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Morphological Impacts Evaluation of Marine Aggregate Extraction at Some Licensed Dredging Sites in Rivers State, Nigeria

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Abstract The morphological impacts of marine aggregate extraction at three licensed dredging sites situated at close proximity on the Okpoka river, Port Harcourt, Nigeria were assessed using hydrographic and geotechnical data as input into Ackers – White and van Rijn sediment transport equations to predict the annual transport volume and recovery rate of the dredged burrow. The average value of annual sediment transport rate volume was 2.04 x $10^6 m^3$, thus the volume of dredged burrow was $6.5x10^6 m^3$, which a recovery rate of 3.2years was obtained. The quality of EIA and EIS reports were poor in two aspects (i) Physical data on Sediment characteristics, Hydrodynamics, Hydrographic/Bathymetric data and Dredging method were scanty and (ii) EIS lacks adequate average on the impacts of the project on socio – economic, ecology, landscape, human health, fisheries on the environment. Since the EIS is indicative of the EIA process, the study recommends that (i) the project proponent must engage competent EIA consultants who are bias in engineering and physical sciences (ii) separate hydrographic/bathymetric survey consultants be commissioned for adequate coverage of the physical environment, and (iii) the regulator must insist on quality EIA and EIS reports, effective mitigation of identified impacts and must demonstrate integrity in handling the EIA process.

Keywords Dredging, marine aggregate, sediment transport, Physical impacts, morphological impacts

1. Introduction

Sand and gravel are valuable natural resources and a major contributor to the demand of marine aggregate materials in Nigeria. Sand is a main constituent of concrete. A cubic metre of concrete is made up of 30 to 35 percent sand and 45 to 50 percent gravel. Thus, the industrial exploration of aggregate resources may be found in construction material for commercial, industrial, or institutional purposes, and for reclamation of low lands, land improvement and coastal development. A developing country like Nigeria is experiencing a phenomenal increase in marine aggregate extraction without data on its annual consumption or reserve unlike other countries. For example, the United Kingdom marine aggregate resource consumption is estimated at about 23 million tonnes per annum with a workable resource of about 1 billion tones [1-2], while Portugal needs about 17 million m^3 per annum of sand [3]. Marine aggregate in Nigeria are mined using three main methods; surface excavation, local drivers scooping the deposits from river beds and hydraulic dredging. The introduction of hydraulic dredgers particularly, the cutter suction dredgers (CSD) in the 14^{th} century with their high production capacities have revolutionized the marine aggregate extraction process over other methods. The main characteristics and important features of the hydraulic dredgers including method of operation, production cycle, limiting factors, ancillary equipment may be found in specialized texts [4].

This phenomenal growth in marine aggregate extraction is an integral part of the material supply chain for infrastructural development, particularly in the low lands of the Niger Delta region, where the resource is extensively used for road embankment construction, reclamation of lowlands for human settlement and industrial development and for various commercial purposes. These development interventions are without negative consequences on the morphology and ecology of the river systems where the marine aggregate are mined. [1] stated that concerns over the effects of marine sand extraction on the environment and fisheries have grown over time especially, where marine aggregate is in high demand combined with multiple dredging licenses at close proximity. The quantitative evaluation of the effects of marine aggregates extraction on Nigerian's rivers is not known. There are no documentations that would permit accurate prediction of short or long term effects of indiscriminate marine aggregate extraction. Assessment of EIA reports of licensed aggregate dredging sites has shown that physical and biological recovery times of the river bed following cessation of extraction are not considered in the environmental impact statement (EIS) report. Yet a qualitative assessment and Save – Our - Soul outcries by the affected communities show that the impacts are enormous. [5] Stated that when the extraction of sand from a river system exceeds the natural production rate, through sediment transport and wash load from the catchment, it could cause major changes in the characteristics of the bed materials and rate of degradation, and many other important aspects of river morphology. [6] found that many years, perhaps decades, would be required for the dredged river bed to revert to its pre – dredging conditions. Marine aggregate extraction causes an initial reduction in the abundance, species diversity and biomass of the benthic community and that the "recovery" period may be more prolonged (i.e. > 4 years), especially for sites dredged repeatedly [7] and [1]. [8] also stated that it is important, the marine environment is protected from significant harm and other legitimate uses are not unacceptably affected by aggregate extraction activities. This paper therefore assesses the morphological impacts of marine aggregate extraction at three licensed sites at Woji, Okujiagu and Oginigba on the Okpoka river system (Figure 1), while Figure 2 shows a typical dredging fleet. The primary objective is to analyse data collated from EIA studies, supplemented with on-site survey measurements and sediment transport computations to assess the morphological impacts of marine aggregate extraction. The assessment was performed using Ackers and White and Van Rijn equations to first predict the annual sediment transport rate and then the recovery time of the river bed following cessation of dredging. Furthermore the paper also explores the reasons for the poor quality environmental impact statements (EISs), making it just a fulfilment of "due process", with little or no contribution to decision making of planned dredging projects. The introduction section gives a succinct background on the magnitude of the problems of marine aggregate extraction. Section 2 presents the baseline data and description of study sites. The materials and methods section contains the description of sediment transport equations. This section is followed by the analysis and results section containing sediment transport computations and determination of recovery rate of submerged dredged burrow. The articles concludes with a review of the existing EIA practice and recommendations towards improving the quality of EIA in the dredging sector. It further stressed the need for a policy framework to ensure that extraction are executed with environmental protection in focus; attainment of sustainable development and ecological quality.

2. Data and Study Area

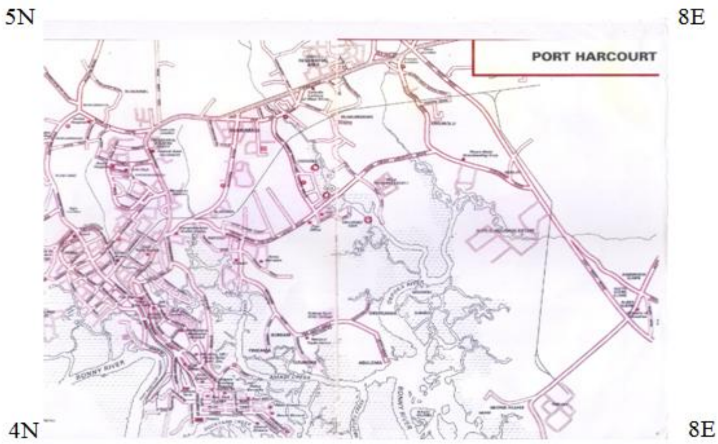

Figure1: Study Map and Locations (●)

The study area comprising Woji, Oginigba and Okujiagu communities are situated on the left bank of Okpoka creek in Port Harcourt city, Nigeria. The sites lie between Latitude 4°49' 27'' N and Longitude 7°2'1''E. The

Okpoka creek is a tidal stream with a meander plan form and also a tributary of Bonny river. The tides are semi – diurnal and mainly come from the Atlantic oceanic tidal propagations which are influenced by the geometry and bottom bathymetry, meteorological factors and river discharge. The average width is 50m.

The outward flow which lasted approximately for 7 hours was $150m^3$/sec while the inward flow (flood) of $45m^3$/sec lasted approximately for 5.5hours. The mean discharge was estimated to be $65m^3$/sec. The maximum water level at spring tide was 7m, the volume of dredged burrow was $6.5x10^6m^3$(obtained by hydrographic survey). The kinematic viscosity (υ) at 30^oC is 0.804 $x10^{-6}m^2/s$. For the given width and depth, the cross–sectional area of flow is computed to be $1,125m^2$, the hydraulic radius (R) = 4.72m, the mean velocity u = $1.47ms^{-1}$, and the shear velocity $u_* = (gRS_o)^{½}$ is 0.221m/sec.

Figure 2: A typical Dredging Fleet

Table 1: Stream Data from hydrographic survey

S/No	Parameter	Values
1.	Mean current $(\bar{u})$	$\bar{u}_{ebb} = 1.47m/s$ $\bar{u}_{flood} = 1.03m/s$
2.	γ_{soil}	$2000kg/m^3$
3.	Water depth (h)	7m
4.	Density (ρ_{H2O})	$1025kg/m^3$
5.	Kinematic Viscosity (υ)	0.804 x $10^{-6}m^2/s$
6.	Mean diameter (D_{50})	0.661mm
7.	Shear velocity (u_*)	0.221m/s
8.	Discharge (Q_{av})	$65m^3/s$
9.	Bed slope (S_o)	0.00105
10.	Porosity(p)	0.38

3. Materials and Methods

3.1. Field Investigations

This research was conducted through a number of studies;

a. ***Hydrographic Survey***: involves the use of eco sounders to determine the bed profile of the river to be dredge. This will be combined with topographic surveying. The data from hydrographic and topographic surveys will be used to quantify the volume of dredged burrow and sediment transport calculations.

b. ***Bathymetric Surveys***: this will enable us acquire current velocity data, discharges, etc which will be combined with flow rates, soil characteristics to compute the input parameters for sediment transport computation

c. ***Field Work***: field work was carried out to determine the volume of dredged burrow.

d. ***Geotechnical Investigation***: samples of bank materials were analyzed in the laboratory to determine the differences in the physical characteristic and to relate these differences to the erosion rates. The properties are: gain size distribution, moisture content, etc.

3.2. Additional data was collated from the following reports;

(i) *EIA study of Reef Courts Estate Port Harcourt, October 2015.*

(ii) *EIA Report of dredging and reclamation project at Snek Island Oginigba, Port Harcourt, 2016.*

(iii) *Technical report on the sandfilling and hydrographic survey at Oginigba water front, Trans – Amadi, Rivers State, all in Nigeria***.**

3.3. Bedload Sediment Transport Equations

The following equations have been selected for computation of bedload sediment transport. (i) Ackers and white [9], [10] and[11],[12].

3.3.1 Ackers and White formula

The Ackers and White formula predicts sediment transport as a primary function of sediment grain size, depth of flow, and depth-averaged velocity. The equations are applicable to uniformly graded non-cohesive sediment with a grain diameter ranging from 0.04mm to 4.0mm [10],[13] and [14]. The Ackers white transport equations relate sediment transport to three dimensionless quantities. The first, a non-dimensional grain size, Dgr is defined as a function of the ratio of the immersed particle weight to the viscous forces acting on the grain. The value is defined as:

$$\mathrm{Dgr} = D\left[\frac{g(s-1)}{v^2}\right]^{\frac{1}{3}} \tag{1}$$

Where D = sediment diameter (i.e., D_{50}); g = acceleration of gravity; s = sediment specific gravity; and v = fluid kinematic viscosity.

The value of Dgr is to categorize the sediment as coarse or transitional with the coefficients given in Table 2, defining the two sediment classifications:

Table 2: Dimensionless quantities for Categorizing D_{gr}

Coefficient	**Dgr> 60**	**60 ≥ Dgr> 1**
C	0.025	$\log C = 2.19\log D_{gr} - 0.98(\log D_{gr})^2 - 3.46$
N	0.0	$1 - 0.56\log D_{gr}$
A_{gr}	0.17	$0.23/D_{gr} + 0.14$
M	1.78	6.83/Dgr + 1.67

The second non dimensional parameter, F_{gr}represents particle mobility defined as the ratio of shear forces to the immersed sediment weight. The general form of the relationship is:

$$F_{gr} = \frac{u_*^n}{\left[g(s-1)D\right]^{\frac{1}{2}}}\left[\frac{\bar{u}}{\sqrt{32}\log\left(\frac{10h}{D}\right)}\right]^{1-n} \tag{2}$$

Where $\bar{u}$ = the depth – average velocity; h = the mean depth of flow; and u_* = the shear velocity. The third non dimensional parameters, G_{gr} ,defines a sediment transport rate as a ratio of shear forces to the immersed weight multiplied by the efficiency of transport. The efficiency term is based on work needed to move the material per unit time and the total fluid power. The transport rate is written as:

$$G_{gr} = \frac{q_t}{\bar{u}D}\left[\frac{u_*}{\bar{u}}\right]^n = c\left[\frac{F_{gr}}{A_{gr}} - 1\right]^m \quad (3)$$

The sediment transport rate G_{gr} is related to the mobility function F_{gr} through the right hand side of equation 3. The magnitude of the total sediment transportq_t given in Equation 3 is sediment mixture, i.e. solids plus voids. So the actual sediment transport rate is written as

$$Qa = q_t*B/(1-p) \quad (4)$$

Where Q_a is the actual total sediment transport rate, B is the width of river, p is porosity (ratio of void volume to total volume) and q_t is sediment transport rate per unit width.

3.3.2. Van Rijn Method

Van Rijn developed a comprehensive theory for sediment transport in rivers using fundamental Physics, supplemented by empirical results. [12] provides details of his full method and also parameterised the results in a set of simpler equations by:

$$q_t = q_b + q_s \quad (5)$$

$$q_a = 0.005\bar{u}h\left(\frac{\bar{u} - \bar{u}_{CR}}{[(s-1)gD_{50}]^{\frac{1}{2}}}\right)^{2.4}\left(\frac{D_{50}}{h}\right)^{1.2} \quad (6)$$

$$q_a = 0.012\bar{u}h\left(\frac{\bar{u} - \bar{u}_{CR}}{[(s-1)gD_{50}]^{\frac{1}{2}}}\right)^{2.4}\left(\frac{D_{50}}{h}\right)(D_*)^{-0.6} \quad (7)$$

Where;

$$u_{CR} = 0.19(D_{50})^{0.1}\log\left(\frac{4h}{D_{90}}\right) \quad for \ \ 0.1 \le D_{50} \le 0.5mm \quad (8)$$

$$u_{CR} = 8.5(D_{50})^{0.6}\log\left(\frac{4h}{D_{90}}\right) \quad for \ \ 0.5 \le D_{50} \le 2.0mm \quad (9)$$

Range of validity, h = 1 – 20m, u = 0.5 – 5.0m/s.

4. Analysis and Results

The computation of sediment transport rate using Ackers – White method proceed on with the determination of D_{gr} on substitution of the parameters in Table 1 giving a value of 19.32. The D_{gr} value of 19.32 falls in the inequality 1<Dgr<60 (see Table 2), from which the coefficients C, n, A_{gr} and m were computed. Thereafter the particle mobility number $F_{gr,}$ and its critical value A_{gr} were computed using Equations 2 and 3 and the results are shown in columns 7 and 8 of Table 3. Also the sediment transport rate (q_t) per unit width of river bed was computed as shown in column 9.On application of effective river bed width of 50m, the value of Q_t computed was 0.04512m^3/sec/m. On adjusting for porosity with a factor of 0.38, Equation 4, gave Q_a value of 0.073m^3/sec, and the equivalent annual volume of sediment transported/deposited is $2.3\times10^6 m^3$ for Ackers white-equation. Following similar steps a Q_t value of 0.0349m^3/sec and Q_a value of 0.0513m3/sec and annual volume of sediment transported/deposited of $1.78x10^6 m^3$ were computed using Van Rijn method. Tables 3 and 4 contain the computed values.

4.1. Ackers-White Method.

The numerical values have been tabulated and explained as follows:

Table 3: Ackers – White Computed Values

d_{50} mm	D_{gr}	c	n	A_{gr}	m	F_{gr}	G_{gr}	q_t $m^3/s/m$	Q_t m^3/s	Q_a m^3/s
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
0.661	19.32	0.0322	0.280	0.152	2.0	0.768	0.547	$9.024x10^{-4}$	0.0451	0.073

Col. 1: mean diameter of sediment particle, Col. 2: dimensionless particle size number, Col. 3, 4 and 6: Ackers and White formula coefficients; Col. 7: Sediment particle mobility number, Col. 8: Stream power sediment transport parameter Col. 5: The critical value of sediment particle mobility number, Col. 9: Sediment transport rate per channel width, Col. 10: Sediment transport rate for total channel width, Col. 11: Sediment transport rate across channel width, allowing for effect of Porosity.

4.2. Van Rijn Method

Table 4: Van Rijn computed Values

d_{50} mm	d_{90} mm	$\bar{u}$ m/s	$\bar{u}_{cr}$ m^3/s	q_s $m^3/s/m$	q_b $m^3/s/m$	q_t $m^3/s/m$	Q_t m^3/s	Q_a m^3/s
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.661	1.4	1.47	0.437	$4.94x10^{-4}$	$2.043x10^{-4}$	$6.980x10^{-4}$	0.0349	0.0513

Col. 1: d_{50} mean diameter of sediment particle; Col. 2: d_{90} dimensionless particle size number; Col. 3: $\bar{u}$ depth-average velocity; Col. 4: $\bar{u}_{cr}$ depth-averaged critical velocity; Col. 5: q_s suspended load transport; Col. 6: q_b bed load transport Col. 7: q_t Sediment transport total per unit width; Col. 8: Q_t Total sediment transport for whole width; Col. 9: Q_a Total sediment transport allowing for effect of Porosity.

4.3. Determination of Recovery Rate

The average value of the two methods is $2.04x10^6m^3$. Consequently, the underwater dredged burrow volume of $6.5x10^6m^3$ extracted will take 3.2years to revert to its pre-dredged condition. [15] has shown that marine aggregate which infilled dredged burrows, resulted from a combination of flume settlement and from the transport and trapping of bed load sediments. Also [16] has shown that significant changes in bathymetry brought about by dredging has the potential to cause a drop in current strength resulting in deposition of sediments. In view of these, the equations of Ackers – White and Van Rijn have been used in preliminary assessment, though the actual river bed boundary consist of a range of particle sizes, a single parameter $D_{50}$was employed, since it fell within the range of validity of these equations.

5. Overview of Existing Guidelines on Marine Aggregate Extraction and EIA

The FMENV established by Decree 58 of 1988 and 59 of 1992 as amended has produced statutory documents dealing with monitoring, control and abatement of industrial waste including the indiscriminate pollution of the environment. Furthermore, the preparation of an EIA document on development projects is a statutory requirement in Nigeria. The environmental impact assessment (EIA) Decree 86 of 1992, among other things, set out procedures and methods to enable the prior consideration of EIA or certain projects such as dredging construction. The need to involve key agencies such as the rivers state ministry of environment, stakeholders and other interest groups in the public hearing process is a key component of the certification process. Apart from the general EIA guidelines, Federal Ministry of Environment (FMENV) has also prepared sectoral guidelines for EIA in the different sectors of the economy. The appropriate one for the proposed dredging project is the one on infrastructure, and specifically the section on "Ports and Harbour Development Projects."

5.1 Nigerian Inland Waterway Authority (NIWA) LAW

The national inland waterway law no.13 of 1997 empowers NIWA to: Undertake capital and maintenance dredging, Undertake hydrological and hydrographic surveys, (i) Subject to the provision of environmental impact assessment o navigational and other dredging activities within the inland water and its right-of-ways. (ii)

Grant permit and licenses for sand dredging, pipeline construction, dredging of slot and crossing of waterways by utility lines, water intake rock blasting and removal. (iii) Approve and control all reclamation of land within the right-of-way, survey, remove and receive derelicts, wrecks and other obstruction from inland waterways.

5.2 Rivers State Regulation

The Nigerian constitution also allows the state to make legislation, edicts governing the environment. Hence in accordance with the provisions of section 24 of FEPA act 58 as amended by Act 59 of 1992 and laws of the Federal Republic of Nigeria.

Rivers state government enacted the rivers state environmental protection law no.2 of 1994. The law clearly spells out the functions of the ministry of environment as far as the protection of the environment for sustainable development is concerned. In addition, to these functions, the law empowers the ministry to (a) Establish such environmental criteria, guidelines, specifications or standards for the protection of the state's air, land and waters as may be necessary to protect the health and welfare of the people (b) Establish procedures for industrial or agricultural activities in order to minimize damage to the environment and natural resources from the state.

5.3 Review of existing statutory regulations and Laws

The Federal Environmental Protection Agency (FEPA) law made it mandatory for projects proponents to undertake an (EIA) study to support their applications. The FEPA and NIMA guidelines do not adequately define the relevant environmental indicators and the parameters that would adequately describe the physical environment. Following the establishment of the FEPA law in 1992, numerous EIA studies have been sanctioned by proponents of proposed developments. The EIA process a shared between the key actors; EIA regulators, Project proponents and the EIA consultants. The EIA consultants are employed by proponents to advise them on relevant EIA policies, practices and procedures, to assist the proponent in dealing with the administrative aspects of the EIA; and to undertake the technical work necessary to assess and mitigate the potential impacts of the proposal (e.g. baseline studies, Environmental Impact Statement (EIS) preparation, response to public submissions etc. The role of EIA regulators is to implement EIA policy and procedures in accordance with the legislative framework (e.g. sign – off on scoping requirements, check EIS quality and authorize publication for public review, verify that the public submissions have been adequately responded to etc); they are the gatekeepers for proponents seeking approval of new proposals. In the view of the shared responsibilities, the weak and poor EIA performance may be blamed on the key actors, and in particular the proponents who always renege their mitigation responsibilities by inducing EIA regulators' to compromise their integrity. Similarly, incompetent EIA consultants have always been engaged, who in turn would produce poor quality EIA reports and EIS statements. These findings are coherent with others (e.g. [17],[18],[19],[20], [21], [22], [23], and [24]) who assert that EIA effectiveness can be viewed in terms of both procedural criteria and substantive outcomes. And who also blame the many weaknesses in the Nigerian EIA process on incompetence of EIA practitioners, inadequate legislative enforcement by the regulatory agencies and poor coordination between stakeholders.

6. Discussion

6.1 Impacts of marine aggregate extraction

The main method of marine aggregate extraction in Nigerian inland waters is the cutter suction dredger. The principal environmental concerns of marine aggregate extraction arise from physical impacts at the river bed and the concomitant biological responses.

Research studies on the physical and biological status of licensed areas following cessation of commercial dredging are not known in Nigeria, unlike other countries in Europe and USA. In this research work, the empirical sediment transport equations by Ackers – White and Van Rijn were used to estimate the annual volume of sediment deposited in the dredged burrows and in turn the recovery rate . Thus a recovery period of 3.2 years was predicted for the licenced sites. Different recovery rate have been reported in literature, for example [25] reported that a recovery time of 6 – 8months is characteristic of muddy waters, while sand and gravel may take 2 – 3yeears depending on the hydrodynamics and 5 – 10 years for biological recovery. [7]

reported that a total recovery was almost achieved 28months after cessation of dredging activity, except for densities and species . [26] and [27] described the effects of sand extraction on benthic communities in the North Sea, reporting a rapid recolonization by surrounding fauna, within 2 – 4 years. The rate predicted in this study falls within the range reported in the cited literature. But as [6] also observed that the impacts is site specific and depend on numerous factors, namely; extraction method, sediment type and mobility, bottom topography, and currents. These factors should be incorporated as routines in morphological modelling software's to accurately the impacts and morphological models must account for coupling between and flow dynamics and the description of sediment motion.

7. Conclusion and Recommendations

This study has found that physical impacts arising marine aggregate extraction dominate other induced impacts such as biological effects and total recovery of the biological effects is only possible when the dredged burrow has reverted to its pre – dredged conditions. A recovery period of 3.2years has been predicted and is in good agreement with other studies for example, [25] secondly, the physical environment data is fundamental to the successful assessment of the impacts of marine aggregate extraction. The relevant physical data may be categorized as ; Sediments, Hydrodynamics, Bathymetry/morphology and dredging method and must include; tides/waves/currents, grain size, porosity, density (void space), depth/bedding, stability and consolidation, depth of extraction at license area, and dredge tracks [28].

In view of the poor quality EIA and EIS reports and the dearth of data on the physical metrics, the study recommends (i) that the project proponent must engage competent EIA consultants bias in engineering or physical sciences (ii) separate hydrographic/bathymetric survey consultants be commissioned for adequate coverage of the physical environment, and (iii) the regulator must insist on quality EIA and EIS reports, effective mitigation of identified impacts and demonstrate integrity in handling EIA matters. (iv) the application of numerical models in the prediction of morphological impacts of marine aggregate extraction.(iv) The planning and licensing of extractions areas and methods used in Nigeria need to be based upon sound guidelines, to minimize the physical impacts.(vi) The need for sound statutory regulations which will transpose into Nigerian law for the protection of natural habitats with respect to the extraction of marine aggregate by dredging is strongly advocated to protect the environment and achieve sustainable development of marine resources.

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