



Module III. Vulnerability and adaptation From theory to practice

Case study 2 A vulnerability study of coastal areas and climate change in Senegal

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Study aims

- To determine whether it is possible to quantify the impact of climate change on coastal areas (CAs)
- To define the vulnerability of CAs
- To identify and quantify the options for adaptation
- Study was conducted in 2000-2001

Methodology

- Based on the standard 7-step methodology (IPCC/CZMS, 1991)
 - Definition of the study framework
 - Description of the current situation
 - Definition of scenarios
 - Impact analysis: biophysical and socio-economic
 - Identification and analysis of adaptation strategies
 - Definition of vulnerability

Step I

Definition of the study framework

- The choice of study area is determined by:
 - Available data and information
 - Whether there has been a preliminary study
 - Time and financial resources available
 - Interests and issues
- Selection of the time horizons
 - Impacts must be visible
 - Compatibility between time horizons of environmentalists (long-term) and economists (shortterm)
 - Requirements of decision-makers

I. Definition of the study framework

- Two study areas were chosen because a preliminary V&A study throughout the whole coastal zone existed
 - The Cap Vert peninsula: a highly urbanised area with sandy beaches and a special ecosystem (dune slacks known as "niayes")
 - The Saloum estuary: a very low-lying, largely rural area with a mangrove ecosystem
- Selection of the time horizons
 - Two time horizons: 2050 and 2100 (these horizons were widely used by the scientific community at the time of the study)



The Cap Vert peninsula

Heavily urbanised Sandy beaches

The Saloum estuary

An estuary with mangroves

Lightly populated with fishing and agricultural activities



Step II Description of the current situation

- The main physical, biological and socioeconomic characteristics of the study areas
- The main actual problems of the coast: erosion, pollution, urbanisation, etc.



Coastal erosion Rufisque: Keuri Kaw, former warehouses

Step III The choice of scenarios

- Climate change scenarios: temperature, rainfall
- Socio-economic scenarios: population, agricultural production
- Sea level rise and flooding levels scenarios

III. The scenarios



III. Climate change scenarios

- Produced by the Atmospheric Physics Laboratory (Gaye *et al.*, 1998)
- Temperature and rainfall anomaly maps compared to the climatic average (1961-1990)
- Database

III. The climate change scenarios: Rainfall



Changes in annual rainfall (%) compared to the climatic average (1961-1990) for Senegal, for different climatic sensitivities. The IS92a emissions scenario was used. The global circulation models (GCM) used were CCCEQ, UKTR and HadCM2 (Gaye *et al.*, 1998).

III. Climate change scenarios

- In the coastal zone by 2050
 - Mean annual temperature increases from +1°C to +1.9°C
 - Decrease in annual rainfall from 1 to 10% for the Cap Vert peninsula and from 5 to 15% in the Saloum estuary
 - Decrease in the intensity of up-wellings

III. Socio-economic scenario

- Annual rate of population increase
 - ► 2.99% in the Cap Vert peninsula
 - ► 2% in the Saloum estuary
- Annual rate of agricultural production increase: 0.41%
- Based on national socio-economic surveys

III. Socio-economic scenario The "discount rate"

- Controversial question (use, rate)
- Multiplication factor

 $Dt = 1 / (1 + r)^t$

Dt is the discount factor for year "t" and discount rate "r" (2 to 7%)

• Two rates were chosen: 3 and 6%

III. Sea level rise scenarios

- Develop a reference scenario (secular variations of sea level): based on the Dakar tide gauge data (1.4 mm per year)
- Choice of projections for future sea level rise due to climate change based on the IS92a emissions scenario
- Consideration of local factors (subsidence, etc.) to develop scenarios of relative sea level rise: minimum subsidence (<0.2 mm/year in the Senegal delta)

III. Sea level rise scenarios

Scenarios	2050	2100
Reference scenario	8.4 cm	15.4 cm
Low hypothesis	7 cm	20 cm
Medium hypothesis	20 cm	49 cm
High hypothesis	39 cm	86 cm

III. Flooding levels

$D = MHW + S_f + W_f + P_f$

MHW: Mean high water level

- S_f: Sea level rise
- W_f: Height of storm surges for a given return period
- P_f: Sea level rise caused by lower atmospheric pressure

III. Flooding levels

- Minimum flooding levels
 - Minimum values for a moderate high water level: 0.2 m for 2050 and 0.3 m for 2100
 - Moderate surge heights: 1.6 m for the north coast, 0.8 m for the south coast and 1 m for the Saloum estuary
 - Sea level rise: reference scenario and low hypothesis for acceleration of sea level rise

Flooding levels (by 2050)

	North coast	South coast	Saloum
Minimum flooding levels			
Reference scenario	1.88 m	1.08 m	1.28 m
Lower hypothesis of sea level rise	1.87 m	1.07 m	1.27 m
Maximum flooding levels			
Reference scenario	6.9 m	6 m	7.1 m
Moderate hypothesis of sea level rise	7 m	6.1 m	7.2 m
High hypothesis of sea level rise	7.2 m	6.3 m	7.4 m

III. Choice of flooding levels

- Small differences between levels
- Limitations of the topographic maps (contour lines equidistance)
- Study aims: looking for trends and not for great precision

Flooding levels chosen

	North coast	South coast	Saloum
Minimum flooding level in 2050	2 m	1 m	1 m
Minimum flooding level in 2100	2 m	2 m	2 m
Maximum flooding level in 2100	8 (10) m	6 m	8 (10) m

The default contour line used are in brackets.

Step IV Impact analysis

- Biophysical impacts
 - Aggravation of coastal erosion [model: Bruun rule]
 - Flooding risks [GIS]
 - Salt water intrusion [models]
 - Ecosystem changes [expert judgement]
 - Fishery resources [expert judgement]

IV. Coastal erosion

- The coastal erosion resulting from rising sea levels is determined by using the Bruun rule
- It applies to sandy coasts
- Conditions: have data on storm surges, beach profiles and bathymetric maps

Coastal erosion: Results

	2050	2100		
Land losses due to coastal erosion in km ² (and percent of the total beach area)				
Cap Vert peninsula	0.24–1.79 km ² (3.8–28.5%)	0.77–3.95 km ² (12.2–62.8%)		
Saloum estuary	0.07–1.82 km ² (4–109%)	0.19–4.02 km ² (11.4–241%)		

IV. Floods

- Determination of the floodable areas and the land-uses in these areas
- Calculations based on:
 - Land-use maps from satellite images
 - Digitized contour maps corresponding to the flood levels
 - Geographical information system software

Cap Vert peninsula

Floodable areas (hatched) with a 2 m flooding level (3% of the total area)

Cap Vert Peninsula

Floodable areas for each land-use with the minimum 2m flooding level

Cartographic units	Floodable areas in km² and (%)
Bare ground Sandy beaches Mobile dunes Flooded areas Natural vegetation	3.6 (39.7%) 0.04 (0.1%) 20.81 (71.4%)
Plant communities on coastal dunes with moderate to low cover Plant communities on coastal dunes with low cover Coastal plant communities with moderate cover Plant communities dominated by woody plants Plant communities of wet and saline habitats Exploited land Market gardening Tree cultivation associated with rain-fed agriculture Mixed agriculture (peanuts, millet and cassava) Casuarina plantations with dense cover Casuarina plantations with moderate cover Cajeput tree plantations Listed forest (Mbao area) Built-up areas Urban zones Peri-urban zones	0.42 (1.3%) 0.07 (0.1%) 0.005 (negligible) 1.9 (0.6%) 11.15 (51.9%) 2.71 (3.4%) 0.11 (negligible) 0.03 (negligible) 0.03 (negligible) 0.12 (0.6%) 0.09 (1.7%) 0.12 (7.3%) 0.16 (2%) 6.46 (5%) 0.053 (0.4%) 0.16 (5.2%)
TOTAL FLOODABLE AREA	48 (3%)

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The Saloum estuary

Floodable areas (hatched)

with a 2 m flooding level

52% of the flooded area

- Mangroves
- Salt production area

Saloum Estuary

Floodable areas for each land-use with the minimum 2m flooding level

Cartographic units	Floodable areas in km² and (%)
Delta area Sand banks Upper mangroves Lower mangroves Salt flats ("tannes") Vegetated dune strips Inland areas Shrub savannah Forested savannah Dry open forest Dense gallery forest Exploited land Forested savannah Plantations, orchards and gardens Cattle tracks Kaolack salt exploitation zone	$\begin{array}{c} 3.1 \ (89\%) \\ 331.6 \ (92.2\%) \\ 218.7 \ (90.3\%) \\ 936.1 \ (78.9\%) \\ 115.2 \ (53\%) \\ \hline \\ 2.9 \ (3.8\%) \\ 5.9 \ (3.2\%) \\ 1.5 \ (8.9\%) \\ 1.2 \ (4.9\%) \\ \hline \\ 59.9 \ (6.7\%) \\ 0.3 \ (4.3\%) \\ 0.2 \ (4.2\%) \\ 13.2 \ (100\%) \end{array}$
TOTAL FLOODABLE AREA	1,689.8 (52%)

IV. Salt water intrusion

- Two approaches are used:
 - For the Thiaroye and northern coast Quaternary sands aquifers and for the Terminal Continental aquifer in the Saloum river, a qualitative estimate based on knowledge of the aquifers' function. For the effect of sea level rise, the Ghyben-Herzberg formula was used to determine the depth and distance from the coast of the interface between freshwater and salt water.
 - For the aquifer in the Dakar infrabasaltic sands, the FEFLOW model was used. The following parameters were used: pumping rates 18,000 m³.day⁻¹ (no change from current situation), a 0.5 m sea level rise in 100 year's time and a 50% reduction in recharge, taking into account the decline in rainfall predicted by the climate change scenario.

Aquifer at the point of the Cap Vert peninsula

FEFLOW model

Contours of dissolved salts concentrations (mg.l⁻¹)

A: At present

B: With a sea level rise of 0.5 m

1,000 mg.l⁻¹ contour

IV. Impacts on ecosystems: The dune slacks ("niayes")

- Expert judgement
- Based on the analysis of the temporal changes in the dunes slacks resulting from drought (former surveys since 1940 and field measurements)
- Little change expected so long as the sea level rise does not exceed 50 cm
- Beyond this, halophytes will increase to the detriment of hydrophytes
- Salinity plays an important role

The "niayes"

Depressions between dunes Relict Guinean vegetation Water table close to the surface Used for market gardening

IV. Impacts on ecosystems: The mangroves

- Expert judgement
- Based on the analysis of the Lagoba breach in the sandpit that simulated a sudden rise in sea level
- Temperature increase will have little effect
- The rise in sea level will have an effect by means of erosion and sedimentation mechanisms (mangroves don't grow on sandy soils) and by salt water intrusion
- The nature of the substrate and salinity play a major role
- There will be major disturbances once the sea level rise exceeds 50 cm: the mangroves will move inland and there will be an inversion in the zonation of mangrove species. These changes will be affected by the topography.

THE MANGROVES

A characteristic ecosystem fulfilling many functions

THE SALOUM ESTUARY

Degradation of the mangroves replaced by salt flats

Djiffere and the Lagoba breach

IV. Fishery resources

- Expert judgement
- Resources will be affected by:
 - Changes (erosion, increased salinity) in coastal habitats that act as nurseries (mangroves)
 - Weakening of upwelling that will affect pelagic species and the migration of groupers
 - Seawater warming: impacts on the presence of tuna (longer) and appearance of less commercially valuable species (trigger fish)

IV. Fishery resources

Variations in fish landings according to the strength of upwelling (for weak upwelling periods)

IV. Estuarine resources

- Will be affected by the rise in sea level if this leads to the disappearance of the mangroves that are the source of nutrients, refuge areas and nurseries
- Greater penetration of seawater will reduce the area of breeding grounds (currents too swift and marine predators more able to enter)
- Risk of manatees disappearing if the inputs of freshwater cease

IV. Socio-economic impacts

- Mainly determined from the analysis of the maps of floodable areas and on the basis of existing statistics
- Population at risk
- Economic assets at risk:
 - Agriculture (agricultural production)
 - Industry (value of investments)
 - Roads (infrastructure assets)
 - Housing (built assets)

IV. Socio-economic impacts

GDP at risk (areas eroded, flooded or affected by salinity)

$$M_t = (S_t/S_T) \times GDP_0 \times (1 + g)^t$$

- M_t is the GDP at risk in year t; S_t is the relative sea level rise in year t; S_T the relative sea level rise in year T; GDP₀ the GDP in the area at risk; and g the rate of increase in GDP
- The following formula is used if a "discount rate" is applied:

⁴³
$$M_{pv} = M_t \times (1 + r)^{-t}$$

Quantified impacts

	Cap Vert	Saloum	
	(1,597 km²)	(4,309 km²)	
Loss of land			
- Flooding	57 – 398 km²	1,690 – 2,911 km²	
- Erosion	1.7 – 2.3 km²	0.5 – 2.3 km²	
Population at risk	730,249 to	847,191 to	
(in 2100)	4,787,828	11,807,410	
Economic value at risk (with a 3% DR)	5 – 34 bn\$	4.6 – 64 bn\$	

These values refer to the minimum and maximum flooding levels between now and 2100. For coastal erosion, the hypothesis of a moderate acceleration in the rise in sea level up to 2100 (49 cm) is adopted.

Step V Adaptation strategies

- Identification of adaptation options
 - Uprooting and displacing populations
 - Protecting coastal areas
 - Beach nourishment
 - Seawalls and dykes
 - Re-afforestation
- Evaluation of these strategies
 - Only the options for which we have experience and cost figures could be evaluated: seawalls and re-afforestation
 - Calculation of the costs and use of the discount rate

V. Evaluating the cost of protection

	Cap Vert (1,597 km ²)	Saloum (4,309 km²)
Economic value at risk (with 3% DR)	5 – 34 bn\$	4.6 – 64 bn\$
Length of coast to be protected	14 - 31 km	400 - 418 km
Protection costs (3% DR)	0.005 – 0.03 m\$ 3 – 19% GDP	0.067 – 0.068 m\$ 43 – 43.6% GDP

The calculations of the protection costs are based on the minimum and maximum flooding levels between now and 2100 and a sea level rise of 49 cm.

V. Adaptation strategies

- Analysis of the protection options
 - Cost of the protection options is much lower than the economic value at risk
 - Protection measures in the Cap Vert peninsula could prevent the landing activities of fishermen
 - In the Saloum estuary, flood-prevention dykes could prevent mangroves from adapting
 - These protection measures must be envisaged in the wider context of the integrated management of coastal areas

The concrete wall at Diokoul (Rufisque)

10 years later!

Problems

Collapse of part of the concrete wall at Rufisque in August 2004

V. Adaptation strategies

- Other adaptation strategies
 - Integrated management policy for coastal areas
 - Sustainable resources management (water and ecosystems)
 - Measures for rehabilitating saline soils
 - Legislative measures
 - Institutional measures
 - Coastal zones research centre

Step VI The vulnerability of coastal areas

- Vulnerability = impacts / adaptation capacities
- Vulnerability criteria
 - Nicholls criteria
 - Other criteria

VULNERABILITY CLASSES (after Nicholls, 1995)

Impact categories	Vulnerability classes			
	Low	Moderate	High	Critical
the total population)	< 1%	1 – 10%	10 - 50%	> 50%
Economic value lost (as % of GDP)	< 1%	1 – 3%	3 - 10%	> 10%
Land losses (as % of the total area)	< 3%	3 - 10%	10 - 30%	> 30%
Wetlands losses (as % of the total area)	< 3%	3 - 10%	10-30%	> 30%
Cost of protection/ adaptation (as % of GDP)	< 0.05%	0.05– 0.25%	0.25 - 1%	> 1%

VI. Vulnerability

- In both cases vulnerability is critical in terms of economic value at risk
- Similarly, the cost of protection is high with respect to GDP, but lower than the economic values to be protected
- Finally, the Saloum estuary has a critical vulnerability because of the large areas of land likely to be lost by flooding

Conclusions: Methodological problems

- Standard IPCC methodology does not solve all the problems!
- Need to have baseline data
- Need to develop methodological tools in African countries (modelling, GIS, assessing the value of non-marketable assets)
- Objective limits of the V&A studies: they cannot quantify everything, nor predict everything!

Conclusions: The conditions required to conduct V&A studies

- Need to have multi-disciplinary national teams
- Require major funding
- Importance of national leadership for impact assessment and for defining response strategies
- National technological context (e.g. the possibilities of processing satellite images)