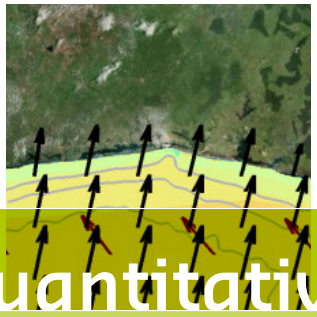
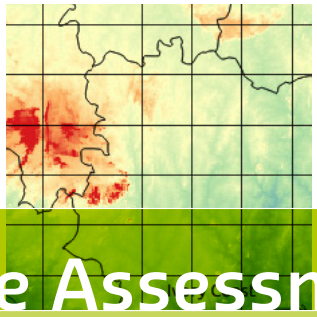
WORLD BANK GROUP
Climate Change

WACA
West Africa Coastal Areas Management Program

WATER PARTNERSHIP PROGRAM

Deltares
Enabling Delta Life

A Quantitative Assessment of Human Interventions and Climate Change on the West African sediment budget

The West African coast consists of a narrow low-lying coastal strip, maintained by sediments from rivers and transported along the coast by waves and currents, a process comparable to a "sand river". Today, however, this sandy coastal barrier is eroding almost everywhere and the already critical situation is likely to be worsened in the future due to climate change. Upon request from The World Bank and in collaboration with the WACA program (West Africa Coastal Areas Program), Deltares has set-up a large-scale coastal sediment budget for the following countries: Ivory Coast, Ghana, Togo and Benin. The study is unique in its methodology as it is based on a consistent set of numerical models, thus reducing the fragmentation of information between different countries.

The West African coast mainly consists of a narrow low-lying coastal strip, over a distance of several thousand kilometers. This coastal strip is protected from the sea by a sandy barrier. Large cities have developed in the past decades in this low-lying back-barrier strip, such as Abidjan, Accra, Lomé and Cotonou.

The West African coastal barrier is maintained by a strong wave-driven longshore transport of sand which can be compared to a "sand river". This sand originates from rivers and from large coastal sand deposits. Today, however, much of the fluvial sand is retained behind river dams and/or interrupted at several locations by harbour jetties. For these reasons the sandy coastal barrier is eroding at several locations; the highest rates of retreat (in the order of 10 m/year or more) occur near river mouths and harbour jetties, i.e. in the most urbanized areas. On top of that, sea-level rise enhances coastal retreat and may be the major factor for coastal retreat by the end of the century. This will lead to the disruption of the coastal barrier if no erosion control measures are taken.

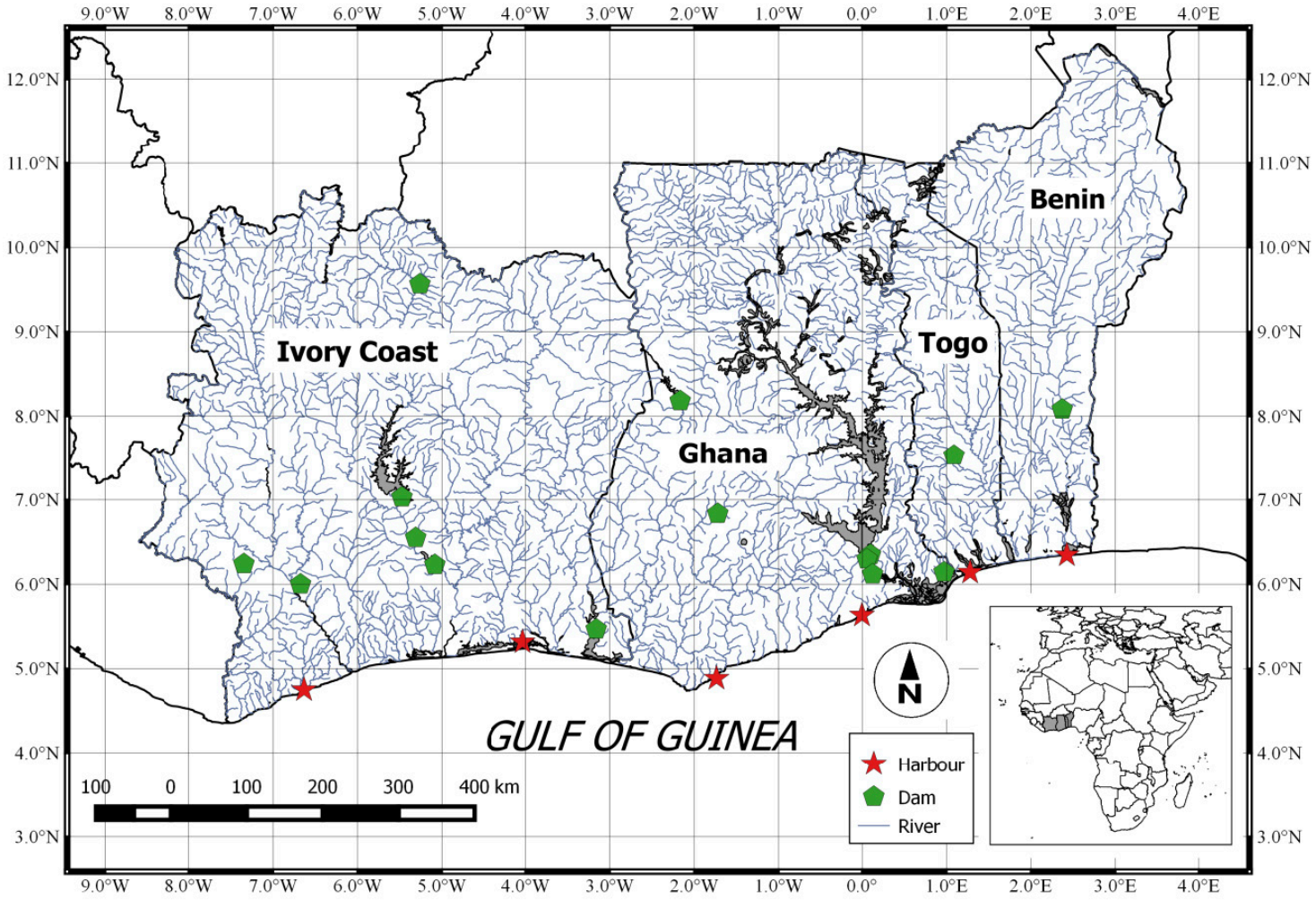
Effects of coastal erosion near the harbour of Lomé.

Objectives of the study

The aim of the study is to develop a consistent large-scale sediment budget for the entire West African Coast which can serve as a first step towards a sub-regional coastal zone management plan for the four targeted countries, i.e. Ivory Coast, Ghana, Togo, and Benin.

This result is achieved based on:

- Estimation, with a consistent numerical modeling based approach examining the annual alongshore sediment transport capacity along the West African coast, from Ivory Coast to Benin. This allows for a quantitative assessment of the effects of different human interventions on the coastal evolution and possible trans-boundary implications. The effect of climate change (i.e. increase in storm intensity, change in wave direction and sea level rise) on the large scale sediment transport capacity is also analysed as part of this study.
- Creating awareness of the interdependency of any action taken along the coast, along the major rivers and on the watershed and its possible consequences. This involves the communication and exchange of information and results with local organizations and relevant stakeholders. Also, a digital coastal viewer is developed within the project in order to facilitate the communication with local stakeholders.



Political units of Ivory Coast, Ghana, Benin and Togo. The main rivers, harbours, and river dams are also indicated.

Study approach

Literature review and desk assessment

Physically, the coasts of Ivory Coast, Ghana, Togo, and Benin are all part of one natural system; the natural processes go across the borders freely, and so do the effects of human intervention. This interdependence necessitates an overall study of the system as a basis for local studies and for the coordination of human actions in the area. Therefore, a comprehensive general picture of the natural conditions and processes along the West African coast is assembled during a literature and data-analysis study, in particular making large use of historical coastlines acquired by Landsat satellite Images (Aqua Monitor tool; http://aqua-monitor.appspot.com/).

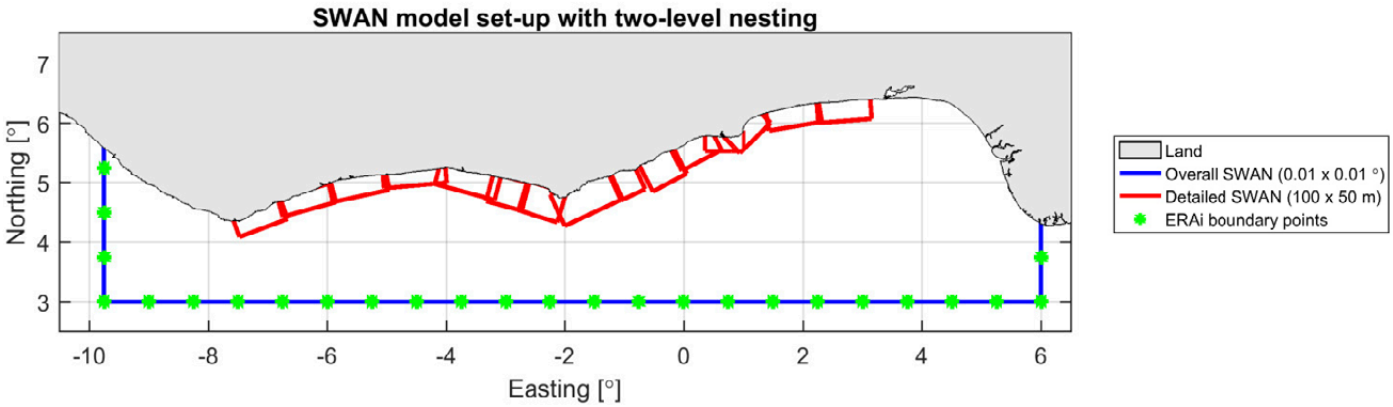
Numerical modelling

The estimation of the annual longshore transport capacity along the West Africa coast is based on an integrated modelling framework consisting of:

- wave models;
- hydrological models;
- sediment-transport and shoreline evolution models

Wave models

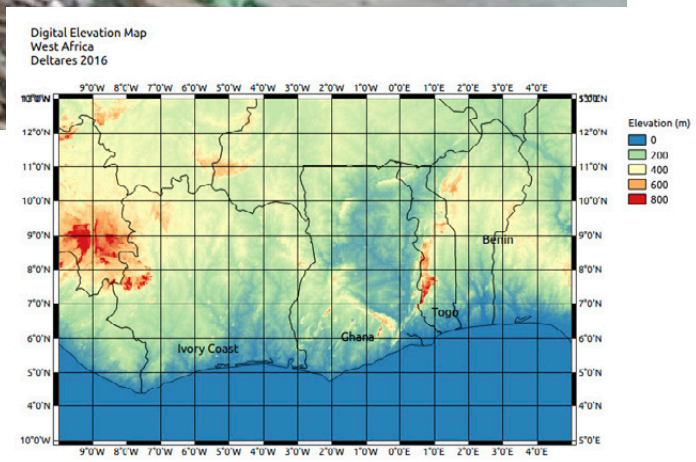
The wave modelling is performed with the DELFT3D-WAVE (SWAN) model. The model simulates wave propagation from offshore to nearshore, taking into account wind generation, dissipation and non-linear wave-wave interaction. The wave model is setup as a large-scale overall model, covering the complete West African coast, with 15 detailed models nested within the overall model to ensure sufficient spatial resolution in the nearshore.



Outlines of the overall wave model (in blue) and the detailed wave models (in red). Green dots represent points where input wave condition is prescribed.

Hydrological model

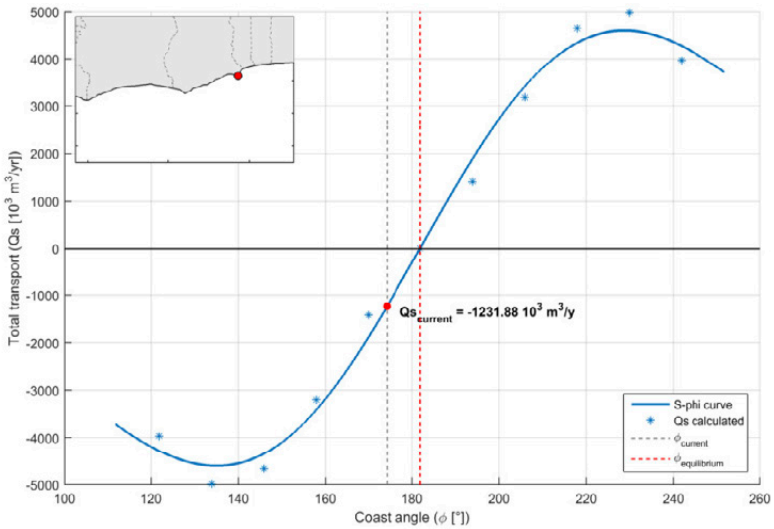
The sediment input from the major rivers in West Africa towards the coastal system is estimated based on empirical relations between the mean annual runoff and the sediment yield. The runoff is computed with a large-scale hydrological model based on the WFlow code. The model carries out hydrological simulations based on a Digital Elevation Map (DEM), land use and soil maps, precipitation and temperature data, and evapotranspiration data.



Digital Elevation Model of the entire study area as used in the hydrological model.

Shoreline evolution model

The coastal evolution is simulated with the UNIBEST-CL+ modelling package: a shoreline evolution model, developed by Deltares. The model calculates the magnitude of longshore sediment transport, forced by wave-induced longshore drift and/or tidal flow, at specific locations along the coast. The calculations provide relations describing the longshore transport magnitude for various coast angles (S-Φ curve) at different locations along the coast. In this way, coastal evolution can be simulated very efficiently, using the information of coastal orientation and local wave angle. Therefore, the model can be used for long-term simulations and large spatial scales, as required by the present study.



S-Φ curve describing the potential transport for various coastline angles (near Keta).

Results

Literature review and desk assessment: examples

From changes of the historical shoreline in proximity to major anthropogenic interventions, and by means of simple volume calculations, it is possible to derive useful information in relation to the alongshore sediment drift which can be used for model validation.

Sedimentation west of the harbour of Cotonou.

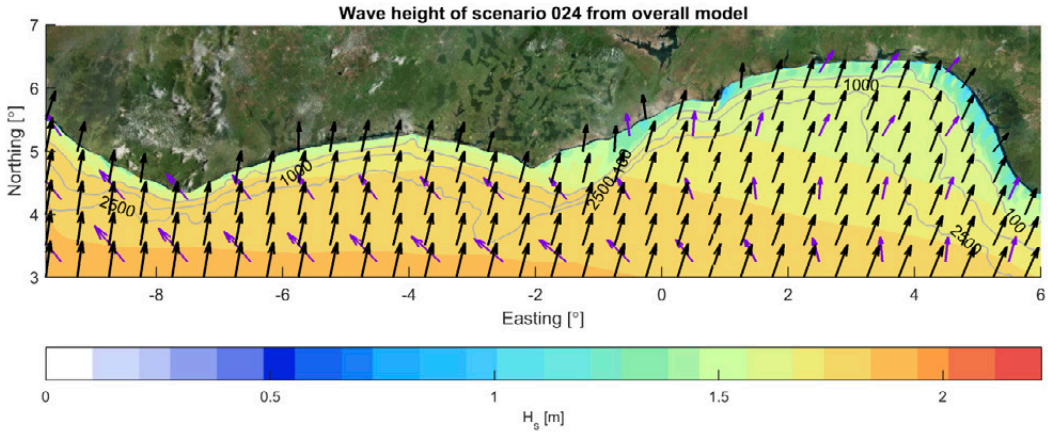
Erosion down-drift of the groyne field near Keta.

Numerical modelling – wave modelling

Several wave modelling simulations are carried out for:

a) the reference situation (situation at present) and
b) different sea level rise and climate change scenario's.

All the different scenarios are used as input to the shoreline model.



Wave model output along the West Africa coast.

Numerical modelling – sediment transport and shoreline modelling.

The results from the sediment transport and shoreline model are first validated versus data derived from the desk study. The validated model is then applied to derive sediment transport rates for the reference situation and for a number of scenarios. Scenario runs are carried out in order to assess the effects of:

- Major anthropogenic interventions (i.e. major harbours and river dams)
- Sea level rise
- Change in wave height and direction due to climate change
- Change in precipitation and temperature due to climate change
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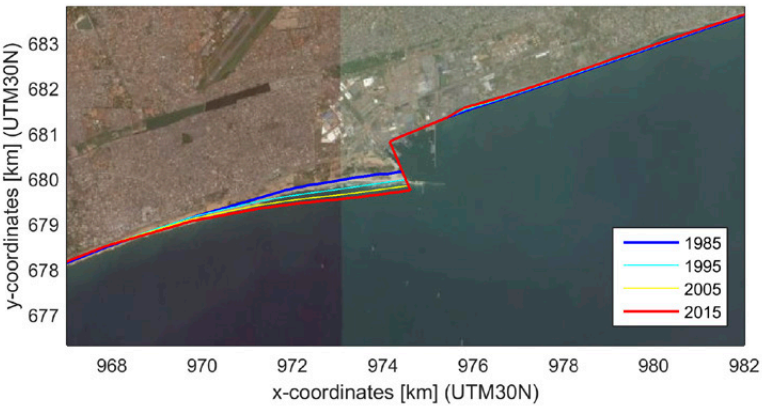

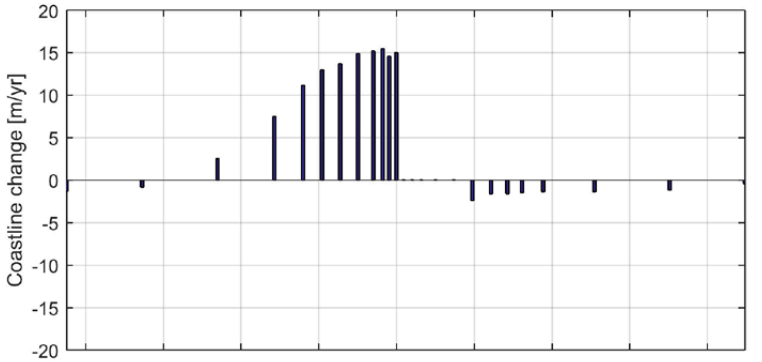

Modelled coastline changes near the harbour of Lomé as validation.

Acknowledgments

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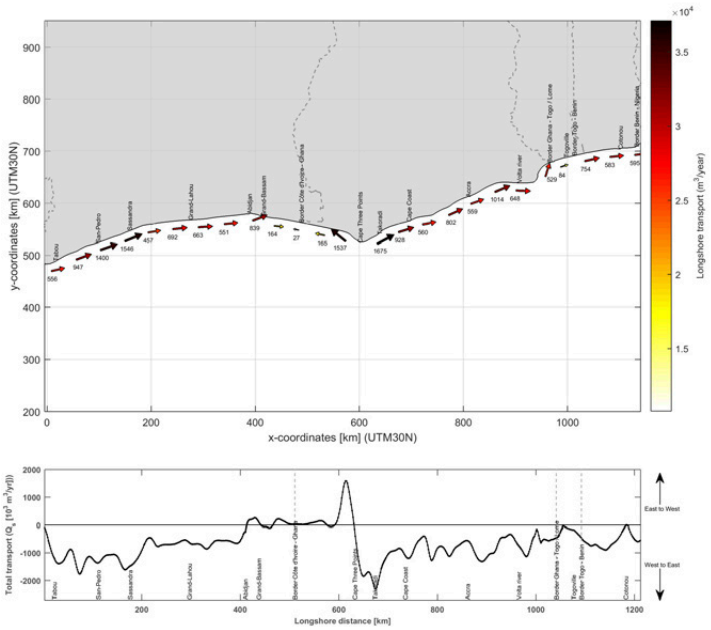
Towards a regional sediment management plan

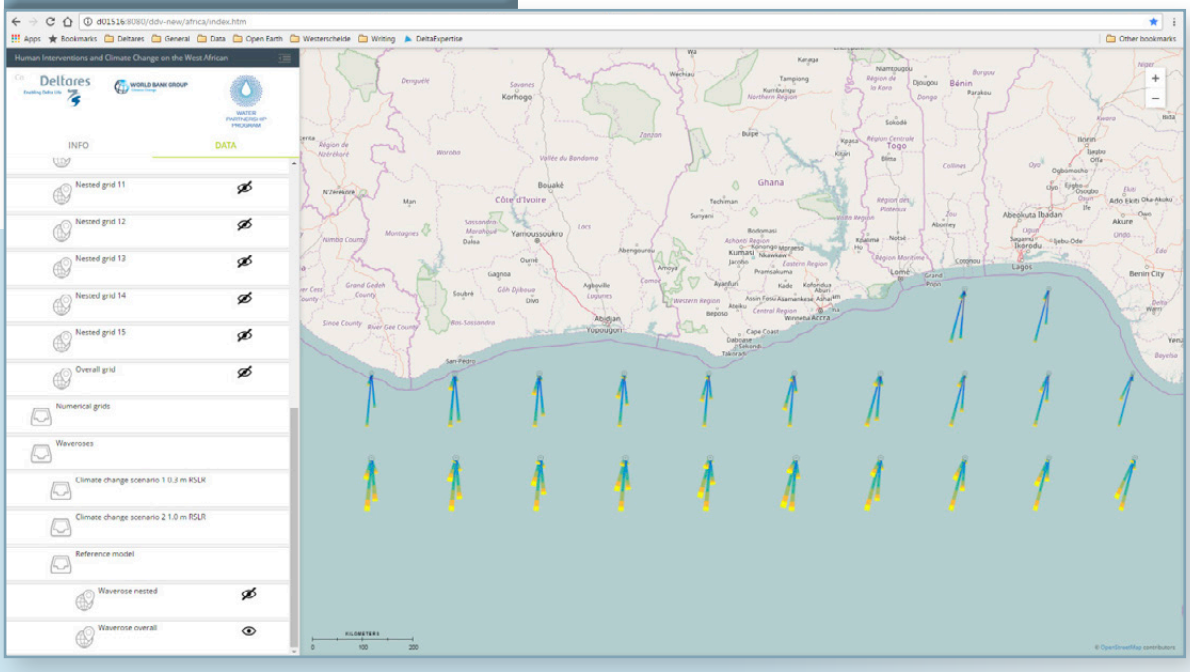
The quantification of the alongshore sediment transport rates ("sand river") along the four countries can provide a first estimate of the possible consequences of major interventions along the coast. In particular, the integrated modelling framework can be used to investigate what could happen if the major interventions already in place are removed from the coastal system, or if efforts to reduce sediment blockage are undertaken (e.g. sediment by-pass systems around the harbours). Also, by simulating the effects of climate change (i.e. changes in sea level, rise, wave height and wave direction) the modelling framework can provide a preliminary estimate of possible expected changes to the sediment budget and coastline position.

An on-line coastal viewer is also developed as part of the study in order to facilitate the communication with the local stakeholders, sharing of the results and to help in setting up a potential regional sediment management plan. Finally, this framework could provide the boundary conditions for the setting up of more detailed models at specific hot-spot locations (i.e. at which solutions are planned).



Computed yearly alongshore sediment transport rates in the reference situation.

http://d01516:8080/africaviewer/africa/index.htm



Web-viewer developed as part of the study for the visualization of the modelling results.

Deltares

Workshop in Grand Lahou

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References

Deltares, 2016. Human Interventions and Climate Change Impacts on the West African Coastal Sand River. A Preliminary Quantitative Assessment. Deltares report, Delft, The Netherlands.

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Deltares is an independent institute for applied research in the field of water, subsurface and infrastructure. Throughout the world, we work on smart solutions, innovations and applications for people, environment and society. Deltares is based in Delft and Utrecht.