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A Morphodynamic Model of Sandy Beach Susceptibility to Tar Pollution and Self-Cleansing on the Nigerian Coast

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ABSTRACT

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This report elucidates the application of the beach morphodynamic concept synthesized by WRIGHT and SHORT (1984) to model the susceptibility of a mesotidal sandy beach along the Nigerian coast to, and self-cleansing of, tar pollution. A 21-month, fortnightly, inventory of stranded tar balls at a total of 16 shore-normal transects spread over a 6 km stretch of beach was made. Concurrently with the above, beach profile changes and littoral process observations were documented. Due to the generally subtle alongshore differences, particularly of the beach textural and topographic characteristics in the study area, coupled with the semidiurnal tide-related complex changes in the nearshore flow field, regression analyses of tar weight and concentration with certain process parameters were expectedly not always highly correlated. However, there are indications that the longevity of tar pollution would be higher on modally dissipative beaches. By contrast, the reflective prone counterparts would be more impoverished of tar balls, thus suggesting a higher self cleansing potential. The above results respectively reflect, primarily, the low and high temporal mobility of the beach types. However, the aforementioned patterns were less pronounced along beach sectors fronted by surf zones characterized by temporally-persistent, longshore-bar trough morphologies, probably due to their co-existing dissipative and reflective characteristics. The present results enable a four fold schematization of beach surf zone profile states, and a qualitative scaling of their pollution potentials in the course of, and after, an offshore oil spill event.

ADDITIONAL INDEX WORDS: *Beach morphodynamics, tar pollution, Nigerian coast*

INTRODUCTION

Sandy beaches are one of man's most cherished natural resources. However, the recurring oil spills associated with, but not limited to, petroleum prospecting and shipping activities offshore pose a threat to their aesthetic and ecologic values.

Oil pollution as evidenced by stranded tar balls on beaches has been widely reported, for example, from Canada (OWENS, 1977), Sierra-Leone (OKERA, 1974), India (DWIVEDI *et al.*, 1975), United States (ROMEO *et al.*, 1981), Israel (GOLIK, 1982), Trinidad and Tobago (GEORGES and OOSTDAM, 1983), Puerto Rico (CORREDOR *et al.*, 1983), and Nigeria (ENYENIHI and ANTIA, 1985; ANTIA and NYONG, 1986). In addition, OOSTDAM (1984) gives a summary of tar pollution along a number of coastlines contiguous to the Indian Ocean, the South China Sea and the Pacific.

Clearly, oil spill-related beach degradation is a problem of global interest and concern. The reports of the various specialized environmental agencies of the United Nations as well as independent studies of OWENS *et al.* (1977), GUNDLACH and HAYES (1978), HAYES *et al.* (1979), OWENS and ROBILLIARD (1977), BEER *et al.* (1983), McLAREN (1985), TSOUK *et al.* (1985), NYONG and ANTIA (1985), and ANTIA (1987c) exemplify past efforts aimed at both understanding the impact and predicting the pathways of oil pollution in the marine environment.

Two of the major shortcomings of most of the above studies are the site-specific nature of their results and the exclusion of the element of time, the latter being inevitable for any realistic oil-pollution ranking scheme of shorelines (OWENS and ROBILLIARD, 1981). Knowledge of the temporal variability in the elements of an oil spill model would, in addition, greatly enhance the instantaneous assessment and delineation of highly sensitive sites during the oil-containment operation.

The present investigation has been conducted bearing in mind the significance of the element of time. It employs the morphodynamic beach concept of WRIGHT and SHORT (1984) to evaluate the environmental conditions conductive to, or militating against, tar stranding on beaches, and

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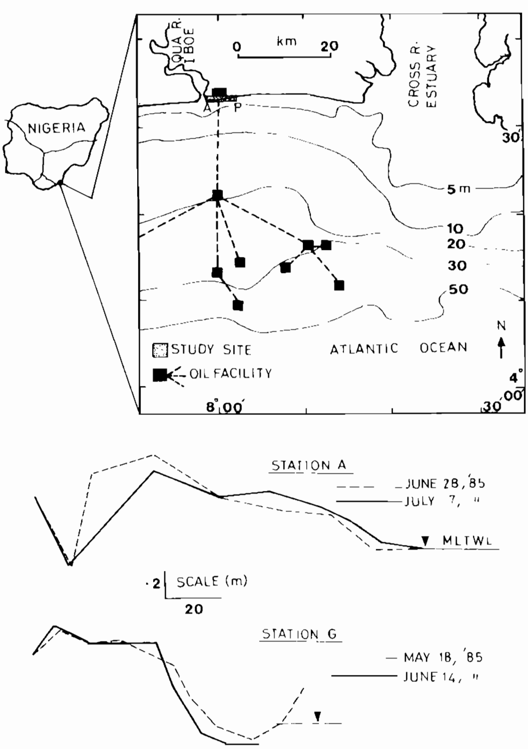

Figure 1. Study area showing some of the oil-producing infrastructures and the representative beach profiles at Ibeno. Note in particular the contrasting response of both foreshores to the storm season wave climate. The dissipative-prone station of A is accretional whereas the reflective-prone G counterpart is erosional.

their subsequent self-cleansing capacity following an offshore oil spill event at any point in time.

STUDY ENVIRONMENT AND METHODS

A 6.2 km stretch of beach on the southeastern coast of Nigeria (Figure 1) was selected for this study. Locally known as Ibeno, the coastline segment on which the beach is located is respectively flanked to the west and east by the estuaries of the Qua Iboe River and Cross River. The studied beach itself is fronted and directly backed by oil producing facilities. For the latter reason, the morphodynamics of this beach have been intensively studied by this writer in the past, partly within the framework of the oil company's baseline ecological studies.

Ibeno Beach is composed of well-sorted, fine- to medium-grained sands (mean diameter 0.18–0.30 mm). The beach slope is typically less than 5°. The offshore bathymetry is generally of low gradient, ranging between 1:1,100 and 1:2,000 in 5–30 m water depth. The present focus in this report is on the beach-surf zone region which is landward of the 3 m isobath.

Littoral process observations at Ibeno are described in detail in ANTIA (1989b). Essentially, winds are predominantly southwesterly (onshore) with a modal velocity range of 4–6 m/sec. Velocities greater than 10 m/sec are attained about 20% of the time. The modal wave period is 8–12 sec while the modal range of breaker height is 50–100 cm. As a consequence of their southwesterly shoaling direction, they generate net easterly longshore currents having velocities generally lower than 1 m/sec. Tides are semidiurnal and mesotidal (2–4 m) in range.

A more detailed scrutiny of the flow record suggests that a reversal in the longshore current direction (westerly-directed) is typical of the beach segment contiguous to the estuary of the Qua Iboe River during the ebbing tide. This, in effect, implies an estuarine ebb-flow-induced refraction of the southwesterly waves. Besides the aforementioned flow reversal, and the much higher ratio of spilling to plunging breaker frequencies in the surf zone proximal to the estuary, no significant (> 20%) alongshore variation in the process variables outlined above was evident.

At the commencement of field studies in July, 1984, a total of 8 stations (A–H) were fortnightly monitored for changes in beach profiles and littoral processes. Each of the above beach sectors depicts some form of berm and backshore in addition to a wide intertidal area. The need to evaluate other beach profile types, *e.g.*, in which berms are lacking and the intertidal zone wide and flatter, resulted in an additional 8 stations (I–P) being established in March, 1986, eastward of stations A–H. The inter-station distance ranges from 150–850 m.

From a continuous observation of surf zone breaker type patterns along the study area, a further distinction between the A–H and I–P beach segments became apparent (Figure 2). As earlier stated, the spiller-plunger ratio is higher at the beach segment (A–H) proximal to the estuary. Essentially, one can infer longshore bar-trough morphologies to be temporally persistent at stations I–P. However, because the beach survey technique employed was defined by the initial scope of the project—inventory of beach tar distribution—a representation of the spatial and

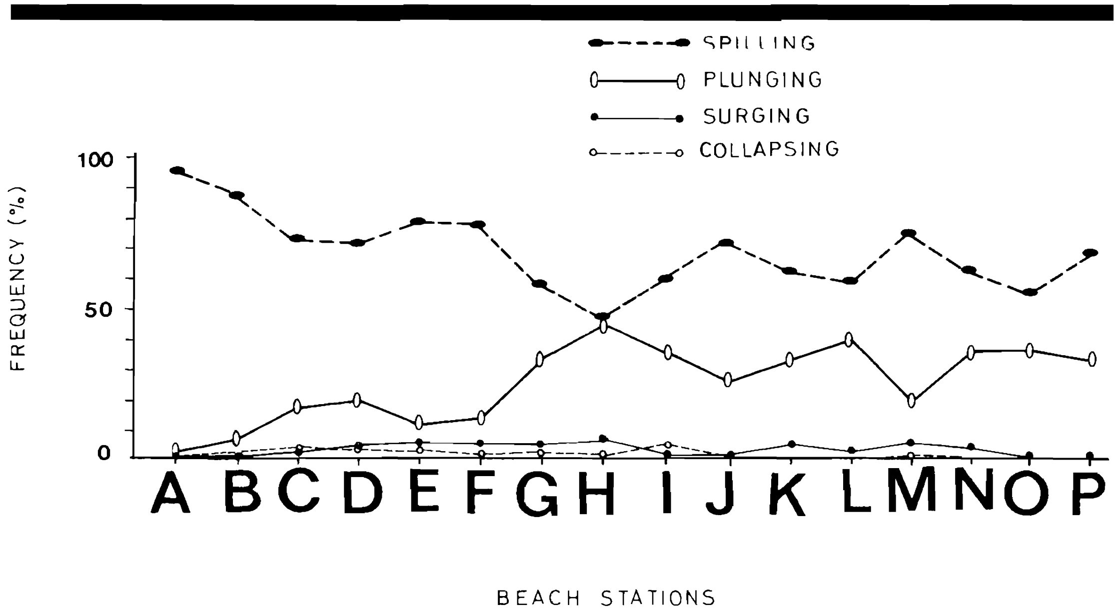

Figure 2. Spatial variation in breaker types at Ibeno Beach.

temporal variations in the surf zone morphology is currently lacking.

The principal data acquired from each of the beach stations were: frequency distribution of breaker types from repetitive counts; visual estimates of surf zone breaker heights with a graduated staff; wave period measurements with a stop watch; longshore current velocities and direction by tracking and timing freely drifting floats; beach profiling up to a permissible water depth (< 1 m) based on the stake and horizon technique of EMERY (1961); and cleanly scraping all surficial beach tar particulates as outlined in the manual prepared by UNESCO (1977).

Stranded beach tar particulates were sampled fortnightly in conjunction with beach profiling along a total of 16, fixed, 1-m wide transects extending between the low tide water line and a backshore reference. The present report is based on a total of 24 observations conducted between March 31, 1985, and December 13, 1986.

Data on tar are expressed in $g\ m^{-1}$ (total weight per unit width of beach front) and $g\ m^{-2}$ (concentration per unit area of beach front). Also, the dynamic behaviour of the beach sectors was ascertained along the lines of WRIGHT and SHORT (1984), who employed the surf-scaling or reflectivity parameter (ϵ) of GUZA and INMAN (1975) which is given thus:

$$\epsilon = H(2\pi T^{-1})^2(g \tan^2\beta)^{-1}$$

in which H is the breaker height (m), T is wave period (sec), g is acceleration of gravity ($m\ sec^{-2}$), and β is beach gradient (°). Values of $\epsilon < 2.5$ and $\epsilon > 33$ respectively define the reflective and dissipative end-member beach states. The mean value of ϵ at the study area as a whole ranged from 12–55, with as much as 32–147% variation from the above mean values.

Finally, it is instructive to state that due to the continual (artificial) removal of stranded tar balls along the established transects, all regression analyses involving beach tar occurrence with the surf zone process parameters primarily reflect conditions conducive to or militating against tar redeposition. The latter knowledge as well as the factors governing beach dynamics enable a conceptualization of the longevity of beach tar once stranded.

RESULTS and DISCUSSION

Time-Series Variation in Stranded Tar Magnitude

Meaningful quantities of tar were not recovered prior to March 1985. The mean ($\bar{X}$) and standard deviation (σ) values of tar weight ($g\ m^{-1}$) given in Figure 3 are based on a sum total of 284 samples. The maximum and minimum mean tar

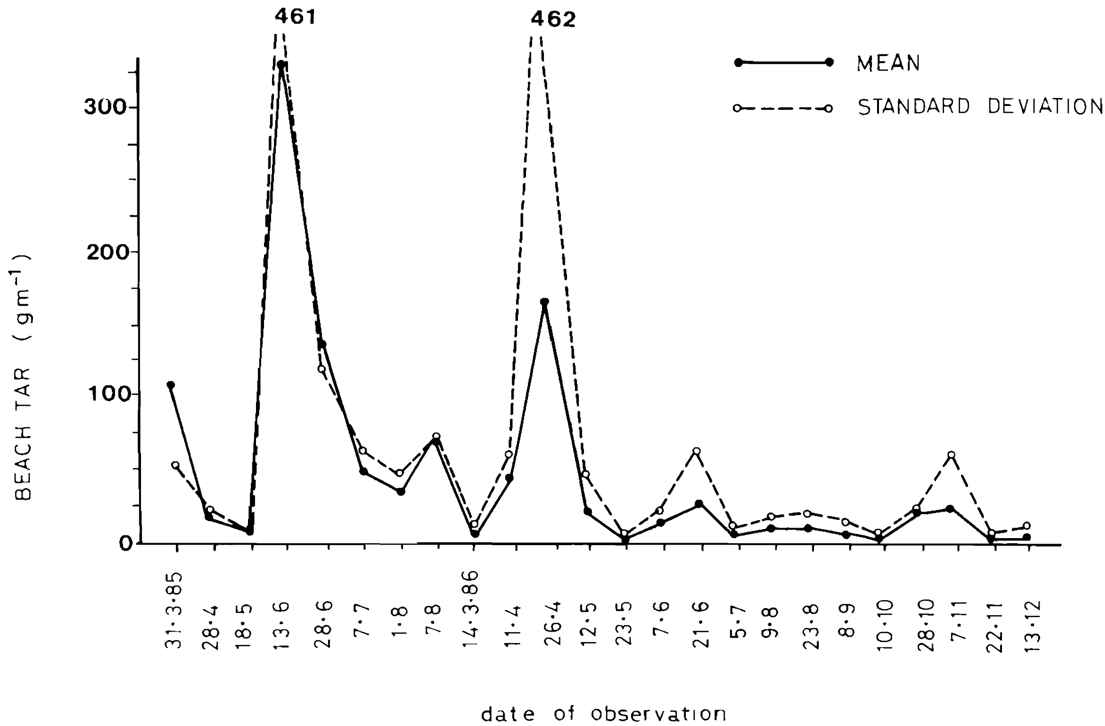

Figure 3. Time series variation in the mean and standard deviation of stranded tar (g m^{-1}) at Ibeno Beach.

weights were 327 and 2 g m^{-1}, respectively. The tendency for the standard deviation values of tar to exceed their mean weight as reported by OOSTDAM (1984) is evident in Figure 3. Such a trend reflects a highly disproportionate alongshore distribution of tar.

Surprisingly, despite the extensive literature on beach tar monitoring, hardly any of these have a tar sampling program from which the results can ideally be compared to the present one. For instance, whereas the sampling program of some investigators was aimed at inter-beach comparisons (*e.g.*, GEORGE and OOSTDAM, 1983; CORREDOR *et al.*, 1983), in which case the small number of transects at each beach can not be considered statistically representative, others provide no information on surf zone process parameters at each of the transects.

The latter point is particularly important in view of the noted significance of longshore movement of tar balls by GOLIK (1982). In any case, the results presented in Figure 3 measure among the highest encountered in the literature for non major spillages. This is even more so given the fact that they represent an average of many transects, some of which, as inferred from the standard deviation values, only depict a minimal accumulation of tar.

Tar Magnitude in Relation to Coastal Seasons

Some studies, such as GOLIK (1982) and GEORGES and OOSTDAM (1983), have indicated a seasonality in the magnitude of stranded beach tar, whereas CORREDOR *et al.* (1983) noted no such pattern. Clearly, field observations such as the above are likely to yield divergent results in view of the multiplicity of factors coming into play.

A major, but not necessarily all-time valid, premise of most of the reports on long-term inventory of stranded tar balls on beaches is that there is a continuous supply (perhaps at a uniform rate) from a source(s) seaward of the surf zone. It is only under such a situation that one can realistically relate the result of a temporal, as against spatial, pattern of beach tar pollution to the seasonally changing coastal conditions.

Even in the above case, one should not loose sight of the fact that the morphodynamic character of certain beaches are not seasonally dependent. Furthermore, especially in high tidal-range beach environments such as Ibeno, the semidiurnal tide-induced contrasts in aspects of the process signature may match or even exceed the seasonal counterpart. By and large, the most significant factor that may mask any potential seasonal trend in the magnitude of stranded beach tar is the aperiodicity in the oil spill event itself.

However, for the purpose of the above assessment, the coastal seasons are characterized, as previously detailed in ANTIA (1989b), by a first-order index of wave energy called wave destructive component (WDC). High numerical WDC values result from high frequencies of large-amplitude, short-period waves. Conversely, high frequencies of small-amplitude, long-period waves result in low WDC values. In the study area, WDC values were generally higher during the storm season (May–October) than the calm counterpart (November–January). In both cases, as well as during the transitional season (February–April), no marked alongshore variations were evident.

Results of regression analyses presented in Table 1 indicates that tar concentration (x variable) increases with elevated WDC values (y variable) all through the coastal seasons. With the exception of the transitional season, total tar weight similarly showed a positive trend. However, as evident by the regression coefficient (r) values, the association between the quantities of stranded beach tar and WDC values was strongest during the storm season.

Assuming no anomalous increase in the offshore stock of tar, the increased beach tar stranding during the storm season is the opposite of what one would have anticipated considering the higher rates of beach dynamics. However, in a more detailed beach study (ANTIA, 1990a,b), it was shown that beach changes during either the calm or storm season were not uniform alongshore but rather displayed a rhythmic pattern of variation. The latter pattern was hypothetically related to the influence of infragravity edge waves which are standing alongshore as a consequence of reflection by the estuarine/river-mouth bars bounding the coastal segment.

The implication of the above regression analysis is that even under an energetic storm wave-climate, erosion-related self-cleansing of previously stranded beach tar need not be a general phenomenon on exposed coastlines. Thus, areas along the beach (nodal positions of the standing edge wave oscillation) where the runup or erosional impact of incident breaking waves is relatively suppressed will show prolonged longevity of previously deposited pollutants. Continuous accumulation might also take place. On the other hand, tar pollution might be expected to be depleted at the antinodal locations of the oscillation because of the greater sediment mobility associated with the intensed swash-backwash pattern of flow.

Table 1. *Regression coefficient (r) and equation of beach tar weight and concentration (x variable) versus wave destructive component (WDC) values (y variable) during the coastal seasons. The latter is an index of wave energy.*

Variable	r	Equation
Storm Season		
Tar wt v. WDC	+0.7	y = 0.05x + 382.9
Tar conc v. WDC	+0.8	y = 3.9x + 383.2
Calm Season		
Tar wt v. WDC	+0.2	y = 0.1x + 384.1
Tar conc v. WDC	+0.6	y = 82.5x + 356
Transitional Season		
Tar wt v. WDC	0.6	y = 0.5x + 462.9
Tar conc v. WDC	+0.5	y = 4.6x + 366.6

An equally possible cause of the larger quantities in stranded beach tar evident during the storm season might relate to an increased offshore stock. TUCKER (1981) indicated that increased sea surface roughness, which is most likely to occur during the storm season, facilitates the emulsification of an oil slick and, consequently, tar formation. Thus, the smooth sea surface during the calm season will suppress tar formation.

The disparity in tar weight-WDC correlation coefficient values of +0.7 and +0.2 during the storm and calm season respectively (Table 1) would appear to corroborate the above assertion. However, notwithstanding the increased offshore stock of tar associated with the sea surface roughness of the storm season, the amount ultimately stranded on the beach must relate to the complexity of surf zone process parameters like breaker type and height as well as the currents generated by both the primary and secondary wave-field. At this stage of the investigation, only the breaker type is considered in detail, primarily because of its marked alongshore variation (Figure 2).

Table 2. *Regression coefficient (r) of beach tar weight and concentration versus the frequency of surf zone breaker types at two segments (A–H and I–P) of the study area.*

Variables	r	
	A–H	I–P
Tar wt v. Spillers	−0.52	−0.07
Tar conc v. Spillers	0.26	0.09
Tar wt v. Plungers	+0.49	+0.21
Tar conc v. Plungers	+0.22	+0.19
Tar wt v. Surgers	+0.60	+0.13
Tar conc v. Surgers	+0.46	+0.13
Tar wt v. Collapsers	+0.19	+0.09
Tar conc v. Collapsers	−0.30	0.27

Tar Magnitude in Relation to Breaker Types

Breaker type in nature includes spilling, plunging, surging and collapsing. The frequency of occurrence is well known to depend on the wave steepness and gradient of the seabed. Some information regarding the material transport competency and pattern of these breakers are given in KEMP and PLINSTON (1968), KANA (1979) and DALLY (1987). The surgers and collapsers together showed <10% frequency of occurrence and as such would not be emphasized.

In relation to beach tar pollution, TSOUK *et al.* (1985) found that a higher frequency of plunging breakers, typically associated with a relatively narrow surf zone width, was instrumental to the impoverishment of tars on beaches; *i.e.*, enhances their self-cleansing potential.

The results of the regression analysis of tar magnitudes versus the frequency of breaker types for the present study, summarized in Table 2, were not too encouraging. This is evident from the low values of the regression coefficient, r. The results demonstrate the complexity of the surf zone flow regime earlier mentioned.

Interestingly, the latter result shows that the surf zone of the I–P beach segment, which was inferred to be characterized by a stable longshore bar morphology, displayed comparatively weaker correlation than the A–H counterpart. The implication in this case is that the lesser the dominance of a given breaker type (or lack of a distinct morphodynamic beach-state) such as at I–P, the less defined will be the tar pollution-breaker pattern relationship.

The low values of r indicated above notwithstanding, the present observations and interpretations differ from those of TSOUK *et al.* (1985). Firstly, the latter investigation was qualitative and involved different beaches, and hence can not be compared in a statistical sense with the present results. Secondly, breaker type as an index of beach tar pollution appears to have a dual and contrasting role depending on the nearshore profile domain under consideration.

The experimental study of TSOUK *et al.* (1985) was focussed on the beach proper (above the still waterline), and concerned itself, among others, on the relationship between the breaker pattern and the longevity of emplaced oil pollutants. By contrast, the emphasis here is on the relative potentials of the breakers in transporting the tar particulates across the surf zone on to the beach.

In the latter respect, the positive relationship between the frequency of plunging breakers and the magnitude of stranded tar implies that, at least in the non-barred surf zone section of the study area, increased frequency of plunging as well as surging breakers in the surf zone could be indicative of a higher delivery rate of offshore tar particulates on to the beach. The spilling breakers display the converse; *i.e.*, beach tar stranding will be suppressed where the surf zone is dominated by this breaker type.

The relatively low shore-directed tar transport of spillers is explicit in their prolonged breaking process such that incident energy ultimately translated at shore as swash might be too weak to effect an appreciable tar acummulation. The strong seaward-directed undertow of spillers (DALLY, 1987) and their high phase difference; *i.e.*, strong swash impedence (KEMP and PLINSTON, 1968), should further deter stranding of tar on the beach.

Furthermore, for the shoreline-oblique spillers, much of the entrained tar particulates would be drifted alongshore during the prolonged breaking episode in their wide surf zone. In contrast to spillers, the other breaker types dissipate their energy close to the shoreline. Thus, their lower phase difference, energetic swash, and high runup should be conducive to tar stranding on beaches. Finally, the observation of KANA (1979) that plungers exceed spillers in the amount of suspended material transport is further evidence of the increasing trend of stranded tar with the frequency of non-spilling breakers.

Tar Magnitude in Relation to Breaker Height

Both the tar weight and concentration displayed a weak positive association with the surf

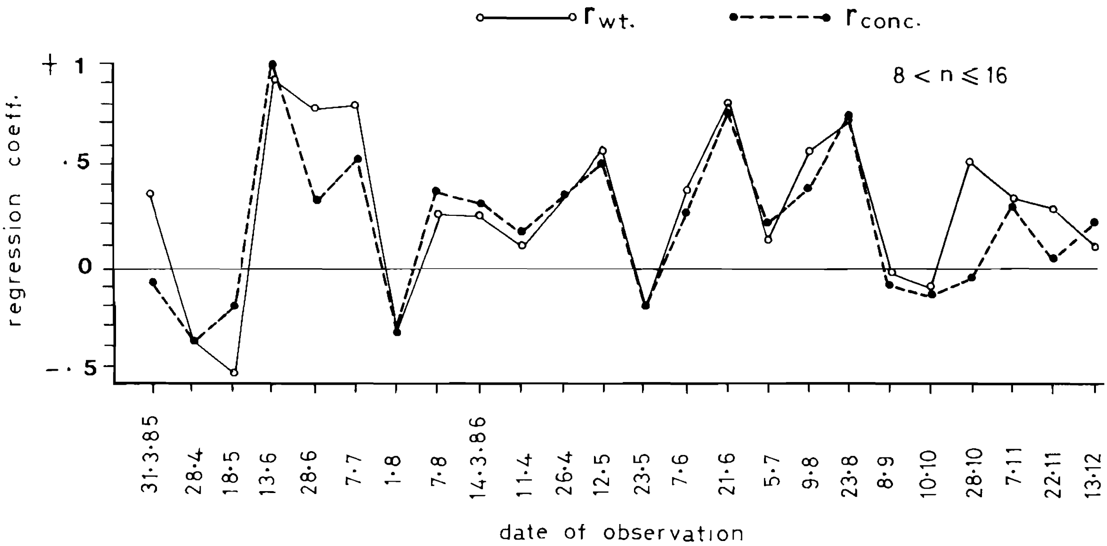

Figure 4. Time series variation in the regression coefficient value of beach tar weight versus beach reflectivity parameter (r_{wt}) and beach tar concentration versus beach reflectivity parameter (r_{conc}).

zone breaker height (r = +0.30 and +0.44, respectively). It might suggest that tar accumulation will increase on beaches fronted by more energetic surf zone conditions, irrespective of the breaker pattern. Such a tendency can be easily contemplated from the fact that the stronger swash accompanying larger waves should have a higher tar emplacement potential.

Like the breaker pattern, it is possible to conceptualize a dual role of wave height or energy in beach pollution. As discussed by TSUOUK *et al.* (1985) and others, the residence time of stranded tar on beaches should ultimately diminish with increasing wave exposure or incident wave height. This is directly related to the rapidity of beach profile change. However, on a stretch of non-engineered ocean coastline such as Ibeno, where no significant coastwise variation in incident wave height is evident, other factors must be invoked.

Tar Data in Relation to Beach Reflectivity Parameter

Studies of WRIGHT and SHORT (1984) elucidate the fact that the susceptibility of beach scarping, temporal variability of beach profiles, and the nature and mode of fluid motions in the surf zone can be predicted by the reflectivity parameter. The above process-response mechanisms should influence the transport of tar to, and longevity on, beaches.

However, it is instructive to note that the degree of reflectivity parameter of a beach may not neccessarily be identical to that of the fronting surf zone. Bearing the above in mind, the results of tar-reflectivity parameter summarized in Figure 4 is strictly applicable to the beach, and therefore indicates the potential longevity of deposited tar balls.

About 75% of the regression coefficient between tar weight and the beach reflectivity parameter (r_{wt}) were positive as against 66% in respect to tar concentration (r_{conc}). At the 95% level, 50% of the r_{wt} values were significant as against 38% for r_{conc}. However, further instructive is the fact that at the 80% level, only 28% of the positive r_{wt} values were not significant as against 50% for the negative r_{wt} values. In essence, therefore, beach self-cleansing potentials following an oil spill event is likely to be enhanced under a reflective-prone beach condition. On the contrary, the longevity of stranded tar particulates would increase on highly dissipative beaches.

The above results are consistent with the vulnerability to erosion of reflective beaches, whereas their dissipative counterparts are temporally stable. In order to further gain some insight into the above result, the average tar weight for the sea-

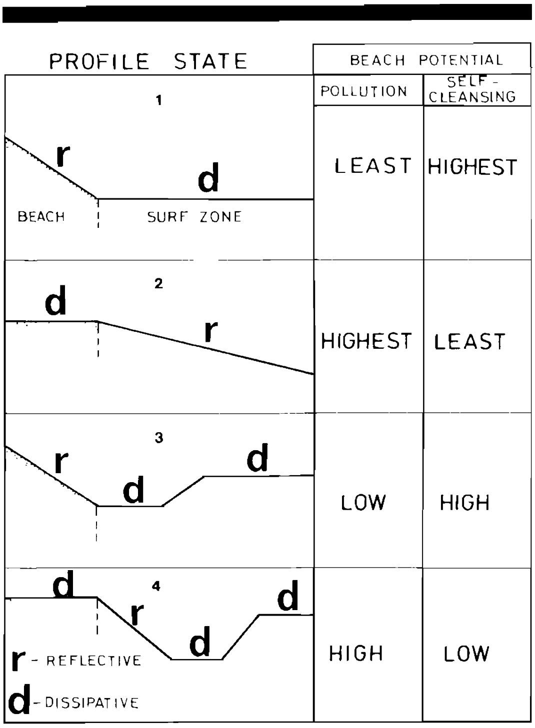

Figure 5. Schematic beach-surf zone profile states and a ranking of the tar pollution and self-cleansing potentials of their beaches.

sons are compared against the background that the beach sectors are on the average more dissipative during the storm and transitional seasons than the calm counterpart. The steepening of the beach slope as a consequence of beach accretion, and the prevalence of low-amplitude, long-period waves are conductive to increased beach reflectivity during the calm coastal season.

The mean tar weight for a total of 236 transects during the dissipative-prone storm and transitional seasons was 40 g m^{-1} as against 8 g m^{-1} for a total of 48 transects during the reflective-prone calm season. The above data clearly corroborate the assertion that even though the process elements of a calm season surf zone (assuming also reflective-prone) might tend to enhance shoreward transport and stranding of tar on the beach, these tar particulates are also very rapidly removed by the high beach mobility associated with the reflective beach-state.

However, while the above explanation is coherent in itself, the additional factor of a general paucity of tar in the offshore during the calm season can not be underscored. This follows from the earlier mentioned low potentials of tar formation under the predominantly smooth sea surface condition during the calm season.

Natural Residence and Removal of Beach Tar: A Conceptual Model

A fruitful approach to modelling beach susceptibility to, and self-cleansing capacity of, stranded tar is recognizing the fact that both beach attributes are mutually exclusive. The attributes become mutually inclusive only where either a surf zone is absent or both the beach and the surf zone exhibit similar morphodynamic characteristics. In any case, the process parameters of the surf zone determines, in the first instance, the availability of tar on the beach and, hence, the initial pollution susceptibility of the latter. The morphodynamic state of the beach as defined by the reflectivity parameter, on the other hand, determines the longevity of the emplaced tar.

From the aforementioned results and discussion, one may conceptualize and qualitatively evaluate the impact of an offshore oil spill under four, temporally-varying, beach-surf zone profile states illustrated in Figure 5. However, the success of this scheme depends greatly on the pre-evaluation of the possible scale of temporal variability of the beach for a given environment. This is because profile states may vary in response to daily tidal cycles (*e.g.*, dissipative surf zone becoming reflective at high water) and/or seasonal and other aperiodic changes in wave energy which, among others, may change the relative effects of swash and backwash.

It is further presumed that bar distance from the beach in the case of states 3 and 4 (Figure 5) is wide enough to ensure wave reformation following bar-effected breaking. In reality, the above profile states are comparable to the longshore bar-trough intermediate state of WRIGHT and SHORT (1984). The complex process signatures of such a barred surf zone are elucidated in WRIGHT *et al.* (1986).

Considering the temporal reduction, relative to deep water, in the shore-breaker amplitude as well as the accentuated horizontal fluid motion (longshore and seaward-directed rip currents) associated with such a morphology, one may envisage a suppressed level of beach susceptibility and a higher self-cleansing potential of tar on beach profile states 3 and 4 than on state 2.

However, between the two bar-trough states, 4 should supersede 3 in the order of increasing beach susceptibility to pollution due to the dissipative-prone nature of the former's beach. The converse is the case with respect to self-cleansing potential. The shoreward decay of incident waves in the surf zone of state 1 accords it a lower pollution susceptibility status over that of state 3.

In summary, in the event of an offshore oil spill, the beach of profile state 1 would be the least susceptible, followed in increasing succession of pollution vulnerability by those of states 3, 4 and 2. This sequence is mainly a function of the surf zone characteristics. On the contrary, on already polluted beaches, self-cleansing efficiency is dictated largely by the dynamics of the beach. Accordingly, the beach of profile state 1 has the highest self-cleansing potentials, followed in decreasing succession by those of states 3, 4 and 2.

CONCLUSIONS

Two of the more important results of this study are the prospects of employing temporally- and spatially-varying patterns of surf zone breakers and the morphodynamic state of the beach as first-order signatures of the extent of the susceptibility of a sandy ocean beach to, and self-cleansing of, stranded tar pollutants. In the main, shoreward tar-transport potential is determined by the relative frequencies of breaker types in the surf zone while the morphodynamic state of the beach dictates the longevity of emplaced tar.

Spiller-dominated surf zones will offer the greatest protection to the beach in the course of an oil spill event. This buffering effect decreases with increasing frequencies of plungers and surgers. However, on already polluted beaches, the longevity of pollutants decreases with increasing beach reflectively. The above results enable the conceptualization of a four-fold beach-surf zone profile state and a qualitative ranking of their response to oil pollution.

Finally, it is stated that the propositions of this interim study are an outcome of methodologies which, although fundamental, are admittedly rather simplistic given the multiplicity and complexity of factors having a bearing on oil spill dynamics. The generally weak correlation between the extent of beach tar pollution and some of the process parameters attests to the above mentioned. This is beside the fact that the model parameters on which tar dynamics in this report are based preclude the role of longshore transport. Even though longshore current velocities (modal range of 30–49 cm/sec) at the monitoring stations at any instant in time may not have varied dramatically, their potentials to transport beach tar particulates can not be underscored. The report of GOLIK (1982) is illuminating in this respect.

It is envisaged that the present results can be considerably improved by a model incorporating both cross-shore and alongshore process parameters. Thus, the present interpretation will be re-evaluated as data on both beach tar distribution and the nearshore flow field from localities of different sediment texture, beach topography, and tidal and wave energy become available. However, for such a comparison to be meaningful, the sampling program and methodology should be as much as possible identical. In this respect, a plea is made that future investigators adopt as much as possible a comparable process-response study approach, even if emphasis, as seems to be the case, is on inter- rather than intra-beach comparisons.

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LITERATURE CITED

ANTIA, E.E., 1987c. Fate of offshore oil spill as a function of surf zone processes on the Nigerian coast. *International Conference on the Chemistry of the Tropical Marine Ecosystem* (Rio de Janeiro, Brazil) (Abstract).

ANTIA, E.E., 1989b. A short-term study of the effects of the changing coastal condition on some geomorphic elements on Nigerian beaches. *Zeitschrift für Geomorphologie*, 73, 1–16.

ANTIA, E.E., 1990a. Edge wave resonances and beach dynamics on the west African coast. *Proceedings of the 15th Colloquim on African Geology* (Nancy, France) (Abstract).

ANTIA, E.E., 1990b. Beach response to edge wave resonances: Field evidence from the west African coast. *Journal of Coastal Research*, Special Issue 9, pp. 395–406.

ANTIA, E.E. and NYONG, E.E., 1986. Preliminary field studies on the relationship between breakers and beach pollution. *Twenty-third Conference on the Nigerian Mining and Geosciences Society* (Port-Harcourt) (Abstract).

BEER, T.; HUMPHRIES, R.B., and BOUWHUIS, R., 1983. Modelling nearshore oil slick. *Marine Pollution Bulletin*, 14. 141–144.

CORREDOR, J.E.; MORELL, J., and MENDEZ, A., 1983. Pelagic petroleum pollution off the south-west coast of Puerto Rico. *Marine Pollution Bulletin*, 14, 166–168.

DALLY, W.R., 1987. Longshore bar formation— Surf beat or undertow? *Proceedings Coastal Sediments* (Louisiana). New York: American Society of Civil Engineers, pp. 71–86.

DWIVEDI, S.N.; PARULEKAR, A.H., and DEVASSY, V.P., 1975. Oil pollution of Goa beaches, India. *Proceedings of the 3rd International Ocean Development Conference* (Tokyo), pp. 139–149.

EMERY, K.O., 1961. A simple method for measuring beach profiles. *Limnology and Oceanography*, 6, 91–93.

ENYENIHI, U.K. and ANTIA, E.E., 1985. Tar balls as indicator of crude petroleum pollution of the beaches of Cross River State, Nigeria. *IOC (UNESCO) Workshop Report 41*, annex 9, 1–8.

GEORGES, C. and OOSTDAM, B.L., 1983. The characteristics and dynamics of tar pollution on beaches of Trinidad and Tobago. *Marine Pollution Bulletin*, 5, 170–178.

GOLIK, A., 1982. The distribution and behaviour of tar balls along the Isreali coast. *Estuarine, Coastal and Shelf Science*, 15, 267–276.

GUNDLACH, E.R. and HAYES, M.O., 1978. Classification of coastal environments in terms of potential vulnerability to oil spill damage. *Marine Technology Journal*, 12, 18–27.

GUZA, R.T. and INMAN, D.L., 1975. Edge wave and beach cusps. *Journal of Geophysical Research*, 80, 2979–3012.

HAYES, M.O.; GUNDLACH, E.R., and D'OZOUVILLE, L., 1979. Role of dynamic coastal processes in the impact and dispersal of the Amoco Cadiz oil spill (March, 1978), Brittany, France. *Proceedings of Oil Spill Conference*, American Petroleum Institute, Washington, D.C., pp. 193–198.

KANA, T.W., 1979. *Suspended Sediment in Breaking Waves*. University of South Carolina, Department of Geology, Technical Report No. 18-CRD, 153p.

KEMP, P.H. and PLINSTON, D.T., 1968. Beaches produced by waves of low phase difference. *Journal of Hydraulic Division*, American Society of Civil Engineers, 94, 1183–1195.

McLAREN, P., 1985. Behaviour of diesel fuel on a high energy beach. *Marine Pollution Bulletin*, 16, 191–196.

NYONG, E.E. and ANTIA, E.E., 1985. A predictive model of vulnerability of Nigeria's coastal region to oil spill. *Proceedings of the International Seminar on the Petroleum Industry and the Nigerian Environment* (Kaduna), pp. 117–122.

OKERA, W., 1974. Tar pollution of Sierra Leone beaches. *Nature*, 252, 682.

OOSTDAM, B.L., 1984. Tar pollution of beaches in the Indian Ocean, the South China and the South Pacific Ocean. *Marine Pollution Bulletin*, 15, 267–270.

OWENS, E.H., 1977. *Coastal Environments of Canada: The Impact and Cleanup of Oil Spills*. Ottawa, Canada: Department of Fish and Environment, 413p.

OWENS, E.H. and ROBILLIARD, G.A., 1981. Shoreline sensitivity and oil spills— A re-evaluation for the 1980's. *Marine Pollution Bulletin*, 12, 75–78.

ROMERO, G.C.; HARVEY, G.R., and ARTWOOD, D.K., 1981. Stranded tar on Florida beaches: September 1979–October 1980. *Marine Pollution Bulletin*, 12, 280–284.

SEXTON, W.J.; MURDAY, M.; MICHEL, J., and HAYES, M.O., 1985. Oil spill sensitivity mapping of the Nigerian shoreline. *Proceedings of the International Seminar on the Petroleum Industry and the Nigerian Environment* (Kaduna), pp. 157–165.

TSOUK E.; AMIR, S., and GOLDSMITH, V., 1985. Natural self-cleansing of oil-polluted beaches by waves. *Marine Pollution Bulletin*, 16, 11–19.

TUCKER, M.J., 1981. The importance of oceanography to the oil industry. *Proceedings of Petromar'80*. London: Graham and Trotman Ltd., pp. 497–512.

UNESCO., 1977. IOC/WMO/UNEP Manuals and Guides No. 7 (supplement), *Manuals for Monitoring of Oil and Petroleum Hydrocarbons in Marine Waters and on Beaches*. New York: UNESCO.

WRIGHT, L.D. and SHORT, A.D., 1984. Morphodynamic variability of surf zones and beaches: A synthesis. *Marine Geology*, 32, 93–118.

WRIGHT, L.D.; NIELSEN, P.; SHI, N.C., and LIST, J.H., 1986. Morphodynamics of a bar-trough zone. *Marine Geology*, 70, 251–285.