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Morpho-Dynamics Shoreline Offset at the Entrance of Qua Iboe River Estuary, South East Coast of Nigeria

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Abstract

The morpho-dynamic variability of shorelines was examined to ascertain the causes of shoreline offset around the entrance of Qua-Iboe River estuary, south-east coast of Nigeria. Shoreline mapping revealed a landward updrift shoreline offset displacement relative to the estuary mouth over a distance of 600 m off the former seaward limit. Daily beach profiles showed an averaged beach width of 200 m with a concave foreshore contiguous to the estuary mouth at the updrift side while the downdrift was characterised by a narrow beach width of 190 m and a convex foreshore. The updrift surf-zone was three times higher in surf-scaling parameters which caused higher rates of erosion and volumetric loss of sediment compared to the downdrift side which was characterised by accretion. The shoreline offset was attributed to the actions and forces of wind/wave, tidal and long-shore currents on the shoreline which were accentuated by storm surge incidence in 2011. A clockwise rotation of the ebb tidal channel in the delta at the estuary mouth estimated at a period of 9 years and a shift in the ebb tidal delta in the downdrift direction offered the best explanation to the updrift erosion phenomenon. Moreover, Estuary-Deltaic-Surf zone processes were noted as a system which modulates the morpho-dynamic variability of the shoreline. A programmed monitoring by appropriate government agencies of the changes and maintenance of the ebb tidal delta through periodic beach replenishment with sediment are recommended as sustainable shoreline protection strategies.

Keywords: Shoreline; Morpho-dynamics; Offset; Estuary; Delta; Accretion; Erosion

Introduction

Shoreline morpho-dynamics and off-set development pattern in relation to surf-zones and estuaries can be casually linked to a number of natural and artificial factors, including tidal regime, degree of wave incursion, wave refraction, wave-breaker angles, surf-scaling parameters, wave breaker height and water depth, long-shore current, fluvial discharge, boat generated turbulence, sand mining, coastal structures, dredging, geology, sea-level rise, etc., [1,2]

The intensity of long-shore current and the rate of erosion and accretion on a beach are directly related to waves breaking at angle to the shoreline. The above, combined with the agitating action of breaking waves, provides energy for transportation of sediments along the beach. Long-shore currents interact with wave surf to produce a long-shore transport of sand and other materials which are fundamental in the formation of many coastal features and numerous instances of coastal erosion and accretion (King,1949; Komar,1976), –cited in Samsuddin et al. [3].

The dissipative or reflective degree of a beach can be indexed by surf-scaling parameters:

$$\epsilon = a_b\, w^2/g \tan^2\beta \ldots\ldots \quad (1)$$

Where a_b is the breaker amplitude, w= radian frequency ($2\pi//T$), and β is the local gradients [4-6]. The low values of ϵ(ϵ=1.0-2.5) define reflective conditions conducive to the occurrence and development of standing waves which are most strongly developed under these conditions. However, the presence of standing-wave motions in reflective, dissipative and intermediate surf-zones are probably important in the moulding of surf zones and beach morphologies [7]. Precisely, fully dissipative beaches and surf zones are characterized by surf scaling parameters (ϵ) in the order of 10^2-10^3 [8].

A shift in shoreline alignment relative to each other, adjoining an estuary/ a tidal inlet, is also controlled by the orientation of the main ebb-tidal channel and the resulting ebb-tidal delta morphology. These ebb-tidal delta processes, as in the case of Price Inlet South Carolina, go through cycles of 4 to 7 years; and the inlet shoreline also goes through cycles of 7 to 42 years duration in which its offset configuration changes Fitzgerald. Furthermore, shorelines can grow (accretion) or recede (erosion) due to waves, currents and the interactions with man-made or natural obstacles.

Moreover, tidal inlets have been considered to have a considerable influence on shoreline behaviour along adjacent shoreline. It gives rise to dramatic modifications over time. It has been suggested that, tidal inlets are responsible for most of the beach erosions along the U.S East coast barrier islands [9-13].

Shoreline offset development is one of the pressing environmental problems around estuarine mouths in the coastal zone of Nigeria. This is attributed to estuarine-ocean flow interactions and the resultant sediment budget-surplus or deficit- on the shoreline adjoining the estuaries. Areal over-flight, geologic map of Nigeria sheet 84 and ground survey show that shoreline in the coastal zone of the Niger Delta is characterized by either landward or seaward geomorphologic displacement relative to estuarine mouths [2].

As the principal concerns of integrated coastal zone management goals are focusing on environmental planning, protection, management,

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conservation of biodiversity and sustainable development, the knowledge and understanding of shoreline processes and development are essential for shoreline management in the Niger Delta in particular and Nigeria at large.

This investigation analyses the causes and development mechanism of offset shoreline adjoining Qua-Iboe River Estuary, South-East coast of Nigeria. Also, it is aimed at recommending sustainable protection and management strategies.

Study Area

Qua- Iboe estuary with its adjoining ocean shoreline is located in Ibeno Local Government Area, AkwaIbom State, along the south-east coast of Nigeria. The specific study sites are the eastern (Iwuokpom) and western (Okorutip) ocean and estuarine shoreline of Qua-Iboeestuary (Figure 1).The ocean-estuarine shoreline is exposed to semi-diurnal tides with tidal range of 2-4 m and south-westerly waves with amplitude less than 20 cm. Modal wave periods close to the shore are 8-12s [12]. Current pattern in the estuary is ebb dominated. Maximum flood and ebb velocities are in the range of 22-33 cm/s and 113-160 cm/s respectively. Long-shore current along the ocean shoreline is predominantly eastward with periodic reversals to the west due to changes in tidal stage. The wind conditions vary annually from calm (November-February) through transitional (February-April) and storm (May-October) [14]. The study area is located in a climatic belt where daily temperature varies between 20°C and 30°C and characterized by heavy annual rain fall (2500 mm-4500 mm) which occurs from April to October, with predominance of south-westerly wind conditions.

The subsurface geology of the study area has not been documented in detail. However, according to Short and Stauble [10] and Sheet-84 of the geological survey of Nigeria [16], the shoreline represents an exposed section of the abandoned beach ridges which are laterally bounded by mangrove swamps of the lower Deltaic plain of Holocene age. It is probably underlain by Sombreiro-Warri Deltaic Plain sand of late Pleistocene. The beach is texturally homogeneous with predominantly well to very well sort much fined grained sand [17].

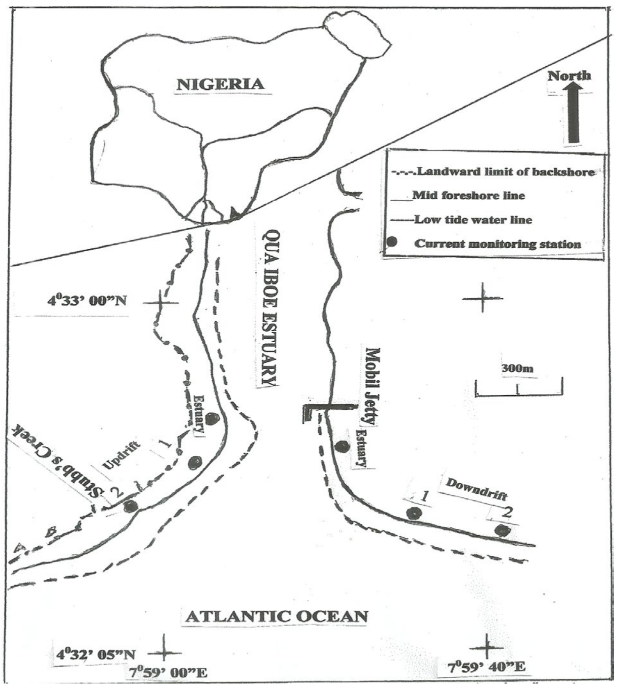

Figure 1: Location map of the study area showing current monitoring/beach profile stations. (Surveyed and produced by Saviour P.U.Akuaibit.October, 2013).

Study Techniques

The study covered a period of nine days from September 28, to October 6, 2013 through Neap (28-9-2013), Mean (2-10-2013) and Spring (5-10-2013) tides. In order to assess the near shore flow interactions and beach morpho-dynamics, the study area was divided into updrift and downdrift morphologic compartments of the shoreline adjoining the western and eastern flanks of Qua-Iboe estuary respectively (Figure 1). Six monitoring stations were established and geo-referenced with GPS: one station, each on the either sides of the estuarine shoreline at 100 m away from the estuary mouth; and two stations, each at 200 m and 500 m locations along the downdrift and updrift ocean shoreline from the estuary mouth respectively. Measurements and observations of hydrodynamic and morpho-dynamic variables which include wave breaker height and water depth, wave breaker pattern, current velocities, beach profiles, etc., were made at each station daily over a near-spring tidal phase.

Results and Discussion

Results

Hydrodynamics: Results of hydrodynamic characteristics of the study area are classified into estuary and surf zone.

Estuary: The flow pattern in the estuary at both updrift and downdrift locations showed northward directed flow during flood tide and southward during ebb tide (Figures 2 and 3).

The peak flood velocities during neap tide were 30 cm/s and 53 cm/s north(N) with average flow velocities of 15.33 cm/sN and 24.22 cm/s N at updrift and downdrift locations respectively. The ebb components depict peak velocities of 111cm/s and 38 cm/s south (S) with average flow velocities of 55.22 cm/sS and 20.89 cm/sS at updrift and downdrift locations accordingly.

The spring tide peak and average flood flow velocity values were 83 cm/sN and 46.33 cm/sN (updrift) while the downdrift counterparts were 98 cm/sS and 60.00 cm/sS. The results of the ebb components show peak and average flow velocities of 125 cm/sS and 72.15 cm/sS at the updrift beach while the downdrift were 96 cm/sS and 56.63 cm/sS.

In summary, 65.80% of average ebb current velocity with a resultant vector of -36.56 cm/sS over the flood component was recorded during neap tide. Mean tide depicted flood dominance characterized by 52.98% of average flow velocity with the resultant vector of 8.29 cm/sN. During spring tide, 54.77% of average ebb flow velocity with a resultant vector of -22.66 cm/sS was recorded against flood current.

Surf zone: From Figures 4 and 5, 91.97% of long-shore current velocities with the highest peak of 125 cm/sE and an average of 59.78 cm/sE were directed to the east at the updrift. The downdift pattern depicted 53.97% of long-shore currents with the highest peak velocity of 88 cm/sW and an average velocity of 51.5 cm/sW due west. The average flow velocities are somewhat higher at the updrift surf zone than the downdrift. The flow directions were east dominant at the updrift while East-West reversals were prevalent at the downdrift surf zone.

Wave parameters: The analysis of wave breaker height and water

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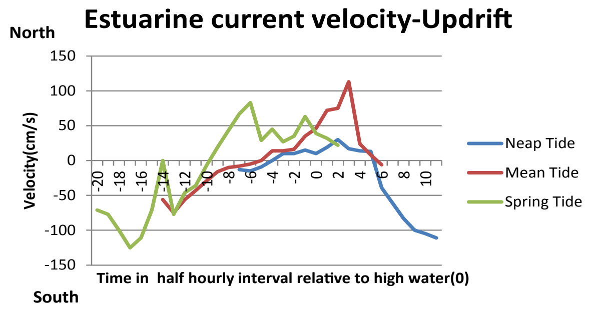

Figure 2: Tidal variation in flow pattern the estuary at updrift shoreline.

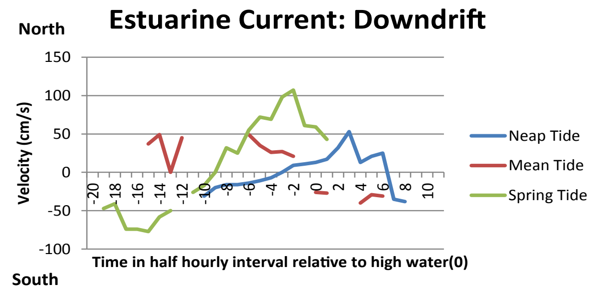

Figure 3: Tidal variation in flow pattern in the estuary at the downdrift shoreline.

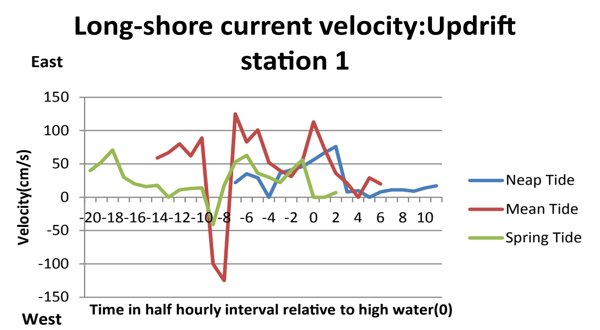

Figure 4: Tidal variation in long-shore current velocity at updrift shoreline.

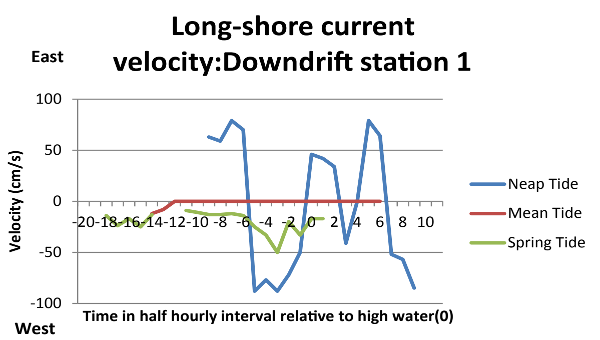

Figure 5: Tidal variation in long-shore.

depth, breaker patterns, breaker angles and surf scaling parameters are presented below.

Temporal variation in wave breaker height: Wave breaker height fluctuated and increased to a maximum of 26 cm at almost predicted high water during neap tide at the updrift location. The downdrift values ranged 20- 30 cm over a tidal cycle during neap tide while mean and spring tide values fluctuated between 30 and 60 cm within three hours before predicted high water (Figures 6 and 7).

Wave breaker angles: Near-shore wave breaker angles at updrift shoreline rotated between 0-30°E and 0-40°W. The wave opened to the west mostly during flood tide and to the east mostly during ebb tide. There were several occurrences of shore parallel breaking waves during the investigation. Also, by visual observations in the field shore normal wave angles and wave refractions to the west were prevalent at the downdrift.

Wave breaker types: The wave breaker types observed in the field were spilling, plunging, collapsing and surging waves. The most frequent breaker types were spilling and plunging breakers in the percentage ratio of 60: 40. The spilling breaker types dominated ebb tide towards low tide and rising tide from low water. Plunging breaker types were frequent during high water.

Surf scaling parameters: The values of surf scaling parameters increased with increase in tidal elevations from neap to spring tide at both updrift and downdrift surf zones. The highest values of 664973 and 241046 were recorded at updrift and downdrift respectively during spring tide. The updrift surf zone is about three times higher in surf scaling parameters than the downdrift (Figures 8 and 9).

Beach sedimentation:

(i) At station 1 which was closer to the estuary, the net sedimentation pattern fluctuated between 0.72 m^3 and -9.6 m^3, the net volumetric change between neap and spring tide was -8.88 m^3 (Figure 10).

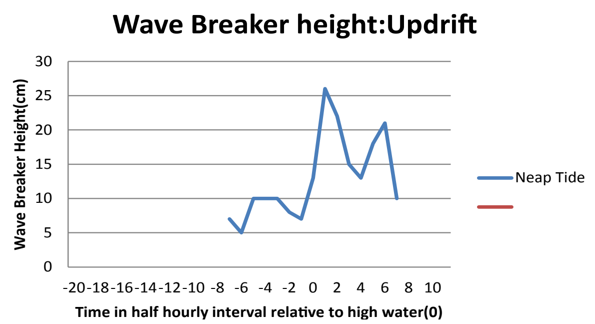

Figure 6: Tidal variation in wave breaker height at updrift shoreline.

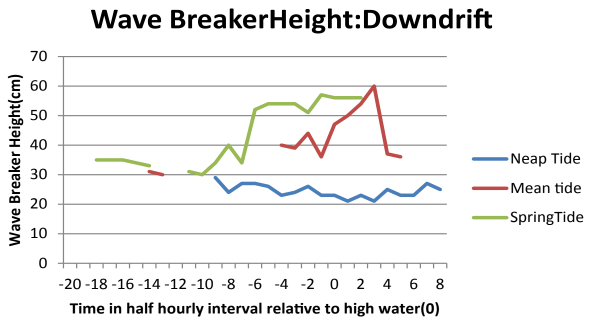

Figure 7: Tidal variations in wave breaker height at downdrift shoreline.

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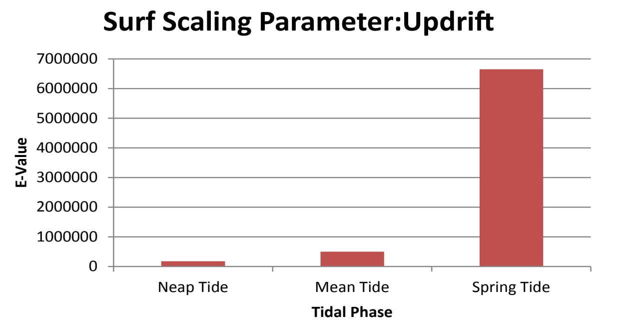

Figure 8: Tidal phase variations in surf-scaling parameters at the updrift shoreline.

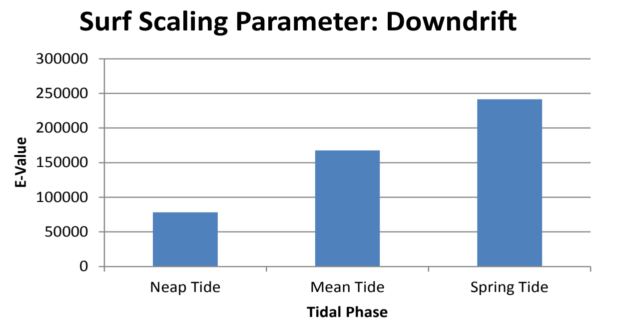

Figure 9: Tidal phase variations in surf scaling parameters at downdrift shoreline.

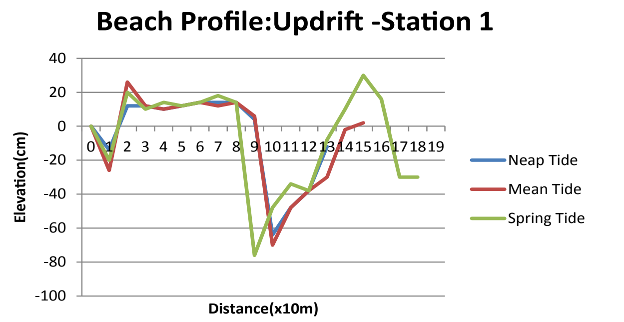

Figure 10: Beach morphologic changes and sedimentation pattern in relation to tidal phase at updrift shoreline at station 1.

(ii) The beach sedimentation values at station 2 away from the estuary computed between neap and spring tide were 4.2 m³ and -0.3 m³. A net value of 3.9 m³ was recorded (Figure 11).

(iii)Station 2 showed accretion while station 1experienced erosion during the study period. However, the net volumetric change of -4.98 m³ indicating erosion was recorded at updrift shoreline stations.

Downdrift shoreline:

(i) The sedimentation pattern at station 1 fluctuated between 39 m³ and -8.28 m³. A net volumetric change of 21.72 m³ was recorded between neap and spring tide (Figure 12).

(ii) Station 2 was characterized by accretion as indicated by sedimentation values of 30 m³ and -10 m³. A net beach volumetric change of 20 m³ was recorded (Figure 13).

In considering the two stations, the total volumetric change of 40.72 m³ was recorded at the downdrift shoreline stations which indicates sediment accretion.

Discussion

Hydrodynamics: The unique characteristics of hydrodynamic parameters in the estuary and surf zones at the study area during flood and ebb tide are veritable indicators of long term coastal processes which are responsible for the variability of the shoreline.

Flood phase: During flood tide, long-shore currents flow patterns at updrift (eastward directed) and down drift (westward directed) surf zones indicate a convergence at the estuary mouth (Figures 4 and 5). The estuary inlet and fluvial discharge create geomorphic and hydrodynamic barriers respectively which compress the inflow of long-shore and flood tidal currents into the estuary thus generating turbulent motions. The progressive incident waves from the ocean

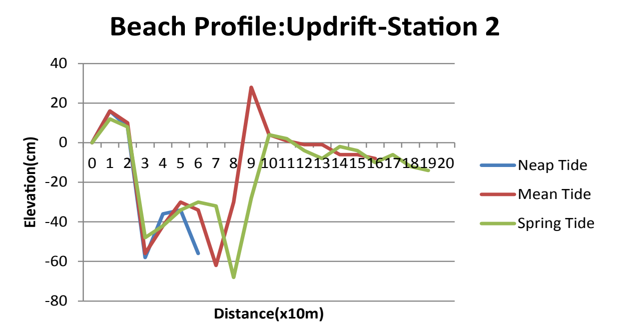

Figure 11: Beach morphologic changes and sedimentation pattern in relation to tidal phase at updrift shoreline at station 2.

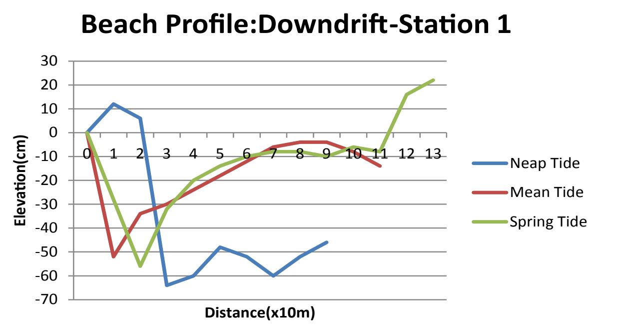

Figure 12: Beach morphologic changes and sedimentation pattern in relation to tidal phase at updrift shoreline at downdrift station 1.

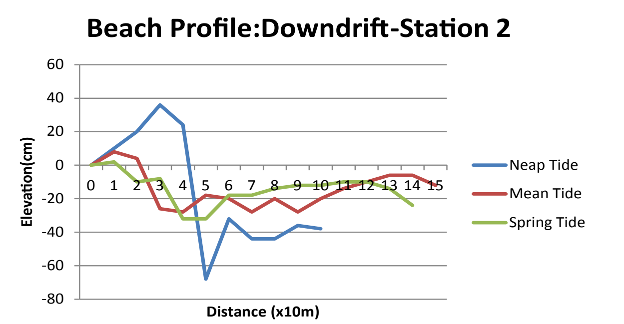

Figure 13: Beach morphologic changes and sedimentation pattern in relation to tidal phase at updrift shoreline at downdrift station 2.

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shoal and refract at the ebb tidal delta into shore normal, eastward and westwards directed components which propagate in trends to the estuary and generate long-shore currents which are directed to the east at the updrift surf zone and to the west at the downdrift surf zone of the shoreline. The convergence of the above three resultant vectors of wave refractions with fluvial current at the estuary inlet result in turbulent interactions. The intensity of turbulence in the estuary mouth increases with increase in flood tide, and the turbulent zone migrate upstream of the estuary as the incident south westerly progressive waves propagate into and break in the estuary. The turbulent motions are expected to scour and stir the bed of ebb-tidal channel and tidal delta of the estuary and agitate sediment into suspension, depending on the grain size diameter, and transport by, and in the direction of flow of flood tidal currents. At high water, the constricted zone of turbulent motions in the estuary inlet diverges and inundates the shoreline interface between the surf zone and the estuary at both updrift and downdrift. The degree of inundation is attributable to the extent of upstream migration of the flood and fluvial currents interface/barrier in the estuary and tidal range which are highest during spring tide. Moreover, surf zone flow interactions, dominated by spilling and plunging breakers at the ratio of 60:40 and average long-shore current velocities of 59.78 cm/s- East and 51.5 cm/s-West, migrated to the mid foreshore of the updrift and downdrift beaches of the adjoining shoreline to the estuary respectively. The occurrences of shore normal incident waves which break parallel to the shore and the accompanying wave swash motions contribute to the cases of cross-shore flow at the downdrift surf zone and the low average long-shore currents velocities recorded at the two beaches. The length, volume and period of wave swash motions on the two beaches increase with tide and tidal range. The wave swash length is primarily a function of beach slope as longer lengths were evident at the downdrift beach which is flatter and has a lower gradient (0.0489) than the updrift (0.1725), especially at the junction between the estuary and surf zone shoreline. The effects of wave breaker heights on swash lengths and periods were very significantly positive towards high water. Plunging and surging breaker types were the major contributors to frequent wave swash motion on the two beaches especially during spring tide. Surging breaker actions were very pronounced in the development of strong wave swash motions at the updrift station closer to the estuary.

Ebb phase: The hydrodynamic pattern during ebb tide is somewhat but not completely the reverse of the flood flow trajectory discussed above. The combination of fluvial and ebb tidal currents during ebb tide contribute to the ebb tidal current flow asymmetry over the flood counterpart which accounted for the downstream migration of the turbulent zone out of the estuary to the margin of the ebb tidal delta in the ocean. This could be seen by a seaward facing observer during low tide as a white foamy or surf arc produced by mainly spilling breakers along the configuration of the ebb tidal delta. The long-shore current flow direction remained eastward at the updrift while west- east flow reversal was significant during neap tide at the downdrift. The west-east flow reversal of long-shore currents at the downdrift during neap tide is attributable to the combined influence of wave actions and beach gradient which dipped gently towards the estuary mouth within the monitoring area. Estuarine ebb tidal currents, as was observed from updrift shoreline during spring tide, flush out of the estuary in the form of fountain with a greater percentage deflecting towards the downdrift, while the ebb currents in the middle channels flow further offshore with a deflection to the updrift after exposed sand bars. At low tide, waves break far off shore off the sand bars (Plate 1). The offshore bar creates calm water area towards the shoreline in the monitoring area and prevents waves from inundating the beach immediately during rising tide.

Beach morpho-dynamics: The pronounced and significant upward concave profiles which characterized the updrift beach are evidence of erosion attributable to high dissipative nature of the beach caused by complex coastal processes (Figures 10 and 11). These include a shift of the ebb-tidal delta towards downdrift, sediment transport by storm surges which started in 2009 and completely inundated and submerged the coastline in 2011, the estuary inlet which serves as a sediment sink, the occurrence of edge waves which travel westward and reversed to the east as long-shore currents along the runnel in the mid foreshore during mid-flood tide stage, strong wave swash and the accompanying backwash currents produced by plunging and surging breakers during flood tide, and aeolian action which transport sediment from the wide backshore to the estuary.

The presence of convex beach profile at the downdrift is an indication of sediment accretion during the study period (Figures 12 and 13). This can be attributed to sediment which bypassed through the inlet from the eroding updrift beach to the downdrift and westward directed long-shore drift of sediment from the shoreward deflected estuarine flow to the area. Besides, the downdrift beach is less dissipative- lower in surf scaling parameters and flatter in gradient which favours deposition than the updrift (Figure 8 and 9). Moreover, the displacement of the ebb-tidal delta towards downdrift enhances accretion at the downdrift shoreline.

Shoreline offset dynamics and development: Prior to storm surge incident in 2011 at the updrift beach (oral communication with indigenes), the estuary inlet was characterized by a downdrift shoreline offset. This was due to high rate of erosion attributable to direct impact of south westerly waves on, and long-shore current transport of sediment along the shoreline. However, the above knowledge could not elucidate the cause and development of multiple intense erosion arcs which configured the downdrift estuarine and surf zone shoreline in 2002. An insight into the above phenomenon as was advanced by [13] indicated that channel meandering in the estuary was the major factor which was responsible for localized erosion sites along the shoreline (Plate 2). As channel meandering is associated with braided channel system downstream, the effect of ebb tidal delta on ebb tidal channel in the estuary could be likened to braided stream system. The deflection of the ebb tidal channel in the estuary towards the downdrift shoreline which caused erosion was an adjustment to the effect of barrier by the ebb tidal delta downstream of the channel thalweg in the estuary. In addition, attributed erosion which result in downdrift or updrift shoreline offset adjoining tidal inlet to ebb-tidal delta processes, as a case of Price Inlet South Carolina, which goes through cycles of 4 to 7 years [14,17]; and the inlet shoreline also goes through cycles of 7 to 42 years duration during which the shoreline offset configuration changes.

Plate 1: Offshore sand bar exposed during low tide at updrift surf zone.

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Moreover, he attributed updrift shoreline erosion and offset to a shift by the ebb tidal delta, and a clockwise rotation and deflection of the ebb tidal delta channel, towards the downdrift shoreline.

The above ebb tidal delta processes can be instructive as a proven explanation to, and as the major cause of, the present updrift shoreline offset adjoining the estuary. It can be traced to the year 2002 when the effect of ebb tidal delta processes manifested as localized and intense erosion problems along the downdrift shoreline [17] and 2009 when the impact was severe at the updrift through 2011 when it was accentuated by storm surge (oral communication). This storm surge could be due to sea-level rise and climate change. Therefore, it can be deduced that the clockwise rotation of the ebb tidal delta underwent a development cycle of 9 years period. Based on the findings of Fitzgerald [9] mentioned earlier, It may take, by estimation, another 9 to 44 years cycles for the present updrift shoreline offset configuration to reverse to its former downdrift offset orientation.

The progradation of the ebb tidal delta towards the updrift provided a wider shallow surf zone surface area for south-westerly incident waves to shoal in a swift motion, refract and propagate in a high speed and dissipate its energy on the updrift shoreline of the coastal community. The ground truth survey and mapping of the impacted shoreline by the storm surge indicated that the degree of the impact increased and concentrated towards the estuary mouth and attenuated from about 500m away from the estuary to the west (Figure 14). It is possible to infer that the area which was inundated by the storm surge event, prior to the incident for many years past was sheltered from the direct impact of south westerly waves by the ebb tidal delta .The other fishing communities along the shoreline, west of the estuary, which were not directly affected by the storm surge, could be located outside the circumference of hydrodynamic shield of the ebb tidal delta from the effect of the waves. The triangular configuration of the submerged area relative to the landward offset shoreline can be resolved into three principal components of forces which operate on the shoreline. These include, tidal currents along the vertical axis, long-shore current due east along the horizontal axis and south-westerly wave/wind actions along the hypotenuse in the north-east direction (Figure 15).

The directions of flow of tidal currents/sediment transport were confirmed in the field by the morphological structure and orientation of sedimentary marks (Plates 3-5). Also, the above diagram suggests that tidal current and wave actions were involved in scouring and agitation of sediments into suspension and bed load, while wind winnowed fine sediments from the backshore and deposited in the estuary. In the other hand, long-shore currents transport sediments into the estuary which are finally transported away from the estuary by ebb tidal currents to the sea.

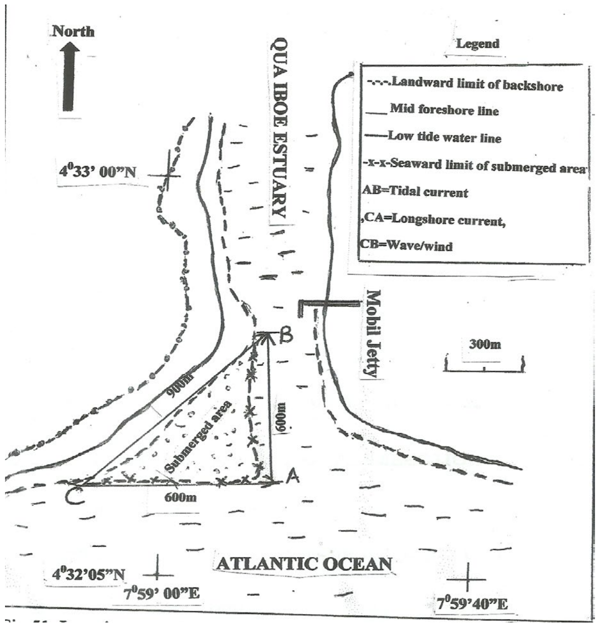

Figure 14: Location map of the study area showing updrift shoreline offset distance and submerged area.(After Udo-Akuaibit,2013).

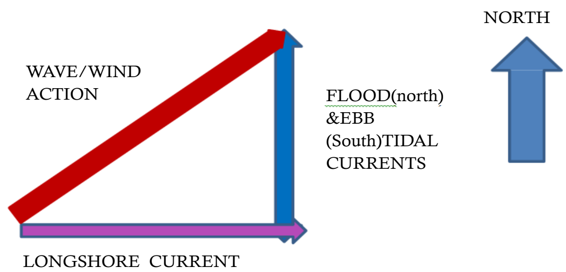

Figure 15: Schematic diagram showing the major agents of erosion and its directions of impact on the submerged area of updriftshoreline.(After Udo-Akuaibit, 2013).

Plate 3: Aeolean sediment transport due north-east at updrift backshore.

Plate 2: Downdrift shoreline of Qua IboeEstuary showing two areas of intense erosion in 2002.

The development of erosion arc of not less than 100m in diameter upstream of the updrift estuarine shoreline is attributed to the rotation and deflection of channel thalweg in the estuary towards the shoreline. Also, apart from sand mining activities for housing and road constructions which take place on the downdrift shoreline, the erosion

Plate 4: Current ripple marks aligned in the direction of flood tidal currents transport due north (left) at updrift foreshore.

Plate 5: Current ripple marks aligned in the direction of long-shore currents transport from west(bottom) to east at the updrift.

arc of about 200 m in diameter at about 1 kilometer east of the estuary inlet, around beach resort and ExxonMobil facilities, is attributed to the deflection of ebb tidal channel thalweg towards the beach by the ebb tidal delta processes (Plate 6).

The knowledge and understanding from the foregone analysis of the near-shore flow interactions and shoreline offset dynamics of the study area suggest that morpho-dynamics of the updrift and downdrift shoreline adjoining Qua Iboe Estuary is strongly dependent on and determined by the estuary, surf zone and ebb tidal delta processes. The three major processes constitute an estuarine-deltaic-surf zone (EDS) system which is in a continuous state of hydro-geomorphic balancing to attain a shoreline of dynamic equilibrium (Figure 16). Out of the three components, estuarine system is the most sensitive to any shear stress on the system. This can be attributed to the geometry of the estuary which is characterized by shallow bathymetry and narrow width (about 500 m) with it associated low discharge capacity which engenders shear stress of significant magnitude to be propagated across the estuary to and from the adjoining shoreline.

Summary

Qua Iboe estuary has an updrift offset shoreline which migrated landward over a distance of 600 m from its former location resulting in the submergence of the coastline area of Okorutip village of not less than 180000 m^2 in 2011. It is attributed to the displacement of the ebb tidal delta, the clockwise rotation and deflection of the ebb tidal channel towards downdrift which was exacerbated by storm tide in 2011 as a consequence of sea-level rise and climate change.

The updrift beach is characterized by erosion at the rate of 178 m^3 per day while the downdrift beach is accreting at the rate of 1490 m^3 per day, and the surf scaling parameter at the updrift is three times higher than the downdrift counterpart. The ebb dominated current pattern in the estuary noted in this study confirmed the earlier finding by Antia. The long-shore current velocity at the updrift beach was constantly directed to the east with minor westward reversal during spring tide, while the downdrift pattern was constantly due west with significant reversal to the east during spring tide.

Estuarine-deltaic-surf zone processes are identified as a dynamic system which controls and determines the morpho-dynamics of the updrift and downdrift shoreline.

Conclusion

The updrift and downdrift beaches are in a dynamic state of periodic and alternate cycles of erosion and accretion respectively, which is controlled by the EDS system. In conclusion, as the entire study area is under the threat of coastal erosion, flooding and recession; proper understanding of EDS processes and shoreline morpho-dynamics in the area are essential for sustainable development and management of the coastline.

Recommendations

1. Mapping of the bathymetry of the estuary and the surf zone adjoining the ebb tidal delta should be carried out before

Plate 6: Erosion arcs along downdrift surf-zone.

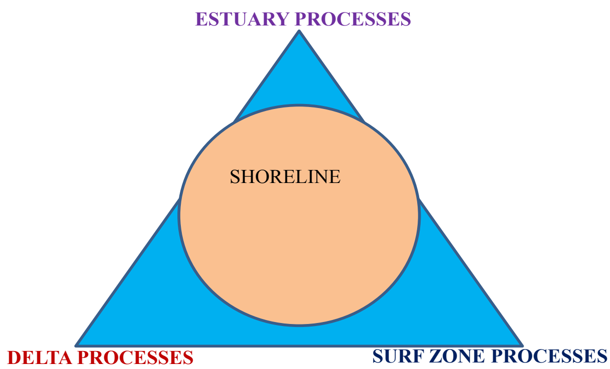

Figure 16: Diagram showing the relationship between shoreline processes and stability.(After Udo-Akuaibit, 2013).

implementation of any major shoreline protection project. This will enable identification of zones of sediment sinks and sources.

2. Regular monitoring and maintenance of the ebb tidal channel in the estuary and the ebb tidal delta are recommended to prevent over accretion of sediments in the delta and subsequent rotation to upload the sediments.
3. Nourishment of eroded shoreline segment with sediment derived from periodic maintenance of the ebb tidal channel in the estuary and the ebb tidal delta is considered as a sustainable option for the shoreline management.
4. The shoreline especially the downdrift beach should be developed for a resort by both government and private organizations.
5. The consideration of estuary- deltaic- surf zone system (EDS) as a factor of safety is indispensable in the design and implementation of the preferred shoreline protection project in the study area.

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