NIPES Journal of Science and Technology Research 3(4) 2021 pp.259 – 270 pISSN-2682-5821, eISSN-2682-5821

NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Mathematical Models of Seasonal Dynamics of Bedload Sediments in Eco-Geomorphologic Units of the Tropical Rivers, Southeastern Nigeria

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Article Information

Keywords:
MANOVA models, climatic seasons, eco-geomorphologic units, bedload sediments, humid tropic, river ecosystem.

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Received 26 October 2021
Revised 19 November 2021
Accepted 16 November 2021
Available online 10 December 2021

https://doi.org/10.37933/nipes/3.4.2021.26

https://nipesjournals.org.ng

Abstract

The application of valid mathematical models of natural phenomena in space among geographers tends to impede testing and clarifying complex associations and variances among the sets of variables. Such information is vital for sound ecosystem and engineering policy/ decision-making toward the protection of fragile and endangered hydrological and geomorphological units in the future. This study adopted the direct field survey and laboratory techniques. Using stratified and systematic sampling methods, eight eco-geomorphological sub-units comprising one first-order stream, six fourth-order tributaries, and the estuary were selected. A total of 32 bedload samples were systematically collected during the four climatic seasons, digest properly to ensure standard compliance, and analyzed in the laboratory. The MANOVA tests of variations, overlapping variances, and homogeneities among the groups of parameters gave Pillai's Trace (2.027), Wilks' Lambda (24.745), Hotelling's Trace (6139.576), and Roy's Largest Root (40035.113) each significant at 0.00 confidence level. The results implied that variations in eco-geomorphologic units and climatic seasons have a significant effect on the dispersal of bedload sediments within the study area. Also, the prevalence of flood and erosion hazards in the area has strong affinity with natural forces and anthropocentric parasitism, with serious threats to the future of the regional ecosystem. This study recommended: (i) sustainable and deliberate promotions of community-driven afforestation programmes with strong supports from the governments and donor agencies to facilitate ecosystem services and mitigate the impacts of climate that induced geomorphic hazards in the area and, (ii) periodic dredging of silted small rivers and construction of drainages/ roads to regulate surface runoff/ discharge from cities to rivers.

1.0 Introduction

The cardinal icons of earth sciences are the nexus of the atmosphere (climatology), lithosphere (geomorphology), hydrosphere (hydrology) and biosphere (bio-geography) which is collectively defined as physical geography. Hence, modern physical geographers usually draw their philosophies and methodologies from earth science tradition with geomorphology at the center. The flexible and complex nature of geographic and earth science phenomena necessitates the adoption of modern methods such as field, laboratory and geo-spatial technologies for enhanced understanding of the linkages especially at the basin scale. The dynamisms in climatic and fluvial processes in the humid tropics are among the focal geographical and earth science phenomena that instigate variations in the circulations of bedload sediments across distinct geographic spaces from tributaries of a river to the ultimate base level at time scales. The quantity and quality of land denudated and sediments discharge across given eco-geomorphological units is believed to vary based on climatic season, nature of vegetation, geology, soil, land use, and specific geomorphometry [1 - 4].

The concept "eco-geomorphology" is an interdisciplinary approach to the study of a river system that integrates geomorphology, hydrology, and ecology [5, 6]. It represents the functional fluvio-geomorphological units with viable interfaces existing among the biotic (e.g. plants, animals, and humans) and abiotic (e.g. rainfall, temperature, sediment, river, and landform) components. The capability of a river to distribute bedload sediments from the eco-geomorphological units (sub-basins) to the estuary is controlled by river discharge, which in turn is a function of climate, vegetation, topography, rock properties, soil, geology, basin area, and human [7]. The hydrologic cycle controls the timing and volume of their delivery from various eco-geomorphologic units of a river basin to the Ocean. The concept "eco-geomorphology" is an interdisciplinary approach to the study of a river system that integrates geomorphology, hydrology, and ecology [5, 6]. It also represents the functional interactive unit among biotic (e.g. plants, animals, and humans) and abiotic (notably climate, sediment/ soil, and landform) components. The complex nature of interactions often varies across ecosystem units and time, which necessitates the choice of viable mathematical models that can aid the elucidation of such relationships among distinct phenomena in disciplines.

Contextually, mathematical models are formal equations that can be used to represent the relationships among geomorphic parameters, their components, and rates of changes within the river ecosystem. Such relationships can range from simple equations to complex software codes or by applying many interlinks to determine the explicit outcomes over discrete time scales such as a hydrological year or climatic seasons [8]. It can take two broad approaches comprising empirical-statistical and deductive-deterministic model [9].

Although there are many operational procedures involved in quantitative evaluation of fluvial landform properties in earth science and geomorphological literature within the past three decades, differences tend to exist based on content, context, and researchers' interest as exhibited in [3, 10, 11, 12]. Amidst the apparent differences, Richards [13] statements offered intriguing viewpoints, thus:

> *"A conceptual image of the landform must be translated into measurable attributes that represent the concept satisfactorily, and can be quantified with accuracy, precision, and reproducibility. Thus, a rigorous operational definition is essential, and this must consider: (a) delimitation of the landform boundary; (b) the quantitative index itself; (c) the sampling scheme required to define a representative subset of the relevant population; (d) the appropriate and available data sources and methods of measurement and; (e) the measurement procedures and practices"* [13].

The choice of procedures is individual's (researcher's) dependent, usually driven by quantitative tools that may range from simple (e.g. mean or percentage) to complex model (e.g. factor analysis or multivariate analysis of variance). However, it is the viability of underlying philosophy that will facilitate the achievement of a given aim and/ or a set of objectives. Hence, the indomitable fact is that Richard's principles offer very instructive methodological guides in the perspective of dynamism in bedload sediments dispersal across eco-geomorphological units of the humid tropical rivers in Southern Nigeria.

The spatial characteristics of landforms such as river basin geomorphometry, climate, and land use often have influences on the bedload particle accumulations and discharge. Surian [14] found that the downstream changes in flow resistance and sediment transportation were closely related to the rate of change in sediment size. Also, Di Stefano and Ferro [15] established that fully dispersed size was important in certain sediment chemical/ physical properties as well as the processes of erosion and sediment transported by overland flow were dependent on the sediment aggregation.

In Baraolt depression of Olt River, Csiszer and Petrea [16] assessed the connections between the tectonics and the geologic structures and how they reflected on landscapes. Cartographic analyses revealed the division of the area into depression in hollows, bays, and other basins compartments. Accordingly, understanding of the geographic coverage (basin area demarcation) remained the starting point in exploring fluvio-morphology dynamics, while the presence of coal is believed to instigated anthropogenic parasitism as depicted on land complexities in the Olt catchment [16].

Much of the identified studies tend to rely on accurate DEM for the calculation of geomorphic metrics (with emphasis on slope and curvature) or extraction of geomorphic features such as channels, hill slopes, hilltops [17]. In spite of the efficacies, Fisher and Tate [18] have reported sources of errors in DEM, which suggests the need to shift emphasis to laboratory and quantitative tools in studying geomorphologic and hydrologic parameters of interest.

The fluvial systems often play a vital role in land sculpturing and responses of drainage networks, adjustment of river, shape, relief, and flow of sediments still form the basis for discussions as exemplified in Whipple, DiBiase, and Crosby, [19]. Besides, an understanding of dynamics in river processes requires in-depth knowledge of bedload sediment generation and discharge because they usually influence channel hydraulics and stability, river quality, and aquatic habitats as well as the rivers' age and utilization.

Although mathematical model (multivariate analyses of variances (MANOVA)) have attracted the attention of researchers in various fields such as mathematics, statistics, economics, business, psychology, and education [20, 21, 22], its applications in physical geography and earth science explorations are rather eclipsed or scarce [3, 12]. The perceived lacuna constitutes a major source of concern, especially when considering the multitude and complex nature of phenomena modern physical geographers and allied earth scientists work with to clearly comprehend and elucidate their interactions for informed river ecosystem service.

The cardinal questions agitating the psyches of the scholars in this study are: (i) Do variations in eco-geomorphologic units and climatic seasons have a significant influence on the dispersals of bedload sediments (sand, silt, clay, organic carbon, and organic matter) in the humid tropical rivers of Southeastern Nigeria? (ii) What are the implications of results on the fluvial and ecosystem services in the humid tropical rivers of Southeastern Nigeria? It is against the perceived issues that this study is instituted to use MANOVA tests as surrogates for assessing the intriguing associations and variations in climatic seasons and eco-geomorphic units on bedload sediments dispersals in the humid tropical rivers of Southeastern Nigeria, using the Kwa Iboe River as a case study.

The paucity in the application of viable models in the robust testing of dynamics, associations and variances among diverse hydrological and geomorphological parameters in the 21st century have necessitated the adoption of mathematical equations as surrogates in evaluating seasonal dynamics of bedload sediments dispersal across eco-geomorphologic units and climatic seasons in the humid tropical rivers of Southeastern Nigeria. In consideration of this, the following specific objectives were investigated.

(i). To determine the influence of variations in eco-geomorphologic units and climatic seasons on the dispersals of bedload sediments in the humid tropical rivers of Nigeria.

(ii). To develop the viable policy frameworks for the sustainability of river and ecosystem resources in the humid tropical belt of the Southeastern Nigeria.

1.1. The Study Area

1.2. Geographical Settings

The Kwa Iboe River eco-geomorphologic unit is located approximately between Latitude 4^0 20' and $5^0$40' North of the Equator and Longitude 7^0 10^1 and 8^0 25^1 East of the Greenwich Meridian [3]. It covers parts of the humid tropical rainforest belt covering part of Abia and Akwa Ibom States of Southeastern Nigeria, ramified by the mangrove swamp forest occupying parts of the continental shelf of the Atlantic Ocean. The populations of the study area are dominated by agrarian communities (fishermen, hunters, and farmers) and miners.

1.3. Climate and Vegetation

The rainfall and temperature patterns across the study area vary based on climatic seasons. The total annual rainfall decreases persistently from the coastal belt of the Atlantic Ocean especially Ibeno, Ikot Abasi, Eket, and old Nsit clan toward the interior. The core coastal border of the Atlantic Ocean received convectional rainfall annually with no month of dry season with tropical wet climate. It has a mean annual rainfall of 2443.3 mm from 1977 to 2013 while the mean annual temperature is 27 ^{0}C [3, 23, 24].

The middle and the upper catchments of the study area recorded 2 to 4 months of dry season annually with Köppen’s Am climate [25, 26]. The hydromorphic soils occur over the impervious shale and the seasonal waterlogging is frequent especially during the rainy periods, thereby providing enable ground for the cultivation of rice, cocoa yam, yam, and allied crops in wetlands eco-geomorphology. The study area often recorded four climatic seasons annually (comprising two dry and two rainy seasons). The short dry season is associated with the month of August (August break) while the long dry season is recorded between the months of December and March, while the coldest month recorded during the month of July.

1.4. Pedo-geomorphological Setting

The soils within the upper part of the study area vary from deeply buried pebbles underlain by finer sands to clay sub-surface soils of distinct grains. Around the Umuohia-Ikwano axis of the Abia State, some traces of Imo clay-shale of the early Eocene formation with deep porous red soils (Ferralsols) tend to dominate the area (Imo State Survey and Urban Planning, 1984). At the middle fringe of Ikwano, Isiala, and Obot Akara, the deep porous brown (Ferrallitic) soils are dominant. The traces of shale are basically at the divide of Imo and Kwa Iboe Rivers offer the soil its shelly grey colour and studded with brown cylindrical to conical structures [3, 26]. Within the Akwa Ibom axis, over 80 percent of the soils composed of deep porous brown soils, collectively called Ferrallitic soils. It is not well mature, hence highly susceptible to varying types of upstream erosion and downstream flood [3]. These soils according to Bassey cited in Usoro and Akpan [25] are widely distributed across Ikot Ekpene, Ukanafun, Essien Udim, Uyo, Abak, Etinan, Nist Ibom, and Nsit Ubium with the exceptions of the floodplain and river channels where hydromorphic soils prevail. The lower part of the study area is under the strong influence of marine activities such as coastal flood and marine erosion due to the proximity to and influence of the Atlantic Ocean.

2.0. Methodology

The upsurge in demands for the application of innovative methods especially laboratory and computer-aided quantitative tools in physical geography and geomorphology in particular, during this 21st century justifies the choice techniques to conform with the globally recommended researches and practices discussed in what follow.

2.1 Sampling and Sediments Collection Techniques

The study area was stratified into eight sub-units using stratified sampling method and each unit represents eco-geomorphologic units for the bedload sediments. The units are composed of one first-order tributary where the basin originated from, six fourth-order eco-geomorphologic units (Anya River, Azuihe River, Awa River, Eteku River, Ubium River, and Stubbs River), and estuary where the river enters the Atlantic Ocean (Figure 1).

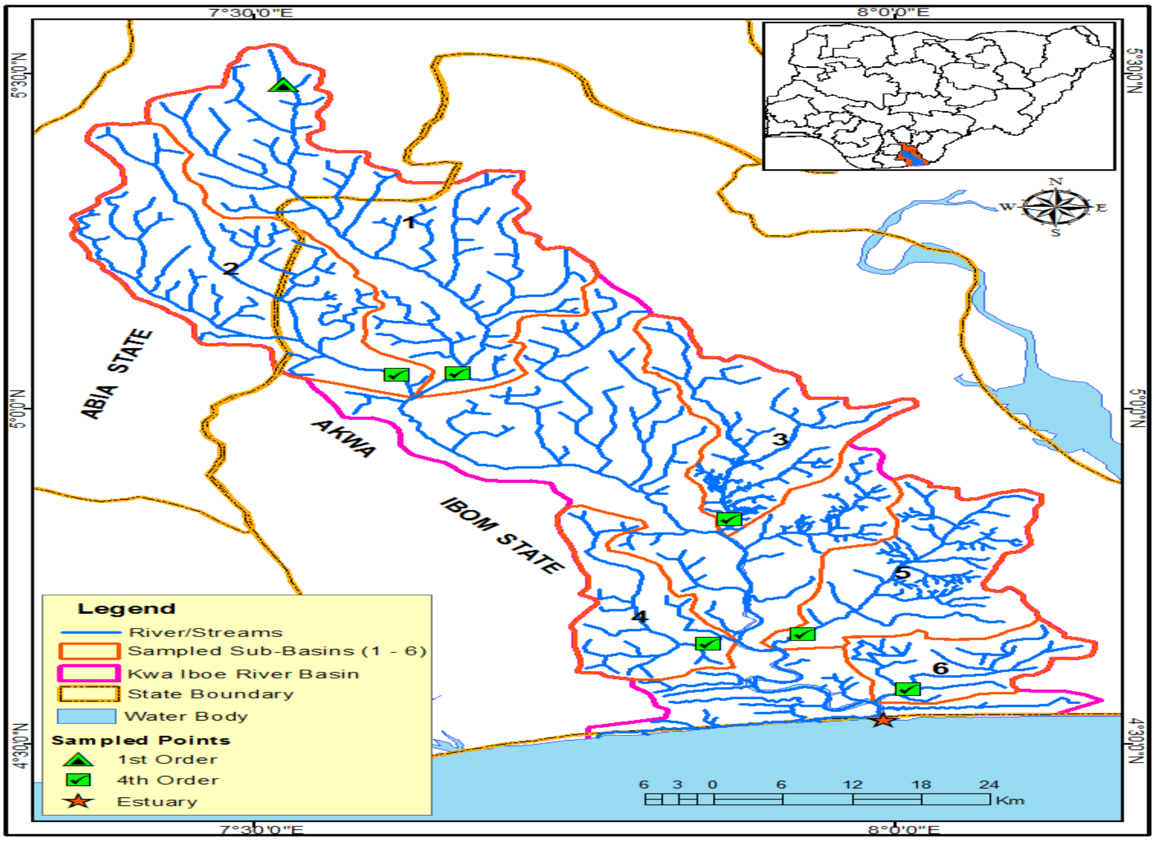

Figure 1: Geospatial Delineation of Study Area showing the Sampling Points.
Source: Adapted from Umo [3].

In each eco-geomorphological unit, three core samples were collected along each transect (at the left, center, and right side) in an undisturbed manner [3]. The collection was carried out using a specially constructed galvanized 8.5 cm by 10 cm diameter sediment corer at a depth of 0 to 15 cm. The rationale was for easy access and collections of bedload sediment deposits that interact with water discharge, as recommended in Umo [3]. The collections were carried out during the months of November for early dry season; second set during February for the peak dry season; a third set during the month of April for the early rainy season and; fourth set during the month of July for the peak rainy season to examine the effects of dynamics in climatic seasons. Each set of bedload sediments collected across eco-geomorphologic units (Figure 1) were stored in a clean plastic polythene bag, labelled orderly, and packaged in a cooler before being transported to the National Laboratory at Umudike for further treatments and analyses.

2.2. Sediments Preparation, Analyses, and Classification

At the laboratory, sedimentation by pipette method was employed as a basis for the eight sediment sample analyses. The details of procedures, experiments, methods and standard compliances as passionately described in [27, 28], and reiterated in Whalley [29], Gouldie *et al.* [30] and Umo [3] were adopted and strictly followed in the laboratory. The sediment classification followed García-Gaines and Frankenstein [31] scheme, with the diameter limits (mm): very fine sand (0.05 – 0.10); fine sand (0.10 – 0.25); medium sand (0.25 – 0.50); coarse sand (0.50 – 1.00); very coarse sand (1.00 – 2.00). The rationales were to facilitate clear physical description of bedload sediment characteristics, comparisons of sample size dispersals at distinct eco-geomorphologic units and relate the samples to the sedimentological history, and enhance statistical modellings.

2.3. Demarcation of Eco-geomorphological Units and Geomorphometry

The study is delimited to river tributaries that made up the Kwa Iboe River. It was carried out using Shuttle Radar Topography Mission (SRTM) with 30 m resolution. The image (Raster) was used for eco-geomorphologic (fluvial) units' delineation and in the derivation of sub-catchment area geomorphometry. The SRTM was complemented with the topographic maps (Afikpo 313 SW; Ikot Ekpene 322 NE; 322 SW) each produced by Federal Survey Department, Lagos on a scale of 1:50,000 to avert the limitation posed by dense vegetation along the wetlands that eclipse the river channel in the satellite imagery (Raster).

The delineation of the study area was carried out using the geospatial methods described in Umo [3], while eco-geomorphological units were demarcated using the standard envisaged by Strahler [32] and recommended in Umo et al. [2]. The fourth-order sub-basins were selected because geomorphologists and allied earth scientists accept medium-sized river basins as well matured for catchment studies [11, 33]. The recorded GPS locations/ ground truth information and maps were rectified and geo-referenced in a GIS environment with Arc-GIS 10.2 model assigning Universal Transverse Mercator (UTM), World Geodetic System (WGS) dating from 1984 as revised in 2004). A 32 N Zone Projection System with ERDAS Imagine 8.5 and Terrain Analysis System were employed as emphasized in Hajam et al [34] and Umo et al [35].

2.4. Data Analyses

Data generated from distinct sources across the eight (8) eco-geomorphologic units and four climatic seasons (Figure 1) were analyzed using MANOVA model (Pillai's Trace, Wilks' Lambda, Hotelling's Trace and Roy's Largest Root) tests to explore the first objective. A regression model was used to ascertain the proportion of variance explained by the independent variables on the linear combination of the dependent variables. One way analysis of variance was employed as a surrogate to test for the variances in the mean dispersal among the studied parameters in the humid tropical rivers of Southeastern Nigeria.

3. Results and Discussion

3.1 Eco-geomorphologic Units, Climatic Seasons and Bedload Sediments' Dispersals

In an attempt to address the research question one that states thus: "do variations in eco-geomorphologic units and climatic seasons have significant influence on the dispersal of bedload sediments (sand, silt, clay, organic carbon, and organic matter) in the humid tropical Rivers of Southeastern Nigeria? Data generated on bedload sediments across eco-geomorphologic units and climatic seasons were analyzed using mathematical models (comprising MANOVA and Regression models) as summarized in Tables 1 and 2.

MANOVA is used to determine the influence of variations in eco-geomorphologic units (sampled location) and climatic seasons on the linear combination of bedload sediments (sand, silt, clay, organic carbon, and organic matter) dispersal, and the results summarized in Table 1. The four statistical tests presented in Table 1 are answering the same question, but with different testing powers as evidenced in the degrees of freedom. Also, the results are reported both as intercept to aid the scaling of the result and sampled location to form the basis for tests of significance as recommended in Umo [3]; Olson [20]; Warne [21].

The assessment of the influence of the size (homogeneity) among the groups of variables across the eco-geomorphologic units and climatic seasons using Pillai's Trace model yields a value of 2.016 which is a good representative result because of its proximity to zero. The result of the Pillai's value means that the sum of size effects within the groups' variance are contributing more to the model, but taking decision must be backed-up by testable level of significance [21, 23]. Hence, the calculated F value associated with Pillai's model gave 2.027. The test of significant at $(0.05)_{40/120}$ confidence level gave a Table value of 1.4290. It is therefore inferred from the results that variations in eco-geomorphologic units and climatic seasons have significant influence on the dispersals of bedload sediments in the humid tropical Rivers of the Southeastern Nigeria.

Similarly, Wilks' Lambda as a tool in MANOVA is used as a surrogate for determining the proportion of variance influenced by ego-geomorphologic unit and climatic seasons on the combination of the groups of dependent variables in study area. The model result presented in Table 1 gives a unique statistical value of 0.000 that shows perfect corroboration of Umo [3] and Nath and Pavur [36] observations that a value of zero means that there is no any variance that is not explained by the independent variables. The result implies that both groups of variables contribute to the model's stability. Consequently, the test of variances using Wilk's Lambda model yields the calculated F value of 24.745. A test of significant at $(0.05)_{40/89}$ confidence level yields a Table value of 1.4290. The high calculated F value suggested that variations in eco-geomorphologic units and climatic seasons do have significant influence on the dispersals of bedload sediments in the area.

Furthermore, the Hotelling's Trace that operates with the highest matrix yields a model value of 13,346.90 and a corresponding F value of 6,139.58. A test of significant at $(0.05)_{40/92}$ confidence level yields a Table value of 1.4290. It is infers from the result of Hotelling model that variations in the locations of eco-geomorphologic units and climatic seasons do have significant influence on the dispersal of the bedload sediments in the humid tropical rivers. The result showed strong collaboration with the decision level reached base on the Pillai's Trace and Wilk's Lambda tests.

In order to measure the association strength (influence) among the groups of variables, Roy's Largest Root is used. This is because of its focus on the proportion of overlapping variance (influence) among the independent factors and the first linear combination of the dependent variables. The model result gives a very high value of 13,345.038. The calculated F value yields 40,035.113. A test of significant at $(0.05)_{8/24}$ confidence level reveals a Table value of 2.3551. The result of the Roy's largest root reveals that variations in the locations of eco-geomorphologic units and climatic seasons have significant influence on the dispersal of bedload sediments in humid tropical rivers.

The results supported Akpan [10] observation that multivariate statistical methods often showed a valid explanatory power to complex array of data in watershed research. Hence, the statistical tests associated with the MANOVA model showed deviation from that of the single response model (ANOVA and t-test) results used in Umo and Enwereuzor [23] due to differences in tested parameters and statistical methods.

Table 1: The Multivariate Tests[a] of Variations among Eco-geomorphologic Units and Climatic Seasons and Bedload Sediment Dispersals

Effect	Model	Value	F	df_h	df_e	Sig.	Decision
Eco-gemorphologic Unit	Pillai's Trace	2.016	2.027	40	120	.002	Rejected
	Wilks' Lambda	.000	24.745	40	89	.000	Rejected
	Hotelling's Trace	13346.905	6139.576	40	92	.000	Rejected
	Roy's Largest Root	13345.038	40035.113	8	24	.000	Rejected

a. Design: Intercept + eco-geomorphologic units. b. Exact statistic. c. The statistic is an upper bound on F that yields a lower bound on the significance level. Decision Level is 0.05 Confidence.

3.2 The Proportion of Variations between Parameters in the Humid Tropical Rivers

In order to establish the proportion of variance attributed to the influence of eco-geomorphologic units and climatic seasons on bedload sediment dispersals in the humid tropical rivers of Southeastern Nigeria, MANOVA is used. The results summarized in Table 2 revealed widespread disparities. The sums of squares associated with each model indicated that sand is 283,607.500, silt is 188.318, clay is 491.010, organic matter shows 11.398, and organic carbon yields 4.219 accordingly. Also, the mean squares associated with the model vary with a value of 35,450.937 for sand, 23.450 for silt, 61.376 for clay, 1.425 for organic matter, and 0.527 for organic carbon.

The calculated F values for the proportion of variation between eco-geomorphologic units and each parameter revealed that sand possessed a value of 3898.921. The silt exhibited a value of 6.403, clay gave a value of 12.075, organic matter yielded a value of 3.481, and organic carbon yields 19.283. The test of significant variations between parameters at $(0.05)_{8/24}$ confidence level reveals a Table value of 2.3551 that is less than the calculated F values presented in Table 2. The results indicate that variations in eco-geomorphologic units have a significant influence on bedload sediments dispersed within the humid tropical rivers of Southeastern Nigeria. The results showed a strong affinity with the initial report by Umo and Enwereuzor [12] of southeastern Nigeria, though differences existed in terms of content, geology geographic coverage, and pedo-geomorphology.

Discounting the MANOVA results, a linear regression model was used as a surrogate to determine the proportion of influence accounted for by variation in eco-geomorphologic units on a linear combination of each bedload sediment dispersal in eco-geomorphologic units. The result of the adjusted R square presented in Table 1 showed that sand attracted a very high positive regression coefficient of 0.999 that explained 99.9 percent of the proportion of variance. The organic carbon has a coefficient of 0.865 that explained 86.5 percent of the effect of variance. Clay particle possessed 0.801 representing 80.1 percent of the variance, silt yields a coefficient of 0.681 that accounted for 68.1 percent of the variance, and organic matter gives 0.537 that explains 53.7 percent of the variance in the series.

The revealed patterns in the results using MANOVA are rather contradictory to Umo and Enwereuzor [12] whose emphasis was placed on ANOVA and t-test models as surrogate for quantifying the pedo-geomorphologic attributes of rivers in Southeastern Nigeria. The contradiction could probably be attributed to the differences in methods and sampled attributes. Also, the high regression coefficients and the corresponding high proportion of variances explained in this context strongly corroborated the pattern of interrelation and variations exhibited in Table 1.

Table 2: The tests of Effects of Variations Between-Bedload Sediments and. Eco-geomorphologic Units

Source	Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	R Squared	Adjusted R Squared
Model	Sand	283607.500[a]	8	35450.937	3898.921	.000	.999	.998
	Silt	188.318[b]	8	23.540	6.403	.000	.681	.575
	Clay	491.010[c]	8	61.376	12.075	.000	.801	.735
	O_M	11.398[d]	8	1.425	3.481	.008	.537	.383
	TOC	4.219[e]	8	.527	19.283	.000	.865	.820
Error	Sand	218.220	24	9.093				
	Silt	88.233	24	3.676				
	Clay	121.990	24	5.083				
	O_M	9.823	24	.409				
	TOC	.656	24	.027				

Source: Author's Fieldwork (2017 -2018).

The error term in the multivariate presented in Table 2 represents the residual of unexplained variance "noise". The errors associated with the sum of squares vary from one bedload sediments to the other across the eco-geomorphologic units. For instance, sand constitutes the highest value of 218.220, followed by clay with 121.990. Silt attracts 88.233 and organic matter is associated with an error margin of 9.823 while the lowest error margin of 0.656 is associated with total organic carbon. The variations in each error margin exhibit a very strong and direct link with the computed values for the sums of squares. However, a similar trend of error in dispersal is recorded for the mean squares summarized in Table 2.

3.3 Policy Implications on River and Ecosystem Sustainability

The ecosystem restoration and sustainability has been largely the purview of biologists and engineers in the 19^{th} and early 20^{th} centuries. However, physical geographers (geomorphologist, climatologist, hydrologist, and bio-geographer) are now assuming the central position for any effort to successfully restore river and allied ecosystem to more natural arrangements, especially, when the focus is on the non-structural domain [37]. The highlights partly justify why physical geographical researches, ideologies, and expertise applications in this post-modern century emphasize more on the eco-geomorphological system services for the sustainability of the Earth's environment.

The dynamics in the dispersal, quantities, and qualities of bedload sediments, landforms and allied fluvial resources within the humid tropical belt of the Southeastern Nigeria had persistently been subjected to despoliation in different eco-geomorphologic units [3, 4, 25, 38], due to exploitative excesses emanating from population growth, urbanization, and climate change impacts. The exploitative excesses from anthropogenic agents have further triggered threats to exotic, yet endangered ecosystem species (in rivers, land, and forests) that humans are supposed to protect, rehabilitate, conserve, and own for posterity.

The tests of variations, overlapping variances, and homogeneities of the groups of parameters using mathematical models sustain that variations in eco-geomorphologic units and climatic seasons have a significant influence on the dispersals of bedload sediments in the humid tropical rivers. A test of the linear combination of each group of dependent variables using weighted models revealed that variations in eco-geomorphologic units have significant influence on the mean dispersal of bedload sediments in the humid tropical rivers of Southeastern Nigeria.

The implication is that persistent increase in the dispersal rate of bedload sediments especially during the early and peak rainy seasons suggest the possibilities of siltation, sedimentation, and drying up of small (1st, 2nd and 3rd) order river ecologies. The increase was accelerated by the impact of climate variability and the poor or absence of appropriate ecosystem services by resource users in the area. Further losses in fluvio-hydrological and biospheric resources imply the risk of continuous rise in global temperature. It will also result in the rising incidences of geomorphological and geo-physical hazards such as storms, floods, erosion, mass wasting, and sediment yield which Southeastern Nigeria had protracted histories.

4.0 Conclusion and Recommendations

There is a sustained dynamics (variabilities) between and among climatic seasons and bedload sediment dispersals across eco-geomorphologic units in the humid tropical rivers of Nigeria. The patterns of dynamics in the characteristics of bedload sediment dispersals constitute more risk to sustainability of ecosystem (hydrospheric, biospheric, lithospheric and atmospheric resources) in the study area, if urgent steps are not taken through partnership between governments, donor agencies and the affected communities to enforce the existing laws for the protection of landscape and ecosystem species in this 21st century.

It is clear from the preceding discourses that a sustain and deliberate promotions of community-driven afforestation programmes with adequate funding from the government and donor agencies will facilitate ecosystem services and mitigate geomorphic hazards such as erosion, flood, sediment yield, and mass wasting that are prevalence in most eco-geomorphologic units at the upper and middle streams of the study area.

The poor states of infrastructure especially roads and drainages necessitate proactive actions. For instances, timely dredging of the already silted small (e.g. 1st, 2nd, and 3rd order) river channels and beds will be very helpful in averting siltation and drying up of endangered sub-catchments. Also, construction of standard drainages will be very helpful in reducing sediment yields and regulating surface runoff and discharge from the cities and town into rivers will boost the sustainability of the river resources for posterity.

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