A Comparative Estimate of Sediment Transport Along the Coast of West Africa.

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ABSTRACT

Based on representative wave data obtained for certain points along the West African coastline, five littoral drift formulae well rated in the coastal sediment transport literature and are used to estimate the amount of littoral drift which is the movement of materials by waves and currents along the entire region of the gulf of guinea. The longshore transport is found to vary from point to point, with the maximum amount estimated, at the coast of Cotonou in the Republic of Benin, while the minimum estimate is found along the Nigerian coastal region.

(Keywords: West Africa, wave climate, littoral drift, longshore sediment transport computation, Gulf of Guinea)

INTRODUCTION

Ever increasing human activities within the continental shelf resulting from housing, industrial, port and harbour operations, petroleum exploration, coastal highway construction, and maintenance, as well as the provision of safe recreational beaches has brought into increasing importance, the need for reliable and accurate estimates of the quantity and distribution of longshore sediment transport along the West African coast, commonly referred to as the Gulf of Guinea.

This is particularly useful when dealing with coasts interrupted by harbour moles or breakwaters used to protect ocean-going vessels while entering or leaving harbours of coastal cities. In such situations, massive erosion is normally experienced at the down drifts region of the coasts, while there is a corresponding accretion at the up drift end. Examples of this undesirable occurrence abound along the West African coast, the most devastating being at the Lagos Coast, Nigeria.

From the representative wave data of each part of the coast, the littoral drift formulae obtained from literature have been utilized in estimating the quantity of littoral drift at each section of the coast. These formulae include two developed by: Coastal Engineering Research Centre, [CERC, 1973 and CERC, 1990] and one each by [Castanho, 1966], Laboratoire Central d'Hydraulique de France (LCHF) as discussed by [Migniot et al., 1975], and finally one by [Bijker, 1967 and Bijker, 1968] from a consideration of CERC's data.

THEORY

All of the five formulae utilized follow from Bagnolds [1963] earlier observations, which have since been confirmed by other investigators, for instance Inman et al. [1968] and Loewy [1970], that the rate of littoral drift along beaches is directly proportional to the longshore component of the specific energy flux of waves impinging on it.

The relationship is generally of the form:

$$G = AE_a \qquad \textbf{(1)}$$

where G = submerged weight transport rate of littoral drift

E_a = a longshore component of the energy flux towards the coast per unit length of coast.

A = is usually taken as an empirical constant though in reality, it is a function of the waves breaking, sediment, and beach characteristics.

The longshore component of the energy flux, E_a, is given by Lamb [1963] as:

$$E_a = E_o K_r^2 \sin \alpha_b \cos\alpha_b \qquad \textbf{(2)}$$

where α_b = angle between the breaking wave crests, and the beach line

E_o = the energy flux in deep water in the direction of wave propagation

K_r = $(\cos\alpha_o/\cos\alpha_b)$ where α_o is the angle between wave crests and contours in deep water.

Assuming linear small amplitude wave theory:

$$E_o = 1/16\ \rho g\ H_o^2\ c_o \qquad \textbf{(3)}$$

where H_o, c_o are wave height, and celerity in deep water respectively. Therefore, we can write:

$$E_a = 1/16\ \rho g\ H_o c_o\ K_r^2 \sin\alpha_b \cos\alpha_b \qquad \textbf{(4)}$$

and thus

$$G = A\rho g\ H_o c_o\ K_r^2 \sin\alpha_b \cos\alpha_b \qquad \textbf{(5)}$$

where the refraction is already catered for by the empirical constant (A) which will be expected to vary for different breakers, beaches, and sediment characteristics, though for most of the time it is taken as a constant.

All of the formulae used in estimating the longshore drift are of this form (they are written in detail below):

(i) The empirical formulae of CERC [1990] is of the form:

$$G = AE_a \qquad \textbf{(6)}$$

where A is an empirical constant that varies between 0.25 and 0.77. In absence of any other data, the value of 0.35 is recommended. The relation converts this to volume transport.

$$Q_L = \frac{I_L}{(1 - p/100)\ (\rho_s - \rho_\omega)g} \qquad \textbf{(7)}$$

where Q_L and I_L are volume and weight transport rate respectively and p is the porosity of sand material which is put at 40%. ρ_s, ρ_ω are densities of sediment and fluid (water), respectively. In this case, E_a was obtained empirically with the aid of graphs from Shore Protection Manual in [CERC, 1990]. This formula is said to give approximately twice the real volume of sediment transport if significant wave data is used in the calculations.

(ii) Another formula of CERC [1973] used is of the same form as Equation (6) except for the mode by which E_a is calculated. In this formula, the longshore component of the Energy flux is given by:

$$E_a = 0.141\rho g^{3/2}\ H_b^{5/2} \cos\alpha_b \sin\alpha_b \qquad \textbf{(8)}$$

The volume rate of littoral drift follows from Equation (7).

(iii) The formula of Castanho [1966] is in the form:

$$G_d = \frac{\omega H_o L_o}{7T}\ E_r \sin\alpha_b \cos\alpha_b \qquad \textbf{(9)}$$

where G_d = dry submerged weight littoral drift

ω = unit weight of water

T = wave period

E_r = ratio between the energy dissipated and the longshore energy component, while all other variables are as earlier defined. An empirical relationship between the deepwater wave steepness, Ho /Lo and E_r is given.

(iv) The formulae of LCHF, as discussed by Migniot et al. [1975] may be written as:

$$Q = H^2 T\ t\ f(\alpha) \bullet gr/s \qquad \textbf{(10)}$$

where t = action time of given wave

gr/s = coefficient of transport

s = wave steepness

r = empirical constant, about 0.4×10^{-5} for fine sand (D_{50} = 0.25mm) and 0.2×10^{-5} for coarse sand (D_{50} = 1.0mm)

The function $f(\alpha)$ is empirical, and has been plotted against the approach angle of the wave crest at –15mm contour, α and Q can be obtained entirely from graphs.

(v) Finally, the formula proposed by Bijker [1967] from CERC data is given as:

$$Q = 1.4 \times 10^{-2} H_o c_o H_r^2 \sin\alpha_b \cos\alpha_b \qquad \textbf{(11)}$$

All variables are as earlier defined.

The most widely used formula in coastal engineering practice for the total longshore sediment transport rate (LST) is the CERC equation [USACE, 1984]. It is based on the principle that the volume of sand in transport, Q_{lst} is proportional to the longshore wave power per unit length of beach and given by:

$$Q_{lst} = \frac{\rho k \sqrt{(g/\Upsilon_b)}}{16\ (\ \rho_s - \rho)\ (\ 1 - a\ )}\ H^{2.5}_{s,b}\ \mathrm{Sin}\ (2\theta_b) \qquad \textbf{(12)}$$

where Υ_b is the breaker index (= H_b/h_b) and k = 0.39 that was derived from the original field study by Komar and Inman [1970] using tracers. In recent studies, Schoones and Theron [1993, 1996] re-examined the 46 most reliable of the 240 existing field measurements that have been compiled to determine a k value of approximate 0.2.

DATA

Wave data, as collected from the various sources indicated earlier, are shown in the first three columns of Tables 1A to 1D. Longshore transport calculations using each of the formulae described above are also shown in these Tables. The final estimates by each equation are tabulated in Tables 2A and 2B.

Table 1A: Longshore Transport at Lagos Coast Nigeria.

WAVE PROPERTIES				**VOLUME OF LONGSHORE TRANSPORT**				
Height H_O (m)	**Period T (s)**	**Direction α (deg)**	**Duration T (days)**	**Castahno Q (m^3)**	**LCHF Q (m^3)**	**Bijker Q (m^3)**	**CECR Q (m^3)**	**EMPIRICAL CERC FORMULA Q (m^3)**
0.3	4.0	15	1.6	159	-	318	194	104
0.3	6.0	15	8.3	493	798	16988	1078	359
0.3	8.0	15	10.3	545	2060	2314	1445	371
0.3	10.0	15	9.4	467	3666	2355	1319	305
0.3	12.0	15	3.8	162	2584	1018	546	110
0.3	14.0	15	1.7	84	1870	529	264	49
0.3	16.0	15	0.3	-	450	-	47	-
0.3	18.0	15	0.1	-	180	-	17	-
0.3	20.0	15	-	-	-	-	-	-
0.6	4.0	15	4.2	2905	-	2039	3142	1968
0.6	6.0	15	21.4	11105	4066	12018	14708	7413
0.6	8.0	15	26.5	10976	10600	15340	19326	7019
0.6	10.0	15	24.1	8211	19280	14576	18304	5401
0.6	12.0	15	9.9	2630	12870	6586	7774	2017
0.6	14.0	15	4.3	1198	9460	3009	3377	789
0.6	16.0	15	0.7	178	1960	496	576	140
0.6	18.0	15	0.3	76	1050	-	252	49
0.6	20.0	15	-	-	-	-	-	-
0.8	4.0	15	5.1	7926	-	3922	6400	5546
0.8	6.0	15	26.0	30298	6760	21790	36301	20663
0.8	8.0	15	32.2	28864	16744	28377	44958	20203
0.8	10.0	15	29.4	20813	32340	25910	44061	14756
0.8	12.0	15	12.0	8722	21600	11716	19446	5521
0.8	14.0	15	5.2	2755	14560	4807	8319	1958
0.8	16.0	15	0.8	453	3120	850	1277	301
0.8	18.0	15	0.3	153	1500	319	539	100
0.8	20.0	15	-	-	-	-	-	-

Table 1A[1]: Longshore Transport At Lagos Coast Nigeria.

WAVE PROPERTIES				VOLUME OF LONGSHORE TRANSPORT				
Height H_O (m)	**Period T (s)**	**Direction α (deg)**	**Duration T (days)**	**Castahno Q (m^3)**	**LCHF Q (m^3)**	**Bijker Q (m^3)**	**CECR Q (m^3)**	**EMPIRICAL CERC FORMULAR Q (m^3)**
1.0	4.0	15	3.8	10459	304	3907	8093	7775
1.0	6.0	15	19.4	43549	6208	22461	45722	29769
1.0	8.0	15	24.1	43597	16629	28318	60081	28176
1.0	10.0	15	22.0	31625	28600	26421	56421	20898
1.0	12.0	15	9.0	11946	20700	11975	24192	7892
1.0	14.0	15	3.9	4362	13260	5021	10635	2850
1.0	16.0	15	0.6	590	3000	887	1714	438
1.0	18.0	15	0.2	199	1200	299	561	146
1.0	20.0	15	-	-	-	-	-	-
1.2	4.0	15	1.2	5606	1080	1597	3882	4150
1.2	6.0	15	6.2	21066	2418	9053	22606	14293
1.2	8.0	15	7.7	23543	6160	12241	29947	15976
1.2	10.0	15	7.1	16709	11360	10981	27216	11457
1.2	12.0	15	2.9	5544	8120	4610	12364	4011
1.2	14.0	15	1.3	2479	5330	2213	5530	1648
1.2	16.0	15	0.2	340	1200	347	898	231
1.2	18.0	15	0.1	143	740	179	463	104
1.2	20.0	15	-	-	-	-	-	-
1.4	4.0	15	0.6	4162	66	990	2764	3254
1.4	6.0	15	3.0	17687	1260	5573	15919	12201
1.4	8.0	15	3.7	18282	3441	7257	20717	11913
1.4	10.0	15	3.4	13102	6460	7021	19686	9219
1.4	12.0	15	1.4	4734	4480	2818	8444	3084
1.4	14.0	15	0.6	1699	3000	1301	3688	1220
1.4	16.0	15	0.1	254	690	227	662	186
1.4	18.0	15	-	-	-	-	-	-
1.4	20.0	15	-	-	-	-	-	-
1.6	4.0	15	0.2	2139	24	401	1250	1609
1.6	6.0	15	0.9	7644	450	1991	6507	5324
1.6	8.0	15	1.2	8456	1320	2831	9334	5679
1.6	10.0	15	1.1	6367	2310	2595	8776	4164
1.6	12.0	15	0.4	1903	1360	988	3271	1325
1.6	14.0	15	0.2	793	1080	494	1675	568
1.6	16.0	15	-	-	-	-	-	-
1.6	18.0	15	-	-	-	-	-	-
1.6	20.0	15	-	-	-	-	-	-
2.0	4.0	15	-	-	-	-	-	-
2.0	6.0	15	0.1	1513	61	298	1223	1116
2.0	8.0	15	0.2	2595	260	648	2639	1819
2.0	10.0	15	0.1	1105	280	331	1376	744
2.0	12.0	15	0.1	991	450	353	1234	661
TOTAL LITTORAL DRIFT VOLUME Cubic meter (m^3)				454356m^3	320810 m^3	336565 m^3	653346 m^3	309042m^3
TOTAL LITTORAL DRIFT VOLUME (yd^3)				594275yd^3	419604 yd^3	440210 yd^3	854544 yd^3	404212yd^3

Table 1B: Longshore Transport at Abidjan – Cote D'Ivoire.

WAVE PROPERTIES				**VOLUME OF LONGSHORE TRANSPORT**				
Height H_O (m)	**Period T (s)**	**Direction α (deg)**	**Duration T (days)**	**CASTANHO Q (m^3)**	**LCHF Q (m^3)**	**Bijker Q (m^3)**	**CECR Q (m^3)**	**EMPIRICAL CERC FORMULAR Q (m^3)**
1.6	12	13	365	2066784	1095000	1000000	2984789	1036373

Table 1C: Longshore Transport at Cotonou – Republic Of Benin.

WAVE PROPERTIES				**VOLUME OF LONGSHORE TRANSPORT**				
Height H_O (m)	**Period T (s)**	**Direction α (deg)**	**Duration T (days)**	**Castahno Q (m^3)**	**LCHF Q (m^3)**	**Bijker Q (m^3)**	**CECR Q (m^3)**	**EMPIRICAL CERC FORMULAR Q (m^3)**
2.05	12	30	197.1	7584976	2069550	1205684	2936277	2339779
1.95	12	12	131.4	862115	525600	387836	1751666	662774
1.60	12	-15	36.5	-183264	-127750	-90193	-298574	-120909
1.6	8	-15	36.5	-257216	-38325	-86093	-269450	-172728
				8189875	2556825	1507427	4418493	9146670
2.05	8	30	197.1	9233575	670140	1071152	2753484	3119703
1.95	8	12	131.4	1016729	157680	339454	1634973	917688
1.60	8	-15	36.5	-257216	-38325	-86093	-269450	-172728
1.60	12	-15	36.5	-183264	-127750	-90193	-298574	-120909

Table 1D: Longshore Transport at Lome – Togo.

WAVE PROPERTIES				**VOLUME OF LONGSHORE TRANSPORT**				
Height H_O (m)	**Period T (s)**	**Direction α (deg)**	**Duration T (days)**	**Castahno Q (m^3)**	**LCHF Q (m^3)**	**Bijker Q (m^3)**	**CECR Q (m^3)**	**EMPIRICAL CERC FORMULAR Q (m^3)**
1.71	12	30	197.1	4860844	1773900	968975	1908293	1431826
63	12	12	131.4	535718	446760	3021213	1142207	423399
1.33	12	-15	36.5	-111362	-105850	-69695	-191196	-70730
1.33	8	-15	36.5	-142898	-30295	-64335	-181015	-97934
				5253661	2190365	1212305	2869408	1757291
1.71	8	30	197.1	5682511	532170	844660	1796135	1872384
1.63	8	12	131.4	576588	131400	252036	1060776	521104
1.33	8	-15	36.5	-142898	-30295	-64335	-181015	-97934
1.33	12	-15	36.5	-111362	-105850	-69695	-191196	-70730

Table 2A: Annual Volume (M^3) of Littoral Drift as per each Formula.

Formula	CERC*	Empirical CERC (Formula)	L.C.H.F.	Castahno	Bijker
LAGOS	326673	309042	320810	454356	336565
ABIDJAN	1492395	1036373	1095000	2066784	1000000
COTONOU	2209247	2829825	2556825	8189875	1507427
LOME	1434704	1757291	2190365	5253661	1212305

Table 2B: Annual Volume (M^3) of Littoral Drift as per each Formula.

Formula	CERC*	Empirical CERC (Formula)	L.C.H.F.	Castahno	Bijker	AVERAGE	
						5 Formulas	3 Most Consistent
LAGOS	326673	309042	320810	454356	336565	349489	328016
ABIDJAN	1492395	1036373	1095000	2066784	1000000	1338110	1043791
COTONOU	2209247	282925	2556825	8189875	1507427	3458640	2531966
LOME	1434704	1757291	2190365	5253661	12123305	2369665	1468100

DISCUSSION AND CONCLUSION

A close look at the calculated figures show that at the Lagos coastline, the rate of littoral drift is about 330,000 m^3 per year, whereas at Lome, Cotonou, and Abidjan these values may be put at 1.5 million, 2.5 million, and 1.0 million cubic meters, respectively.

It is quite obvious then that the rate of sediment transport varies from place to place along the West African coast. This is in contrast to the opinion of some specialists holding the view of a constant rate of sediment transport for the region.

The morphological features of the West African coast verify this result, by the fact that waves are impinged at different points and from different angles, though they may originate from the same region. In addition, it appears the waves are not equally developed when they reach the West African coast the more agitative wave conditions are experienced in Lome, Cotonou, etc. further west along the West African coast as indicated by the wave data.

The agreement of the estimates of longshore transports along the Lagos coast by the various formulae is worthy of mention. This is possible because of detailed wave climate data available for the Lagos coast.

Though great precaution has been taken to arrive at these results, as more data becomes available with regards to the wave spectrum and the general hydrodynamics of the West African zone, it will become possible to improve the accuracy of estimating longshore sediment transport rate along the West African coast.

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