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ABSTRACT NO. 156

"COASTAL DYNAMIC ASSESSMENT IN THE COAST OF THE GAMBIA FROM 1984 TO 2043: GIS AND REMOTE SENSING APPROACHES"

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Introduction

- Coastline retreat resulting from rising sea levels is one of the most threatening effects of climate change in coastal areas.
- Human activities contribute significantly to coastal erosion through sand extraction and uncontrolled settlement.
- This study aims to analyze the dynamics of the coastline of the Gambia from 1984 to 2043 using GIS and remote sensing techniques.

Study Area

The Gambia is the smallest country (~ 11,300 km^2) on the African continent, with the geographical coordinates of latitude and longitude 13.46666666, -16.56666666 respectively. It has three major landscape types: floodplain (lowland), colluvial slopes (hydromorphic), and highland. It features about 200 km of sheltered shoreline along the Gambia River, in addition to 80 km of open coastline that borders the Atlantic Ocean.

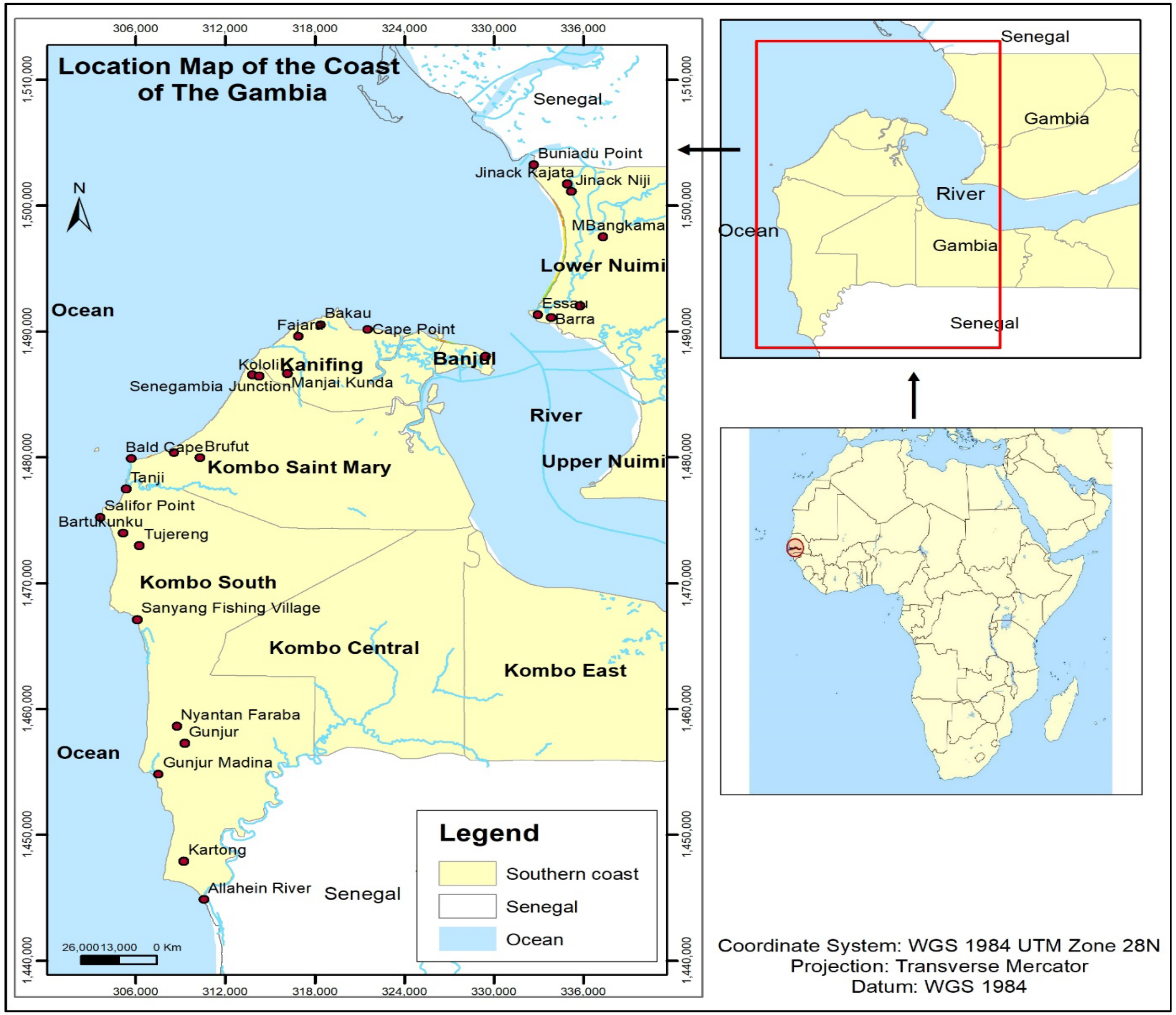

Figure 1: Location map of the coast of The Gambia

Data Source

- For the purposes of this study, Landsat images for four dates were collected (1984,1994, 2004, 2014, and 2023).

Table: Characteristics of earth observation data used.

Satellite/Sensor	Path/Row	Number of bands	Spatial resolution (m)	Acquisition date
Landsat 5/TM	205/051	7	30	17/12/1984
Landsat 5/TM	205/051	7	30	22/05/1994
Landsat 7/ETM	205/051	9	30	06/03/2004
Landsat 8/OLI_TIRS	205/051	9	30	22/02/2014
Landsat 9/OLI_TIRS	205/051	9	30	28/04/2023

Methodology

Processing of Landsat images and coastline identification

- Landsat imagery was processed using a QGIS software's semi-automatic classification plugin.
- The plugin consists of a semi-automatic classification tool programmed in python to monitor land cover in an intuitive way.
- The plugin was applied to process the Landsat images and to identify the shoreline by means of the land cover classification tool included in the plugin.
- Additionally, this tool permits post-processing using instruments to enhance and assess the classification's accuracy or incorporate additional data (Congedo, 2021).

Methodology cont'd

- In this study, the shoreline is considered as the limit between the continent and sea and its delineation was done using the classified and digitalized MNDWI image.
- The Modified Normalised Difference Water Index (MNDWI) has been employed in this study to more effectively distinguish between the land surface and the sea.
- The Near Infrared (NIR) and Short-Wave Infrared (SWIR) bands were used in the band rationing technique.
- For Landsat 5 TM and Landsat 7, the bands 2 and 5 were utilised. Bands 3 and 6 were used for Landsat 8 and 9.
- The maximum value in MNDWI is +1, while the lowest number is -1. The classification threshold is set at zero (0) (Munasinghe et al., 2021 in (Pouye et al., 2023). See equations 1 and 2.

Methodology cont'd

Landsat 5 TM and Landsat 7 ETM	$MNDWI = \frac{\text{Band 2 (Green)} - \text{Band 5 (SWIR)}}{\text{Band 2 (Green)} + \text{Band 5 (SWIR)}}$
Landsat 8 and 9 OLI	$MNDWI = \frac{\text{Band 3 (Green)} - \text{Band 6 (SWIR1)}}{\text{Band 3 (Green)} + \text{Band 6 (SWIR1)}}$

The MNDWI images were classed to discern better the land and sea boundary to represent the coastlines. The coastline was then digitalized using the vector layer created from these identified raster images.

Coastline dynamics computation with Digital Shoreline Analysis System (DSAS)

- The DSAS programme, an extension of ArcGIS, is used to analyse the dynamics of The Gambia's coastline from 1984 to 2023.

- After the digitalization of the shoreline and baseline in the DSAS geodatabase file, the DSAS toolbar is used to compute the coastline dynamic of The Gambia by setting the default Parameters window which specifies the name of the file for the baseline and shoreline inputs.

- The parameters **Net Shoreline Movement (NSM)**, and **End Point Rate (EPR)** were used to calculate the dynamic of the coastline.

- The distance in metres (m) between each transect's oldest and most recent shorelines is known as the Net Shoreline Movement. Through the statistical method of End Point Rate (EPR), the Net Shoreline Movement (NSM) is divided by the time interval between the oldest and youngest shorelines (Dolan et al., 1991 ; Crowell et al., 1997 in Himmelstoss et al., 2018).

$$End\ Point\ Rate\ (EPR) = \frac{Net\ Shoreline\ Movement}{Time\ between\ Oldest\ and\ Recent}$$

Coastal dynamic assessment in the coast of The Gambia from 1984 to 2043: GIS and Remote sensing approaches cont'd

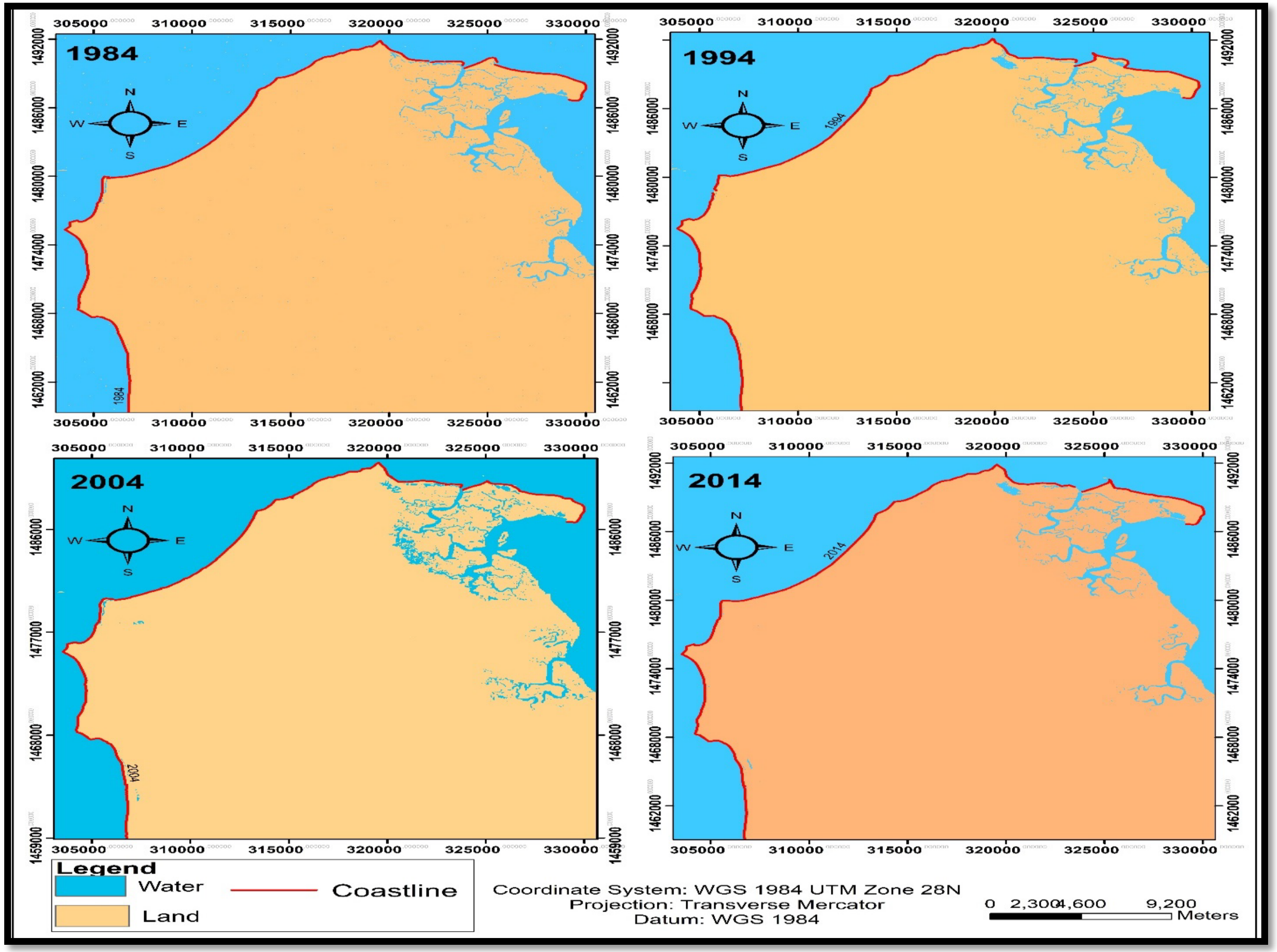

Figure: Coastline evolution for the years 1984, 1994, 2004, and 2014 based on Landsat images, (Source: Student)

Forecasting of the coastline positions in 2033 and 2043

- The shoreline positions for 2033 and 2043 were predicted in this study.
- For that, a simulation based on the current velocity rate is run automatically using the Buffer tool.
- The shoreline position is predicted using the **Velocity =Distance/Elapsed time formula for the years 2023, 2033, and 2043.**
- **Using 2023 as the starting point** and **a rate of change of X metres for the coastline's retreat**, assuming a steady average rate of change at that time, **the coastline will retreat**, depending on its current position, **to a distance of Y metres in 2033**.

Estimation of uncertainty

- By summing their square, the shoreline uncertainty is calculated in this study.
- To calculate the uncertainty of the End Point Rate (EPRunc), the square root of the summation of squares is divided by the number of years between the two shorelines (Pouye et al., 2022).
  - $\boldsymbol{EPRunc = \sqrt{((uncy\ A)^2 + (uncy\ B)^2)}/(dateA - dateB)}$

Where

- Uncy A represents uncertainty derived from shoreline A's attribute field,
- Uncy B represents uncertainty derived from shoreline B's attribute field.
- Dates A and B represent the shoreline that is the oldest (B) and the most recent (A).

Dynamic of the coastline from 1984 to 2023

Dynamic of the coastline from 1984 to 2023 (m/year)					
	Short term dynamics				Long term dynamics
Regions	1984-1994	1994-2004	2004-2014	2014-2023	1984-2023
Kombo South	-35.6	34.3	-0.54	0.27	-0.08
Kombo Saint Mary	-16	13	-1.11	0.84	-0.7
Kanifing	20.8	-22.5	-0.3	1.41	-0.8
Banjul	34.2	-30.4	3.6	-2	1.6
Lower Niumi	-34.1	32.3	-0.10	-1.29	0.03

Source: Student

Long term dynamics of the Southern coastline of The Gambia from 1984 to 2023

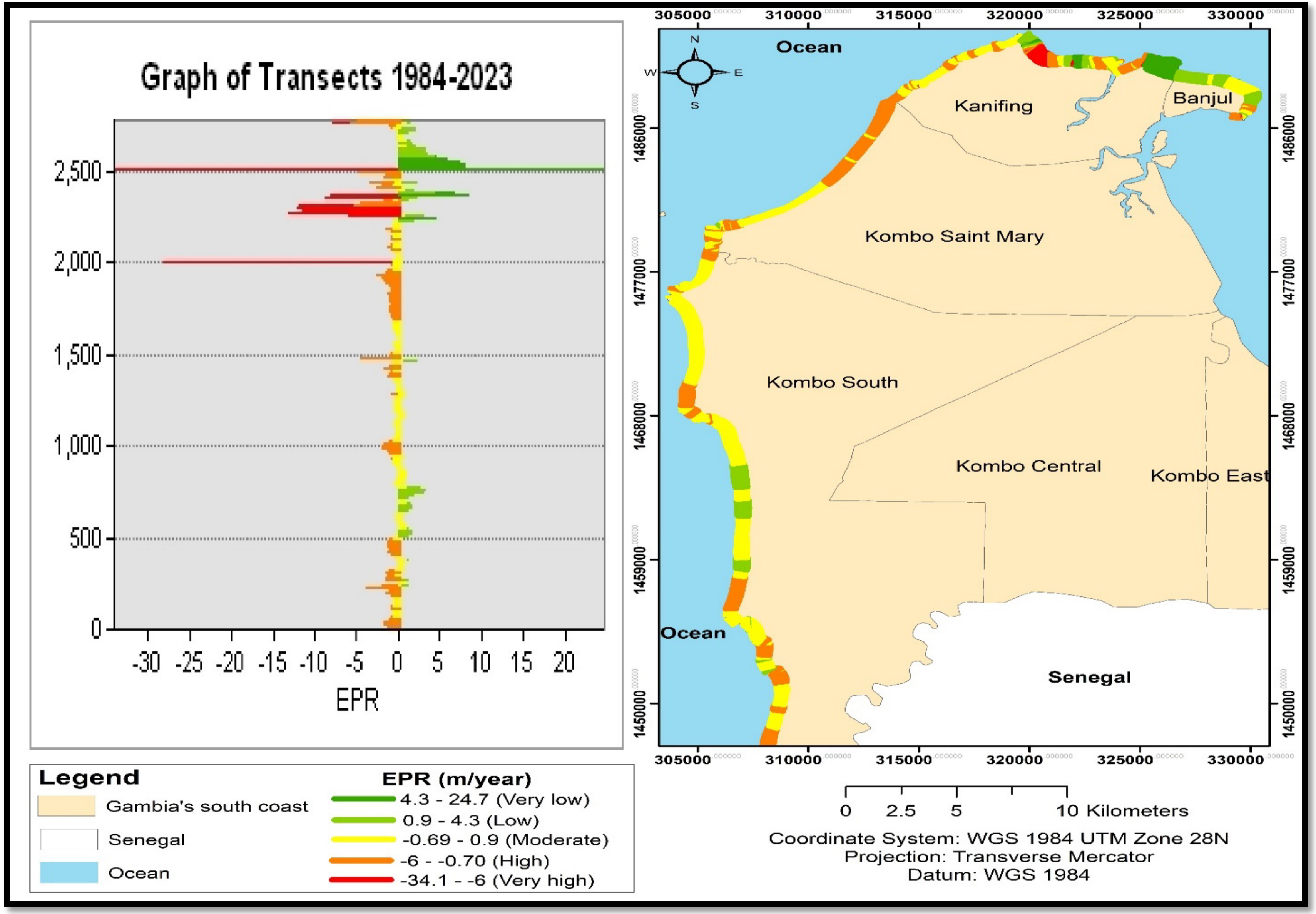

Figure: Coastline dynamic from 1984 to 2023 of the Southern coast of The Gambia (Source: Student)

Discussion

Long-term coastline dynamics of The Gambia’s Southern coast from 1984 to 2023.

- The overall numerical values show a history of consistent patterns and changing coastal character.
- The shoreline at Kombo South has been gradually receding over time, with a negative dynamic of -0.08 metres per year. Similar long-term recessionary patterns may be seen in Kombo Saint Mary, with a little larger negative dynamic of -0.7 metres per year.
- Our investigation is extended to Kanifing, where the coastline's long-term dynamics indicate a consistent retreat with a negative dynamic of -0.8 metres per year.
- A specific situation is shown in Banjul, which has a positive long-term dynamic of 1.6 metres per year.

Long term dynamics of the Northern coastline of The Gambia

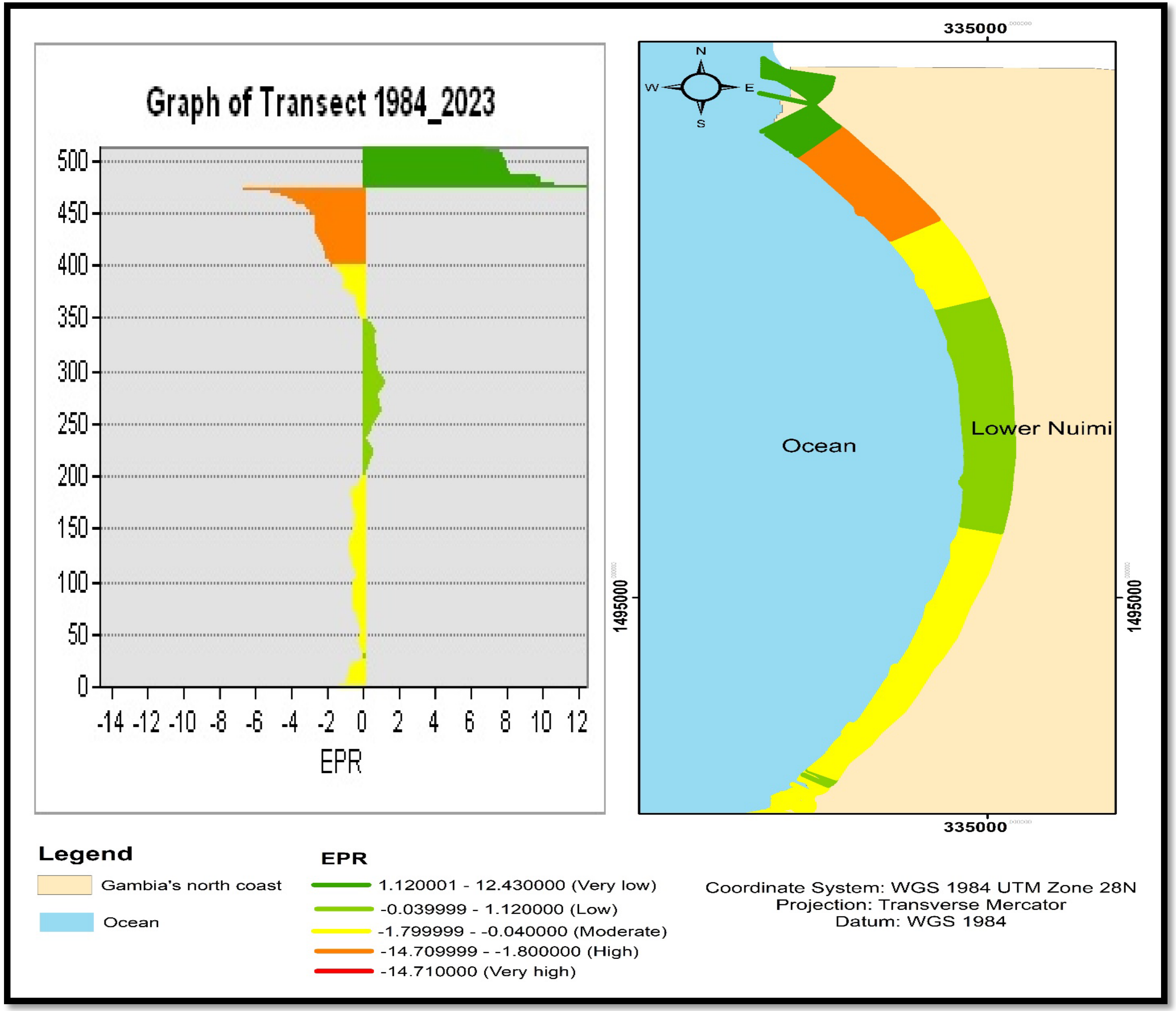

Figure: Coastline dynamic from 1984 to 2023 of the Northern coast of The Gambia (Source: Student)

Discussion

Long-term coastline dynamics of The Gambia's Northern coast from 1984 to 2023.

- Long-term dynamics over the entire 1984-2023 period reveal a marginal positive dynamic of 0.03 metres per year.
- This suggests a subtle overall progression or stability of the Lower Niumi coastline, despite the fluctuations observed in the short-term dynamics.
- The cumulative effect reflects the interaction of various factors that have shaped the northern coast of The Gambia over the decades.

Prediction

Prediction of the coastline position for 2033 to 2043 (m/year)			
Regions	**2014-2023**	**2033**	**2043**
Kombo South	0.27	2.7	5.4
Kombo Saint Mary	0.84	8.4	16.8
Kanifing	1.41	14.1	28.2
Banjul	-2	-20	-40
Lower Niumi	-1.29	-12.9	-25.8

- The forecast catapults the region into a decade of accelerated growth, projecting a dynamic of 2.7 metres per year in 2033. In 2043, the projection of 5.4 metres per year doubles the rate of the previous decade.
- Kombo Saint Mary, with a historical positive trend of 0.84 metres per year, is following a similar trajectory. The forecast predicts a substantial acceleration in the positive trend, reaching 8.4 metres per year in 2033. The forecast for 2043 maintains the doubled rate, projecting a dynamic of 16.8 metres per year.

Discussion on Prediction of the coastline position for 2033 to 2043 (m/year)

- **Kanifing** is recording a historic **positive dynamic of 1.41 metres per year in 2023**. Forecasts indicate substantial growth, with an anticipated dynamic of 14.1 metres per year in 2033.

- This trajectory reflects the positive forecasts for **Kombo South and Kombo Saint Mary**. In 2043, the projection of 28.2 metres per year maintains the doubled rate, signalling a sustained period of intensified coastal advance.

- **On the other hand, a gloomier picture emerges when we focus on Banjul**. The historical **negative dynamic of -2 metres per year from 2014 to 2023** paints a persistent picture of coastal retreat.

- **Forecasts for 2033** anticipate an intensification of the negative trend, **projecting a dynamic of -20 metres per year**. The next **forecast for 2043** maintains **the doubled rate**, projecting a **dynamic of -40 metres per year**.

The **Lower Niumi** experienced **a negative trend of -1.29 metres per year** over the period **from 2014 to 2023**. Forecasts **for 2033** predict a continuation of the negative trend, with **an expected dynamic of -12.9 metres per year**.

This indicates an intensification of the recession or coastal erosion over this period. The **projection for 2043** maintains the **doubled rate**, anticipating **a dynamic of -25.8 metres per year**. This challenging forecast suggests a sustained and intensified negative trend, indicating continuing challenges and potential vulnerabilities in this region.

Uncertainty of the coastline dynamic from 1984 to 2023 (m/year)

Uncertainty of the coastline dynamic from 1984 to 2023 (m/year)					
Regions	**1984-1994**	**1994-2004**	**2004-2014**	**2014-2023**	**1984-2023**
Kombo South	4.5	4.3	4.2	4.6	1.1
Kombo Saint Mary	4.5	4.3	4.2	4.6	1.1
Kanifing	4.5	4.3	4.2	4.6	1.1
Banjul	4.5	4.3	4.2	4.6	1.1
Lower Niumi	4.5	4.3	4.2	4.6	1.1

- The uncertainty for the period 1984-1994 is 4.5 metres per year. This indicates a significant margin of variability in the observed coastline dynamics. The high uncertainty prompts consideration of the various factors influencing the coastline, including natural processes, human intervention and measurement limitations.
- The following decade (1994-2004) maintains a constant level of uncertainty of 4.3 metres per year. This stability of uncertainty suggests a degree of reliability in the measurement methodologies employed during this period, while highlighting the ongoing challenges of accurately determining coastline dynamics.

Discussion on uncertainty

- For the period 2004-2014, the uncertainty remains unchanged at 4.2 metres per year.
- This period shows a sustained level of variability in measurements, highlighting the continuing challenges in accurately quantifying the dynamic nature of the coastline.
- For the period 2014-2023, the uncertainty increases slightly to 4.6 metres per year. This increase may reflect increased complexity or changing environmental conditions over this period. Understanding the sources of this increased uncertainty is essential for sound coastal management and decision-making.
- The cumulative uncertainty for the whole period (1984-2023) is 1.1 metres per year. While individual decades show fluctuations, the overall uncertainty provides an overall perspective.
- This average suggests a level of stability in the accuracy of measurements over the long term, indicating a balance in the consideration of the various factors influencing coastline dynamics.

Conclusion

- Climate change challenges The Gambia, particularly it coastal zones through coastal erosion resulting from sea level rise and human activities along the coast.
- This study of coastline dynamic assessment of the coast of The Gambia from 1984 to 2043, provides valuable information on the evolution of the coastal landscape in the face of climate change.
- The trends observed, in particular, the significant retreat of the coastline in the early decades and subsequent reversals, highlight the complex interaction of environmental factors and human activities contributing to coastal erosion.
- This study not only improves our understanding of historical and predicted shoreline dynamics, but also serves as a vital guide to ongoing monitoring and coastal adaptation efforts.
- Recognising the importance of this research, it provides a valuable resource for policy and decision makers, environmentalists and researchers, to help formulate sustainable and integrated coastal management strategies in the face of ongoing and predicted changes on the country’s coast.

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