPCC, 1997). Estimation using the Reference Approach and other Tiers, and data requirements for each Tier were treated in great detail. In the second week participants had hands-on-exercises on all the Modules of the Guidelines using data that was collected prior to the workshop. Participants were able to identify data gaps and remedy these as much as possible during the development of the sectoral inventories reported in Chapter 2 of this report.

6.3.2: Training on Assessment of Greenhouse Gas Mitigation Options

Material used in this training workshop was based on the Guidebook produced by the USCSP (Sathaye and Meyers (eds.), 1995*)*. Training was conducted on the Basic Methods and Concepts of Mitigation Assessment and for the Energy (industrial, residential, commercial, transport, renewable), Agriculture, Rangelands and Grasslands, Land-use and Forestry and Waste Management Sectors. Participants were introduced to the basic steps in the analysis of mitigation options. These steps include:

- Determination and collection of the data and information needed for the assessment;
- Screening to identify mitigation options significant to the country;
- Development of baseline and climate change scenarios of the options;
- Development and projection of future GHG net emissions and cost scenarios
- Evaluation of the cost-effectiveness of mitigation options; and
- Development and evaluation of the policies, institutional arrangements, and incentives necessary for the implementation of the cost-effective mitigation options.

The success of the training was limited by the knowledge of the resource person in the economics of climate change and specifically as related to mitigation assessment.

6.3.3: Training on Vulnerability and Adaptation Assessment

Using Guidance and lectures (Benioff et al, 1995) developed by the USCSP, a Vulnerability and Adaptation (V&A) Assessment workshop was also organised as one component of the implementation of the project to develop this national communication. The workshop enabled a large number of the members of the NCC to be trained in conducting V & A assessments. Participants were taught the various steps involved in conducting the assessment which vary from defining the scope of the problem and assessment process, defining and describing the scenarios underlying the assessment, determining the biophysical impacts, evaluating the adaptation measures, practices and technologies, integration of the sectoral results and presentation of the report. Participants were also introduced to the determination of the proper scope of the assessment which involves:

- Identification of assessment goals;
- Definition of sectors to be studied;
- Selection of the study region (e.g., administrative units, geographic or physiographic units, ecological zone, climatic zone and sensitive regions) ;
- Selection of the time frame (usually 20-100 years);
- Determination of data needs of the study; and
- Development of the context and schedule for the assessment.

Participants were introduced to the Preliminary Screening technique and Simulations technique. During the training on the simulation techniques, participants discussed and had hands-on-exercises on the execution of the various biophysical Models (DSSAT, WATBAL, SPUR2, HSI, Holdridge Life Zone Classification and a Forest Gap Model) that have been used to assess impacts of climate change on the economic sectors of The Gambia.

6.3.4: Training on the Development and Evaluation of CDM Projects

With funding form the UCCEE, the NCC also benefited from two training workshops to enhance the capacity of members of the NCC in the identification and evaluation of Projects that are eligible for funding under the CDM. The objective of the initial workshop was to enhance public awareness on climate change, with particular emphasis on the CDM, and scope for a manageable list (about 10) of mitigation project options and proposals.

Participants were introduced to the CDM as an instrument aimed at fostering cooperation between developed and developing country Parties to the Kyoto Protocol of the UNFCCC in meeting the objectives and principles of the Convention. The mechanism will assist Developing Country Parties in achieving sustainable development and assist Developed Country Parties in achieving compliance with their commitments and in reducing the concentration of GHGs in the atmosphere. As a tool for enhancing sustainable development, participants were enlightened that the CDM must contribute to sustained economic growth, poverty eradication, technological transfer and capacity building. In relation to adaptation, it will be necessary to establish a seed fund for funding of adaptation projects that ensure food security, water availability, flood control, infrastructural integrity and robustness and primary energy flexibility.

Participants also learned that the ability of the CDM to live up to its promise will be dependent upon the extent to which the process can ensure the participation of the major stakeholders in its design and implementation. The major stakeholders being government, private enterprise, academic institutions, grassroots communities, non-governmental organizations (NGOs) and community based organizations (CBOs). Participants were introduced to the CDM Project cycle (Identification and Packaging, Funding, Implementation, Monitoring and Verification and Certification) and eligibility criteria.

Using CDM eligibility as the basis of all evaluation, this manageable list of project proposals arrived at during the initial workshop was the subject of a second workshop for more detailed analysis using screening criteria and economic evaluation. The major issues covered during this workshop were:

1. Additionality concept of a project;
2. Construct Base case for GHG reduction by project and cost-savings to Non-Annex I Countries compared to Base Case;
3. Principles and practices of estimating:
   i. project level GHG reductions using examples in selected sectors
   ii. costs of GHG reduction with reference to Base Case using Examples in selected sectors
   iii. potential CER revenues + Sensitivity analysis
   iv. various measures of the Net-Benefits of the project (NPV, IRR, and Payback) potential project investors using examples in selected sectors.
4. Option by Option Analysis; and
5. Cost Curve and Mitigation strategy and issues of implementation and multi-criteria analysis.

The Cost Benefit Analysis covered Payback Period (simple and discounted + advantages and disadvantages), how to choose the discount rate, to calculate NPV (advantages + disadvantages), and levelized costing. The difference in mitigation costing and project costing (e.g. CDM) was emphasized.

CDM Project appraisal was also treated and the point of departure from mitigation analysis as viewed by country (Cost-Saving Concept) and CDM as viewed by Investor (Cost-Effectiveness/attractiveness/viability) was emphasized. Additional CDM selection criteria (apart from financial) were presented to assist in final selection of CDM projects. Various notions of how CDM projects could operate and who may invest were also presented, information which was thought could be useful in developing a CDM project pipeline.

Participants had hands-on-exercises using national data and conceptualized project proposals to:

- conduct sensitive analysis with different discount rates and experimented on deriving the Internal Rate of Return (IRR) using spreadsheet;
- demonstration and calculation of both Net Financial Cost and Financial;
- demonstration and calculation of NPV and IRR with or without linear depreciation for capital layout;
- calculate GHG emission reductions compared to baseline; and
- derive IRR with and without CER revenue to demonstrate level of profitability.

6.3.5: Training on the Development of National Climate Change Action Plan

A training workshop on the Preparation of National Climate Change Action Plan was also conducted. This was based on the training documentation and exercises (Benioff and Warren,

1996) provided to the NCC under the USCSP. The training workshop covered the ten suggested steps in the process for developing climate change action plans. These steps are:

1. Design and effective planning process;
2. Determine the overall plan objectives and sectors of interest;
3. Preparation of a comprehensive workplan;
4. Evaluation and development of sectoral and cross-sectoral measures;
5. Perform comparative analysis of measures across sectors and refine recommended measures;
6. Prepare implementation strategies for selected measures;
7. Prepare and adopt climate change plan;
8. Prepare National communication;
9. Integrate the plan with other development plans and programes; and
10. Implement plan.

During the preparation of the National Climate Change Action Plan presented in Chapter 9 it was not possible to utilize all the suggested steps in this training manual but the training received and the manual were useful in the process of development of the Climate Change Strategy and Action Plan.

6.4: Public Awareness

During the implementation of the various studies that went into the development of this Initial National Communication, sensitization and public awareness campaigns were held at all levels of Gambian society. The main objectives of the stakeholder consultations was to enhance public awareness on climate and climate change and to develop the National Climate Change Action Plan. The consultations were held jointly with Task Forces of the other national Multilateral Environment Agreements (MEAs) on Biodiversity and Desertification. Using a bottom-up approach, the consultations were held at the district, divisional and national level.

The District level Consultations were conducted at 16 locations countrywide and involved 150 to 200 participants per location. Participants were selected from women groups, government extension, youth leaders, NGOs, CBOs, cultural and drama groups, etc., as well as various trades of people such as herders, fishermen, wood carvers, carpenters, blacksmiths and crop farmers. These consultations consisted of oral presentations followed by working group sessions. Members of the communities were requested to describe actions they have taken to cope with any abnormal climate or weather and to suggest any measures that could be undertaken in response to future climatic changes.

The reports of the 16 District level consultations were presented at the Divisional Level Consultations. These consultations involved new stakeholders as well as active participants from the District Level Consultations. The new and reviewed information from these consultations was used to compile six Divisional Level Consultation reports, which were presented and considered at the National Level Consultation resulting in the development of a National Level Consultation report. The NCC then supplemented the stakeholder consultations with additional consultations at the policy- and decision-making level. A five-day Policy-Makers Workshop was organised at which high-level government officials presented sectoral policy and legal documents, and development programs. This workshop initiated efforts to mainstream climate change issues into development policies and programs.

The consultations also provided traditional and grassroots level knowledge related to climate change. Overall, the process indicated that people at the grassroots level have valuable knowledge of the environment they live in and, with time, have developed strategies to cope with negative effects. The NCC made use of this knowledge in identifying adaptation measures in the face of climate change. Connecting environmental effects to climate variability and change, though, was not always straightforward.

In addition to the stakeholder consultations, the public also received information on climate change from the Print Media and Radio Programmes conducted by the NCC. The membership of the NCC includes both print and electronic media and this representation assisted in the dissemination of climate change information and activities.

The following activities are planned to enhance public awareness:

1. Development of a Newsletter and Web Site for greater dissemination of information to the general public. With the installation of Internet facilities and training provided to the members of the NCC the development of a Web Site could be achieved in the very near future.
2. Development of sensitization materials to enhance public awareness of climate change.
3. Translation of the sensitization material into the various local languages.

The main constraints in enhancing public awareness are the inadequate human and institutional capacity within the NCC to develop sensitization materials to enhance public awareness on climate change.

6.5: References

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CHAPTER 7

7: CAPACITY BUILDING AND TECHNOLOGY TRANSFER

7.1: Introduction

Article 4.5 of the UNFCCC implores developed country Parties to support the development and enhancement of endogenous capacities and technologies of developing country Parties. It is also stated in Article 5 that Parties should take into account the particular concerns and needs of developing countries and cooperate in improving their endogenous capacities and capabilities to participate in the efforts to implement commitments under that Article.

7.2: Capacity Development

At various sessions of the Conference Of Parties (COP) and its subsidiary bodies, the issue of capacity building has been extensively discussed and decisions taken. By its Decision 2/CP.7, the COP adopted the framework for capacity building in developing countries. The framework sets out the scope of, and provides the basis for action on capacity building related to the implementation of the Convention and preparation for the effective participation of developing countries in the Kyoto Protocol process.

7.2.1: Activities undertaken

During the past 10 years the capacity of the NCC has been built through training workshops (see Chapter 6). These workshops covered the development of National Inventories of Greenhouse Gas emissions, assessment of greenhouse gas mitigation measures, assessment of vulnerability of the national economy and ecosystems to projected climate change, and development and evaluation of CDM projects. These were executed and funded by the GEF through UNEP and UNDP, the USCSP, the UCCEE and the IPCC. The Gambia also benefited in limited training in negotiation skills through side events organised at SB 12 in Lyon in 2000. The NCC is, however, constrained in the capacity to execute methodological concepts of cost assessment of mitigation and adaptation measures and to develop full projects in these areas.

Institutional capacity development is limited to procurement of computer hardware and software through projects funded by the USCSP, the UCCEE and GEF Projects implemented by UNEP and UNDP. A CDM Office has also been set-up with assistance from UCCEE in RISOE, Denmark. The GEF/UNDP/UNITAR LDC project provided training and equipment, and established a Networking and Internet system for the UNFCCC Focal Secretariat. This has particularly improved access to global environment information and communication between the UNFCCC Focal Secretariat and the UNFCCC Secretariat, IPCC and other multilateral environment organizations.

The GEF has provided financial and technical resources to The Gambia to enable the Task Forces of the MEAs of Biodiversity, Desertification and Climate Change to undertake country-level capacity needs assessments and to develop specific capacity-building activities consistent with the Conventions. The NEA is coordinating this activity. The NCC will pay particular attention to the capacity development framework annexed to Decision 2/CP-7 of the UNFCCC. The NCC would identify the specific needs, options and priorities for capacity building for The Gambia and this will be achieved through the participation of a wide range of stakeholders, including government, national and international organizations, civil society and the private sector. Where possible and more effective, the services of regional Centres of Excellence will be utilized to develop and support capacity-building activities in The Gambia.

7.2.2: Activities to be undertaken

Adequate human and institutional capacity is a necessary condition for the implementation of the UNFCCC. To build on the limited national capacity developed over the years the following will be required.

1. The current capacity of the National Climate Secretariat of The Gambia is limited to coordination and development of national GHG inventories and evaluating sectoral impacts of climate change. There is limited expertise in the assessment of mitigation and adaptation options, participation in the Kyoto Protocol process and development of appropriate implementation strategies. Thus, it is a high priority to strengthening the capacity of the national climate change secretariat to enable the effective participation in the implementation of the Convention and its Kyoto Protocol process. This will involve:
   (a) The development of a comprehensive climate change action plan and integrated implementation strategy that takes into account the capacity building needs of the various institutions participating in climate change activities particularly in research and training;
   (b) Development of education and training programmes, and specialized skills or expertise and scientific institutions with the necessary equipment and scientific information; and
   (c) Enhancement of public awareness on climate change at all levels with the ultimate objective of improving decision- and policy-making through re-orientation and development of appropriate policies.

2. In the area of development of inventory of national GHG emissions the members of the National Task Force assigned the study will need capacity to move beyond the mechanical use of the 1996 Revised IPCC Guidelines and the emission factors contained in those guidelines. The Task Force should be capacitated and involved in the development of national and/or regional specific emission factors with the ultimate objective of reducing uncertainties in the national inventory statistics. This is likely to be achieved through the involvement of The Gambia in the UNDP/GEF emissions factor project in West Africa.

3. Technical expertise of some members of the NCC has been developed to execute climate change scenario development tools (GRADs, SENGEN, IMAGE, etc.) and biophysical models (DSSAT, WATBAL, SPUR2, etc.) in the assessment of vulnerability (impacts and adaptation) of the economy to climate change. However, these members of the Committee have very limited expertise in influencing the source codes of these models so as to "*fine tune*" them to the Gambian environment. For a comprehensive vulnerability

assessment the technical capacities and skills of experts need to be developed and enhanced beyond those acquired through workshops. The experts need to be trained on modeling at institutions of higher learning through fellowships and/or internships. There is a need for the leading global climate modeling groups to collaborate with the GCRU of The Gambia in building the capacity of members of the NCC in the development and execution of climate change and biophysical models. The collaborative efforts should include the transfer of the model technology to Gambians.

4. Understanding and participating in the climate change debate and development and implementation of climate change programmes is a process that depends on access to a reliable body of scientific information. The information is developed from raw data acquired from national, regional and global system of observation networks. The Gambia has limited historical climate data (less than 50 years) and the meteorological and hydrological networks established in the late 1970s and 1980s have deteriorated and gaps in data have been realized from the mid-1990s. Inadequate or non-availability of equipment for systematic collection of long-term instrumental observation of climate system variables has the consequence of limiting vital data required in the development of adequate and accurate input variables to model and simulate climate and climate change. At the current rate of deterioration of the observation networks in The Gambia, the future contribution of data for national, regional and global climate change simulation will be limited. It is thus a priority in The Gambia to reverse this deterioration of the observation networks and improve the data and information availability. Improvement will entail acquisition of automatic recording equipment and expansion of networks to get more representative coverage of the country.

7.3: Technology Transfer

By its Decision 4/CP.7 the COP adopted the framework for meaningful and effective actions to enhance the implementation of Article 4, paragraph 5, of the Convention by increasing and improving the transfer of and access to environmentally sound technologies (ESTs) and know-how. The successful development and transfer of ESTs and know-how require a country-driven, integrated approach, at national and sectoral levels and this should involve cooperation among various stakeholders. Activities include technology needs assessments, technology information, enabling environments, capacity building and mechanisms for technology transfer.

7.3.1: Activities undertaken

During the past 15 years, The Gambia has promoted and encouraged the shift to more environmentally friendly technologies based on the awareness of the consequences of desertification and environmental degradation in the 1970s and the 1980s. The shift has been from fossil fuel to renewable (solar and wind) energy. Penetration of solar energy technology is high in the Health, Communication, Water Resources and, Commercial and Residential sectors of the economy.

In the Health sector most of the facilities at the District Health Centres are powered by solar-photo-voltaic technology. Telephone and telex facilities in the hinterland of the country are also powered by solar technology. Water lifting and supply systems are powered by diesel, solar and wind generators. The diesel generators are being replaced by solar and wind generators because of reduced operational cost in addition to environmental benefits of reduced pollution. However, the penetration of wind energy is lower than solar energy due to lower wind speeds as one moves further inland from the ocean. The Commercial (mostly hotels) and Residential sectors have also embraced solar technology through the use of Solar Home Systems for lighting and heating. Penetration of solar systems in the residential sector is lower due to the attached initial cost of acquisition and installation of facilities. A large quantity of LPG is also being used for cooking in the residential sector to displace biomass (wood and charcoal) fuel. According to the results of the inventory of GHG emissions, this category of fuel emits less GHGs than biomass fuel.

The Gambia is therefore aware and receptive of clean technologies. There are a lot of opportunities and avenues in The Gambia for collaboration in the transfer and diffusion of climate friendly technology.

7.3.2: Activities to be undertaken

Activities that need to be undertaken include, among others:

1. Technology needs assessment;
2. Establishment of an efficient information system in support of technology transfer; and
3. Capacity building in the promotion of the widespread dissemination, application and development of environmentally sound technologies and know-how.

CHAPTER 8

8: IMPLEMENTATION STRATEGY OF THE UNFCCC

8.1: Introduction

For The Gambia, climate change is viewed as a development path. Hence, the UNFCCC is being implemented with sustainable development guiding all future activities and programmes. Based on the identified mitigation and adaptation measures in the preceding chapters of this National Communication, the following strategy was developed for the future implementation of the Convention in The Gambia. The successful implementation of the strategy and the Convention depend on the availability of the human and financial capacities in the country, and the required cooperation identified in Chapter 9 of this communication.

The NCC and its collaborating institutions are constrained by inadequate human and institutional capacity to finalize this Action Plan. The major area of difficulty is in the economic analysis and presentation of the cost of the activities and their implementation. The first task therefore is the finalisation of the Plan.

Specific strategies for implementation of sectoral plans are defined in the sections below. Implementation of mitigation and adaptation measures identified in this National Communication will be coordinated by the NCC Focal Point and the NCC. Relevant Departments will implement the Sectoral Plans in collaboration with concerned institutions particularly the NGOs, Local Government Authorities (LGAs) and CBOs. Most of the NGOs, LGOs and CBOs that will be involved in the implementation of the various plans are already members of the NCC. These have long standing working relations with the local communities and this relationship will be exploited. Since the human resources required for the implementation is in place, the NCC will be responsible for the coordination. Financial resources identified will need to be met from Government and Donor contributions.

The Cross-cutting Issues Task Force (CITF) of the NCC will undertake outreach activities, including public meetings to solicit support and comment on the measures, educational campaigns, and media events. The NCC and collaborating institutions will be responsible for monitoring and evaluating the implementation of the proposed measures.

8.2: Sectoral Activities and their Implementation

8.2.1: Coastal zone of The Gambia

Priority actions include:

1. *Management of the Sand Bar at the Laguna and Palm Grove hotels;*
2. *Construction of 16 km of dykes to protect villages bordering the wetlands and swamplands from seasonal flooding;*
3. *Rehabilitation of the groyne systems;*
4. *Construction of revetments, seawalls/bulkheads and breakwater systems in order to protect the economically and culturally important areas;*

5. *Development and enactment of appropriate regulations and policies relevant to construction, urban growth planning, and wetland preservation and mitigation; and*
6. *Development of a Coastal Zone Management Plan.*

Implementation strategy
The priority actions identified for the Coastal Zone will be translated into project proposals. The Coastal Zone Management Working Group under the NEA will lead the implementation of all projects developed under this Action Plan. Collaborating institutions will be the DWR, DPWM, Dfish, the Association of Fishermen and the Municipal Councils in Banjul, Kanifing and Brikama.

8.2.2: Water resources sector

Priority actions include:
1. *Regulation of abstraction of freshwater from the river to maintain a delicate equilibrium between flow and saline intrusion;*
2. *Introduction of legislative measures such as licensing and permits for withdrawal of river water for irrigation;*
3. *Improvement of the efficiency of existing irrigation systems and introduction and encouragement of the use of more efficient irrigation systems such as sprinkler and drip irrigation systems;*
4. *Promote water harvesting;*
5. *Development and utilization of better planning tools such as aquifer simulation models and a predictive/operational saltwater intrusion models;*
6. *Construction of dikes or small dams in most of the smaller streams of the river; and*
7. *Improvement of tidal water level monitoring and water resources assessment capability of the water resources institutions.*

Implementation strategy
The DWR will lead the implementation of activities developed under the water resources sector. The Water and Sanitation Working Group, the Administrative Divisions and related institutions of the NCC will assist the DWR.

8.2.3: Agriculture (crop production sub-sector)

Priority actions for the crop production sub-sector include:
1. *Integrated Crop/Livestock Farming;*
2. *Methane recovery from abattoirs and peri-urban dairy farms;*
3. *Waste recycling for agricultural production through composting;*
4. *Efficient management of soil and water so as to reduce runoff and nitrogen leaching and also improve soil conditions to enhance crop production;*
5. *Contour farming and construction of dykes, crop residue farming, fallowing and crop rotation for the maintenance of soil structure; and*
6. *Crop cultivar screening, training of rural development agents and on-farm adaptive research on crop management practices.*

Implementation strategy
Department of Agricultural Services will lead the implementation of elements of the Action Plan for the agricultural sector. Collaborating agencies will be DLS, DOP, NARI, SWMU, Gambia Rice Growers Association, Framers Platform, and NGOs such as GARDA.

8.2.4: Rangelands and livestock

Priority actions for the rangelands and livestock sector:
1. *Active selection of plant species;*
2. *Control animal stocking; and*
3. *Promote and encourage new grazing strategies.*

Implementation strategy
The Department of Livestock Services will lead the implementation of these activities.

8.2.5: Fisheries sector

Priority actions include:
1. *Introduce biological monitoring;*
2. *Enforced fishing control measures;*
3. *Promote aquaculture;*
4. *Modify and strengthen fisheries management policies and institutions;*
5. *Strengthen and expand catch-monitoring activities;*
6. *Preserve and restore essential habitats and promote fisheries conservation and environmental education;*
7. *Foster international and interdisciplinary research; and*
8. *Use hatcheries to enhance natural recruitment.*

Implementation strategy
The Dfish will lead the implementation of elements of this Action Plan. CBOs at the grassroots level, such as Village Fisheries Associations, will collaborate with the Dfish.

8.2.6: Forest and wetland ecosystems

Priority actions for the forestry and wetlands include:
1. *Establishment of Plantations, National Parks and PAs;*
2. *Reforestation of landscapes with fragmented forest areas;*
3. *Conservation of existing carbon pools in forests;*
4. *Expansion of carbon stocks in forest ecosystems;*
5. *Switching from fossil-fuel-based to biomass-based energy products;*
6. *Introduction and promotion of incentive programs;*
7. *Development of Seed Banks; and*
8. *Promotion of effective management practices and flexible criteria for intervention.*

Implementation strategy
The DOF and the DPWM will implement the Forestry and Wetlands Action Plan with the Forestry Department taking the lead. MHC, the only active member of the NCC from the private sector, will be actively involved in the implementation of this National Action Plan. The Dfish and related NGOs and CBOs will collaborate in the implementation. These NGOs and CBOs include GARDA, Gambia Environment Association, Gambia Fishermen Association, and Gambia Association of Timber and Wood Cutters.

8.2.7: Energy sector

Priority actions in the energy sector:
1. *Promote energy efficiency and reduce energy use by applying basic house keeping and retrofitting;*
2. *Promote and use of renewable energy (Solar Home Systems);*
3. *Replacement of firewood and charcoal by LPG as a source of domestic energy supply, and*
4. *Revitalization and promoting of river transport.*

Implementation strategy
Government, non-governmental organizations and rural communities will jointly implement the Energy Action Plan. The Department of Energy under the Department of State for Trade and Industry will be the Lead Agency. Local experts shall be drawn from GREC, REA, and other private firms such as VM, GAMSOLAR.

For sustainability, consumers will be adequately charged to eventually cover the capital outlays and running costs. Experts from outside the communities will eventually be replaced by members of the communities, who would have then acquired the necessary training and skills.

8.2.8: Waste management sector

Priority actions in the waste management sector:
(a) Landfill/Dump site management;
(b) Alternative waste-management strategies;
(c) Wastewater Treatment;
(d) Aerobic Treatment; and
(e) Recovery and utilization of methane from anaerobic digestion of wastewater or sludge.

Implementation strategy
The Department of State for Local Government will lead implementation of elements of the Waste Management Action Plan by using the Municipal Councils countrywide. Collaborating institutions include the NEA, DWR, Department of Health and MHC. Relevant NGOs and CBOs will also assist at the local level.

8.2.9: Cross-cutting issues (education, training and public awareness, research and systematic observations)

Priority actions on cross cutting issues:

1. *Incorporate climate change in curricula for the lower and upper basic cycles and at the tertiary level;*
2. *Use mass media techniques such as television/video, radio, print media, traditional communicators and extension agents in well designed campaigns aimed at enhancing public awareness;*
3. *Develop educational and sensitization materials to enhance public awareness on climate change;*
4. *Enhance the capacity of the members of the NCC through training in economic assessment of mitigation and adaptation measures and projects;*
5. *Realign current practices and policies to take into account climate variability, the projected climate change and sustainable economic and environment development and management;*
6. *Conduct institutional reforms and mainstreaming of climate change into national development programmes of The Gambia;*
7. *Replace and upgrade conventional hydrological and meteorological equipment;*
8. *Rehabilitate and expand existing station networks for more representative monitoring of weather, climate and other environmental issues;*
9. *Provide better and bigger capacity data processing and storage equipment for the upgrading, networking and interconnectivity of the various data base systems of the Department and other collaborating institutions; and*
10. *Strengthen the human resources and capacity of the institutions involved in the collection, processing and maintenance of data and information related to meteorology, hydrology and climatology.*

Implementation strategy

The Cross-cutting issues Task Team, led by the Gambia Technical Training Institute (GTTI), will be responsible of the implementation of these activities. Other institutions that will participate in the implementation of cross-cutting issues are the Gambia College, the Department of Curriculum Development, and NGOs.

CHAPTER 9

9: INTERNATIONAL COOPERATION IN CLIMATE CHANGE

9.1: Introduction

In Article 3 paragraph 5 of the UNFCCC, Parties are called upon to cooperate in the promotion of a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties. Article 4 of the Convention specifically calls for cooperation of Parties:

1. In the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of GHGs;
2. In the conservation and enhancement, as appropriate, of sinks and reservoirs of all GHGs not controlled by the Montreal Protocol;
3. In scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system;
4. In the full, open and prompt exchange of relevant scientific, technological, technical, socio-economic and legal information related to the climate system and climate change, and to the economic and social consequences of various response strategies; and
5. In education, training and public awareness related to climate change.

Article 2, paragraph (b) and article 10, paragraphs (c), (d) and (e) of the Kyoto Protocol also strengthens these Convention commitments. Article 2(b) of the Protocol explicitly requests Annex I Parties to cooperate with other Parties to enhance the individual and combined effectiveness of their policies and measures adopted under Article 2 of the Kyoto Protocol.

9.2: Cooperation with Multilateral Agencies

The Gambia participated in the INC negotiations for the UNFCCC and all IPCC activities prior to and after the INC. The Gambia also cooperated and collaborated with the UNFCCC Secretariat, GEF, UNEP, UNDP and the NCSP in the implementation of climate change activities. These activities are detailed in previous chapters of this Initial Communication.

9.3: Cooperation with Bilateral Governments

At the bilateral level The Gambia cooperated and collaborated with the US Government through the USCSP. This cooperation was very effective in building the capacity of the NCC of The Gambia in terms of the acquisition and utilization of methodologies, particularly in the assessment of the impacts of climate change. The Gambia also cooperated with Mozambique, Cote d'Ivoire and Leshoto in the implementation of climate change activities particularly in inventory development and impacts assessment.

9.4: Future Cooperation Requirements

Past and existing bilateral and multilateral cooperation has contributed to The Gambia being able to participate in the climate change debate and process and thus meet some of her commitments.

Public awareness and political commitment are no longer constraints in the implementation of climate change. However, existing scientific, technical, technological and financial capacity and the level of human resources development of the country have limited effective participation.

Within the available national capacity and assistance provided by bilateral and multilateral partners, The Gambia has been able to put together a strategy (see Chapter 8) for the implementation of the UNFCCC. The implementation of this strategy and the Convention by The Gambia is dependent on the future cooperation between The Gambia and other Parties to the Convention and its Protocol. It is particularly dependent on the availability of technical, technological and financial resources, and human resources required for the implementation of the Convention and the Protocol. Specifically, bilateral and multilateral cooperation and collaboration will be required in the following areas:

1. **Re-orientation and development of national policies and programmes to take climate change fully into account in formulating a sustainable development path:** What is needed is to develop policies and measures with opportunities to facilitate sustainable development and strategies that make climate-sensitive sectors resilient to climate variability and change. The policies should lead to reduced pressure on resources and enhance adaptive capacity.

2. **Enhance climate change education and awareness particularly at basic cycle in schools**: A sensitized population is capable of changing attitude towards building a better climate system for responding to climate change. This can be achieved by conducting training, education and public awareness campaigns at all levels of society particularly in basic cycle schools. It will be necessary to develop educational materials and conduct extensive training on climate and climate change. School curricula should be re-oriented and developed to include climate and climate change education.

3. **Rehabilitation of observation networks:** Long-term and accurate data and information are prerequisite for climate change modeling. These are available from an extensive and reliable network of recording stations. Similar to many countries, the networks of observing systems have deteriorated during the past few years. Data and information gaps are increasing and this will continue to lead to uncertainties in research and modeling results. Bilateral and multilateral cooperation are required to address this situation.

4. **Further capacity building for Gambians:** Members of the NCC have been trained in the assessment of vulnerability to climate change. The methodologies used are sectoral and the integration of the results proved difficult. Integrated assessment methodologies and analytical tools are available in the market but not in The Gambia. It will be necessary to introduce and build the capacity of Gambians in conducting integrated assessment of vulnerability to climate change. The building of capacity should go beyond applying models from outside The Gambia but should be concentrated on building models for the Gambian environment and ecosystems.