Online ISSN: 2249-4626
Print ISSN: 0975-5896

Global Journal of Science Frontier Research: H

Environment & Earth Science

Highlights

- Water Solar Electrolysis
- Case Study of ABUAD Teaching
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Discovering Thoughts, Inventing Future

VOLUME 14 ISSUE 5 VERSION 1.0

Global Journal of Science Frontier Research: H
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Volume 14 Issue 5 (Ver. 1.0)

Open Association of Research Society

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License No.: 42125/022010/1186
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USA Tax ID: 98-0673427

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USA Toll Free: +001-888-839-7392
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Packaging & Continental Dispatching

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Contents of the Issue

Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 14 Issue 5 Version 1.0 Year 2014
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Geophysical Survey for Groundwater Resource Appraissal in a basement Complex Terrain for Agricultural Purposes; Case Study of ABUAD Teaching and Research Farm, Ado Ekiti, Southwest Nigeria

By Oladimeji Lawrence Ademilua, Olufemi Felix Ojo, Akinola Bolaji Eluwole & Oladipupo Babatunde Ademilua
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Keywords: *aquifer, VLF-EM, vertical electrical sounding.*

GJSFR-H Classification : *FOR Code: 260501*

Strictly as per the compliance and regulations of :

Geophysical Survey for Groundwater Resource Appraissal in a basement Complex Terrain for Agricultural Purposes; Case Study of ABUAD Teaching and Research Farm, Ado Ekiti, Southwest Nigeria

Oladimeji Lawrence Ademilua [α], Olufemi Felix Ojo [σ], Akinola Bolaji Eluwole [ρ] & Oladipupo Babatunde Ademilua [Ѡ]

Abstract- A combined geophysical survey involving the Very Low Frequency Electromagnetic and the Electrical resistivity survey has been carried out in the Teaching and Research Farm of the Afe Babalola University along Ado – Ikare road, Ado Ekiti with a view to determining the subsurface layers and thickness of the overburden as a means to appraising the ground water potential in the study area. Seventeen (17) west east traverses were established from which VLF – Electromagnetic data were acquired at a station interval of 5m each, the modeling and interpretation results from these were used to delimit the farm area into a total of 29 points from where vertical electrical soundings were carried out for further detailed survey using the Schlumberger electrode array configuration. The sounding data was processed and interpreted using WINRESIST interpretation software. The resistivities and thicknesses of the layers at the VES points were revealed. The results showed the presence of four geoelectric layers from the top soil / laterite, the clay / clayey sand, the weathered/partly fractured basement and the presumably fresh bedrock. The KH type curve represents the most frequent of the type curves obtained, this is followed by other curves; QH, HA, H and the AA types. Two types of aquifers, which are the weathered and fractured basement aquifers, have been delineated in this study. From the syntheses of the isopach maps of the weathered layer and overburden thicknesses as well as the curve type and parametric data analyses, four positions have exhibited promising characteristics for possible groundwater development. These positions arranged in order of hydrogeologic significance are VES V5, V17, V23 and V10, while other positions including V7, V11, V14, V19, V20, ,V27, V28 exhibited low prospects. Two boreholes RB1 and RB2 located at VES points V5 and V17 have therefore been proposed for the study area from within the High prospect positions.. These points are located within the coordinates N07^0 36.942' E005^0 18.046' for V5 and N07^0 36.9991' E005^0 18.079' for V17.

Keywords: aquifer, VLF-EM, vertical electrical sounding, top soil, weathered basement, fresh bedrock.

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I. Introduction

Afe Babalola University, Ado-Ekiti (ABUAD) is a fast growing private University in Nigeria. The continuous increase in progressive infrastructural development within the University resulting in the establishment of a University Teaching and Research Farm necessitated the development of a sustainable water supply network for irrigation and other domestic uses. Water is an essential commodity for the survival of every living thing (plants and animals). Most human beings generally require about 2.5 liters of water everyday for direct consumption. The average amount of water used domestically each day by every person is around 200 liters (Hamil and Bell, 1986). Normally the easiest and most convenient way to meet the public demand for water is to utilize surface water resources. Unfortunately, fresh water rivers and lakes are less plentiful than may at first be imagined. In addition, they are irregularly distributed across the globe. To complicate matters further, these resources are often polluted where available. The groundwater on the contrary is significantly protected from surface pollutants as the earth media (composed of different subsurface layers) act as a natural filter to infiltrated water. Groundwater development is relatively cheap and therefore constitutes a viable option or supplement to the expensive earth and concrete dam systems of surface water supply, where potential groundwater is good. This makes the evaluation of groundwater potential in the study area an important research. Groundwater occurs in geological formations, which depends on the geology of the area. Some of the geological formations that hold groundwater can either be described as: aquifers, aquicludes or aquitards. Electrical and electromagnetic techniques are used in groundwater geophysical investigations because of the correlations that often exist betwee electrical properties, geologic formations and their fluid content (Flathe, 1970; Zohdy *et al.,*1974). The direct current electrical resistivity

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method for conducting a vertical electrical sounding (VES) has proved very popular with groundwater studies due to the simplicity of the technique and the ruggedness of the instrumentation. The use of geophysical techniques for groundwater studies has been necessitated by a desire to reduce the risk of drilling dry holes and also a desire to offset costs associated with poor groundwater production. In the present study, the Very Low Frequency Electromagnetic (VLF-EM) method has been used for reconnaissance and delineation of the Farm area into positions with relatively average to high conductivities which are diagnostic of appreciable thicknesses or fracture. A total of 17 VLF-EM Traverses were established for the purpose. The positions so delinated were there after followed up with the secondary but more detailed electrical resistivity method using Schlumberger array to determine the nature of the superficial material and the subsurface rocks underlying it with a view of determining appropriate points for the location and drilling of productive groundwater boreholes for irrigation, associated agricultural and domestic purposes in the University Teaching and Research farm .

II. Site Location And Geology

The University Teaching and Research farm is situated at the Southwestern part of the main campus of Afe Babalola University, Ado-Ekiti (ABUAD) which could be found within latitudes 7^0 36′ 53''N and 7^0 37' 12'' N and longitudes 5^0 17′45'' E and 5^0 18' 10''E, Southwest, Nigeria on a vast area of low-land cultivated in part and comprising of several agricultural plants like mango, gmelina and teak trees, palm trees, a fish pond and other ancilliary infrastructures. (Fig. 1). A fairly thick overburden covers the area with varying thicknesses. Underlying the overburden are crystalline rocks consisting of granitic rock, which is equally exposed along the course of the river that flows across the area (Rahaman,1988; Ajibade and Umeji 1989). The geologic setting of the area is typical of the migmatite gneiss complex rocks of the Precambrian Basement Complex of southwestern Nigeria (Rahaman, 1988), comprising of undifferentiated granite, charnockitic rocks, medium to coarse granite and migmatite gneiss rocks. The River Ogbese which is situated at the southern part of the farm and which flows eastward in the area constitute the major drainage network as well as the veritable source of recharge in the area (Figure 1). The vegetation in the area is of rainforest type, characterized by short dry season and long wet season, with high annual rainfall of about 1,300 mm. Annual mean temperature is between 180 C and 330 C with relatively high humidity (NIMET, 2007.

III. Research Methodology

In the first approach, the Very Low Frequency Electromagnetic (VLF-EM) method involving the establishment of 17 Traverses were used for reconnaissance and delineation of the Farm area into positions with relatively average to high conductivities which are diagnostic of appreciable overburden thicknesses or fracture. The positions so delinated were thereafter followed up with the secondary and more detailed electrical resistivity method using the vertical electrical sounding (VES) to determine the nature of the superficial material and the subsurface rocks underlying the points. The Schlumberger configuration was employed throughout the work. Ojelabi *et' al* (2002) and Ayolabi *et'al* (2009) have shown that this configuration has a high penetrating depth per unit current electrode spacing and that it is more suitable for subsurface delineation and groundwater exploration in a basement complex region. A total of 27 VES points that were delineated from the VLF-EM results were occupied and sampled. Also two other points, VES 28 and 29 were occupied for the purpose of obtaining parametric data (layer thicknesses and resistivities) beside already drilled boreholes in the study area which have not been performing satisfactorily. The OMEGA Terrameter was used for the fieldwork, with the maximum current electrode separation (AB) of 200m. The apparent resistivity data are presented as sounding curves. The VES data represented as sounding curves were quantitatively and qualitatively interpreted to determine the number of subsurface layers, their resistivities as well as thicknesses. The two basic approaches to the interpretation of the curves are the manual partial curve matching method using two layer model curves,while the initial model parameters resulting from the curve matching procedures were then fed into the computer for iteration processing using the software WINRESIST to obtain the final curves as well as the final model parameters as shown in Figures 2. The curve types obtained are the KH, H, HA, and QH. The Summary of the analysis is as shown in Table 1. The obtained final parameters from the curve in terms of the layer thicknesses and resistivities are then analysed to obtain the thicknesses of the overburden i.e the depth to the fresh bedrock at each VES point as well as the thickness of weathered/partly fractured layer at each VES point. These data were then posted on the base map using the software ARCGIS and then contoured to produce the overburden thickness and the weathered layer thicknesses maps (Figs. 4 and 5).

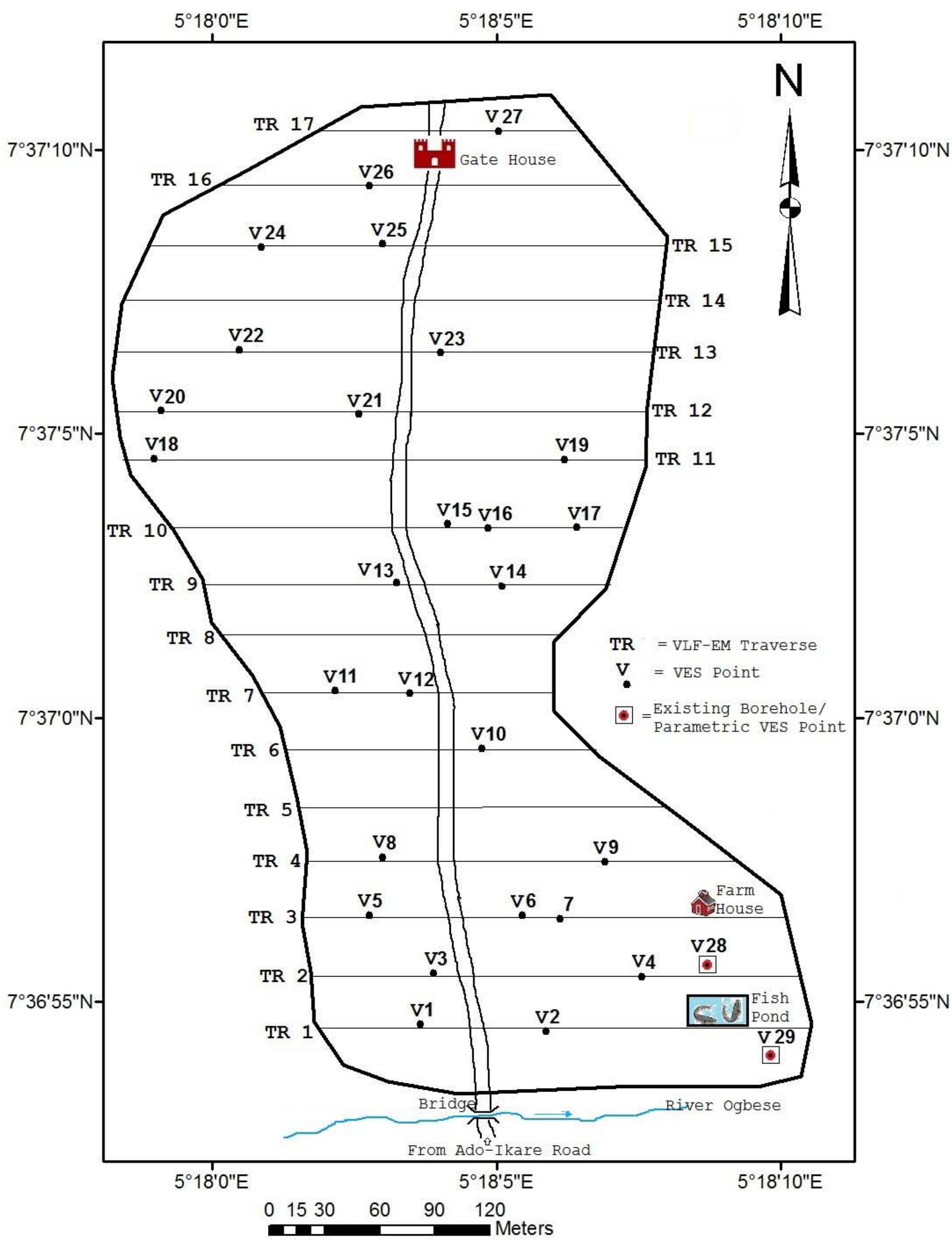


Figure 1 : Base Map of Afe Babalola University Teaching and Research Farm Showing VLF-EM Traverse lines and the delineated VES points

Table 1 : Summary of VES Analysis

VES NO	Layers	Thickness (m)	Resistivity (Ωm)	Curves Type
1	Topsoil/laterite	0.9	313.3	KH
	Clay/clayey sand	2.6	891.1	
	Weathered basement	5.2	576	
	Fresh bedrock	??	8916.8	

2	Topsoil/laterite	0.7	64.7	QH
	Clay/clayey sand	0.6	40.8	
	Weathered basement	2.4	29.2	
	Fresh bedrock	??	1322.1	
3	Topsoil/laterite	0.6	454.1	HK
	Clay/clayey sand	0.3	430.4	
	Weathered basement	7.1	132	
	Fresh bedrock	??	2538.6	
4	Topsoil/laterite	0.8	81	KH
	Clay/clayey sand	1.0	79	
	Weathered basement	3.0	37.7	
	Fresh bedrock	??	7536.7	
5	Topsoil/laterite	0.8	98.5	KH
	Clay/clayey sand	5.7	342.8	
	Weathered basement	12.9	63.24	
	Fresh bedrock	??	2580.3	
6	Topsoil/laterite	0.4	22.52	AA
	Clay/clayey sand	0.5	71.69	
	Weathered basement	2.5	507	
	Fresh bedrock	??	23387.3	
7	Topsoil/laterite	0.8	383.3	QH
	Clay/clayey sand	0.2	862.8	
	Weathered basement	0.8	11.1	
	Fresh bedrock	??	6826.3	
8	Topsoil/laterite	1.4	247.4	H
	Weathered basement	2.3	174.5	
	Fresh basement	??	1787.9	
9	Topsoil/laterite	1.1	229.9	HA
	Clay/clayey sand	3.5	79.9	
	Weathered basement	3.3	104.1	
	Basement	??	878.7	
10	Topsoil/laterite	3.2	641.8	KH
	Clay/clayey sand	6.5	1117.3	
	Weathered basement	6.7	180.0	
	Fresh bedrock	??	2515.9	
11	Topsoil/laterite	0.6	159.5	KH
	Clay/clayey sand	1.3	317.7	
	Weathered basement	2.9	35.5	
	Fresh bedrock	??	2080.3	
12	Topsoil/laterite	0.5	550.5	KH
	Clay/clayey sand	1.3	1334	
	Weathered basement	3.5	40.8	
	Fresh bedrock	??	1796.9	
13	Topsoil/laterite	1.0	414.7	QH
	Clay/clayey sand	0.5	394.4	
	Weathered basement	8.9	131.7	

	Fresh bedrock	??	2346.8	
14	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.4 0.7 3.6 ??	158.2 1069.8 43.3 1601.2	KH
15	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.4 0.9 4.5 ??	132.4 1038.2 27.5 9442.8	KH
16	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.5 0.8 11.3 ??	225.4 760.3 87.6 10603.3	KH
17	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.8 3.7 15.3 ??	165.9 513.5 228.9 35007.5	KH
18	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.6 0.4 10.3 ??	875.8 1583.3 76.5 8778.9	KH
19	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.6 0.8 5.3 ??	173.4 426.3 32.8 24604.2	KH
20	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.9 0.4 3.9 ??	1238.7 1733.5 124.5 2428.2	KH
21	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.7 1.3 8.1 ??	361.9 546.1 76.4 10218.9	KH
22	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.6 0.5 6.5 ??	358.6 573.5 69.3 1203.9	KH
23	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.8 1.0 13.5 ??	219.1 242.4 53.3 3995.7	KH
24	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	1.1 0.6 9.3 ??	388.5 506.4 46.8 6399.3	KH

25	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.9 0.6 7.8 ??	363.9 245.6 42.7 3278.6	QH
26	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.8 0.6 8.4 ??	408.5 398.8 41.1 6238.7	QH
27	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.7 2.5 1.2 ??	490.5 138.5 7.1 20663.9	QH
28	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.4 0.7 2.4 ??	39.3 175.0 17.6 37704.1	KH
29	Topsoil/laterite Clay/clayey sand Weathered basement Fresh bedrock	0.4 0.7 3.2 ??	66.1 317.1 27.1 6782.8	KH

Table 2 : Summary of Overburden and Weathered Layer Thicknesses

VES No.	Overburden Thicknesses (m)	Weathered Layer Thicknesses (m)	Weathered Layer Resistivities Ohm-m
1.	8.70	5.20	576.00
2.	3.70	2.40	29.20
3.	8.00	7.10	132.00
4.	4.80	3.00	37.70
5.	19.40	12.90	63.24
6.	3.40	2.50	507
7.	1.80	0.80	11.10
8.	3.70	2.30	174.50
9.	7.90	3.30	104.10
10.	16.40	6.70	180.00
11.	4.80	2.90	35.50
12.	5.30	3.50	40.80
13.	10.40	8.90	131.70
14.	4.70	3.60	43.30
15.	5.80	4.50	27.50
16.	12.60	11.30	87.60
17.	19.80	15.30	228.90
18.	11.30	10.30	76.50
19.	6.70	5.30	32.80

20.	5.20	3.90	124.50
21.	10.10	8.10	76.40
22.	7.60	6.50	69.30
23.	15.3	13.50	53.30
24.	11.00	9.30	46.80
25.	9.30	7.80	42.70
26.	9.80	8.40	41.10
27.	4.40	1.20	7.10
28.	3.50	2.40	17.60
29.	4.30	3.20	27.10

IV. Results And Discussion

From the 1D-layered model generated, the resistivities associated with each layer were derived together with corresponding thicknesses. The representatives of the twenty nine (29) curves as obtained from the computer iteration processes are as shown in Figures 2. The sounding curves show three layer and four layer earth models. The three layer earth are characterized by H curve type which represents about 3% of the curve types in the study area. This curve type is usually diagnostic of weathered layer aquifer existing as a single unit, where the thickness is appreciable, the aquifer could be expected to yield appreciably, otherwise it could not be relied upon. The four layer models are characterized by KH,QH, HK, HA and the AA curve types which altogether covers over 97% of the study area (see Figure 3). Both the QH, KH and HK types are diagnostic of the weathered and fractured layer (confined) aquifer systems, while the HA type is diagnostic of weathered/fractured layer (unconfined) aquifer systems (Olorunfemi and Fasuyi 1993; Ademilua 1997; Ademilua and Olorunfemi 2000). These combined aquifer systems are noteworthy for enhanced groundwater yields when delineated, especially when occasioned with appreciable thicknesses of both or either of the units. Therefore and going by the high frequencies of these curves, especially the KH- which accounts for 66 % it is anticipated that optimum yield would be derivable from the recommended positions within the area. The observed geo-electric layers as correlated from the driller's records of the existing borehole in the study area include the top soil / laterite, clay / clayey sand, weathered/partly fractured basement and the fresh basement. The resistivities of the first geoelectric layer range from 39.3Ωm to 1238.0Ωm and its thicknesses from 0.4m to 3.2m. The second geoelectric layer has resistivities ranging from 40.8Ωm to 1733.5Ωm and thicknesses from 0.3m to 6.5m. The resistivities of the third geoelectric layer range from 7.1Ωm to 576Ωm and its thicknesses range from 0.8m to 15.3m. The resistivities of the fourth geoelectric layer which is the presumably fresh bedrock range from 878.7Ωm to 37704.1Ωm with infinite thickness. Olayinka et'al., (1997) recommended the value of overburden thicknesses ranging between 20m and 30m for a productive well, Olorunfemi and Okhue (1992) and Oladapo, et'al (2004) also prescribed an overburden thickness of 25m for viable groundwater abstraction. It has been reported that in the basement areas of Zimbabwe between 20m and 25 m of overburden is the minimum required before siting a borehole (Wright, 1992). The overburden thicknesses nearing these ranges or approximate values were obtained in VES stations V17 with 19.8m; V5 with 19.4m; V10 with 16.4m;V23 with15.3m in the study area which are supportive of groundwater development at the points where they are located.

a) *Isopach Map of Weathered Basement*

The thicknesses of the weathered/partly fractured basement layer were obtained from the VES interpretation results and plotted against the VES stations and contoured as shown in Figure 4 using the ARCGIS software, a 1m contour interval was used. The map shows variation in thickness of overburden closures across . Peak and high contour closures depicting possible areas of attention were revealed and these could be found in VES positions V5 in the SWpart,V17 in the eastern part, V23 in the north central and, V27 in the north eastern parts.The corresponding resistivity curve types are the KH-. The low closures are obtainable at VES positions V20 V18 . It is noteworthy that low closures characterized the parametric VES positions V28 and V29, which is symptomatic of low yield. This finding is corroborative of the actual current yield performance and rating of the well which has been adjudged low.

b) *Isopach Map of Overburden*

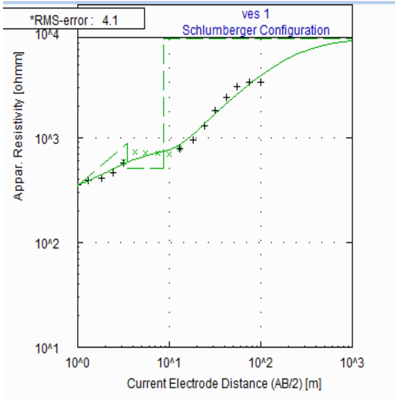
The thicknesses of the overburden as well as the weathered layer obtained from the interpretation results were summarized as shown in Table 2 . Again, the values for the overburden were plotted against the VES stations and contoured using the ARCGIS software as shown in Figure 5, a 1m contour interval was used. The map displayed the variation in overburden thickness closures across the study area .Furthermore, high contour closures depicting possible areas of priority attention were delineated and as was the case with the previous isopach map of the weathered layer, these could be found in VES positions V5 in the South western part, V17 in the eastern part, V23 in the north central and, V27 in the north eastern parts. The corresponding resistivity curve types are the KH-. The low closures are obtainable at VES positions V20 and V18. It is noteworthy to discover that low closures characterized the parametric VES positions V28 and V29, which is symptomatic of low yield. This finding is corroborative of the actual current yield performance rating of the well which has been adjudged low.

c) Groundwater Potential Evaluation

The groundwater potential evaluation of the area was derived from the syntheses of the curve type analyses, as well as the composite maps of the isopach maps of the weathered layer and the overburden thicknesses (Tables 1and 2; Figures 3,4, and 5). Comparing Figures 4 and 5, there exist a strong relationship between the high closure areas delineated by each of these maps as the both of them highlight the VES positions V5, V17, V23 and V27 as good groundwater potential zones, while there is good coincidence with each other in areas characterised by low contour closures. The tables and maps were synthesized and integrated for the identification and designation of the good groundwater potential VES positions which are points characterized by high contour closures, while points with low closures or non closures are regarded as low prospect zones. From the syntheses of the isopach maps of the weathered layer and overburden thicknesses as well as the curve type and parametric data analyses, Four positions have exhibited promising characteristics for possible groundwater development, these positions arranged in order of hydrogeologic significance are VES 5, 17, 23 and 27, while other positions including V7, V11, V14, V19, V20, ,V27, V28 exhibited low prospects. Two boreholes RB1 and RB2 located at VES positions V5 and V17 have therefore been proposed for the study area. These points are located within the coordinates N070 36.942' E0050 18.046' for V5, and N070 36.9991' E0050 18.079' for V17. The other VES positions outside these four positions within the the study area could therefore be regarded as poor and has no appeal for groundwater development.

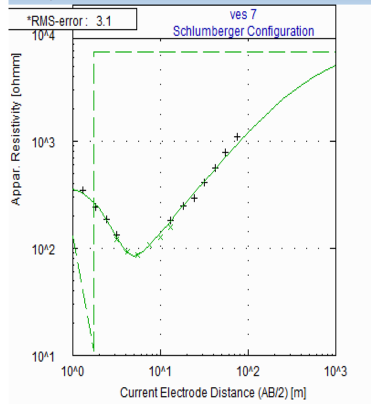
V. Conclusion

The geoelectric parameters (layer resistivities and thicknesses) which are known to be of hydrogeologic relevance, gathered from the VES interpretation were used to generate maps (weathered/fractured layer thickness map and the overburden thickness map). The maps were initially examined individually by identifying VES positions with high closures of the geoelectric parameters favourable to groundwater occurrence, Groundwater exploration in the basement is based on weathered and or fractured basement aquifers. The groundwater potential of the aquifer may be significantly enhanced if the thickness of the layers are high. However, relatively low values of this parameter can also indicate poor groundwater potential. The fairly low bedrock resistivity confirms the presence of fractures and hence water contained within the fissures (Beeson and Jones, 1988, and Olayinka and Olorunfemi, 1992, Lateef 2012, Adeoti et'al 2012). The high frequencies of the good groundwater diagnostic VES curves, especially the KH- which accounts for 66 % is symptomatic that optimum yield would be derivable from the recommended positions within the area. Based on all the findings made in the interpretation of the VES data, 4 VES stations have been chosen as the most viable locations for the development of groundwater resources in the study area. These include VES 5, 17, 23 and 27, However, other positions including V7, V11, V14, V19, V20, ,V27, V28 exhibited low prospects. Two boreholes RB1 and RB2 located at VES positions V5 and V17 have therefore been proposed for the study area. These points are located within the coordinates N070 36.942' E0050 18.046' for V5 and N070 36.9991' E0050 18.079' for V17. The two boreholes RB1 and RB2 have been recommended for drilling at these points not only because of the foregoing arguments in support of the decision, but furthermore considering other relevant and hydrogeophysically significant factors in terms of the geoelectric parameters (thicknesses and resistivities) at the points which are equally indicative of good groundwater potential that can be considered for groundwater development at ABUAD teaching and research farm.



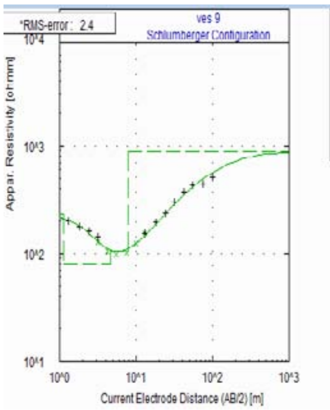
No	Res	Thick	Depth
1	313.3	0.9	0.9
2	891.1	2.6	3.5
3	516.0	5.2	8.7
4	8916.8	-.-	-.-

* RMS on smoothed data



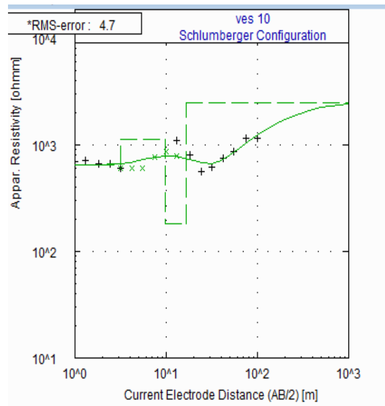
No	Res	Thick	Depth
1	383.3	0.8	0.8
2	862.8	0.2	1.0
3	11.1	0.8	1.7
4	6826.3	-.-	-.-

* RMS on smoothed data



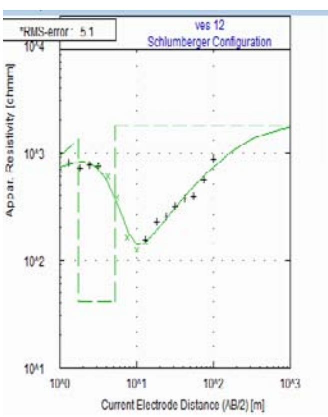
No	Res	Thick	Depth
1	229.9	1.1	1.1
2	79.9	3.5	4.6
3	104.1	3.3	7.9
4	878.7	-.-	-.-

* RMS on smoothed data



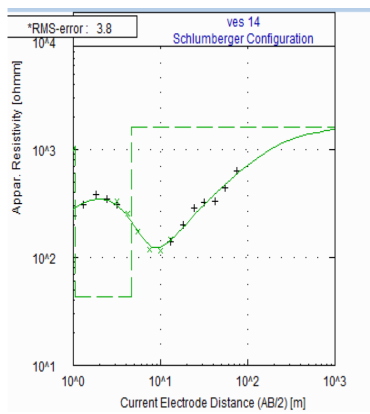
No	Res	Thick	Depth
1	641.8	3.2	3.2
2	1117.3	6.5	9.6
3	180.0	6.7	16.4
4	2515.9	-.-	-.-

* RMS on smoothed data



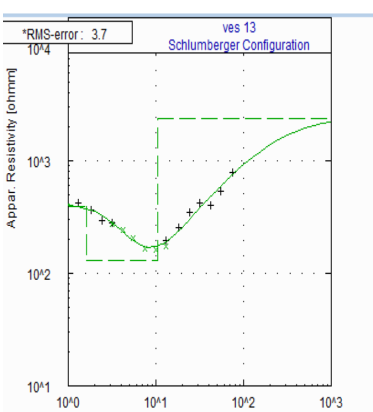
No	Res	Thick	Depth
1	550.5	0.5	0.5
2	1334.0	1.3	1.7
3	40.8	3.5	5.2
4	1796.9	-.-	-.-

* RMS on smoothed data



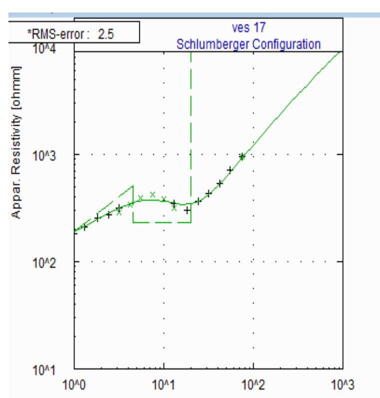
No	Res	Thick	Depth
1	158.2	0.4	0.4
2	1069.8	0.7	1.1
3	43.3	3.6	4.6
4	1601.2	-.-	-.-

* RMS on smoothed data



No	Res	Thick	Depth
1	414.7	1.0	1.0
2	394.4	0.6	1.6
3	131.7	8.9	10.6
4	2346.8	-.-	-.-

* RMS on smoothed data



No	Res	Thick	Depth
1	165.9	0.8	0.8
2	513.5	3.7	4.6
3	228.9	15.3	19.9
4	35007.7	-.-	-.-

* RMS on smoothed data

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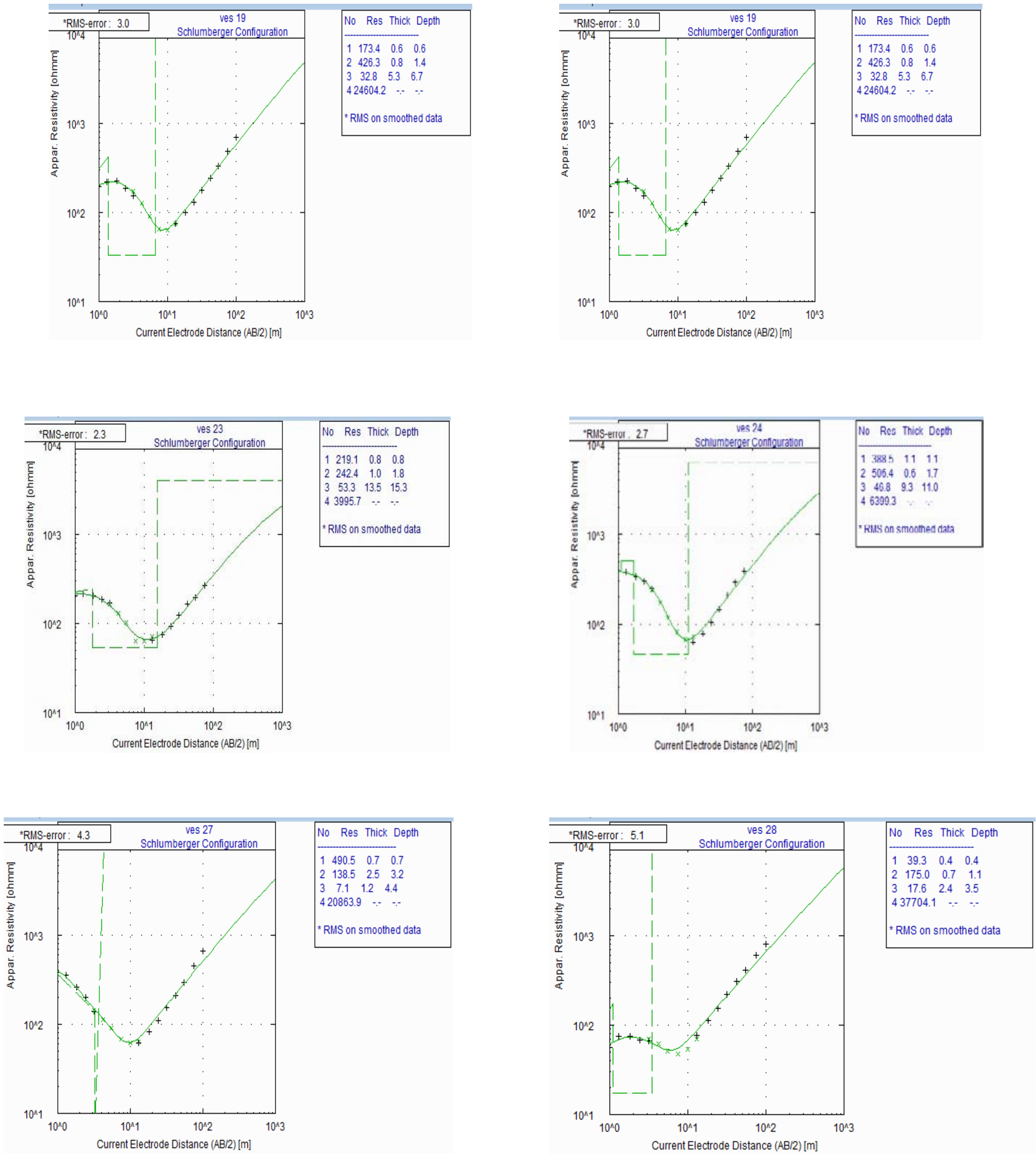
Current Electrode (AB/2) [m]



Figures 2 : Representative VES Interpretation Model Results using the WINRESIST Software

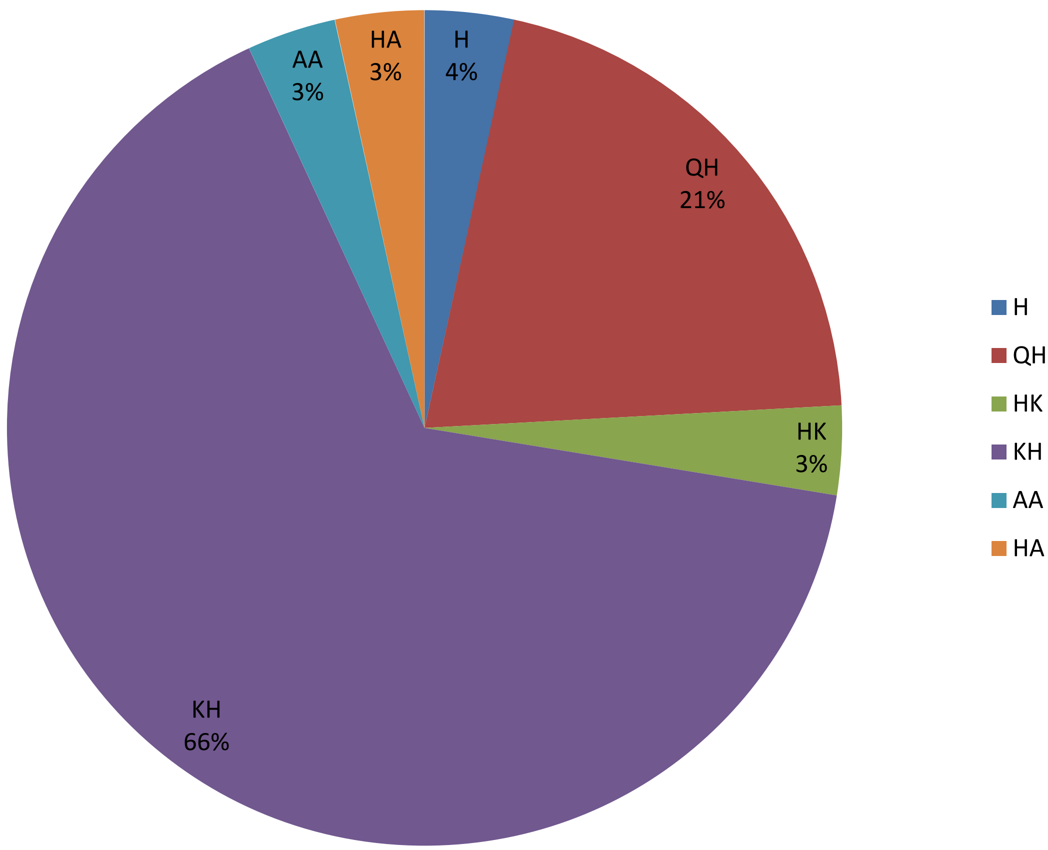


Figure 3 : Pie chart showing the frequency of curve types obtained from the study area

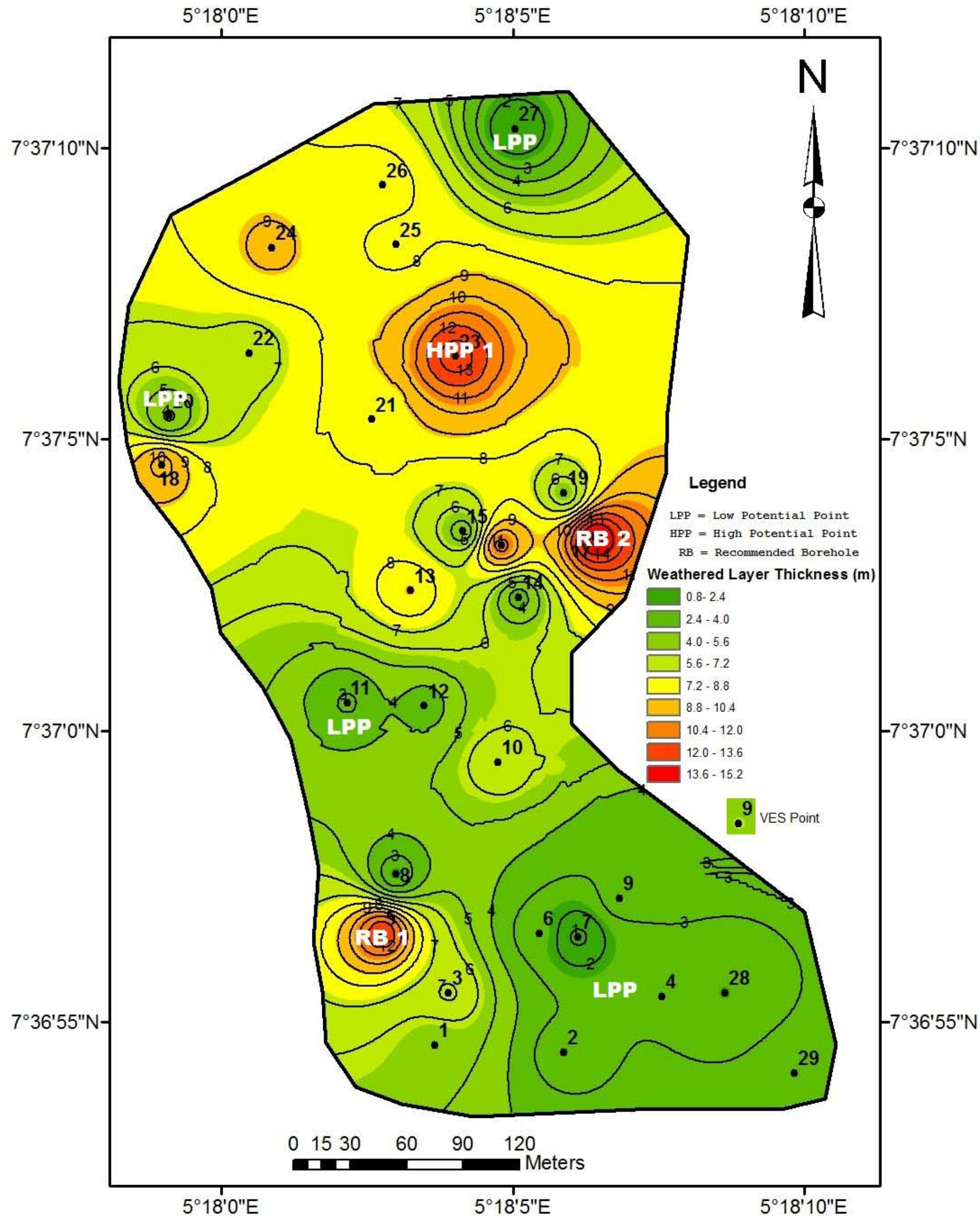


Figure 4 : Isopach Map of Weathered Layer Thickness of the study area

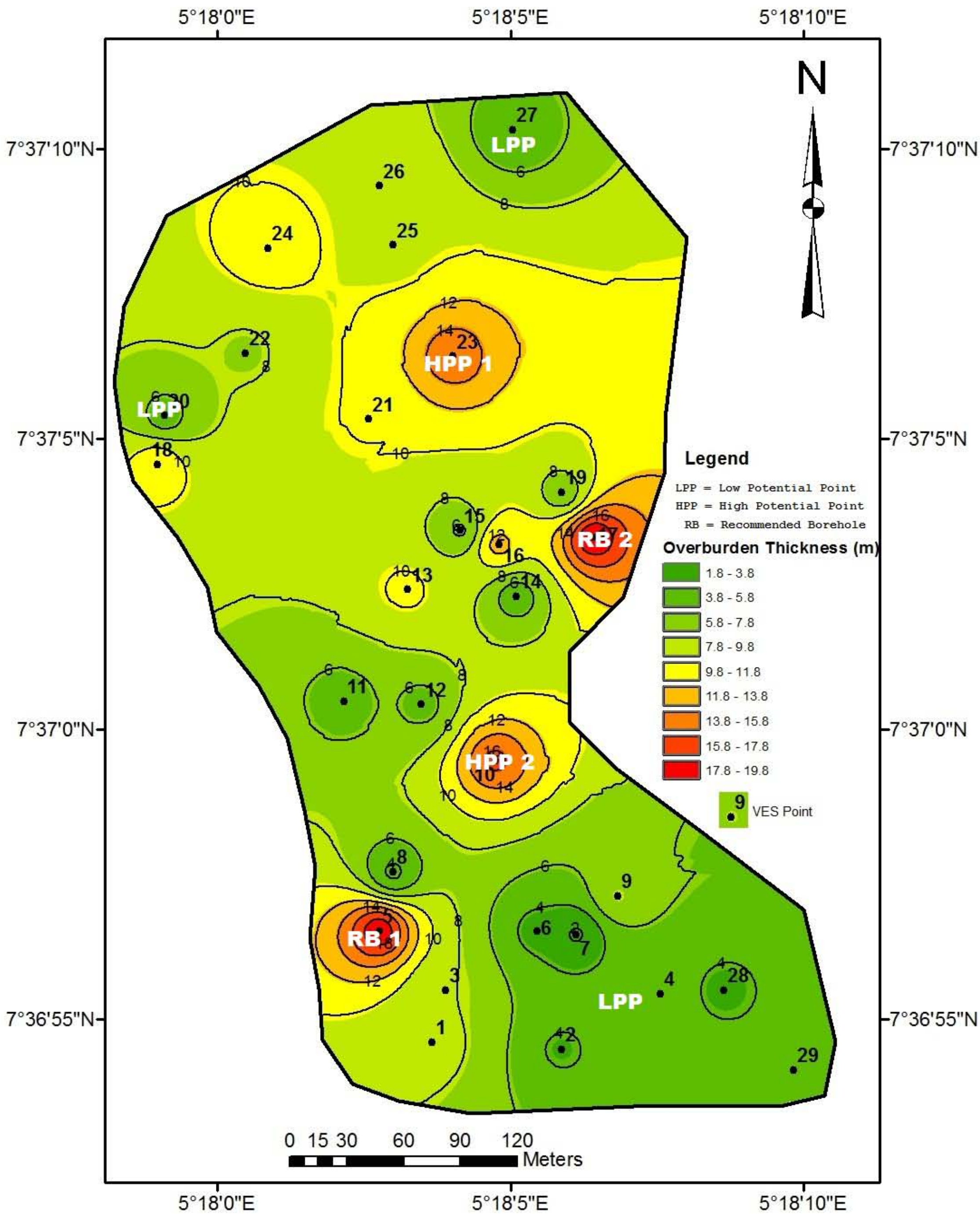


Figure 5 : Isopach map of Overburden Thickness of the study area

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 14 Issue 5 Version 1.0 Year 2014
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

The Influence of Tidal Currents on Coastal Erosion in a Tropical Micro-Tidal Environment – the Case of Columbus Bay, Trinidad

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University of the West Indies, St Augustine Campus, Trinidad and Tobago

Abstract- Trinidad as a Small Island Developing State (SID) has limited land resources which must be managed against the threat of coastal erosion. Columbus Bay, located on the south-western peninsula of the island is negatively affected by high rates of coastal erosion. Erosion in this area has resulted in a reduction in beach amenity, loss of valuable agricultural land, critical mangrove habitats and damage to infrastructure. Although the erosion problem is well documented, the challenges lie in management due to the limited understanding of the interaction of coastal processes and sediment transport in the area. While other studies have identified the existence and causal link between coastal erosion and tidal currents in macro-tidal environments, this study examines the interaction of tides on coastal processes and sediment transport in a micro-tidal setting. The study combines traditional field and levelling techniques alongside numerical modelling on data from 2009-2013. It utilizes the Spectral Wave (SW), Hydrodynamic (HD) and Sediment Transport (ST) modules of MIKE 21.

Keywords: *sediment transport, erosion, Columbus Bay, MIKE 21, sustainable land management.*

GJSFR-H Classification : *FOR Code: 850507*

Strictly as per the compliance and regulations of :

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Abstract- Trinidad as a Small Island Developing State (SID) has limited land resources which must be managed against the threat of coastal erosion. Columbus Bay, located on the south-western peninsula of the island is negatively affected by high rates of coastal erosion. Erosion in this area has resulted in a reduction in beach amenity, loss of valuable agricultural land, critical mangrove habitats and damage to infrastructure. Although the erosion problem is well documented, the challenges lie in management due to the limited understanding of the interaction of coastal processes and sediment transport in the area. While other studies have identified the existence and causal link between coastal erosion and tidal currents in macro-tidal environments, this study examines the interaction of tides on coastal processes and sediment transport in a micro-tidal setting. The study combines traditional field and levelling techniques alongside numerical modelling on data from 2009-2013. It utilizes the Spectral Wave (SW), Hydrodynamic (HD) and Sediment Transport (ST) modules of MIKE 21. Results indicate that tidal current speed and direction are the main drivers of sediment transport in the bay with most of the erosion occurring during the ebb state. Computed ebb current speeds have a range between 0.18 and 0.36 m/s during spring conditions and 0.36 and 0.54 m/s during neap conditions, with a north easterly direction. Recommendations are made for engineered groynes in an attempt to reduce coastal erosion as targeted management interventions for the area.

Keywords: sediment transport, erosion, Columbus Bay, MIKE 21, sustainable land management.

I. Introduction

The formation of coastal morphology such as cliffs, platforms, headlands and bays are as a result of the interaction between marine processes in the coastal zone. Waves, currents and tides interact (Park and Edge, 2011) and in doing so, contribute to shoreline changes such as erosion (Coelho *et al.,* 2009). The interruption of these natural coastal processes by human interjection in the absence of adequate research has highlighted negative impacts (Barnard, Hansen, and Erikson, 2012; Bromhead and Ibsen, 2006; Cambers, 2009; Hsu, Lin, and Tseng, 2007; Komar, 2010; Lorenzo, Alonso, and Pages, 2007). Independently, the effect of tides on coastlines has been well documented and is identified as being responsible for sediment transport in estuaries and macro-tidal environments globally (Masselink and Hughes, 2003). However, there remains a paucity of data as it relates to coastal erosion in a tropical embayed micro-tidal setting, which affects the way in which these types of environments are integrated into management concerns. In the Caribbean, these are as are severely understudied, although they are also the areas of high value for development. A poor understanding of the impact of tides in these are as leads to weak management strategies resulting in the loss of valuable land in varying magnitudes.

The effect of tides on beach dynamics and coastal erosion was studied for a number of places such as Gulf of California (Alvarez and Jones, 2004), West Palm Beach, Florida (Trenhaile, 2004), Dauphin Island, Alabama (Froede, 2007), North Shore of Oahu, Hawaii (Caldwell, Vitousek, and Aucan, 2009), North Yorkshire, England (Lim *et al.,* 2011) and Ocean Beach, California (Barnard, Hansen and Erikson, 2012). Darsan (2013) examined the influence of tidal cycles on beach dynamics at Cocos Bay, east coast Trinidad over a short term. The study found that erosion was linked to rising tide while accretion was due to falling tide diurnally. Erosion also dominated the spring tide conditions and accretion during neap tides. In addition to the tidal cycles that occur over the short-term, a study conducted by (Gratiot *et al.,* 2008) has demonstrated that the 18.6 year nodal tidal cycle contributes significantly to regional coastal changes.

Although the threats of coastal erosion due to existing oceanographic conditions, in particularly tides are well recognized, the challenge of incorporating this into management decisions is limited by the understanding of coastal erosion processes. The latter requires complex mathematical analysis coupled with an extensive cohort of data acquisition of various parameters which include, but are not limited to tides, currents, waves and wind data. This data collection often requires substantial human and financial resources which are sometimes unavailable, resulting in an absence of coastal dynamics considerations into

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land use planning (Martinez del Pozo and Anfuso, 2008; Sayah *et al.,* 2005). This usually translates into coastal infrastructure installations with reduced life spans, which lead to huge finacial burdens.

Over the last decade, there is evidence of a change towards the use and incorporation of coastal processes into management, thanks to growing appreciation and recognition of numerical modelling (Gonzalez-Leija *et al.,* 2013), (Johnson *et al.,* 2005; Kabiling and Odroniec, 2010; Kankara *et al.,* 2013; Rajith *et al.,* 2008; Xue, 2001; Warren and Bach, 1992). Predicting hydrodynamics due to tides is shown to provide a better understanding of near shore current behavior (Mazio *et al.,* 2004). This has afforded coastal engineers the ability to use these models to simulate existing oceanographic processes and use this information to predict the behavior and influences of dynamic coastal erosion processes. However, in the Caribbean SIDS and in Trinidad and Tobago, usage of numerical modelling remain scarce.

Sediment transport modeling utilizing the MIKE 21 model has proven to be useful in simulating existing hydrodynamics due to tides (Sorensen, Kofoed-Hansen, and Jones, 2006), currents and waves (Appendini *et al.,* 2012; Dupont, 2010; Niemann *et al.,* 2010; Remya *et al.,* 2012). Further, this model supports the identification of areas of potential erosion or accretion given its ability to simulate these conditions (Broker *et al.,* 2007; Zyserman and Johnson, 2002). Such modeling provides calculated wave power, wave height, wave radiation stresses, wave direction, current speed and direction, total load magnitude and direction and rate of bed level change in relation to the existing oceanographic conditions. These collectively form the basis of defining sediment transport in an area and thereby determine the erosion potential. The end result is that more environmental data is available for inclusion into effective land management decisions.

Land management is critical to a sustainable pathway for Trinidad (Singh, 2005),there fore one of the policy decisions is to ensure that sustainable management of its resources remains a priority. Columbus Bay located on the south west peninsula of Trinidad, has experienced erosion of the land for the past forty years (Oostdam, 1982). This area is important because it supports a sensitive mangrove habitat which provides a natural buffer to the south western coastline against storm surge and further coastal erosion. It also sustains a vibrant agricultural industry which contributes significantly to local livelihoods. Recently, this bay has been earmarked for possible infrastructural development to support the projected growth in the oil industry- an activity which is prominent on the west coast of Trinidad.

Columbus bay, located on the south western peninsula in Trinidad has been eroding for the past forty years and the problem persists despite some management interventions. (Deane, 1973) suggests that long shore currents generated by waves approaching from storms and squalls create long shore currents capable of moving sediment. (Oostdam, 1982) also supports this theory and adds that tidal currents may also be responsible for the movement of sediment. Dean (1973) used modeled wave data and computed near shore wave events due to shoaling and refraction. Oostdam (1982) employed langrarian measurements of currents at various locations in the bay, but does not provide current magnitudes throughout the bay. Both studies used values of near shore coastal conditions (wave height and current speeds) to indicate the resulting impact on sediment transport, but neither provided quantitative values for sediment transport, nor identified the factors responsible for the observed coastal erosion. In view of this, the objective of this study is to adopt a modeling approach to investigate the effect of tides on coastal processes in a low-energy micro-tidal tropical environment using Columbus Bay, Trinidad as the study area. Further, the outputs from the model will be used to deduce the main drivers of sediment transport and by extension coastal erosion in the bay. Complimentary to these findings, are targeted approaches which are recommended to effectively manage the erosion problem in the study area.

II. Study Area

The tidal regime experienced in Trinidad is a function of tidal waves from both the Caribbean Sea and the Atlantic Ocean (Gade, 1961). Trinidad's tidal type is described as mixed, with a predominantly semi-diurnal influence (Bertrand *et al.,* 1992). The maximum tidal range experienced in Trinidad is 1.3m (Edwards, 1983).Columbus Bay is characterized by a 4km stretch of beach situated between Los Gallos headland in the north-west and Corral Point in the south-west situated in the island of Trinidad **(Fig. 1)**. Interspersed along the coastline are mangroves, agricultural activity and other geomorphological features including a recently collapsed arch, and caves which are eroding. In the open waters adjacent to Los Gallos are three eroded stacks which are believed to be remnants of the headland (Deane, 1973).

The study area is influenced by a large anti-cyclonic gyre which characterizes its current patterns (Gopaul and Wolf, 1995) and a residual flow from south to north fed by the Guiana current (van Andel and Postma, 1954). According to Oostdam (1982), the flows occurring through the Serpents Mouth register bottom speeds of $17cms^{-1}$ and is dominated by a northerly flow pattern which is directed offshore. The author further reported a reduction in speed $5cms^{-1}$ in the central part of Columbus Bay. Adding to this pattern are southwardly directed currents with magnitudes of $4cm^{-1}$ in the vicinity of Los Gallos. Oostdam (1982) postulated that the influx of water through the Serpents Mouth partially returns southward in both the bottom and surface layers in the form of an eddy. Long-shore currents have a predominant southward direction and are generated by approaching waves. This current coupled with the southward return of water subsequently converges with the northerly flow in the vicinity of Corral Point and Punta del Arena, resulting in a sediment plume at Corral Point. Longshore currents at Columbus bay were recorded on an average of $22 cms^{-1}$ (Oostdam, 1982). These longshore currents have the potential to influence the existing circulation patterns by increasing or decreasing resultant magnitudes thus influencing the potential for sediment transport, and coastal erosion.

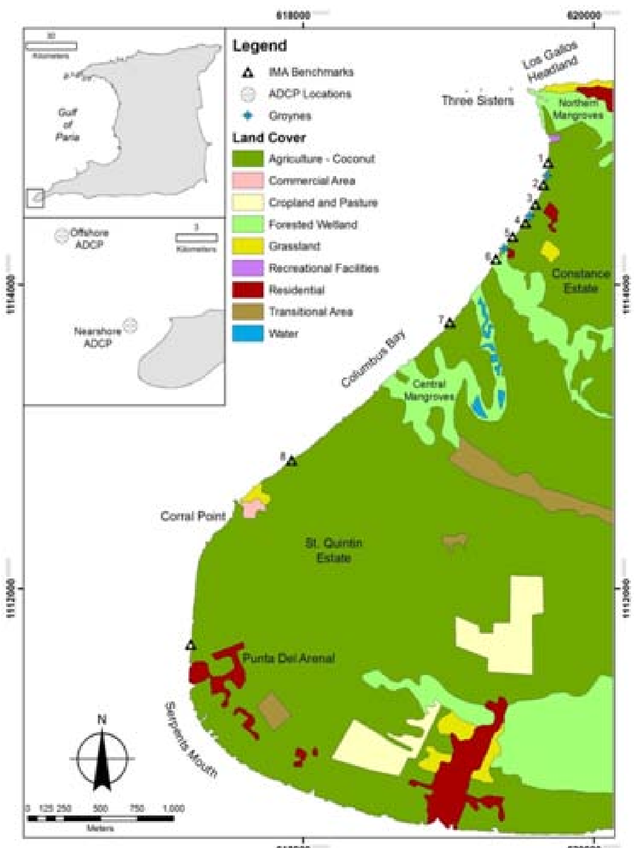

Figure 1 : Study area located at Columbus Bay, south-western peninsula, Trinidad

Wave processes also play a critical role in sediment transport and by extension erosion. In the study area, wave conditions are characterized by low wave heights of periods less than 4secs. These waves generated from the North East Trade Winds result in wind waves ranging between 0.39m and 0.46m (Deane, 1973). However, swell wave events which mainly occur in the hurricane season (June to November) have wave amplitudes that range between 0.76m and 1.5m (Deane, 1973). Tides are micro-tidal with a spring range of approximately 1.5m and these were also found to influence current speed and direction experienced in the bay (Oostdam, 1982).

Sediment analysis provides an indication of transport trends and can point to origins which are important in coastal processes studies. At Columbus Bay, the sediments range from fine to very fine-grained quartz sands. Silt forms part of the sediment composition but is found mainly in the north of the bay. Minor deposits of gravel are observed at Los Gallos and Corral Point. Bathymetry reveals that the area is gently sloping with isobaths between 2m to 22m. Mapping of the bathymetry indicates a narrow channel at Corral point which can play a potentially significant role in sediment transport. Young unconsolidated sediments (sandstone formation) of varying degrees of mineralization characterize the coastline of Columbus Bay thus making the area highly vulnerable to erosion, especially from the influence of tides, wave and currents (Deane, 1973). The continual coastal erosion at Columbus Bay has witnessed the decimation of agricultural crops, which is an annual occurrence (Fig. 2b,d, g). In an attempt to arrest this erosion and protect the agricultural estate, the land owner installed three sandbag groynes in the northern section of the bay, between stations 1 to 5 (Fig.2b,d).

The coastal erosion at Columbus Bay has been studied in an attempt to understand the causative factors (Darsan, Ramnath, and Alexis, 2012; Deane, 1971; Deane, 1973; Hudson, 1988; Kanhai, 2009; Kenny, 2002; Kenny, 2007;Oostdam, 1982). Most recently, (Alexis, 2012) noted accretion within the groyne field, with enhanced coastline retreat rates of -2.87m/yr outside of the groyne field in the southern section of the bay at station 7 (Figs. 1& 2).

Figure 2 : Visible coastline erosion at Columbus Bay

III. Methods

The methodology combines traditional levelling techniques and numerical modelling. The study utilizes the MIKE 21 numerical model and applies the MIKE 21 Spectral Wave (SW) model, the MIKE 21 Hydrodynamic (HD) flow model and the MIKE 21 Sediment Transport (ST) model. Field data are integral to the model and in this regard various parameters were measured and input into the model (Table 1). Data were collected at the offshore location using an Acoustic Doppler Current Profiler (ADCP) and used to 'impose' the wave and flow models. Similarly data were collected at the near shore location were used to calibrate and verify the models.

Table 1 : Oceanographic data collected and used as input for MIKE 21 models

Type	Parameters Measured	Data Period and Interval	Data Input into the Coupled MIKE 21 Model*	
			Spectral Wave (SW)	Hydrodynamic (HD)
Offshore: Geographic Co-ordinates 611 627 E 1121079 N				
Waves	Significant Wave Height, Hs (m) Wave period, Tp (sec) Wave Direction, θ (˚)	18/04/2013 to 16/07/2013 1 hour intervals	✓	
Currents	Current Speed (ms^{-1})	18/04/2013 to 16/07/2013 10 minutes intervals		✓
Water Levels	Water Level (m)	18/04/2013 to 16/07/2013 10 minute intervals		✓
Nearshore: Geographic Co-ordinates 616 653 E 1114791 N				
Waves	Significant Wave Height, Hs (m) Wave period, Tp (sec) Wave Direction, θ (˚)	26/03/2013 to 17/07/2013 hourly intervals	✓✓	
Currents	Current Speed (ms^{-1})	26/03/2013 to 17/07/2013 10 minute intervals		✓✓
Water Levels	Water Level (m)	26/03/2013 to 17/07/2013. 10 minute intervals		✓✓

Key ✓- used input for models ✓✓- used for calibration/validation of models * - output from these models used as inputs for sediment transport model

The basis of the model development is the creation of a computational mesh and boundary conditions. The former provides bathymetry information by incorporating bathymetric data which was collected using a dual frequency echo-sounder and global positioning satellite survey devices in real time kinematic mode. This bathymetry topography forms a critical component in determining the influence of waves and currents on sediment transport rates which effect morphological change. These computations are provided at each simulation time step. Boundary conditions are the principal drivers that influence sediment transport and morphology and were used to provide initial conditions to support computation of nearshore parameters. The results from the SW and HD modules were input in to the ST module to compute the along shore sediment transport rates which are used to modify the existing bathymetry. This modified bathymetry is then used by the SW and HD modules to compute the wave and current patterns in the subsequent time step after Broker *et al.,* (2007) (Fig.3).

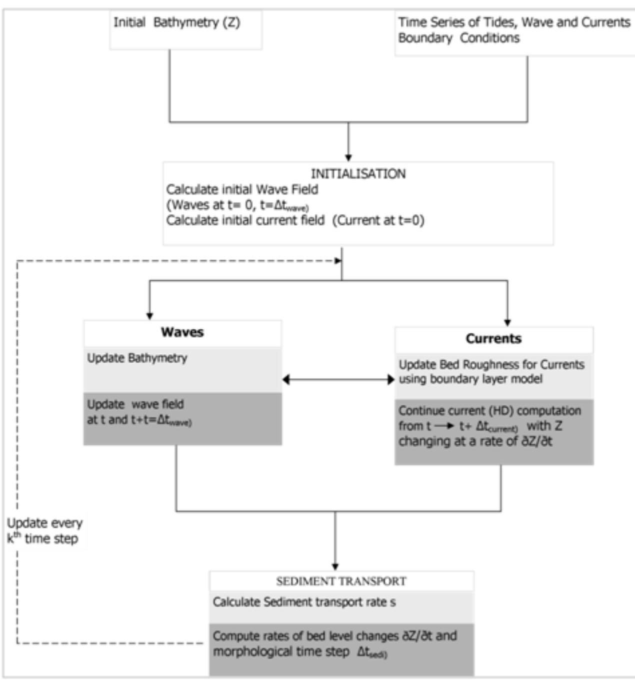

Figure 3 : Flow diagram of methodology (Modified from Broker *et al.,* 2007)

a) Development of Flexible Mesh

The development of a flexible mesh is a critical component in this modeling process which incorporates the bathymetry using a triangular grid. These triangular elements are contoured to the curved coastline of Columbus Bay which represents the bathymetry. Given that sediment transport occurs mainly in the near-shore, the choice of triangular elements range from a maximum of 4.5km^2 to a minimum of 9m^2 in the near-shore area. In total, the flexible mesh developed for this study contained 34,282 nodes and 54,702 elements.

b) Boundary Conditions

- *MIKE 21 SW boundary conditions*

Offshore wave parameters of e significant wave height (Hs), wave period (T), wave direction (θ) and dimensionless factor (n) were input into the model along the east, west and north boundaries (Fig.4).

- *MIKE 21 HD boundary conditions*

Estimating flow conditions in the bay using this model require a two time varying data sets to be specified as boundary conditions. These are: a) horizontal (u) and vertical (v) components of current magnitude, specified in m/s and b) water levels referenced to mean sea level (MSL), specified in meters (m). These data were collected simultaneously with wave data at the time interval and period specified in Table 1. These data were specified along all the boundaries.

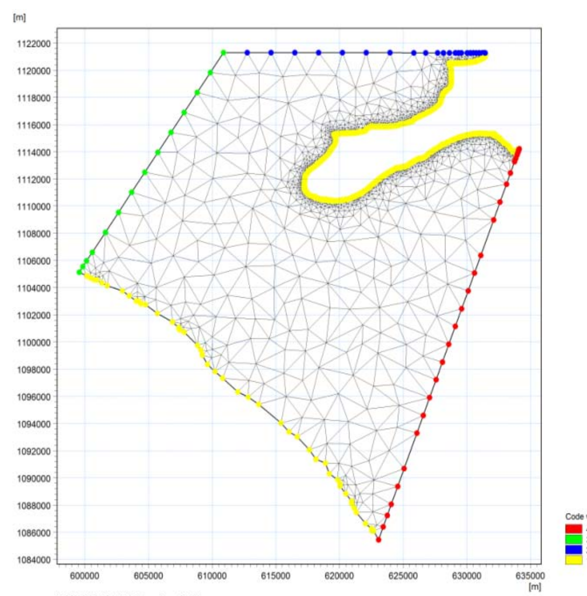

Figure 4 : Model boundaries used for SW and HD model. The east (red), west (green), and north (blue) boundaries allow oceanographic parameters to be specified for the model area. The yellow boundaries represent land and do not allow water to enter

IV. Model Set-up

The MIKE 21 SW model was run in a quasi-stationary mode using directionally decoupled parametric formulation with time series wave data at the specified boundaries. The model was run for a period of six days from19th April to 24th April, 2013, with a time step of one hour, to produce model results which were used for the calibration process. During this process, the frictional co-efficient was varied a number of times starting with the default value of 0.04 until the results achieved in the model were similar to that of the parameters measured at the near shore location (Fig. 5).

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Similarly the MIKE 21 HD model was computed using shallow water equations with a low order time integration using a minimum time step of 0.01 secs and a maximum time step of 300 secs. The model was run at a time step of 1800 secs. The bed resistance was defined using a Manning coefficient and turbulence was introduced using the Smagorinsky eddy viscosity model. The model was run for a period of six days between the 19th April to the 24th April, 2013 to support the calibration process as per the established duration as seen in (Broker *et al.,* 2007). For this process, the Manning number was varied starting from the default value of 32m $m^{(1/3)}$/s together with the Smagorinsky eddy viscosity which was varied from the default value of 0.28. These co-efficients were varied until the modeled time series data and that of the measured were similar.

Results from the SW and HD models were then used as the forcing input for computing the sediment transport model at each element in the triangular mesh. A sediment transport table was formulated by discretizing measured data into bands. This ensured that combinations of bathymetry, current, wave and sediment conditions appearing in the model were within the range of measured data. This provided a basis for the ST model to derive sediment transport with significant levels of efficiency. The transport tables were calculated using the Cnoidal wave theory (Scoones and Theron, 1995; Isobe, 1985). A mean grain size of 0.11mm was used, a porosity of 0.4 and a grading coefficient of 1.1 were taken as constraints for the sediment properties (Alexis, 2012).

a) Calibration and verification

The calibration process involved the computation of the root mean square error (RMSE) of modeled and measured data, of the coefficients used in the model. Further, the SW and HD models were validated by running the models for a three month period (19th April to 16th June, 2013) and one month period (19th April to 18th May, 2013) respectively, in order to determine the RMSE of measured and modeled data.

i. *SW model*

For the SW model, a final value of 0.25 was used in the calibration process as the frictional coefficient. This resulted in a RMSE of 0.2 for measured and modeled data obtained from the nearshore site. This frictional co-efficient was then used for further model simulation between the period 19th April to 16th June, 2013. The modeled and measured data for parameters on wave height, wave period and wave direction are illustrated in Fig. 5. Further the resultant modeled data when compared with measured data shows significant similarity with a calculated RMSE of 0.2.

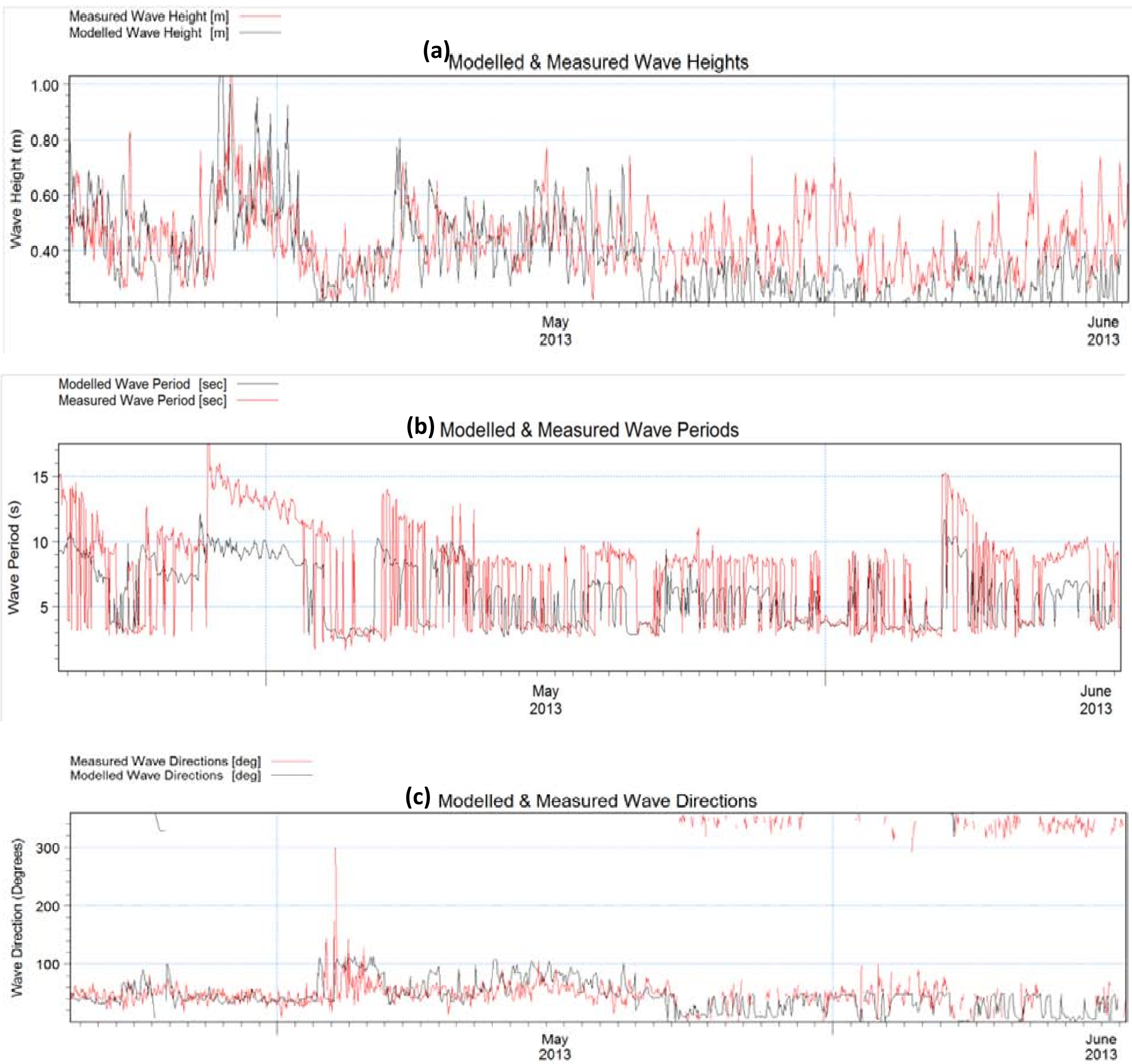

Figure 5 : Modelled and measured (a) wave heights (b) wave periods and (c) wave directions from (19th April to 16th June, 2013) showing similar trends

ii. *HD model*

A similar process was conducted for the calibration of the HD model. Upon the completion of the calibration process, the final Manning number in put into the model was 26m$^{1/3}$/s. This value was used to perform further model simulations and a comparison was made between measured and modeled current magnitudes and direction. This model ran for a period of one month from 19th April to 18th May, 2013. Resultant modeled current magnitudes and speeds were graphically plotted against measured magnitudes and direction (Fig. 6). Finally, to ensure that the model results reflect the measured data, the measured and modeled data were verified by computing the RMSE which produced a value of 0.2.

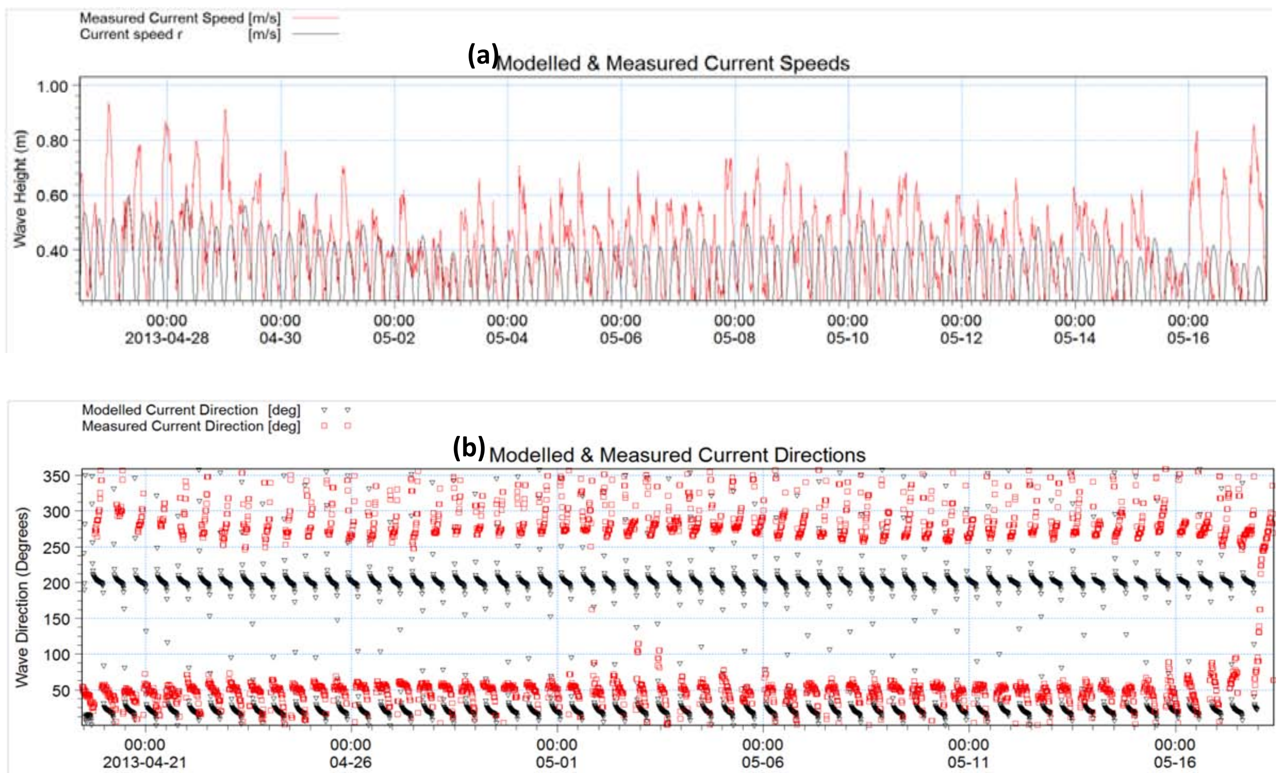

Figure 6 : Modelled and measured (a) current speeds and (b) current directions from (19th April to 18th May, 2013) showing similar trends

b) Beach profiling

Beach profiles were measured using standard surveying techniques, with the use of a Sokkia B20 automatic survey level, a dome-head tripod, a 100m measuring tape, a 7.60m survey staff and a Brunt on direct pointing compass. Readings were taken from the station at a 4m interval along the profile direction and to a water depth of approximately 1.50m. The break in slope method was also employed so that notable changes along the profile direction such as the vegetation line, high water mark or a change in gradient such as a scarp or cusp, were also accounted for and recorded. Beach profiles were monitored monthly at the 8 shore-normal beach profile transects situated along Columbus Bay. These profiling stations were surveyed from October, 2009 to April, 2013 and the beach profiles were conducted during a spring low tide to maximise profile lengths. These profile data were used to monitor the coastline retreat and erosion rates over the study period.

V. Results

The coupled model produced a number of results such as wave power, wave height, wave radiation stresses, wave direction, current speed and direction, total load magnitude and direction and rate of bed level change. These were analyzed against the tidal influences which are spring and neap conditions at flood and ebb states.

a) Wave conditions at Columbus Bay

i. *Wave power*

Results indicate that the wave direction is constant and approaches from the north-west. Flood conditions in terms of wave power show values between 1.6kWm^{-1} and 4.0kWm^{-1} which were higher when compared to ebb conditions of 0kWm^{-1} to 3.2kWm^{-1} (Fig.7). These values seem to suggest that during a flood tide condition, it is likely that more sediment is mobilized thereby increasing the potential for transport and influencing the rate of erosion.

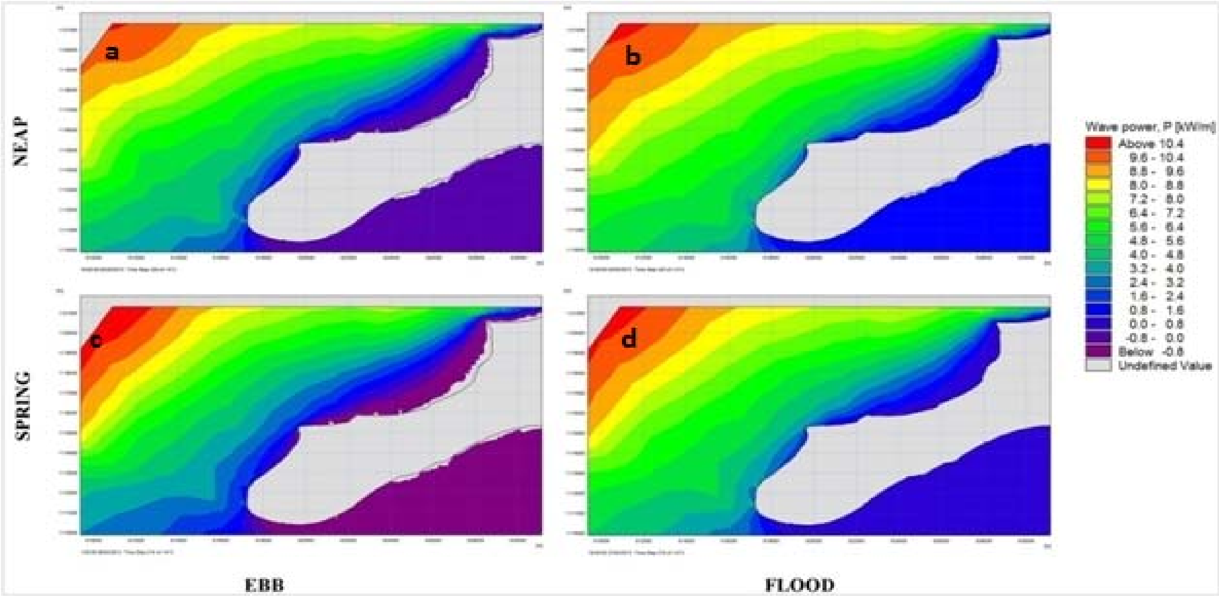

Figure 7 : Modelled wave power during Spring and Neap Cycles (a) wave power ranging between 0 and 3.2kW/m during neap ebb, (b) wave power ranging between 1.6 and 4.8kW/m during neap flood, (c) wave power ranging between 0 and 2.4kW/m during spring ebb and (d) wave power ranging between 1.6 and 4.0kW/m during spring flood. Generally low wave power is noted in Columbus Bay < 4.0kW/m which suggest little sediment transport due to waves

ii. *Wave height and direction*

The differences observed between spring and neap conditions regarding wave heights were minimal (Fig. 8). For both cycles, wave approached from the north west with offshore wave conditions ranging between 1.04m and 1.2m and near shore waves between 0.64m and 0.96m. This observation points to a reduction in wave energy caused by dissipation as a result of bathymetry interaction.

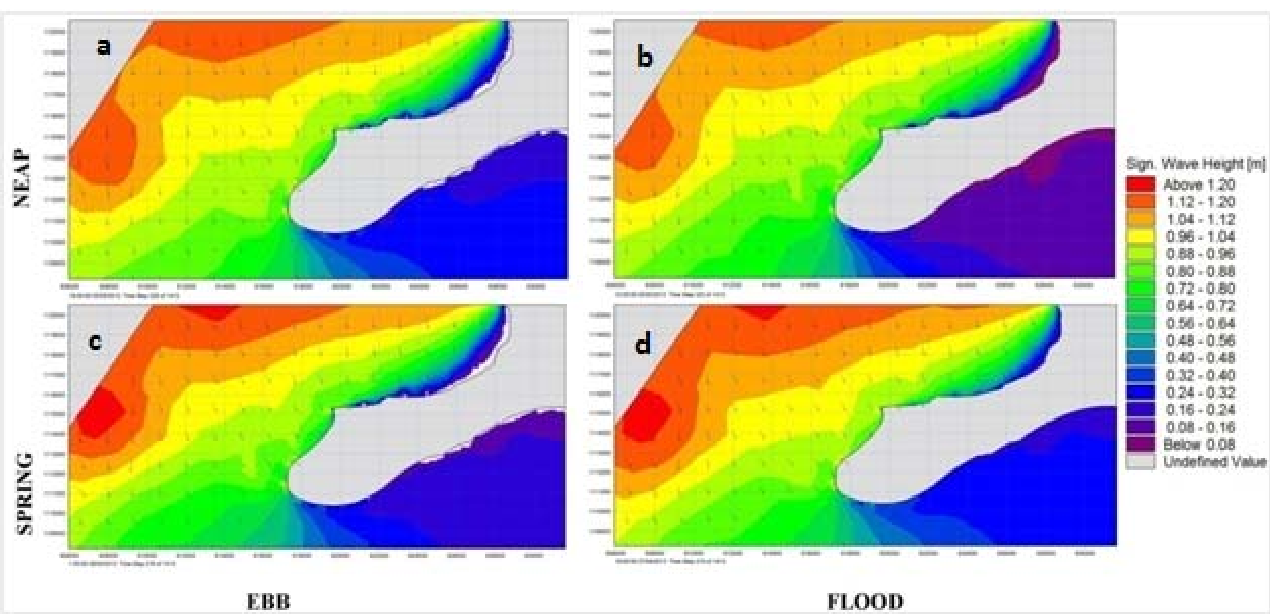

Figure 8 : Modelled significant wave height during Spring and Neap Cycles. (Arrows indicate wave direction). (a) wave height ranging between 0.72 and 0.88m during neap ebb, (b) wave height ranging between 0.64 and 0.80 m during neap flood, (c) wave height ranging between 0.72 and 0.88m during ebb spring, (d) wave height ranging between 0.80 and 0.96m. Modelled waves in Columbus Bay are from the north-west forming a perpendicular angle to the shoreline. This suggests very little sediment transport occurs due to waves as the angle to the shoreline is not oblique.

iii. *Wave radiation stresses (Sxy)*

The ebb and flood conditions for both spring and neap cycles show similar values. Observed values ranged between $-0.175 m^3/s^2$ and $-0.075 m^3/s^2$ for both ebb and flood conditions respectively (Fig. 9). These negative values indicate that sediment from the beach area is being removed as a result of wave radiation stresses.

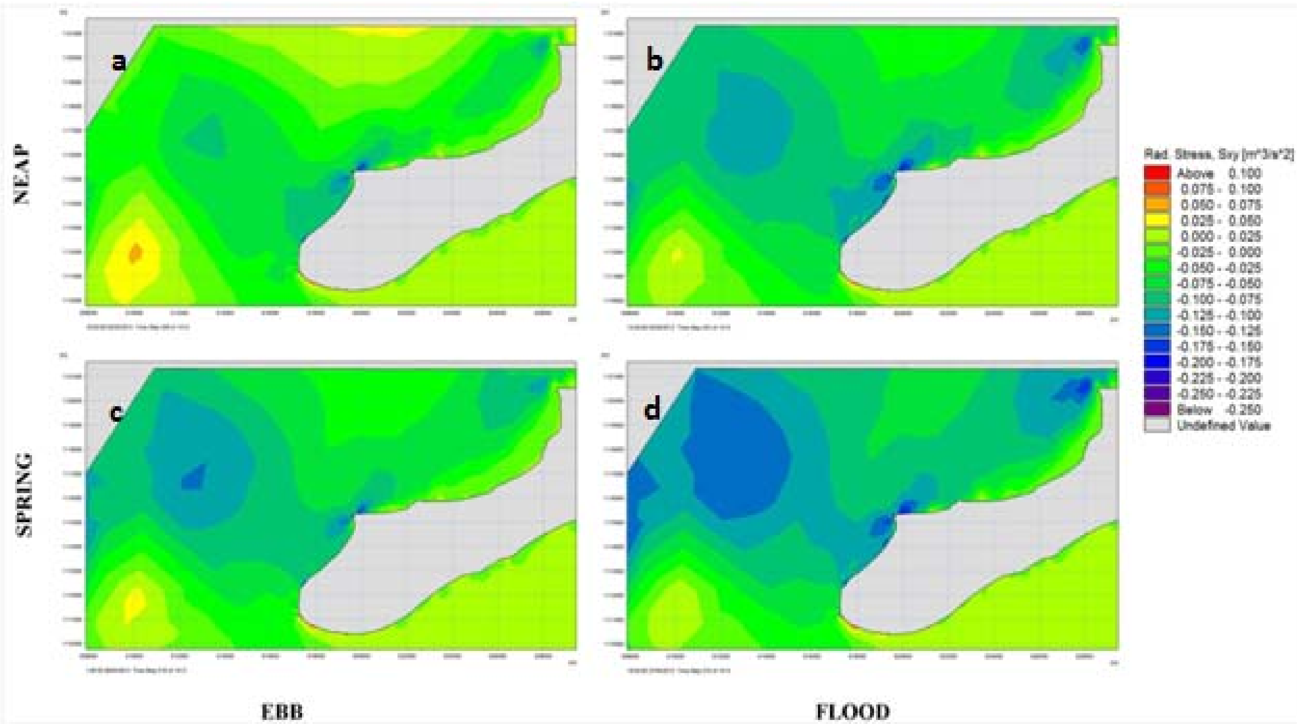

Figure 9 : Modelled wave radiation stresses during Spring and Neap Cycles. (a) wave radiation stress ranging between -0.125 and -0.075 during neap ebb, (b) wave radiation stress ranging between -0.175 and -0.075 during neap flood, (c) wave radiation stress ranging between -0.175 and -0.075 during spring ebb, (d) wave radiation stress ranging between -0.175 and -0.100 during spring flood. In Columbus Bay wave radiation stress is low and does not suggest significant sediment transport. Higher wave radiation stresses are noted around the headland possibly due to small eddies being formed

b) *Hydrodynamic conditions at Columbus Bay*

i. *Current speeds and directions*

The modeled results illustrate that there is a difference in speed between ebb and flow tidal states, in particular the ebb currents producing a higher magnitude (Fig. 10). Ebb currents are shown to be stronger than flood currents with values ranging between 0.18 to $0.36 ms^{-1}$ on a spring tide and 0.36 to $0.54 ms^{-1}$ on a neap tide. During a spring flood tide, currents range between 0.06 and $0.24 ms^{-1}$ and a neap flood tide produce currents between 0.06 and $0.12 ms^{-1}$. Maximum speeds of $0.54 ms^{-1}$ were observed on the ebb neap tide. In terms of current direction, there is a marked reversal in the flow during the ebb and flood tidal states. This difference is translated into a southwest flow during a flood tide and north east flow on an ebb. These results suggest that tidal flows are more influential on sediment transport when compared to waves.

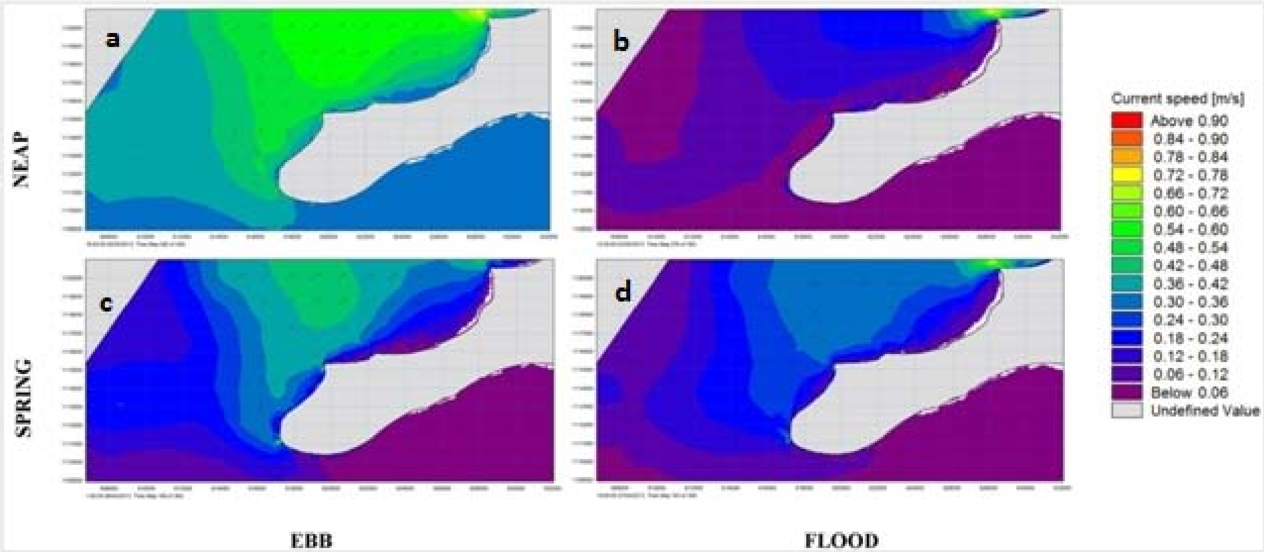

Figure 10 : Modelled current speed and direction during Spring and Neap Cycles. (Arrows indicate current direction). (a) current speed ranging between 0.36 and 0.54ms^{-1} during neap ebb and current is directed to the north east (b) current speed ranging between 0.06 and 0.12ms^{-1} during neap flood and directed to the south west, (c) current speed ranging between 0.18 and 0.36ms^{-1} during ebb spring and directed to the north east, (d) current speed ranging between 0.06 and 0.24ms^{-1} during spring flood and directed to the south west. Currents within Columbus Bay have the potential to move sediment but have higher potential to do so during the ebb than the flood state. During the ebb state sediment is pushed to the north east consistent with the current direction

c) *Sediment transport conditions*

i. *Rate of bed level change*

The rate of bed level change for spring and neap cycles is negligible, measuring -1.0 to 0.2m in the spring and -0.8 to 0.8m in the neap .In contrast, there are marked differences between tidal ebb and flood states. During ebb conditions negative values of rate of bed level change were observed, with rate of bed level changes ranging between -0.8 and -0.4m during spring ebb and -1.0 and -0.6m during neap ebb (Fig.11).These negative values indicate erosion during the ebb tides. During flood conditions for spring and neap tides, positive rates of bed level change (between 0.0 and 0.8m) are observed, indicative of accretion.

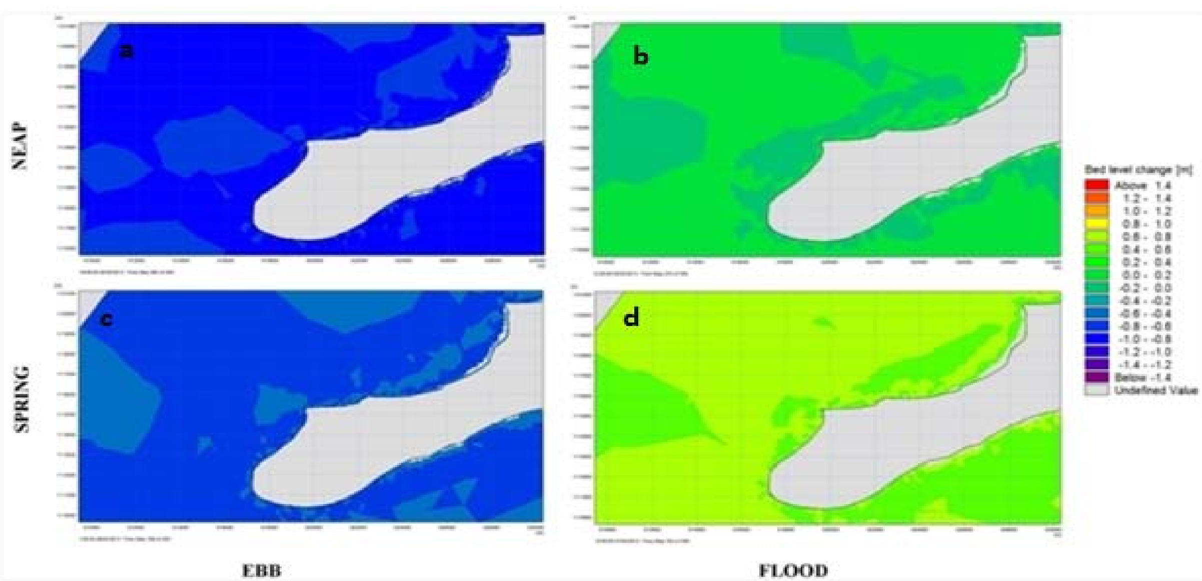

Figure 11 : Rate of bed level change during Spring and Neap Cycles. (a) rate of bed level change ranging between -1.0 and -0.6 during neap ebb. (b) rate of bed level change ranging between 0 to 0.2 neap flow, (c) rate of bed level change ranging between -0.8 and -0.4 spring ebb (d) rate of bed level change ranging between 0.4 and 0.8 during spring flood. Positive bed level change occurs during the flood state and during the ebb negative bed level change occurs. This negative bed level change coincides with higher current speeds during the ebb tide state

d) Beach profile analysis

The information on the monthly beach profile monitoring was collated to annual profiles for this study using eight stations in the study area. This was done to complement the modeling output and to provide an indication of the coastline retreat observed over the study period (Fig.12). Station1 located just updrift of the first groyne has recorded accretion on the berm, but the rest of the profile experienced a general lowering of sand levels over the study period. In contrast, Station 2 located (just downdrift of the first groyne) has accreted from 2009 to 2010 after the installation of groynes. Further, no coastline retreat was observed at this location, although dynamic profile changes have occurred between 2010 and 2013. Station 3 located updrift of the second groyne shows signs of erosion due to lowering of sand levels, and not as coastline retreat. At station 4, located between the second and third groynes, the profile has recorded accretion from 2009 to 2010. From 2013 to 2013, the profile continues to display dynamism though at higher sand elevations when compared to 2009.

At station 5, (located just downdrift of the third groyne) there was no coastline retreat, and with the exception of January 2012, the profile was not as dynamic as at the other stations. The benchmark at Station 6 located just outside of the groyne field was lost to coastline erosion, and as such was not surveyed thereafter. Station 7 located at the central section of the bay has continued to experience high rates (just over 2 m/yr) of coastline retreat. Station 8 located in the southern section of the bay is the most vulnerable. In addition to high rates of coastline retreat (approx. 2 m/yr), the profile is also experiencing a significant level of lowering of sand elevations. These results support the continued erosion trend as reported by Alexis (2012). Accretion was observed in the lee of the sand bag groynes located between stations 1 to 6. From station 7 in a southward direction, the coastal erosion continues to be a serious problem. This is evident by the coastline retreat recorded at stations 7 and 8 (Fig. 12).

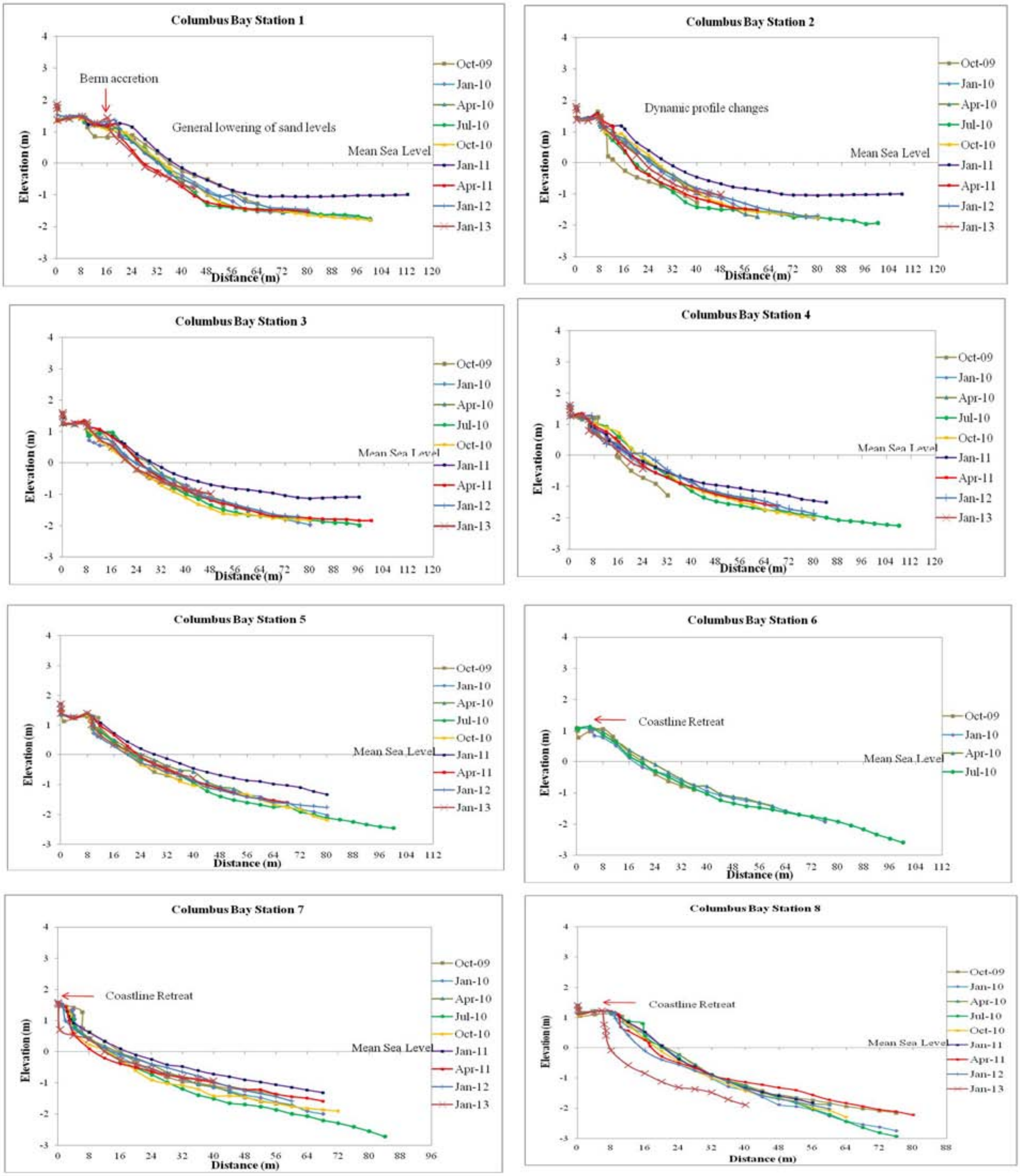

Figure 12 : Selected beach profiles for stations 1-8 (October 2009 to January 2013). Coastline retreat is noted at Stations 6, 7 and 8

VI. Discussion

a) Wave conditions at Columbus Bay

The difference in wave power during spring and neap tide cycles was negligible. This seems to suggest that these cycles do not influence the waves at Columbus Bay to any noticeable extent. Wave power was observed to be negligible in the lee of the Los Gallos headland. This result is expected as the headland acts as a buffer to wave energy. Overall, the output from the modeled wave power suggests that waves are not a determinant factor for sediment transport in the bay. The demonstrated low wave height values in the near shore area translate into a low energy environment which suggests a minimal influence on sediment transport. Sediment transport is influenced by simultaneous interaction of both wave height and direction. The observed low wave heights and wave

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direction are not conducive to sediment transport as it makes a perpendicular angle with the shoreline, and would not set up strong long shore currents. Under fair weather conditions, these wave characteristics have little or no influence on the sediment transport operating in the bay.

b) Hydrodynamic conditions at Columbus Bay

Results suggest that currents during the ebb flow are responsible for the majority of sediment transport along Columbus Bay. The currents during an ebb flow have a north-easterly direction causing sediment to be transported in that direction. It is also evident that in the vicinity of the headland, such phenomenon is influential in causing sediment accretion in this area. Due to the semi-diurnal nature of the tidal regime, it is possible that the flow reversal experienced also aids in tidal re-suspension of sediments, which promote sediment transport. These findings concur with those of Alvarez and Jones (2004) and Darsan (2013).

c) Sediment transport conditions

The study area is influenced by the Guiana current which has a residual flow from south to north through the Serpents Mouth (van Andel and Postma, 1954; Oostdam, 1982; Gopaul and Wolf, 1995). Results show that the current speed and direction are the main drivers of sediment transport in the bay with most of the erosion occurring during the ebb state. Based on this modeled result, it is possible that during the ebb flow, the combined effect of tidal ebb currents and the Guiana current flowing in the same direction, leads to increased sediment transport. Given that the bay experiences ebb states on a semi diurnal basis, this therefore amounts to significant erosion mainly driven by tides. Such findings are invaluable to management decisions as it aids in targeted intervention toward arresting erosion and promoting sustainable land management.

d) Beach profile analysis

The installed groynes in the northern section of the bay would undoubtedly interrupt sediment transport within the area of installation. The long shore current direction is towards the south-west, and under typical conditions, accretion would be observed up drift of each groyne, with erosion occurring on the down drift side. Beach profile data indicated accretion at site 2 just down drift of groyne 1, which is unusual. Station 3 located updrift of the second groyne also showed signs of erosion, and should have been accreting under the dominant long shore current direction. The accretion observed at station 2, and the erosion at station 3 may be due to the influence of the stronger tidal ebb current from the opposite direction - and is in agreement with the modelled hydrodynamic conditions of the bay. These findings suggest the presence of the combined effect of long shore currents and tidal ebb currents which are keeping the sediment entrained and thereby promoting erosion in the observed areas along the bay.

e) Contribution to land management

Erosion of any magnitude in Columbus Bay can affect sustainable land management given the level of interaction between the coastal processes in the form of erosion and the land use in the area. Columbus Bay has a mixture of land use including a critical mangrove habitat which provides valuable ecosystem services especially in soil stabilization. In addition, the presence of agricultural and residential activities forms the micro–economic activities in the area. These activities over the years are been affecting by land loss. In an effort to promote sustainable land management of this area, one prudent approach will be to institute some measures which considers the coastal dynamics to protect the land from coastal erosion. Such approach will be beneficial as it will allow the wetlands to continue to provide the environmental services while simultaneously allowing agricultural activities to strive, thereby sustaining the economy of the area. The results shows that the coastal processes in Columbus Bay is dynamic and therefore consideration needs to be given to some form of engineered solutions. However, the choice of coastal defense must be carefully considered as improper utilization or poorly designed engineering structures can actually exacerbate the erosion problems.

Given that currents are one of the major contributing factors to erosion in this area, perhaps the use of strategically placed groynes may be an option for planners which will reduce currents in the lee of structures thereby promoting accretion. These groynes could be used to trap sediment being transported with the north easterly directed ebb current. Given that accretion was noted in the lee of the groynes 1 to 6, further evaluation of conceptual groyne field layouts should be further tested using the MIKE 21 coupled model. A note of caution is that any proposed groyne field should be tested with various spacing and lengths for groynes to determine the impact on sediment transport as these parameters influence the efficiency of the groynes (Reeve and Fleming, 2004).

The outcomes of this study are relevant as it furthers the understanding of the existing conditions at the bay. These data can be used as a baseline to which further comparison can be made of oceanographic conditions, should engineering solutions be given greater consideration as an option in sustainable land management. In broader terms, this study has given policy makers an opportunity of incorporating marine data into land planning. Traditionally, land use planning involves solely the land area of the country which has proven to be less effective in coastal areas. This has led to more reactive approaches to coastal management in the event of erosion and storm surges among others, thereby resulting in a significant financial implication in terms of sea defense and in the long term, settlement relocation. These problems are set to increase given the predicted and actual impacts from the effects of climate change.

The integration of marine processes and their impacts into land planning can lead to more comprehensive planning which can minimize some of the issues cited above. This approach is highly beneficial especially in Small Island States (SIDS) such as Trinidad where land resource is limited coupled with growing population pressure (Singh, 2008; Singh, 2005). Therefore this approach of incorporating the marine component into land planning as exemplified by this study seems to be the way forward.

VII. Conclusions

The coastal area of Columbus Bay is part of a very dynamic system due to its geographic and oceanographic setting. The ongoing coastal erosion directly influences the shoreline evolution of the bay and poses challenges for effective land management. Results indicated that the most influential factor in effecting sediment transport was current speed and direction during the ebb state. While tidally generated currents in macro-tidal, estuarine, and tidal inlets have been well documented to be influential in coastal erosion, this study has revealed a similar influence in a tropical micro-tidal setting. Wave energy, although present, plays a negligible role in this environmental setting, and as such, appropriate measures to mitigate the coastal erosion must address the tidal currents operating in the bay. The deploying of sand bag groynes has proven to be somewhat effective in the northern section of the bay, though more engineering considerations need to be given in an effort to develop a design that suits the conditions present. In addition, proper placement of the groynes needs consideration in order to ensure effectiveness.

This study has demonstrated the influences offshore phenomena such as sediment transport can have on the shoreline, and the role such information could play in informing land use planning. Often land management decisions are made without the use of robust scientific data, often leading to more pronounced problems such as increased erosion, further damage of infrastructure and loss of amenity thereby affecting human well being. This study has demonstrated the importance of understanding the coastal dynamic processes and also points to the potential benefits such work plays in supporting sustainable land management approaches, a notion being highly advocated as needed in SIDS around the world.

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 14 Issue 5 Version 1.0 Year 2014
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Timber Merchantable Residue Quantities and Harvesting Efficiency in Tropical Forests of Ghana; Drivers of Wood Residue Utilization for Forest Conservation

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Keywords: *deforestation in ghana, efficient wood utilization, forest conservation, harvesting efficiency, merchantable residues.*

GJSFR-D Classification : *FOR Code: 820199*

TIMBERMERCHANTABLERESIDUEQUANTITIESANDHARVESTINGEFFICIENCYINTROPICALFORESTSOFGHANADRIVERSOFWOODRESIDUEUTILIZATIONFORFORESTCONSERVATION

Strictly as per the compliance and regulations of :

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Dadzie Peter Kessels [α] & Martin Amoah [σ]

Abstract- The practice of continuous extraction of only the main boles from felled trees to meet high demand for timber is one major cause of deforestation in Ghana, but merchantable residues (branchwood and stem off-cuts) left un-extracted can be utilized to increase efficient wood utilization to conserve the forests and the entire ecological system. This study assessed harvesting efficiency, and quantified residues left in the forests after harvesting, to ascertain the extent to which residues utilization can affect forest preservation. Volumes of timber sections of 154 trees from 3 forest ecological sites were quantified using Smalian's equation, after which harvesting efficiencies were determined. Results indicated merchantable residue quantity of 742.57m^3 (24.69%) ranging from 16.34% for *C. pentandra* to 40.45% for *Khaya ivorensis* and overall harvesting efficiency of 75.31% (ranging from 59.54%- *Khaya ivorensis* to 83.66% -*Ceiba pentandra*). ANOVA indicated significant difference P=0.000 at 95% confidence level in harvesting efficiencies among species but not sites (P=0.435), and in both branchwoods and off-cuts volumes among species and sites P=0.000. Stronger positive correlation existed between extracted log volume and total merchantable wood (R^2=0.866) than extracted log volume and total merchantable residue volume (R^2=0.128). Extraction and utilization of merchantable residues were found to have the potential of conserving about 8 hectares of forest land. It was concluded that, extraction and eventual commercialization of merchantable residues can substantially improve efficiency in wood utilization and could conserve the forest vegetation and ecology.

Keywords: deforestation in Ghana, efficient wood utilization, forest conservation, harvesting efficiency, merchantable residues.

I. Introduction

Assessment of wood residue quantity and logging efficiency is an integral part of biomass and raw material availability assessment and is necessary for many applications including commercial exploitation of timber to the global carbon cycle (Basuki, et. al., 2009). On account of the importance of such assessment, it is reported that under the United Nations Framework Convention on Climate Change (UNFCCC), countries have to report regularly on the state of their forest resources and emerging mechanisms, such as Reducing Emissions for Deforestation and Degradation (REDD) in developing countries (UNFCCC 2008; Basuki et al. 2009).

Besides the demand from UNFCCC, in the face of dwindling timber resources and the effects of deforestation, inventory on total merchantable wood and residues provide indications on potential timber resources (raw materials) availability for industry and efficient utilization of wood (Amoah and Becker 2009) which have all become issues of much concern to stakeholders in sustainable wood utilization and forest management, as well as environmentalists (Peskette et al. 2008; Marfo 2010; The REED Desk 2014). Similarly, it is reported that the timber resources play very important environmental and economic roles in many countries, including Ghana, and for that matter their efficient utilization is of vital importance. Environmentally, the forest cover protects the soil from erosion, protects rivers and streams to ensure quality water availability for consumption, and also helps to provide continuous and sustainable clean air for living organisms including man (Okai 2003; Oregon Forest Resources Institute 2011; Antwi 1999). The forest is therefore responsible for the protection and preservation of the entire forest ecosystem and climate including carbon sequestration (Rinebolt 1996), but tropical forests hold an average of about 50% more carbon and therefore sequester more carbon than those outside the tropics (Peskette et al. 2008; Houghton 2005). Meanwhile, in the wake of Ghana's continuous increase in oil exploration and production activities, the environmental role of carbon sequestration of the tropical forests in Ghana becomes extremely crucial and essential (Ministry of Lands and Natural Resources-MLNR 2012).

Again, and even more importantly in this regard, adolescent and matured trees, rather than young ones, are the major sources of carbon sink in the tropics

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(Oregon Forest Resources Institute 2011; Ministry of Lands and Natural Resources-MLNR 2012). However, there appears a gloomy picture about green house gas (especially CO_2) emissions (GHGEs) in Ghana in the near future. In 2006 the total GHGE was about 24 metric tonnes of CO_2 equivalent. This emission level, which is ranked low (i.e. 108th globally), has the potential to increase as the country emerges as crude oil producer (Ministry of Lands and Natural Resources 2012). Thus GHGEs in Ghana are forecasted to increase above the 2006 levels and will gradually put the climatic structure and conditions in danger for all living organisms, including man (Ministry of Lands and Natural Resources 2012) and therefore, the forests need to be conserved to avert any environmental and health consequences from carbon dioxide emissions.

Economically, forests in Ghana provide timber and other products that serve as one major foreign exchange earner for the country's economy and raw material base for the timber related industries, and also provide jobs for the population. Export of timber products is ranked third after cocoa and minerals, in Ghana's export products mix and provided about 7% by value of all exports in 2011 (Ministry of Lands and Natural Resources 2012). It is however reported that, deforestation and dwindling trend of Ghana's wood resources have led to a fall in forest products contribution to GDP to a current level of 4% (Ministry of Lands and Natural Resources –MLNR. 2012). Additionally, the wood processing sector employs more than 100,000 people and supports the livelihoods of about 15% of the population (Agyarko 2001; Asumadu 2004).

However, deforestation of Ghana's forests appears to threaten the aforementioned benefits and essential environmental responsibilities of the forests. It is reported that deforestation has been identified as a critical environmental issue and Ghana has lost more than 33.7% of its forests, equivalent to 2,500,000 hectares, since the early 1990s (FAO 2010). Between 2005 and 2010, the rate of deforestation has been estimated at 2.19% per annum; the sixth highest deforestation rate globally for that period (FAO 2010). Also, deforestation in Ghana generally translates into about €877,346.903 loss in revenue per annum (World Bank 1988). Moreover, the continuous deforestation situation and its associated timber shortages among other factors, have resulted in some wood processing industries to either fold-up or not operating at full capacity and these have led and are still leading to loss of jobs (Oteng-Amoako et al. 2008). Therefore, since timber resources are major factors in wood products industries' operations, it is evident that the dwindling trend is not only negatively affecting the GDP of the country but also the general economic lives of a lot of people and their dependants.

It is however reported that the major causes among several causes of deforestation include inefficient logging -where only stemwood is extracted for processing to meeting increasing demand for wood and wood products, and misuse of wood residues like branches and off-cuts (World Bank 1988; Hawthorne and Abu-Juam 1995; Ayarkwa et al. 2000 a, b; Okai 2002; Agyarko 2001). From the aforementioned issues it stands to be only a necessity that, cogent steps are taken towards obtaining additional or supplementary raw materials for the continuous existence of the remaining wood products industries (WPIs) while safeguarding the environment and climate. One readily available way of achieving this is to use almost all parts of felled trees (whole tree utilization concept) especially harvesting residues (branches and off-cuts) all of which can possibly serve as supplements or alternatives to stemwood in wood products manufacturing (Haygreen and Bowyer 1996).

Meanwhile, efforts to promote branchwood and off-cuts' utilization triggers the questions of 'what is the current merchantable quantity of the materials, and how much contribution can that make in reducing depletion or conserving the forests?' However, in Ghanaian forests, there have been some studies on quantity of residues (Nketiah 1992; Ofori et al.1993; Eshun 2000). But the most recent studies on 135 felled trees indicated availability of about 25% of merchantable logging residues with Small-End Diameter (SED) averaging 31 cm and 60cm and varied lengths of between 3.0 and 8.5m (Amoah and Becker 2009). Meanwhile normal branchwoods comprise those with diameters of equal or larger than 5cm (Gurau et al. 2008) and therefore there appear to be some normal branchwoods that were not covered in the previous studies. Moreover, the sighted previous studies recommended regular studies to be conducted to ascertain current quantity of residues and this is supported by Basuki et al. (2009) that such inventory should be done over relatively short periods of time, usually 2 to 10 years. Again, trees differ in anatomical properties through physical properties to mechanical properties as a result of genetic, systematic, site soils and climatic or environmental conditions (Haygreen and Bowyer 1996; Pillsbury and Pryer 1989; Ofori et al. 2009; Zobel and Talbert 1991; Tsoumis 1991). It is therefore possible that there can be significant variations in quantity of branchwood and off-cuts among species and sites. But these appear to be limited, not established or unpublished.

It is therefore still important for branchwoods and off-cuts, left after harvesting operations to be quantified to provide information on the current quantity of merchantable residues and timber harvesting efficiency in Ghana and how far the extraction of the residues for commercial processing and utilization can help reduce depletion of Ghana's forests. It is however reported that stump harvesting disturbs the soil structure, increase the risk of soil erosion, and depletes soil nutrient and carbon capital, and all these adversely affect woodland biodiversity and tree health which consequently pose risk to sustainable forest management (Moffat et al. 2011). These effects could be more in tropical forests resulting from complex buttresses on the stumps. The main aim of this present study was to ascertain the current timber harvesting efficiency and quantity of residues that can be commercialized to reduce the undue pressure on stemwood which has led to the continuous felling of trees and subsequent deforestation and degradation, while at the same time avoiding further disturbances of the forest ecosystem and environment. Specific objectives are to estimate: 1) above stump residue quantities; 2) harvesting/logging efficiency and whether there are significant differences in branchwoods, stem off-cuts, and logging efficiency among wood species, and study sites or not; 3) the relationship between extracted log volume and total merchantable wood, and extracted log volume and total merchantable residues.

II. Methodology

a) *Study sites*

This study was carried out in four natural forest reserves located in three ecological zones/sites in Ghana. They included Asukawkaw ($1^0\,0^0$ and $0^0\,0^0$ W; $6^0\,0^0$ and $7^0\,0^0$ N, Moist Semi-Deciduous -South-East zone forest -referred to as site 1 in this study) located at Nkawkaw in the Eastern Region; Abonyere, and Bosambepo reserves ($2^0\,0^0$ and $3^0\,0^0$ W, and $7^0\,0^0$ and $8^0\,0^0$ N, Moist Semi-Deciduous North-West zone forests - referred to as site 2 in this study) located at Akordie in the Brong-Ahafo Region; and Suii river reserve ($2^0\,0^0$ and $3^0\,0^0$ W and latitude $6^0\,0^0$ and $7^0\,0^0$ N, Moist Evergreen zone forest - referred to as site 3 in this study) and located at Sefwi Wiawso in the Western Region (Abeney et al. 2012; Ministry of Lands and Natural Resources - MLNR 2012). The 3 regions where these reserves are located form about 60% of the 5 main regions that have forest reserves in Ghana and which are home to about 71.62% of total forest estate of the country (Antwi 1999).

The range of annual temperature and precipitation of the 3 sites were 23.9-26.9°C and 1200-1400mm; 24.3-27.8°C and 1400-1600mm; and 24.5-28.2°C and 1600-1800mm respectively for sites 1, 2 and 3 (Logah et al. 2013).

b) *Data collection*

Estimation of above-stump total merchantable wood volumes'.

In this study, total above-stump merchantable wood volume (TMWV) refered to extracted log volume (ELV) plus total merchantable residue volume (TMRV) but do not include stumps. Hence *TMWV= TMRV+ ELV.* Smalian's formula was used for the estimation of all volumes in this study (Briggs 1994; Forest Products Management Development Institute 1998). Smalian's formula has acceptably been used to estimate volume of all tree sections (except stumps) as done by Eshun (2000). Though the formula is reported to overestimate stem logs by about 6%, it is considered relatively accurate among cubic scaling formulae (Forest Products Management Development Institute 1998; Patterson *et al.* 2007).

i. *Estimation of merchantable residue volume*

Total merchantable residue volume (TMRV) of each tree and species comprised; 1) Total volume of stem off-cuts (TV_{sof}) which also consisted of volume of stem butt-end off-cuts (V_{sbt}) and volume of stem crown-end off-cuts (V_{scr}), and 2) Volume of branch logs (V_{bch}), of trees and species. i.e. TMRV = TV_{sof} (V_{sbt} + V_{scr}) + TV_{bch}.

a. *Estimation of Volume of stem off-cuts (V_{sof})*

For each tree, V_{sof} was determined by adding/combining the volume of stem butt-end off-cut (V_{sbt}) and volume of stem crown-end off-cuts (V_{scr}), i.e. $V_{sof} = V_{sbt} + V_{scr}$. For both V_{sbt} and V_{scr}, two diameters (at near right-angles to each other) were measured from both the top end (where the first log was cut), and at the base end (where the tree was felled off the stump). The distance between the two ends was measured as the total length of each, after which the diameters and lengths were substituted into Smalian's formula to determine the volume for each off-cut for each tree. The total for each species was found as the sum of the volumes of each tree within the species. At instances where measurements of diameters at any end and full lengths of some sections were not possible, such measurements were estimated and added, as proposed by Dean (2003).

b. *Volume of merchantable branchwood*

Merchantable branch logs volume (V_{bch}) in terms of suitability for lumber production, were considered to be branches without sweeps or crooks and also excluding the basal portions of branch forks (which are basically knots) and damaged branches. As a result, measurements on branches were done in segments (short lengths or billets) to avoid major natural defects (like curvature, sweeps, crooks etc. that can have influence on measurements) similar to what was proposed by Pillsbury and Pryor (1989).

For each tree within the sample, all merchantable branches with diameters ≥ 15cm were measured. For each branch/segment, diameters were taken at the base just above the fork and at the top, just before the next branching. The distances between these two points where diameters were taken, were measured as the length of the branch/segment. Although Pillsbury and Pryor (1989) measured branch segments to include the basal area of branch forks, because such areas are basically knots, they were therefore not considered in this study as being part of merchantable branch log for lumber production. This is also because, knots reduce mechanical strength of wood and can also pose sawing difficulties like blunting of saws. (Haygreen and Bowyer 1996). All visible branches on each tree were measured, but in some cases, there were identified branches which were not accessible for measurements of diameters at each end or full length owing to their locations and the volume of foliage that covered them. For such branches those measurements were estimated and added, as was proposed by Dean (2003). Afterwards, volumes of all segments for each tree were tallied together as the volume of branchwood (V_{bch}) for that tree. The total volume of branchwood (TV_{bch}) for each species was found as the sum of the volume of each tree within the species.

ii. *Volume of extracted log (main boles delivered at the mill's gate)*

Stock survey numbers and species' names recorded on stumps of all trees whose off-cuts and branchwoods were measured, were used to trace their utilised/extracted logs volume (ELV) from log loading yard records (otherwise called felling records) of the respective logging sites (reserves). This was done so as to obtain the exact volumes of logs actually extracted from the sampled trees and which was of much importance in this study for regression analysis. The ELV for each species was found as the sum of the volume of each tree within the species.

c) *Data analysis*

All the 154 sampled trees were used for analyses of; TMRV (branchwood and stem off-cuts) and ELV from the three ecological zones/sites, and the harvesting efficiencies among the various timber species and the 3 sites. Both descriptive and inferential statistical analyses (comprising means and standard deviations, percentages and analysis of variance-ANOVA) using MS-excel 2003 and 2007, and SPSS 16.0 version were done to compare group means and determine differences among obtained values. Linear regression analyses were also conducted to establish the relationship between ELV and TMWV, and ELV and TMRV for the 7 species found to be common to all the 3 sites (species specific model), all species within the 3 sites (site specific model) and all species and sites together (mixed species and site model) to predict TMWV and TMRV using ELV as an indirect predictor variable. Equations 1 and 2 depict the relationship between ELV and TMWV, and ELV and TMRV respectively.

$$TMWV = \alpha\, ELV + C \qquad (1)$$

$$TMRV = \alpha\, ELV + C \qquad (2)$$

Where α indicates the quantum of increase/decrease in either TMWV or TMRV for each cubic meter (m^3) rise/fall in ELV and C is a constant {i.e.; intercept indicating the value of TMWV or TMRV at situations where ELV is zero}.

III. Results

a) *Total merchantable residue quantity and harvesting efficiency*

The 154 randomly sampled trees consisted of 20 different species and their distribution across the 3 study sites are: site 1=11, site 2= 10 and site 3=19 species with only 7 species being common to all the 3 sites (Table 1). The 11 species from site 1 provided the highest mean extracted log volume (ELV) of 15.51m^3 per tree but a mean total merchantable residue volume (TMRV) of 4.85m^3 per tree whereas the 10 species from site 2 provided the least mean ELV of 13.40m^3 per tree and a mean TMRV of 4.34m^3 per tree. However, the 19 species from site 3 produced the highest TMRV of 5.13m^3 per tree.

For the individual species, (Table 1) *Triplochiton scleroxylon* out numbered the other species across the sites and represented about 23.4% of the total sample size. The ELV for the various species ranged from the highest of 33.91m^3/tree for *Ceiba pentandra* from site 1 to the lowest of 6.74m^3/tree for *Celtis mildbraedii* from site 2. However, the TMRV ranged from the highest of 14.2/tree for *Entandrophragma angolense* from site 3 to the lowest of 1.32m^3/tree for *Nesorgodonia papaverifera* also from site 3.

Table 1 : Summary of data collected on extracted log volume and merchantable residue from the 3 study sites

Wood Species	N	Mean ± SD of Extracted log volume (ELV) per tree (m^3)			Mean ± SD of Total merchantable residue volume (TMRV) per tree (m^3)		
		Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
P. africanum (dahoma)	24	13.39 ±7.46	23.89±5.70	9.60±2.26	6.03±3.71	7.69 ±0.77	4.37 ±1.03
A. toxicaria (kyenkyen)	11	20.92±10.12	17.37	17.77±1.35	5.47±3.05	4.61	7.26±0.55
T. scleroxylon (Wawa)	36	15.26 ±4.59	14.91±4.19	14.89±4.00	3.07±1.36	4.19±3.25	5.18±1.39
C. mildbraedii (Esa)	11	12.52 ±3.84	6.74 ±1.87	7.20	1.68 ±1.02	3.45±4.10	2.34
E. angolense (edinam)	7	19.56 ±6.69	-	13.95±3.76	6.78 ±2.75	-	14.20±3.44
Khaya spp. (mahogany)	6	10.71 ±7.55	16.61	12.87 ±3.70	8.03±4.61	9.00	7.53±2.16
E. cylindricum (sapele)	14	14.25 ±3.27	-	15.06 ±4.35	4.15 ±1.78	-	3.73±0.94
T. superba (ofram)	15	9.23 ±1.91	10.6 ±1.35	13.99±3.78	4.46 ±2.04	3.33±4.39	4.13±1.18
A. pterocarpoides (yaya)	2	18.19 ±4.67	-	-	8.98 ±6.56	-	-
C. pentandra (onyina)	6	33.91±0.85	14.82	16.79	4.48±1.03	4.92	6.06
N. papaverifera (danta)	3	9.25	10.58	8.00	4.13	5.04	1.32
C. gabunensis (denya)	3	-	18.09 ±0.46	12.96	-	7.74±3.28	4.26
P. macrocarpa (koto/kyere)	7	-	7.08 ±1.03	8.32 ±2.21	-	0.77 ±0.34	1.92±0.61
E. utile (utile)	1	-	-	20.56	-	-	5.34
A. ferruginea (albizia)	2	-	-	13.87±5.56	-	-	2.27±0.91
Milicia excelsa (Iroko/odum)	1	-	-	19.83	-	-	0.59
Guarea spp. (guarea)	1	-	-	7.70	-	-	3.10
G. ehie (hyedua)	1	-	-	7.50	-	-	1.34
T. heckelii (Baku)	1	-	-	20.90	-	-	7.05
A. robusta (Asanfena)	2	-	-	8.47±4.18	-	-	3.13 ±1.55
TOTAL	154	15.51±7.85	13.40±6.78	13.64±4.57	4.85±3.14	4.34 ±3.52	5.13±3.45

The total merchantable wood volume (TMWV) of the 154 samp 154 timber trees was about 2,964m^3 out of which the volume of logs delivered at the mills gate or extracted log volume (ELV) was about 2,221m^3 (Table 2). The ELV averaged 75.31% of the TMWV and this represents the general average harvesting efficiency of the 3 sites/ecological zones in this study. On the average, harvesting efficiencies of the various wood species found in all 3 sites however, ranged from the highest of about 83.66% for *Ceiba pentandra* (onyina) to the lowest of 59.54% for *Khaya ivorensis* (mahogany). The general TMRV (stem off-cuts + branchwoods) was found to be 742.57m^3 representing about 25% of the TMWV.

Table 2 : Merchantable wood quantities and logging efficiencies among various wood species

Species		Extracted log volume –ELV (m^3)	Merchantable residue volume- MRV			Total merchantable wood-TMWV (m^3)
Names	N		Branchwoods (m^3)	Stem off-cuts (m^3)	Total –TMRV (m^3)	
P. africanum (dahoma)	24	345.17 (67.76)	132.40(29.31)	13.94(2.93)	146.35(32.24)	491.52
A. toxicaria (kyenkyen)	11	213.98(76.04)	43.37 (15.70)	23.16(8.26)	66.52(23.96)	280.50
T. scleroxylon (wawa)	36	540.67(78.27)	90.83 (13.51)	58.56(8.21)	149.39(21.72)	690.06
C. mildbraedii (esa)	11	109.28(81.92)	22.30 (14.98)	3.92 (3.10)	26.21(18.08)	135.50
Khaya spp. (Mahogany)	6	74.48 (59.54)	34.39 (29.25)	13.76(11.20)	48.15(40.45)	122.64
T. superba (ofram)	15	162.69(76.07)	34.09 (13.98)	23.89 (9.95)	57.97(23.93)	220.66
C. pentandra (onyina)	6	167.24(83.66)	14.03 (7.94)	14.88 (8.40)	28.90(16.34)	196.14
Total of 7species common to all sites	109	1613.51(75.06)	371.41(17.98)	152.09(6.95)	523.50(24.93)	2137.01
Total of other species	45	607.90(75.90)	184.59(19.23)	34.47 (4.87)	219.07(24.09)	826.97
Total of all species	154	2221.41(75.31)	556.01(18.35)	186.56(6.34)	742.57(24.69)	2963.98

Numbers in parentheses are volume in relation to TMWV expressed in percentages (efficiencies)

b) *Differences in merchantable branchwood, stem (off-ctus) and harvesting efficiencies among species and study sites*

Analyses of variance (ANOVA) indicated significant differences at 95% confidence level, in branchwood among the various wood species (P = 0.000; Table 3) and the study sites (P= 0.013; Table 4). Moreover, there were also significant differences in the quantity of stem off-cuts among the various wood species (P = 0.004; Table 5) and among the study sites (P= 0.000; Table 6) all at 95% confidence level.

Table 3 : ANOVA of merchantable branchwood in total merchantable wood volume among species

Source	Type III Sum of Squares	df	Mean Square	F- Value	P-Value	Partial Eta Squared
Corrected Model	9730.221[a]	19	512.117	3.487	.000***	.331
Intercept	14898.219	1	14898.219	101.439	.000***	.431
Wood Species	9730.221	19	512.117	3.487	.000***	.331
Error	19680.449	134	146.869			
Total	81245.048	154				
Corrected Total	29410.670	153				

*a. R Squared = .331 (Adjusted R Squared = .236). Significant ** * P< 0.001*

Table 4 : ANOVA of merchantable branchwood in total merchantable wood volume among study sites

Source	Type III Sum of Squares	df	Mean Square	F-Value	P-Value	Partial Eta Squared
Corrected Model	1654.699[a]	2	827.350	4.501	.013**	.056
Intercept	46219.727	1	46219.727	251.448	.000***	.625
Study sites	1654.699	2	827.350	4.501	.013**	.056
Error	27755.971	151	183.814			
Total	81245.048	154				
Corrected Total	29410.670	153				

*a. R Squared = .056 (Adjusted R Squared = .044). Significant *** P< 0.001; ** P< 0.05*

Table 5 : ANOVA of off-cuts in total merchantable wood volume among species

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1448.450[a]	19	76.234	2.276	.004***	.244
Intercept	1811.105	1	1811.105	54.078	.000***	.288
Wood Species	1448.450	19	76.234	2.276	.004***	.244
Error	4487.772	134	33.491			
Total	11994.268	154				
Corrected Total	5936.222	153				

*a. R Squared = .244 (Adjusted R Squared = .137). Significant *** P< 0.01*

Table 6 : ANOVA of off-cuts in total merchantable wood volume among study sites

Source	Type III Sum of Squares	df	Mean Square	F-Value	P-Value	Partial Eta Squared
Corrected Model	2407.514[a]	2	1203.757	51.511	.000***	.406
Intercept	5647.571	1	5647.571	241.670	.000***	.615
Study sites	2407.514	2	1203.757	51.511	.000***	.406
Error	3528.707	151	23.369			
Total	11994.268	154				
Corrected Total	5936.222	153				

*a. R Squared = .406 (Adjusted R Squared = .398). Significant *** P< 0.01*

Moreover, analyses of variance indicated significant difference (P= 0.000; Table 7) in logging efficiencies among the species but not among the study sites (P = 0.435; Table 8) with R^2 values of 0.292 and 0.011 respectively. Wood species therefore explained 29% of the variation in logging efficiencies among the species.

Table 7 : ANOVA of Logging efficiencies among the wood species.

Source	Type III Sum of Squares	df	Mean Square	F-Value	P-Value	Partial Eta Squared
Corrected Model	7646.085[a]	19	402.426	2.910	.000***	.292
Intercept	285817.412	1	285817.412	2066.850	.000***	.939
Wood Species	7646.085	19	402.426	2.910	.000***	.292
Error	18530.385	134	138.286			
Total	899585.443	154				
Corrected Total	26176.470	153				

*a. R Squared = .292 (Adjusted R Squared = .192). Significant *** P< 0.001*

Table 8 : ANOVA of Logging efficiencies among the study sites.

Source	Type III Sum of Squares	df	Mean Square	F-Value	P-Value	Partial Eta Squared
Corrected Model	286.834[a]	2	143.417	.836	.435[ns]	.011
Intercept	815794.179	1	815794.179	4758.079	.000***	.969
Study sites	286.834	2	143.417	.836	.435[ns]	.011
Error	25889.636	151	171.455			
Total	899585.443	154				
Corrected Total	26176.470	153				

*a. R Squared = .011 (Adjusted R Squared = .002). Non-Significant [ns] P> 0.1; Significant *** P< 0.001*

c) *Relationship between total merchantable wood and extracted log, and total merchantable residue and extracted log*

Linear regression analyses of the relationships between ELV and TMWV, and between ELV and TMRV, for the 7 species found common in all 3 study sites indicated strong, positive and significant correlation between ELV and TMWV at 95% level of confidence with R^2 values from 0.50-*Terminalia superba* to 0.99-*Ceiba pentandra* and P values of 0.000 generally (Table 9). The relationship between ELV with TMRV of the species, were though positive, they were generally not strong and not significant at 95% level of confidence with R^2 values ranging from 0.01to 0.48 espectively for *Piptadeniastrum africanum* and *Celtis mildbradii* (Table 9).

Table 9 : Relationship between extracted log volume and total merchant wood volume, and total merchantable residue volume for seven species common to all 3 study sites (species specific model),

Species	Total merchantable wood vol. (TMWV)			Total merchantable residue Vol. (TMRV)		
	Regression Equation	R^2	P-Value	Regression Equation	R^2	P-Value
P. africanuum	y =1.308 x +1.654	0.95	0.000	y=0.284 x + 1.425	0.48	0.000
A. toxicaria	y=1.072 x + 4.642	0.92	0.000	y=0.044 x + 3.075	0.02	0.510
T. scleroxylon	y = 1.121 x+ 2.324	0.89	0.000	y =0 .043 x + 1.875	0.06	0.079
C. mildbraedii	y= 0.948 x + 2.892	0.71	0.001	y = -0.065 x + 2.681	0.01	0.804
Khaya spp.	y = 1.522x+ 1.539	0. 98	0.000	y = 0.414 x+ 0.584	0.30	0.007
T. superba	y=1.189 x + 1.806	0.50	0.003	y = 0.151 x+ 3.916	0.02	0.572
C. pentandra	y = 0.943 x + 6.392	0.99	0.000	y = -0.015 x+ 2.774	0.001	0.289

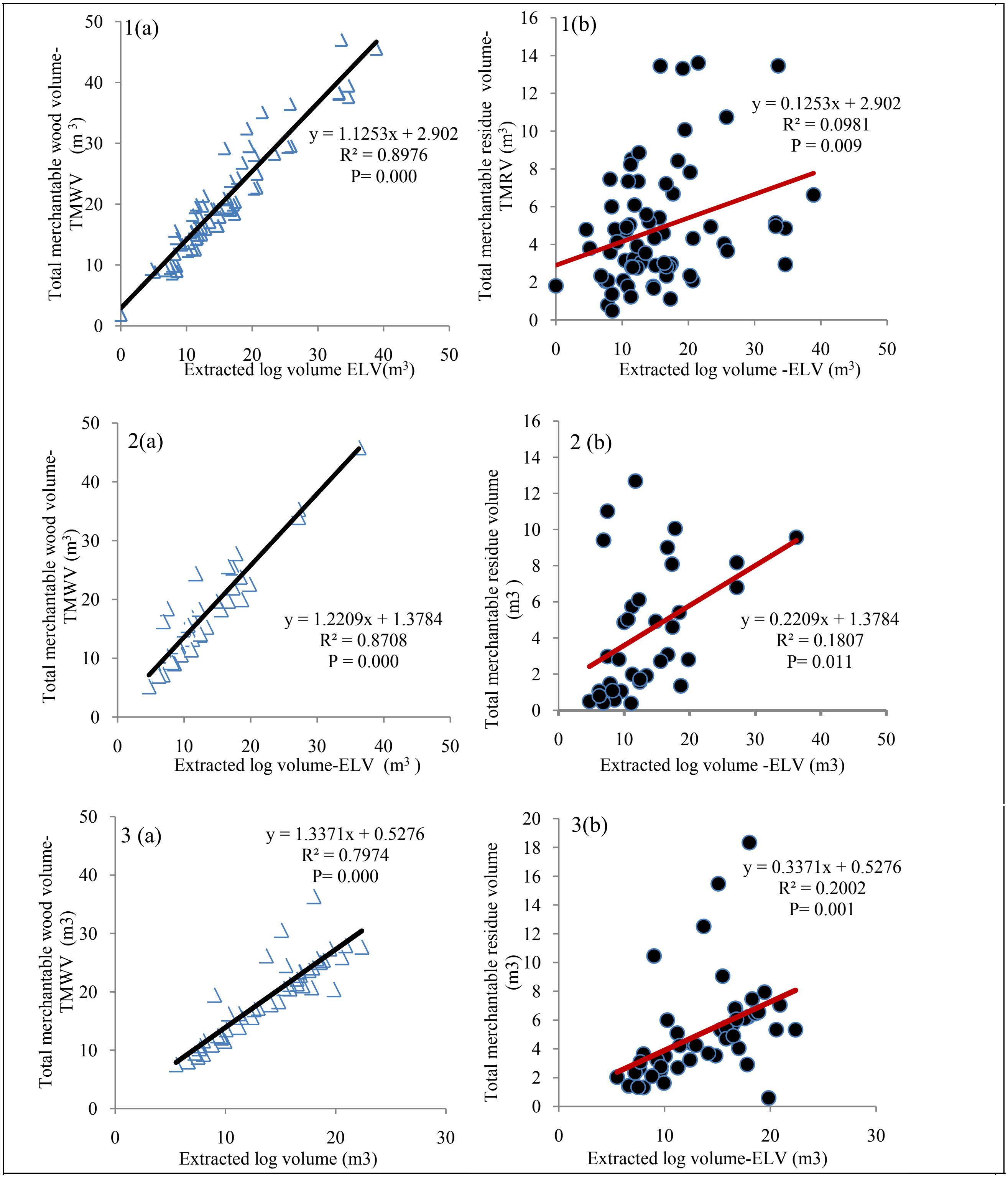

Figure 1 : Relationship between: (a) extracted log volume and total merchantable wood volume, and (b) extracted log volume and total merchantable residue volume at each site (site specific models); 1=Site 1, 2= Site 2, 3= Site 3

The relationship between ELV and TMWV, and TMRV at the 3 study sites were all positive (site specific model-Fig. 1). From Fig.1, the correlation of ELV and TMWV were stronger and highly significant (R^2 ranging from 0.797-site 3 to 0.898-site 1 and P=0.000 for all) at 95% confidence level. But the relationships of ELV and TMRV, though were not strong at any site, they appeared significant (R^2 ranging from 0.098-site 1 to 0.200-site 3; and P=0.009-site 1 to 0.001-site 3). The R^2 values point out that, at each forest reserve/site, ELV

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can predict the TMWV more accurately than it can predict the TMRV.

Moreover, the final model that looked at all the 20 species together (154 trees in all) and from the 3 study sites combined (mixed species and sites model), also indicated positive, strong (R^2= 0.867) and highly significant (P= 0.000) correlation between ELV and TMWV at 95% confidence level (Fig. 2). However, the correlation between ELV and TMRV was not strong (R^2= 0.128) but significant (P=0.000) at 95% confidence level. These R^2 values suggest that whereas ELV is a weak predictor variable for TMRV, it is a strong predictor variable for TMWV.

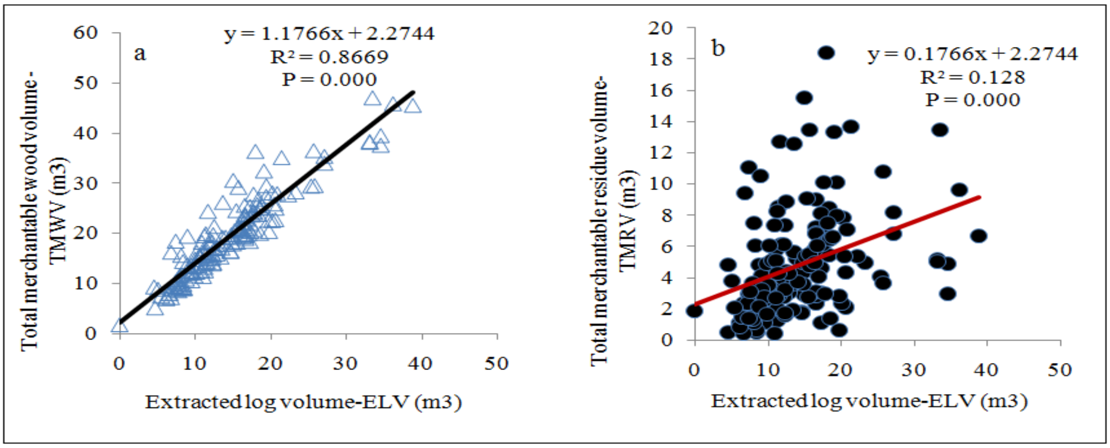

Figure 2 **:** Relationship between: (a) extracted log volume and total merchantable wood volume, and (b) extracted log volume and total merchantable residue volume for all species (154 Trees) from all 3 sites altogether (mixed species and sites model)

IV. Discussions

a) *Total merchantable residue quantity and harvesting efficiency*

The total merchantable residue quantity (25%) and harvesting efficiency (75%) obtained in this present study appear to corroborate findings of earlier studies in Ghanaian tropical forests (Eshun 2000; Ofori et al. 1993; Amoah and Becker 2009). These seem to indicate that from the 1990s, the general harvesting efficiency or logging recovery in Ghanaian tropical forests has generally not changed much. The findings could also mean that, although harvesting efficiency in some Ghanaian forests could be about 50% (Acquah and White 1998; Adam et al. 1993), generally, it appears that the consciousness of timber firms about the need to extract much of the main bole since the 1990s due to scarcity of timber has not changed. This consciousness was reflective in observed efforts by forest managers at the study sites as they continuously impressed upon loggers to reduce stump heights as much as possible, based on which loggers tried to fell trees close to the ground (≤1m above ground). Meanwhile it is worth noting that the 50% recovery rate obtained in the stated previous studies could be attributed to differences in methodologies and how merchantable wood was also defined in those studies. The consistency of the total merchantable residue quantity (about 25%) with previous studies, though this study did not include stumps in contrast with previous ones, for environmental reasons, could be ascribed to the inclusion of branchwoods of less than 30cm diameters down to a minimum of 13.5cm. These inclusions were based on reports that normal branchwoods are those of diameter ≥5cm (Gurau et al. 2008; Haygreen and bowyer 1996), but the previous studies covered only branchwoods ≥30cm in diameter. In support of these reports, Okai, (2003) successfully produced prototype furniture from 10cm to 25cm diameter branchwoods. Since the previous studies did not cover branchwoods of diameter < 30cm, the inclusion of branchwoods of diameters below 30cm in this present study, appeared to have increased branchwood quantity relative to findings from the other previous studies (Eshun 2000; Ofori et al. 1993; Amoah and Becker 2009) and this might have compensated for the stumps that were not covered.

On accounts of the covered diameters being within the normal branchwood bracket, the total merchantable residue volume (TMRV) obtained was considered to be of adequate quality to guarantee their extraction and subsequent utilization. Thus from the data in Table 2, an equivalent volume of about 38 trees {i.e., (743/2964) x154} could have been saved if firms had extracted the TMRV from the felled trees for processing and eventual utilization. According to Amoah and Becker (2009), about 5 trees per hectare are felled during felling cycles in tropical forests. To this end, the 38 trees that would have been saved should the TMRV were extracted, translates into about 7.6 hectares (i.e, 38/5). This implies that, should firms had extracted the merchantable residues for processing, about 7.6 hectares of forest land would have remained unlogged or conserved. This quantum of forest area would have then been available to provide the other service functions of forests (i.e. protection of soil and water bodies, shielding biodiversity, maintaining climate and protecting the entire ecological system), at least till the next felling cycle. It also means that, timber volume equivalent to 38 trees would have been added to the volume obtained already from the main boles for production, if the firm had extracted the TMRV from the felled trees. Better still, it implies that, the extraction of the residues will make available to the firms additional quantity of wood equivalent to logging about 8ha. of forest land. Meanwhile, the running cost of machinery and equipment in logging additional 8ha. may possibly be higher than extracting the residues from the already logged trees, which is an added advantage to residue extraction.

b) Differences in merchantable branchwood, stem (off-cuts) and harvesting efficiencies among species and study sites

The significant differences of branchwoods ($P = 0.013$) and stem off-cuts ($P= 0.000$) among study sites (Tables 4 and 6 respectively) were not so expected but the non-significant difference ($P=0.435$) of logging efficiency among study sites (Table 8) was expected. This is because, all the sites were being logged by the same firm and apparently with similar logistics and equipment for operations, except that worker groups were different among the sites. Hence the significant differences could be attributed to some attributes or attitudes of the different worker groups. Although worker groups from the same firm were expected to have similar skills, training and orientation on harvesting practices, there is the possibility of some workers disregarding any orientation and training on harvesting practices that avoid waste etc, especially in the absence of their superiors at the sites.

It is also reported that, differences in timber yield among different forest sites could basically be due to environmental factors like temperature, relative humidity, rainfall patterns, soil type and nutrients, and land topography (low or high lands) differentials (Chave et al. 2001; Basuki, et al. 2009; Ketterings et al 2001). In fact soil nutrient content and fluctuations account for a third of biomass variability among different forest sites ('Laurance et al. 1999). Additionally, water retention and drainage capacity are factors that also have greater influence on biomass variability among sites as they could lead to leaching of soil nutrients (Chave et al. 2001) and also destruction of various tree parts. Therefore some of these factors/variables might have led to the differences in the harvesting efficiency, branchwood and stem off-cuts quantity among the sites.

The significant differences in branchwood and stem off-cut quantities, and efficiencies among various species (Tables 3, 5 and 7 respectively) could also be partly due to tree architecture and genetics (canopy areas, plant/tree form or geometry, bole height, branching type and size of branches, buttress height and sizes)- Ketterings et al. 2001; Ford 1985). This appears to have been manifested in this study. The species with relatively large canopy areas and grow to about 50-65m high like *P. africanum* and *K. ivorensis* (Lemmens 2008; Richter and Dallwitz 2000) were those that had higher percentages of branchwoods but relatively lower logging efficiencies as compared to *C.pentandra*, a species that is branchless up to 35m high and grows over 60m high (Duvall 2011). This might have led to *Ceiba pentandra's* high extracted log volume and highest harvesting efficiency (83.66%; Table 2), but it was observed that due to its height before branching, most branches got damaged resulting from ground impact upon felling and making many of them not merchantable. This might have also made *Ceiba* had the least branchwood quantity (7.94%). Moreover, in all, tree canopy disturbances from past logging operations and tree positions within the forest canopy are among other factors that could also lead to significant differences in TMRVs among species (Ford 1985; Ketterings et al. 2001).

c) Relationship between total merchantable wood and extracted log, and total merchantable residue and extracted log

The relationship resulted in 3 models that predicted total merchantable wood volume (TMWV) and total merchantable residue volume TMRV from extracted log volume (ELV) for; individual species, all species at each study sites, and all (mixed) species and sites. These have some practical and theoretical implications. First, they will enable stakeholders (both industrialists and academics) in the wood industry to easily predict TMWV and TMRV from logs delivered at the mill gate (ELV) without necessarily having to spend energy, time and money to go to the forests to take inventory. Again, they will make negotiations on above-stump residue easier for both sellers and buyers, as the models could be used to easily estimate the volumes of such residues for; the species, all species from particular forest site, and all species from any of the 3 study sites for pricing and other purposes.

The R^2 values of the models for TMWV (0.50 for *T. superba*-Table 9 and 0.866 for all species-Fig. 2) appeared to be within the range found in previous studies (Amoah and Bercker 2009). This may therefore suggest that the R^2 value (0.02 for T. superba – Table 9 and 0.128 for all species-Fig. 2) is a true reflection of the weak correlation between ELV and TMRV. On account of the R^2 values obtained from the 3 models developed in this study, it could be concluded that ELV is a better predictor variable for TMWV but not too good for TMRV. However, the species specific model appeared to have a higher degree of predictive accuracy for both TMWV and TMRV relative to the other 2 models, at least for the 7 species that were common to the 3 study sites.

It is however necessary to indicate that, since the species covered in this study were dominated by

Triplochiton scleroxylon and Pitadiniastrum africanum (Table 1), the site specific, and the mixed species and sites specific models could be said to be basically applicable to *T. scleroxylon and P. africanum* than the other species (as found by Amoah and Becker 2009). Again the use of the models may have some limitations. For instance, should the harvesting efficiency changes substantially over some period of time, the models may not be accurate for that period within which such changes occurred since the ELV, which determines the harvesting efficiency, is the sole predictor variable. In the light of this, the models could be validated periodically based on new samples and data to assess current situation of the estimates. Moreover, an alternative variable to ELV could also be used either alone or in combination with ELV in models to estimate both TMWV and TMRV. This step may see a variable or a combination of variables that can estimate TMRV to a better level of accuracy than as has been done by ELV. However, until this is done, it will be appropriate to apply the model for TMWV after which the ELV could be subtracted to obtain the above-stump TMRV (i.e; TMWV-ELV=TMRV) without necessarily having to go to the forests before the residues could be quantified and priced.

VI. Conclusions

Based on the results obtained in this study, the following conclusions were drawn;

1. On the average, harvesting efficiency from the 3 sites was 75% and it is within the range of previous studies.
2. Total merchantable residues quantity that can be extracted for eventual utilization (25% of total above stump merchantable wood) found in this present study agrees with previous studies.
3. Extraction and utilization of merchantable residues can result in improvement in the harvesting efficiecy and also lead to the conservation of a substantial quantity of forest land to protect the ecosystem or provide a substantial additional quantity of timber to augment timber raw materials available to the firms and this is also consistent with previous studies.
4. If timber processing firms in Ghana happen not to be much interested in utilizing the merchantable residues, at least, cottage industries or firms could be established in the forest communities to create jobs, improve the economic lives of the people, provide timber for the communities so as to reduce illegal chainsaw operations in the forest which will in turn contribute towards reducing depletion of the forests and also contribute to their conservation.
5. Generally, total merchantable wood quantity, total merchantable residue quantity and harvesting efficiency are significantly different among species.
6. Except harvesting efficiency, both total merchantable wood and residue quantities are significantly different among forest sites/ecological zones and this was consistent with literature.
7. Volumes of logs delivered at the mill gate (extracted log volume) is a better predictor variable for total merchantable wood volume than total merchantable residue volume. However, the species specific model happened to have higher prediction accuracy (R^2 from 0.50 to 0.99) and should therefore be considered first in predicting TMWV and TMRV. Nonetheless, it will be better to use the extracted log volume to quantify total merchantable wood volume after which the extracted log volume could be deducted to obtain the merchantable residue volume.

V. Acknowledgement

Sincerest gratitude goes to Lumber and Logs Ltd. (LLL), a timber firm in Ghana and based in Kumasi city, for permitting entry into its concessions for data collection. We also thank Mr. Michael Afful, a former student of Kumasi Polytechnic and now a staff at Furniture Design and Production Department of Accra Polytechnic for his help during data collection process.

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 14 Issue 5 Version 1.0 Year 2014
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Water Solar Electrolysis for Hydrogen Production: Electric Caracterisation

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Abstract- The hydrogen production by water electrolysis consumes electric power (much even). To make this process profitable, we exploited two parameters: the origin of the consumed current and the optimization of the power supply. Indeed, the current is renewable origin (photovoltaic). The connection in parallel of the electrolysers with the photovoltaic module made it possible to increase the production of hydrogen while reducing the electric power consumption. In addition, the use of a voltage regulator made it possible to stabilize the voltage and thus to maintain the hydrogen production on a constant level during all the day.

Keywords: *hydrogen, electrolysis, characterization, photovoltaic.*

GJSFR-H Classification : *FOR Code: 660204, 859999p*

WATERSOLARELECTROLYSISFORHYDROGENPRODUCTIONELECTRICCARACTERISATION

Strictly as per the compliance and regulations of :

Water Solar Electrolysis for Hydrogen Production: Electric Caracterisation

Romdhane Ben Slama [α], Nabil BouAzizi [σ], Yassine Hamouda [ρ] & Saif Eddine Jawadi [ω]

Abstract- The hydrogen production by water electrolysis consumes electric power (much even). To make this process profitable, we exploited two parameters: the origin of the consumed current and the optimization of the power supply. Indeed, the current is renewable origin (photovoltaic). The connection in parallel of the electrolysers with the photovoltaic module made it possible to increase the production of hydrogen while reducing the electric power consumption. In addition, the use of a voltage regulator made it possible to stabilize the voltage and thus to maintain the hydrogen production on a constant level during all the day.

Keywords: hydrogen, electrolysis, characterization, photovoltaic.

Nomenclature:

I	Electrical current (A)
U	Voltage (V)
P	Power (W)
PCI	Lower heating value (J/kg)
Qv	Flow rate (m^3/s)
V	volume of the test tube (m^3)
t	tube filling time (s)
W	electrical energy (J)
ρ	density of hydrogen (Kg/m^3)
Indices :	
a	absorbed
u	useful
nom	nominal
ab	absorbed

I. Introduction

The production of hydrogen, vector of energy, by electrolysis way interests many authors [1-6]. Their studies relate at the same time, to the production of hydrogen through renewable energies or even the nuclear power, various new materials of electrodes and electrolytes, and even the urine. However, our former publications [7-12] are interested in the choice of nature of electrodes, electrolyte and additive.

In this article, we are interested in the electric characterization of the phenomenon.

Indeed, electrolysis requires a power supply, such as photovoltaic origin.

The couple intensity-voltage of the power is to be determined by the choice of the optimum point according to the characteristic curve of the photovoltaic module and the load. The type of assembly of the electrolysers series or parallel is to be determined. Lastly, the influence of the installation of a voltage regulator makes it possible to stabilize the physical sizes measured with optimal values.

II. Experimental Protocol

A photovoltaic module of 55 Watts used to supply the electrolyser, as well as a standard regulator marks??? and a battery 12 V, 50 AH.

The currents and tension are measured by fixtures in the model, accuracy ± 5 %.

The produced hydrogen flow is given by taking account of the filling time of a test tube of known volume *given*

The calculated sizes are:

- Hydrogen production flow rate: Qv = V/t (m^3/s)

With:

- Absorptive power by the electrolyser: Pa = U.I (W)
- Useful power of the electrolyser: Pu = PCI. Q. p (W)

PCI: lower thermal value of hydrogen (119.910^6 J/Kg)

- ρ: density of hydrogen (0.09 Kg/m^3)
- Consumed electric power: W = Pa . t (J)
- Useful efficiency: η = PCI. (V / (Pa . t)) . ρ (-)
- Consumed electric power per unit of volume:

$$W/V = Pa.\, t / V = Pa/Q \quad (J/cm^3)$$

$$W/V = Pa \,.\, t \,.22{,}4/ V \ (kJ/mol)$$

with: P (W), t (s) and V (cm^3)

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Figure 1 : Photo du panneau, batterie, régulateur, charge et électrolyseur.

Figure 1 : Photo of the panel, battery, regulator, load and electrolyser.

III. Power Supply of the Electrolyser Study

With an aim of having a constant hydrogen production, we tried to stabilize the power supply by using the model presented previously while combining the regulator and the battery.

a) Characteristic curve of the photovoltaic module (I=f(U))

While varying the position of the rheostat of the installation relating to the photovoltaic module, according to figure 2, the couple intensity-voltage changes, from where the layout of figure 3.

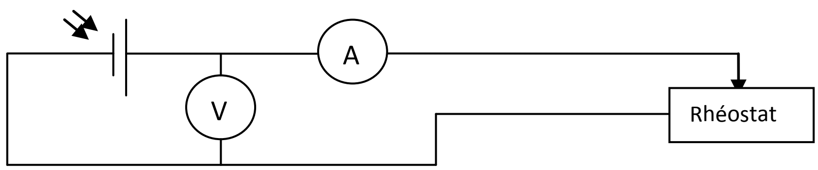

Figure 2 : Synoptic diagram to determine the curve I=f (U) of the photovoltaic module

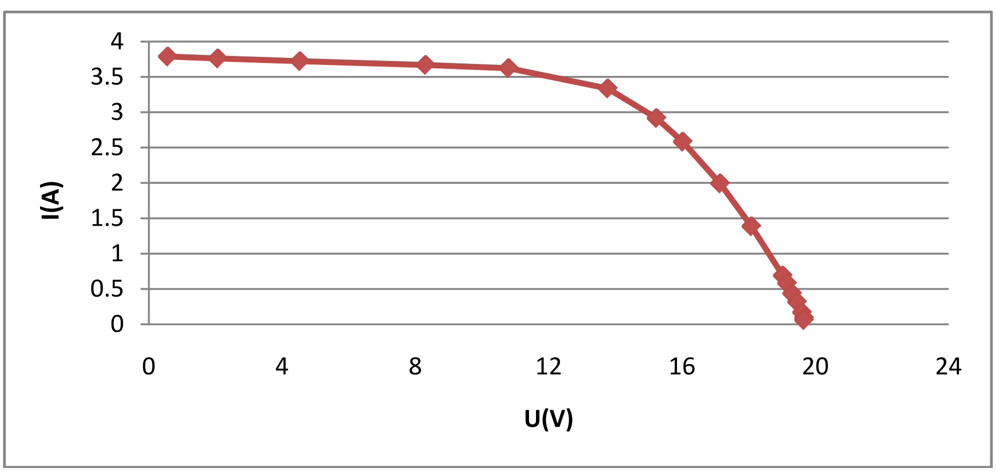

Figure 3 : Characteristic curve of the photovoltaic module (I=f(U))

The curve of figure 3 is made mainly of two parts:

1^{st} *part:* Zone of operation [between points (0V, 3.A) and (14V, 3.A)]

2^{nd} *part:* The following part of the curve: the current and the tension are inversely proportional càd that the reduction in the consumed current generates an increase in the tension.

The point of operation (16 V, 2.50A)

b) Characteristic curve of the electrolyser (I=f(U))

The electrolyser can be directly connected with the photovoltaic module or through the regulator connected with the battery. The electrolyte used is the brine of a power station of desalination of water. The rheostat makes it possible to vary the load.

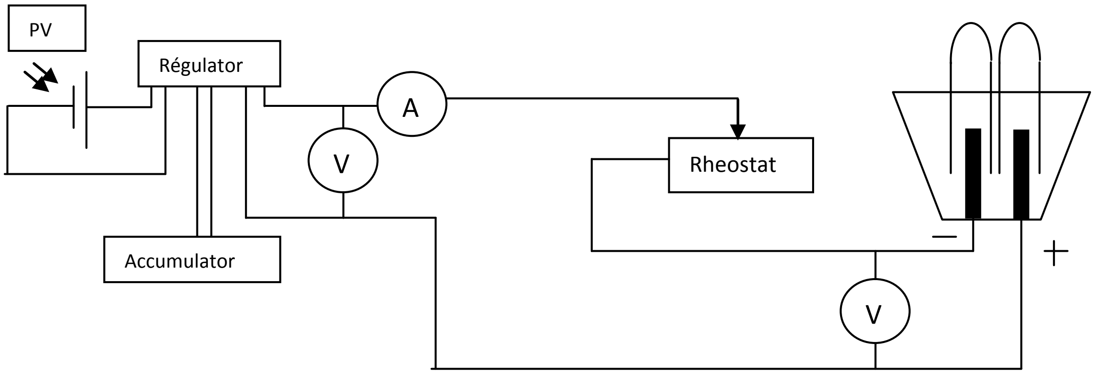

Figure 4 : Synoptic diagram to determine the curve of the electrolyser I=f (U)

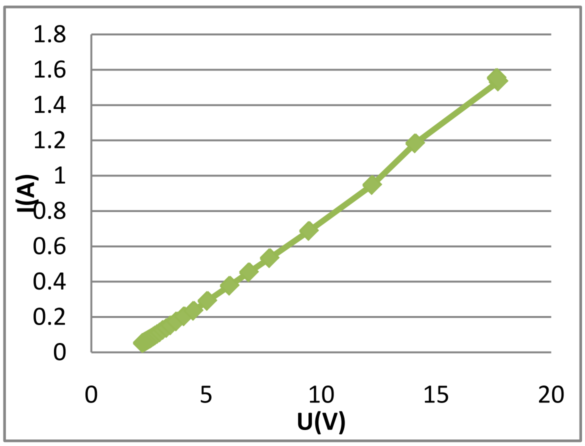

Figure 5 : Curve I=f(U) of the electrolyser connected directly with the photovoltaic module –Al/Cu Electrodes – Water: Rejection of the station of desalination

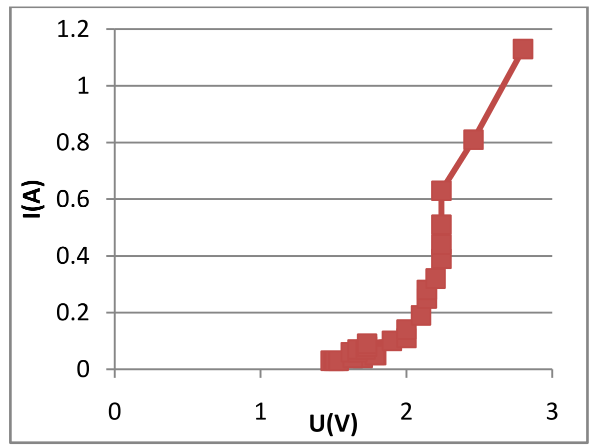

Figure 6 : Curve I=f(U) of the electrolyser connected to the regulator –Al/Cu Electrodes – Water: Rejection of the station of desalination

c) *Point of operation*

According to the figures 7-8 below, it is remarkable that with the regulator, the electrolyser functions in a zone below the nominal zone.

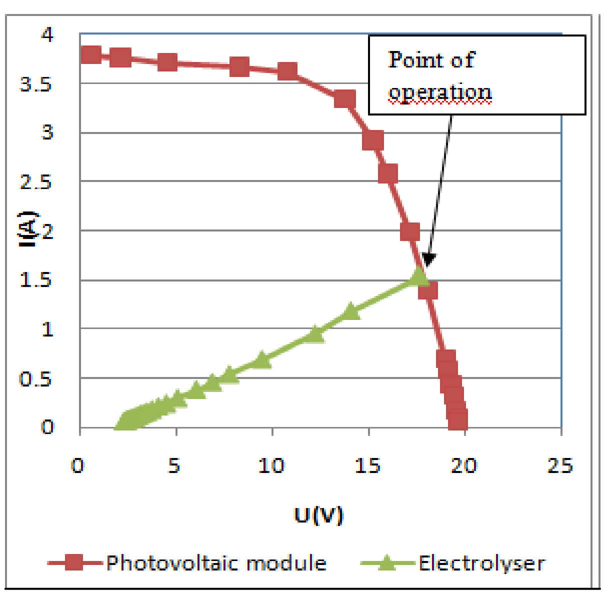

Figure 7 : Graphic determination of the point of operation PV-electrolyser

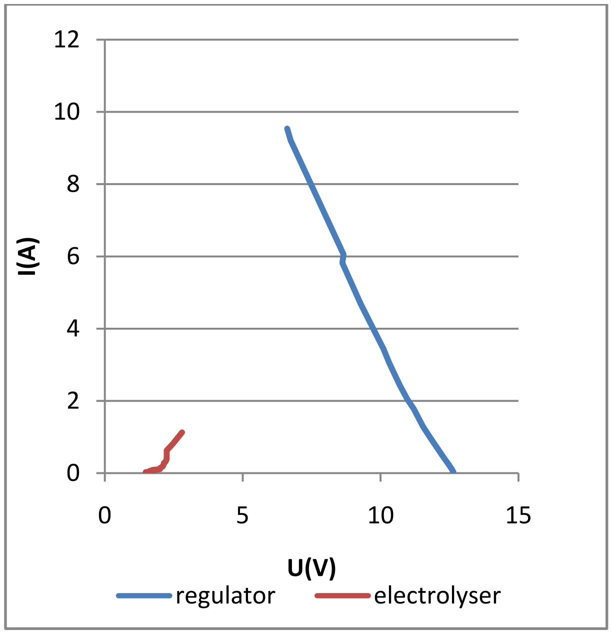

Figure 8 : Graphic determination of the point of operation Regulator-electrolyser

IV. Serial And Parallel Connections of the Electrolysers

To carry out these two experiments, we started by connecting the three electrolysers in parallels then in series.

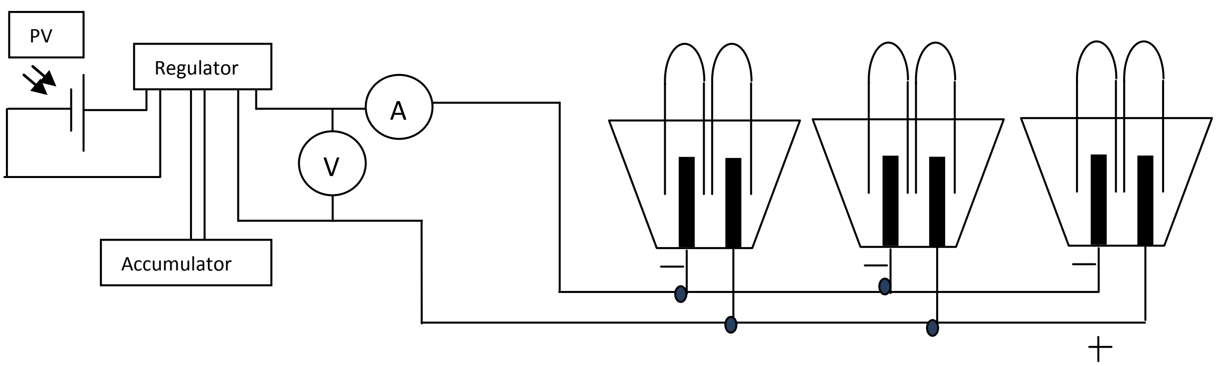

Figure 9 : Parallel connection of the three electrolysers

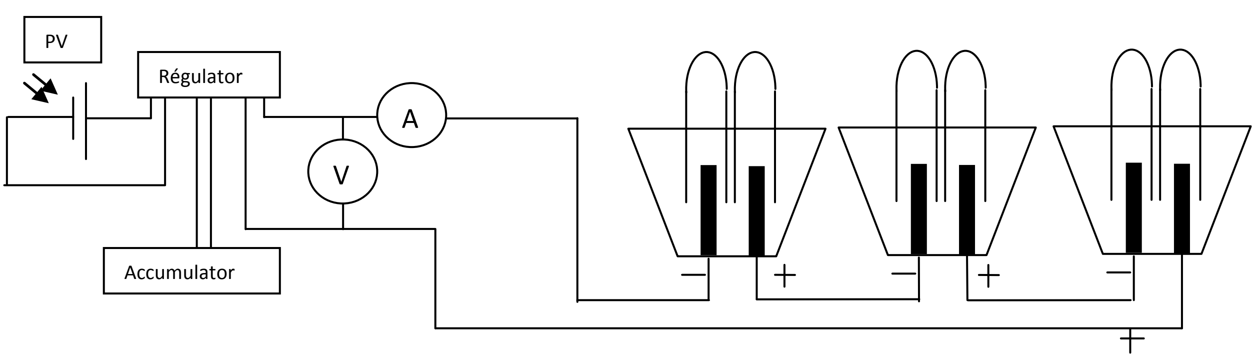

Figure 10 : Serial connection of the three electrolysers

Figure 11 shows that the produced hydrogen flow with the parallel connection is higher than with the serial connection, because with this last the equivalent resistance of the electrolysers is equal to the sum of resistances; on the other hand with the parallel connction the equivalent resistance of the electrolysers is increasingly smaller than the smallest resistance of the electrolysers. Thus, if resistance decreases, the power supply increases and consequently the hydrogen production increases.

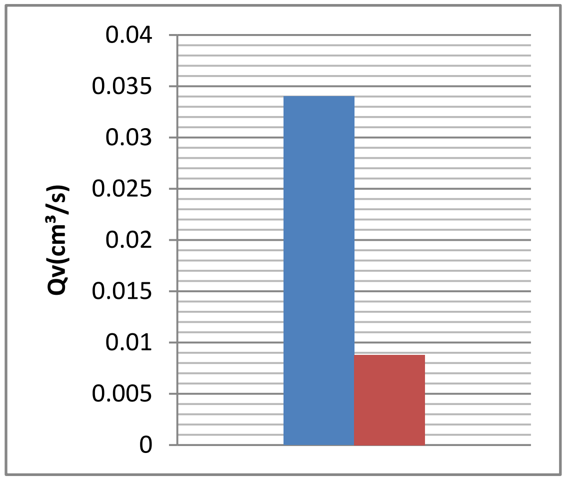

Figure 11 : Produced hydrogen flow by the three electrolysers

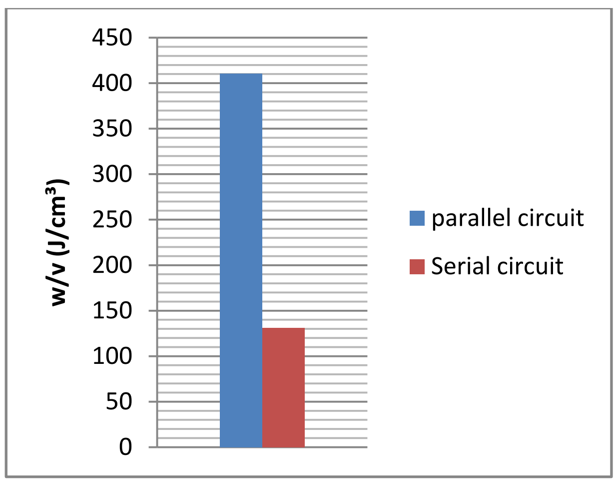

Figure 12 : Specific energy consumption by the three electrolysers

V. Connection Of The Electrolysers Directly To The Module PV And Through The Regulator

To show the effect of the regulator in the stabilization of the supply voltage of the electrolysers and consequently the produced hydrogen flow and the other results of measurement, the two assemblies will be carried out one directly with the module and the other through the regulator.

Various kinds of electrolytes will be tested such as waste water, the water rejections of the distillation station and the Chemical Group of Gabes and the rejection of the therapeutic bath of Metouia Gabes, like the pinks water, the Basilica water and the Kalatous water, without forgetting sea water.

a) Direct connection to the module PV

The electrolysers, assembled in parallel, will be directly connected with the photovoltaic module. The performances of electrolysis are measured: produced hydrogen flow and power consumption.

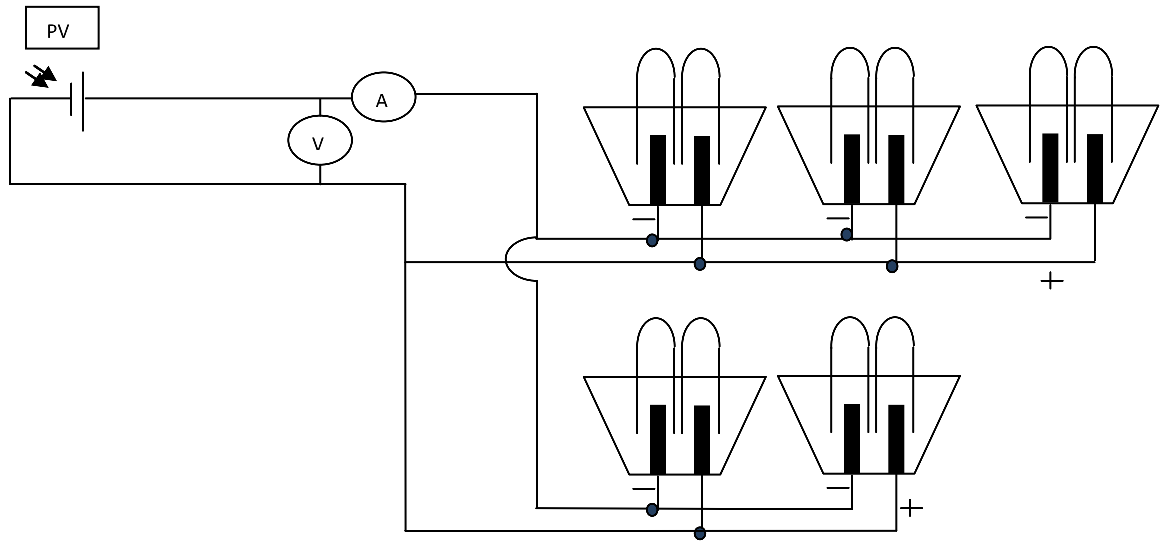

Figure 13 : Synoptic diagram of the parallel assembly of the electrolysers with the PV. Influences of the electrolytes types

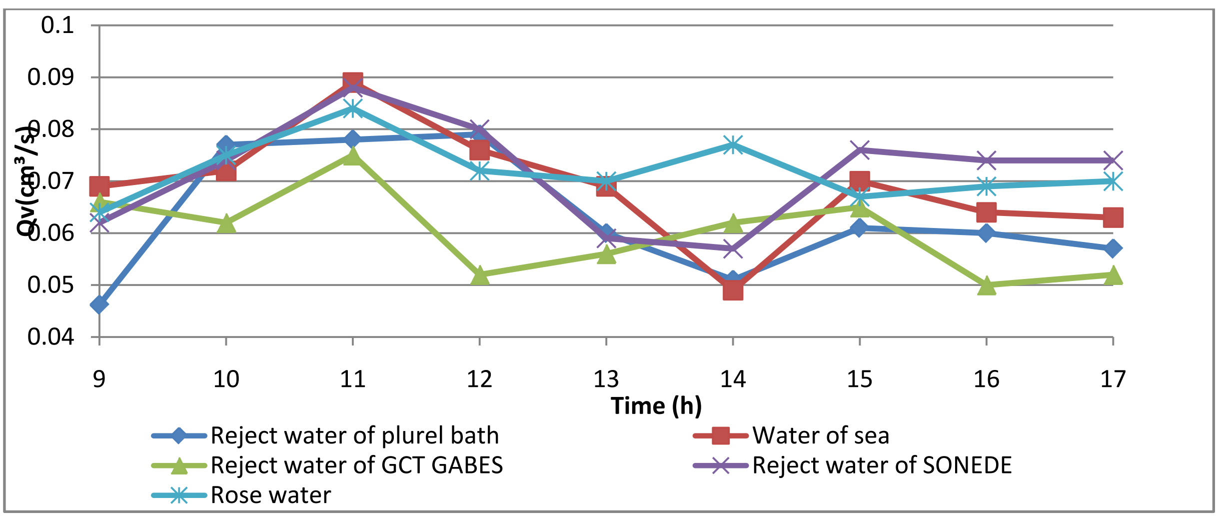

Figure 14 : Variation of the hydrogen flow with the time and the of electrolyte type - salinity 200g/l, Co(+)/Co(-), direct Connection with module PV

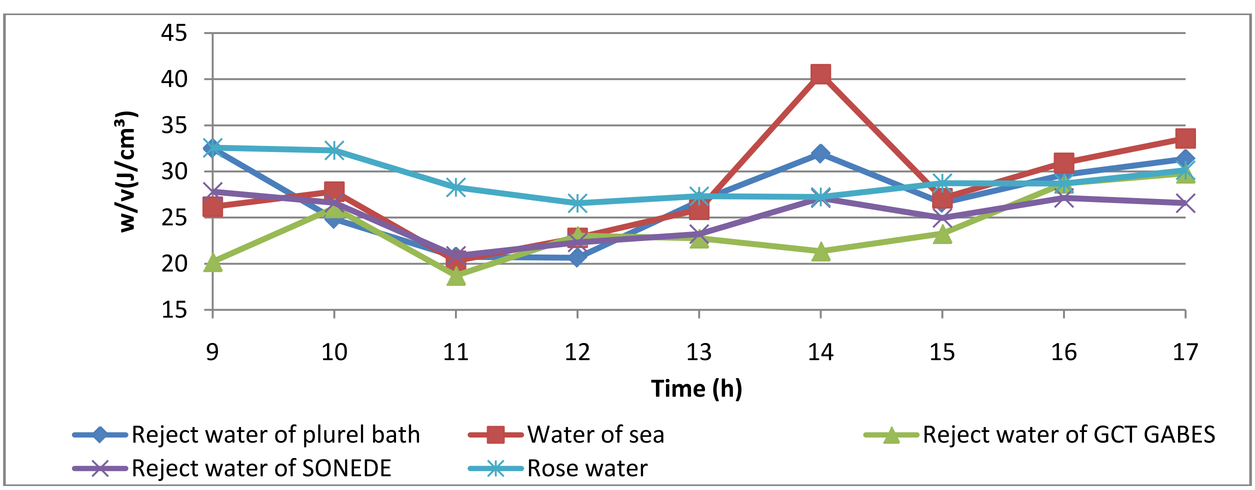

Figure 15 : Variation of the consumed energy with the time and the of electrolyte type - salinity 200g/l, Co(+)/Co(-), direct connection with module PV

The results of produced hydrogen flow and power consumption according to the electrolyte and time are discussed under the effect of the variation of the tension delivered by the module PV, itself due to the variation of solar flux. This will be corrected by the connection through the regulator.

b) Connection to the module PV through the regulator

The electrolysers, always assembled in parallel, will be connected with the photovoltaic module via the regulator. In the same way the performances of electrolysis are measured: produced hydrogen flow and power consumption.

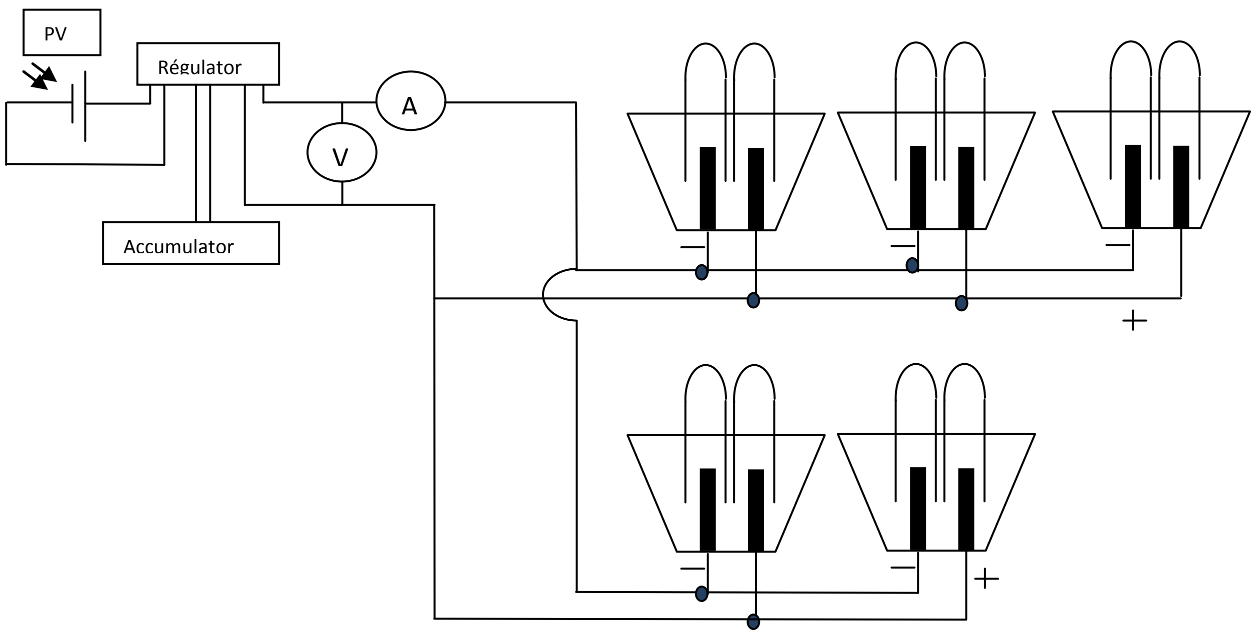

Figure 16 : Synoptic diagram of the parallel assembly of the electrolysers with the regulator. Influences of the electrolytes types

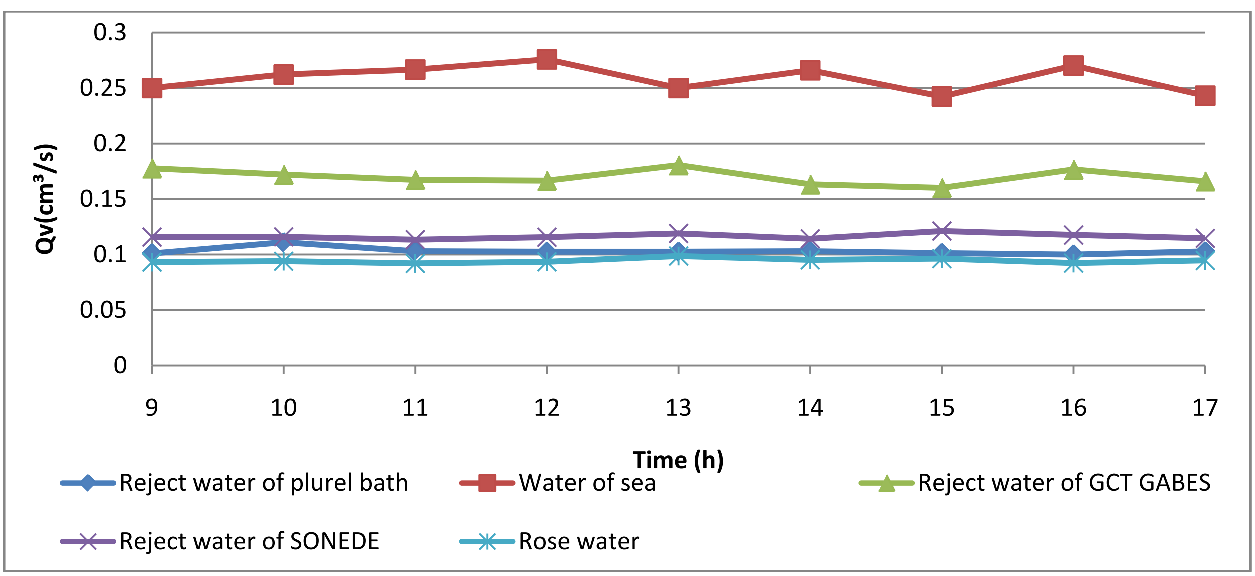

Figure 17 : Variation of the hydrogen flow with the time and the of electrolyte type - salinity 200g/l, Co(+)/Co(-). Connection with the regulator

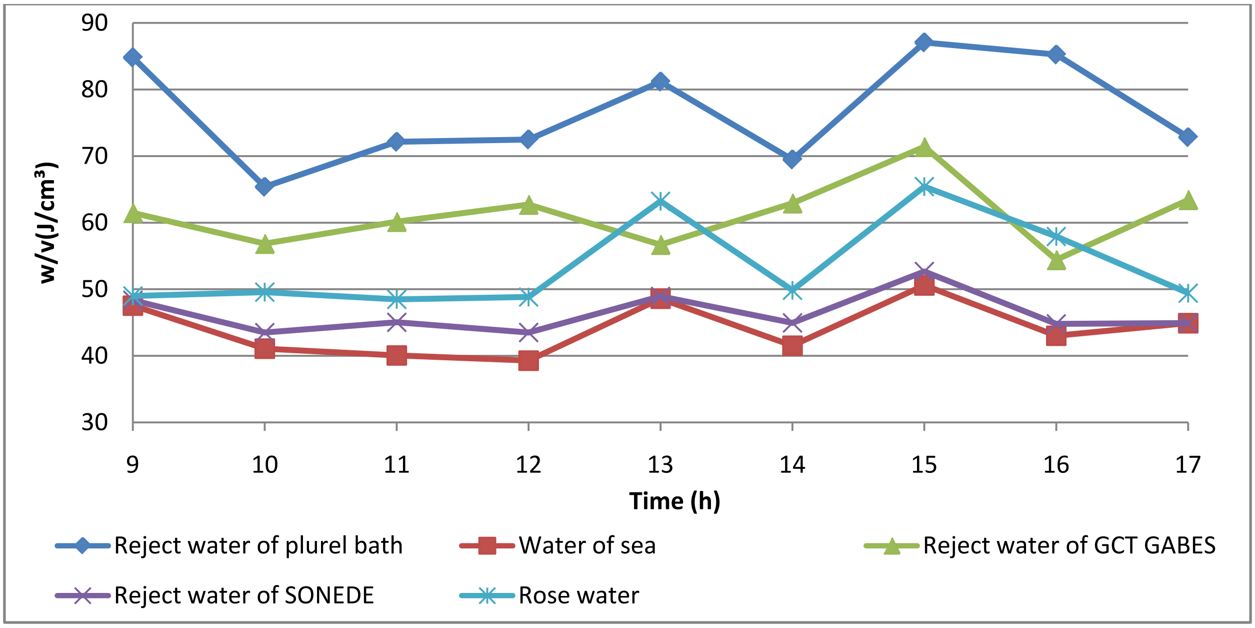

Figure 18 : Variation of the consumed energy with the time and the of electrolyte type - salinity 200g/l, Co(+)/Co(-). Connection with the regulato

For two figures 17 and 18, the uniformity of the curves according to the electrolyte type is due to the presence of the regulator, without which, the fluctuation of the solar radiation would disturb the supply voltage.

The produced hydrogen flow is better for sea water, follow-up of the rejection water of a phosphate treatment plant, brine of desalination. The result is reversed for the specific consumption of energy. What is beneficial.

VI. Conclusion

For the water electrolysis, one recommends the assembly of the electrolysers in parallel, which induces a better hydrogen production. Indeed, the supply voltage is independent of the number of electrolysers, contrary to the serial connection.

The coupling of the electrolysers to module PV must be done at the optimal operation point (high couple tension-current).

The connection of the voltage regulator between the module and the electrolysers makes it possible to stabilize the supply voltage and consequently the performances of electrolysis (flow of produced hydrogen and consumed electric power).

The good choice of the electrolyte type makes it possible to maximize the hydrogen production and to minimize electric consumption. Among those studied in this article, the sea water proves to be interesting.

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Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 14 Issue 5 Version 1.0 Year 2014
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Grain Size and Depositional Pattern of Sediment from Okeluse Area, Southwestern Nigeria

By Oredein, O. S., Adewumi A. J. & Odunsi, O. M.
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Keywords: grain-size; deposition; sediment; okeluse.

GJSFR-H Classification : *FOR Code: 040310*

GRAINSIZEANDDEPOSITIONALPATTERNOFSEDIMENTFROMOKELUSEAREASOUTHWESTERNNIGERIA

Strictly as per the compliance and regulations of :

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Abstract- Grain size and depositional pattern of sediment from Okeluse area, Southwestern Nigeria have been carried to evaluate its textural parameters and statistical measures to depict the depositional pattern of sediments in the study area. A total of ten samples were collected for this study. The method of sampling adopted for this study was spot sampling method. The samples were processed and sieved following international standards. Statistical parameters studied include. The graphic mean values (M_z) Range from 1.333 - 2.267. The inclusive graphic skewness (sk_1) of grain analysis data show that they are negatively skewed and implies that the sediments are strongly coarsely, coarsely and nearly symmetrical skewed. Sediments in OKL_1, OKL_2 and OKL_{10} are strongly coarsely skewed, while OKL_3, OKL_4, OKL_5, OKL_6, OKL_8 and OKL_9 are coarsely skewed. OKL_7 is nearly symmetrical skewed. The sorting (kurtosis) of the sediments shows that they are either leptokurtic or very platykurtic. OKL_3, OKL_5 and OKL_7 are very platykurtic, while OKL_1, OKL_2, OKL_4, OKL_6, OKL_8, OKL_9 and OKL_{10} are leptokurtic. The grain size distribution reveals that the transporting medium must have undergone series of rise and fall in its velocity. In the present study, all the ten samples analyzed shows the dominance of saltation and suspension domains of size-population.

Keywords: grain-size; deposition; sediment; okeluse.

I. Introduction

Okeluse area of southwestern Nigeria is a sedimentary terrain with less exposure of the sedimentary sequences in the area (Latitude 5°35'E and longitude 6°45'N) (Figure 1). The succession is represented by the intercalation of sand and sandy shale. So far, no sedimentological analyses have been carried out in Okeluse except geophysical estimation of limestone deposit in the area (Ehinola *et al*, 2012). Ola-Buriamo *et al* (2012) described the lithologic units of the area and provided palynological details of the study area. Adewumi *et al* (2014) applied Geographic Information System to study hydrogeochemistry of groundwater across Okeluse area of Ondo State, Southwestern Nigeria. The present work includes the generation of basic data on textural parameters and statistical measures viz. mean, median, standard deviation, skewness, kurtosis etc. Based on various basic statistical data, the bivariate plots between different parameters have also been construed to interpret the depositional pattern of the sediments from the study area. Many workers across Nigeria and in the world have determined the sedimentologic and depositional characteristics of several sedimentary basins (Srivastava and Mankar, 2008; Ogala *et al*, 2009).

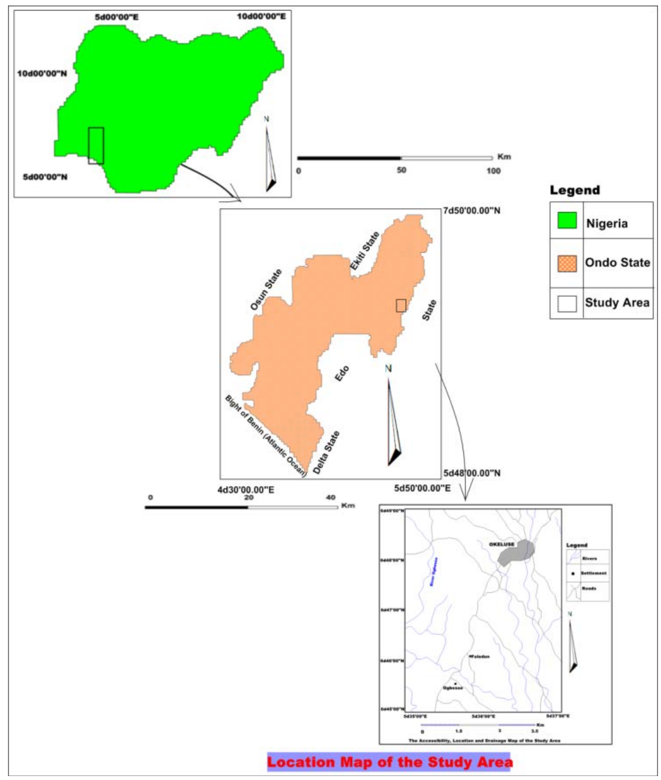

Figure 1 : Location map of the study area

II. Geology and Stratigraph of the Study Area

The study area is found within the Dahomey basin (Figure 2) which is one of the main basins found in Nigeria on the western part of the Niger Delta. It extends from Southeastern Ghana through Togo and Benin Republic on the west side to the Okitipupa ridge on the east side in the southern part of Nigeria. Various workers (Russ, 1957; Jones and Hockey, 1964; Omatsola and Adegoke, 1981; Agagu, 1985) had worked on the stratigraphy of the Eastern Dahomey basin from surface as well as sub-surface data. In most part of the stratigraphy is dominated by monotony of sand and shale altercation with minor proportions of limestones

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and clays (Agagu, 1985). The stratigraphy of the Eastern margin of the Cretaceous to Tertiary sedimentary basin, which unconformably overlies the basement complex, includes the following lithostratigraphic limits.

Abeokuta Group: The basement complex rock throughout the entire Dahomey basin is overlain unconformably by the Abeokuta group which is the oldest unit (Jones and Hockey, 1964). It consists of conglomerates, sand stones, sandy siltstones, clays, shales and thin limestone beds. This unit has been from the Neocomian to Paleocene and it is the thickest single sedimentary unit in the basin. This unit contains heavy oil and it is the prime target for petroleum exploration. (Omatsola and Adegoke, 1981) subdivided the group into 3 distinct formations, based on the lithologic homogeneity and similarity of origin, the following are the subdivisions.

Ise Formation: This is the oldest formation in the group and it unconformably overlies the basement complex. It consists of conglomerate at the base, gritty to medium grained loose sand, capped by kaolinite clay (Omatsola and Adegoke, 1981; Agagu, 1985). The maximum thickness of the members is about 1965m and 600m penetrated by the Ise-2 well, while similar section were exposed near Ode-Remo on the Lagos- Ibadan expressway. The grains are sub-angular to subrounded, poorly sorted, and positively skewed. From the grain size distribution, clastic sediments are leptokurtic, and nearly symmetrical. Clays from the major matrix and poor cementation makes the rock very friable. The age was given as Neocomian and the unit has not been found to be bituminous both at surface and subsurface section.

Afowo Formation: Afowo formation indicates the commencement of deposition in a transitional environmental after the entire basal and continental Ise formation. The sediments are composed of interbedded sands, shales and clays, which ranges from medium to fine grained in size (Omatsola and Adegoke, 1981; Agagu, 1985) outcrops of this formation are commonly encountered within the bituminous sands belt and are easily recognizable because of the presence of sticky and viscous heavy oil seeping out of the sand portion of the Afowo formation. The age is Maastrichitian.

Araromi Formation: Sediments of the Araromi formation represent the Youngest Topmost sedimentary sequence in the group. The formation is composed of shales, fine-grained sand, thin interbeds of limestone clay and lignite bands (Agagu, 1985). It is an equivalent of a unit known as Araromi shale. The shale are grey to black in colour, are marine and rich in organic matter. The age range is from Maastrichitian to Paleocene. The Abeokuta group, begin the thickest single sedimentary basin and consisting of interbeds of organic rich shale with porous and permeable sandstone together with its depth of burial makes it a prime target for petroleum exploration Dahomey basin, (Agagu, 1985). The lithology in the study area shows an intercalation of sandstone and shale. The basal sediments are gravelly.

III. Sampling Sites and Research Methods

A total of ten samples were collected for this study. The field work was carried with the aim of sampling sediments in the area for textural analysis and to depict the depositional pattern of sediments in the study area. The method of sampling adopted for this study was spot sampling method. Sampling method was adopted because it allows the analyses of several sedimentary layers deposited at different times. A representative sample was collected for each stratum since they are usually homogenous. A pit of seven feet was dug to get to the underlying strata. The sediments were collected from bottom to top. Before each stratum was studied, the surfaces of the stratum were scraped off so that sediments that do not belong to the stratum were not sampled. The hand-trowel used for sampling any stratum was properly rinsed before using to sample another stratum. Each sample collected was placed in well labeled polythene bags with codes (OKL_1-OKL_{10}). OKL means Okeluse, while the figures represent the number of stratum being sampled. The depths of each stratum were measured from bottom to top so as to know the thickness of each stratum. 500 grams of each sample was weighed using an electronic weighing balance after they have been arranged according to depth. The samples collected were placed in labeled beakers which were then placed and dried in the oven at a temperature of about 70°C.

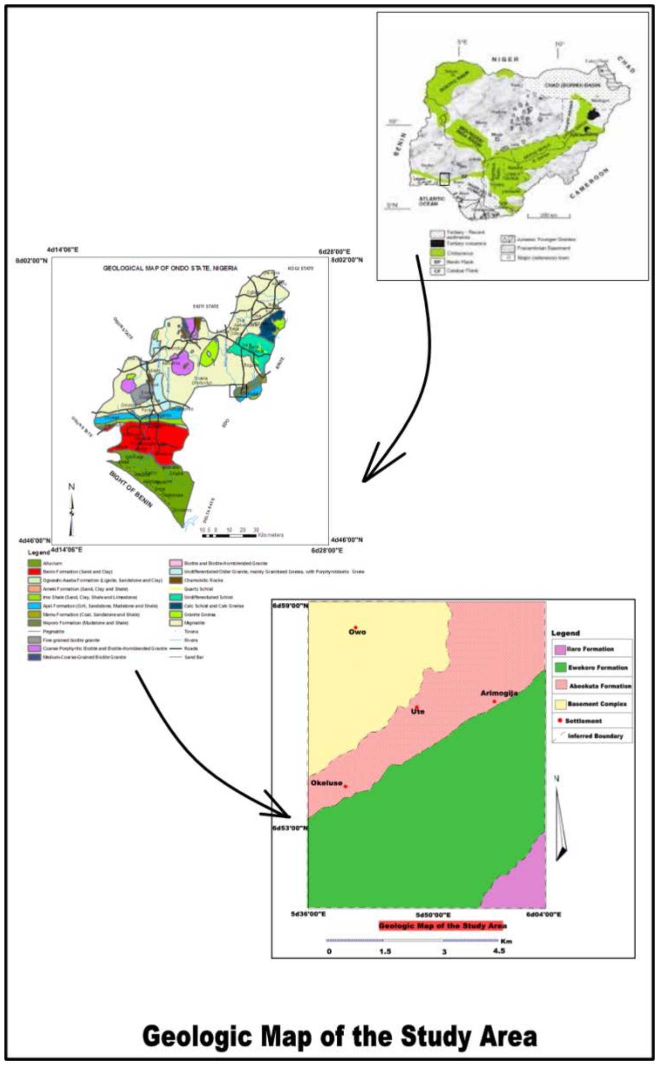

Figure 2 : The geologic map of the study area (Geologic map of Nigeria, after Ogala; Geologic map of Ondo State, after Nigeria Geological Survey of Nigeria, 2012; Geologic map of the study area, modified after Ehinola *et al.*,)

a) Sieve Analysis

After the samples have been dried, sieve analysis was carried out for each of the samples. Lumped samples were disintegrated so that the sieve analysis result can be authentic. Sieving technique is applied to separate the grains of various size-classes, as proposed by Ingram (1971) and used by Srivastava and Mankar (2008). Initially, 500 grams of sample was prepared by removing carbonate and organic matters by treating with 10% dilute hydrochloric acid and 6% hydrogen peroxide respectively. The samples completely free from carbonate and organic matter is subjected for sieve analysis. The sieve used was the Impact Laboratory test sieve (ISO 3310) with a shaker and an amplifier. The sieves were arranged in such a way that the one with the highest opening was placed at the top while the one with the smallest opening was placed at the bottom with the base pan the base. The dried samples were placed at the top, covered up and placed on a shaker. The amplifier was used to operate the shaker at a medium frequency. The sieve analysis was carried for about twenty minutes while checking at intervals. After the sieve analyses have been completed, the sediment in each sieves were weighed and recorded. These procedures were carried out for each of the ten samples.

This basic data i.e. weight percentage frequency data is converted into cumulative weight percentage. The cumulative curves constructed on the basis of weight percentage data, served as basic tool for the generation of other statistical parameters (Table 2) as proposed by Folk (1980), Reinick and Singh (1980), Pettijohn (1984), Lindholmn (1987) and Sengupta (1996). The average values of various graphic measures in individual lithologies were calculated to depict of trend of sediment in the study area (Table 2).

b) Grain-Size Analysis

i. *Frequency Curves*

The comparative study of the histograms of retained fractions of sieve analysis i.e. weight percentage frequency curves (McBride, 1971) of entire samples show that the sediments are generally sand which range from fine to coarse sand. The cumulative weight percentage frequency curve is the representation of cumulative data of weight percentage on the vertical arithmetic ordinate ranging from one to hundred, whereas, φ value ranges from -1.00φ to 3.99φ. Most of the curves show almost similar trend, exhibiting a little sorting of grains and dominance of medium sand-size sediments (Figure 3).

c) Statistical Parameters

i. *Graphic Mean*

According to Folk (1980), the best graphic measure for determining overall size of sediment is the Graphic Mean. The Graphic Mean (M_z), is given by the formula:$M_z = (\emptyset 16 + \emptyset 50 + \emptyset 84)/_3$. This corresponds very closely to the mean as computed by the method of moments, yet it is much easier to find. It is much superior to the median because it is based on three points and gives a better overall picture. The graphic mean values (M_z) were used for the classification of sediments in the study area as it describes the average grain size of the sediments. It ranges from 1.333 - 2.267. The lowest mean value is 1.333 which belongs to sample OKL_7, while the peak value of 2.267 is associated with sample OKL_9. The result of the mean as shown in table reveals that OKL_1, OKL_3, OKL_5, and OKL_7 are medium grained sediments whereas OKL_2, OKL_4, OKL_6, OKL_8, OKL_9 and OKL_{10} are fine grained sediments. It is observed that there is an intercalation between the medium grained sediments and the fine grained sediments. The implication of this is that there is always a change in the transporting medium of the sediments. As explained earlier there is a cycle of low and high energy level in the area. This may possibly be attributed to the climatic nature of the area. During the dry season, the transporting medium which is river Ogbesse generally have low energy whereas during the raining season, it attains its maximum velocity depending on the amount of rainfall that falls the area.

ii. *Graphic Standard Deviations*

The Graphic Standard Deviation, (δ_G), is a good measure of sorting and is computed as $\emptyset 84 - \emptyset 16/_2$. However, this takes in only the central two-thirds of the curve and a better measure is the Inclusive Graphic Standard Deviation, (δ_1) which is given by the formula: $\delta_I = \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6.6}$. This formula includes 90% of the distribution and is the best overall measure of sorting, it is simply the standard deviation computed from $\emptyset 16$ and $\emptyset 84$, and (2) the standard deviation as computed from $\emptyset 5$ and $\emptyset 95$ … since this interval (from 5 to 95%) embraces 3.30σ, the standard deviation is found as $\frac{\emptyset 95 - \emptyset 5}{3.30}$. The two are simply averaged together. This explains why the denominators are both multiplied by 2. Standard deviation of the study area is in the order 0.889, 0.975, 1.205, 0.880, 1.351, 0.730, 1.311, 0.774 and 0.699 for OKL_1, OKL_2, OKL_3, OKL_4, OKL_5, OKL_6, OKL_7, OKL_8, OKL_9 and OKL_{10} respectively.

iii. *Graphic Skewness*

According to Folk, the graphic skewness covers only the central 68% of the curve. Inasmuch as most skewness occurs in the "tails" of the curve, this is not sensitive enough measure. Therefore, a better statistic, one that includes 90% of the curve, is the Inclusive Graphic Skewness given by the formula:$SK_I = \frac{\emptyset 16 + \emptyset 84 - 2\emptyset 50}{2(\emptyset 84 - \emptyset 16)} + \frac{\emptyset 5 + \emptyset 95 - 2\emptyset 50}{2(\emptyset 95 - \emptyset 5)}$. The inclusive graphic skewness (sk_1) of grain analysis data (Table 2) show that they are negatively skewed. This implies that the sediments are strongly coarsely, coarsely and nearly symmetrical skewed. Sediments in OKL_1, OKL_2 and OKL_{10} are strongly coarsely skewed, while OKL_3, OKL_4, OKL_5, OKL_6, OKL_8 and OKL_9 are coarsely skewed. OKL_7 is nearly symmetrical skewed.

iv. *Graphic Kurtosis*

The graphic kurtosis (KG) is the peakedness of the distribution and measures the ratio between the sorting in the tails and central portion of the curve. If the tails are better sorted than the central portions, then it is termed as platykurtic, whereas leptokurtic, if the central portion is better sorted. The sorting kurtosis of the sediments (Table 2) shows that they are either leptokurtic or very platykurtic. OKL_3, OKL_5 and OKL_7 are very platykurtic, while OKL_1, OKL_2, OKL_4, OKL_6, OKL_8, OKL_9 and OKL_{10} are leptokurtic (Figure 6).

d) Influence of Transporting Medium on Grain Size Distribution

From figure 4, it is observed that the sediments in the study area range from fine sand to coarse sand. This shows that the transporting agent must have undergone several stages of rise and fall. For fine sediments to be deposited in an environment, low energy of the transporting medium is required. However, for coarse grained sediments to be transported, a high transporting medium is required to transport the sediment from its initial state to its current state. Therefore it can be inferred from the aforementioned statement that the finer sand particles must have been transported when the transporting medium velocity was low, while the coarser sand must have been deposited when the energy of the transporting medium was high. The transporting medium must have undergone series of rise and fall in its velocity. In sediments with bimodal histogram (Figure 5), two flow regimes are suggested, while sediments with unimodal histogram, a single flow regime are suggested.

IV. Inter-Relationship of Size Parameters

The inter-relationship of specific size-parameters is significant to interpret various aspects of depositional environment, as the textural parameters of the sediments are often environmentally sensitive (Folk and Ward, 1957; Passega, 1957; Friedman, 1961, 1967; Moiola and Weiser, 1968; Visher, 1969; Srivastava and Mankar, 2009). Mean versus standard deviation plot of the present samples, shows the clustering of values near the extreme end of right limb of inverted V-shaped established trend of Folk and Ward (1957), denoting a smaller size range of the grains (Figure 4A). The same is confirmed by established sinusoidal curve of mean versus skewness as proposed by Folk and Ward (1957). The sinusoidal nature is because of proportionate admixture of two size-classes of the sediments i.e. fine sand and coarse sand. In general, the ideal fractions are nearly symmetrical but the mixing produces either positive or negative skewness depending upon the proportions of size-classes in the admixture. The present values mostly fall in the negative-skewed area of the graph. None is positively skewed (Figure 4B). It clearly indicates a unimodal nature of most sediment in the study area.

The relation between mean-size and kurtosis is complex and theoretical (Folk and Ward, 1957). The model plot of Folk and Ward (1957) denotes the mixing of two or more size-classes of sediments, which basically affect the sorting in peak and tails i.e. index of kurtosis. The scattering gives rise to an inverted 'V' trend. The plot of present values indicates a dominance of leptokurtic category followed by platykurtic in the size-class range of approximately 1.0-2.0φ i.e. medium sand (Figure 4C). It shows that the sediment-admixture is dominated by medium-sand and subordinate fine-sand. The varying proportions of fine sediments mixed with dominant sand mode makes the sorting worse, particularly in the tails; hence, there is a presence of platykurtic to leptokurtic. Similarly, the plot between skewness and standard deviation produce a scattered trend in the form of nearly circular ring (Folk and Ward, 1957). It may be due to two conditions i.e. either unimodal samples with good sorting or equal mixture of two modes. However, the present scattering shows clustering of grains in one sector (Figure 4D), which denotes the dominance of sand mode having subordinate silt. Because of the silt, the skewness value deviates into the negative sector.

The plot between standard deviation and kurtosis as proposed by Folk and Ward (1957) is again governed by the proportions of two size-modes in the mixture. Worst sorting is found in the bimodal mixtures with equal amounts of two modes, and these also have lowest kurtosis (Folk and Ward, 1957). In the present graph, the scatters are little away from the pure sand region of the original curve of Folk and Ward (1957), showing presence of minor fine-grain content. Majority of the samples are leptokurtic and moderately sorted because of the dominance of medium sand-size sediments (Figure 4E). The plot between skewness versus kurtosis depends on two modes and follows a regular path as the mean-size changes (Folk and Ward, 1957). The present values dominantly fall in an area represented by nearly pure sand with >1 % gravel and <5% silt of the establish plot of Folk and Ward (1957) (Figure 4F).

Certain plots which are considered significant for the interpretation of depositional environment (Friedman, 1961, 1967; Moiola and Weiser, 1968) have also been attempted. The plot between mean versus standard deviation is considered as an effective tool to differentiate between beach and river sands (Friedman, 1967; Moiola and Weiser, 1968). Accordingly, the present plot indicates that the sedimentation of Okeluse took place under river influence (Fig. 8A). Friedman (1967) and Moiola and Weiser (1968) considered the plot between standard deviation (horizontal axis) and skewness (vertical axis) is of great significance to differentiate between beach and river environments. The trends of present values are clearly indicative of river sedimentation (Figure 8B). Friedman (1967) established the relationship between simple sorting measure (SOS) = ½ (φ95 - φ5) and simple kurtosis measure (SKS) = (φ95 + φ5) - 2 φ50 and used it to differentiate between beach and river sediments (Srivastava and Mankar, 2008). The interrelationship plot (Figure 8C) shows the concentration of points in the river sector of the plot as proposed by Friedman (1967).

V. Log-Probability Curves

Log-probability curves proposed by Visher (1969) and used by is the representation of cumulative grain-size distribution on the probability (ordinate) paper, which is very useful to differentiate the sediments according to the mode of their transport i.e. traction, saltation and suspension.

In the present study, all the ten samples have been analyzed, which, in general, shows the dominance of saltation and suspension domains of size-population (Figure 7A - H). The traction between saltation and suspension is normally noticed near 2φ value. The suspension population may range up to 25%. The traction population represents minor quantity of poorly-sorted sediments, seldom exceeding 5%. The saltation population is comparatively more sorted than the fine-grained suspension population. Occasionally, the

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saltation population is divided into two sub-populations, truncating around 1.5φ value, which may be due to internal forces causing rolling or sliding (Visher, 1969).

The present plots are comparable with established trend for modern and ancient fluvial deposits as illustrated by Visher (1969), in which both saltation and suspension populations dominate.

VI. Discussion and Conclusions

Grain-size analysis of ten sediments representing 7m thick, fine to coarse grained sand of Okeluse, southwestern Nigeria collected through point sampling method have been carried out. The important conclusions drawn are as follows:

The frequency curves are dominantly indicative of fine to coarse-grained nature of the sand of the study area. The graphic mean value indicates the dominance of medium sand-size particles. The sediments, in general, show moderate sorting and are dominantly near-symmetrical to fine-skewed in nature. In majority of the cases, both peak and tails are negatively sorted giving rise to leptokurtic to paltykurtic condition. Various bivariate plots between mean, skewness, kurtosis and standard deviation are also interpreted following the criteria as proposed by Folk and Ward (1957). Some of the plots are indicative of unimodal nature of sediments, in which, sand-size is the principle mode. Some of the plots show a bimodal nature of sediments which also indicate sand-size sediments Standard deviation versus mean and standard deviation versus skewness indicates a fluvial environment of deposition as proposed by Friedman (1967) and Moiola and Weiser (1968). The same is also an outcome of SOS versus SKS (Friedman, 1967). The sediments are mostly rolled and deposited by traction currents, however, a few samples showing suspension mode is because of more quantity of fine grained material. The log-probability curves are also suggestive of fluvial environment of deposition as proposed by Visher (1969).

VII. Acknowledgements

The authors appreciate the management of Achievers University, Owo and the Dean of the College of Natural and Applied Sciences (CONAS) and the Head of Department of Geological Sciences Department of the same institution for providing an enabling environment to carry out this research work.

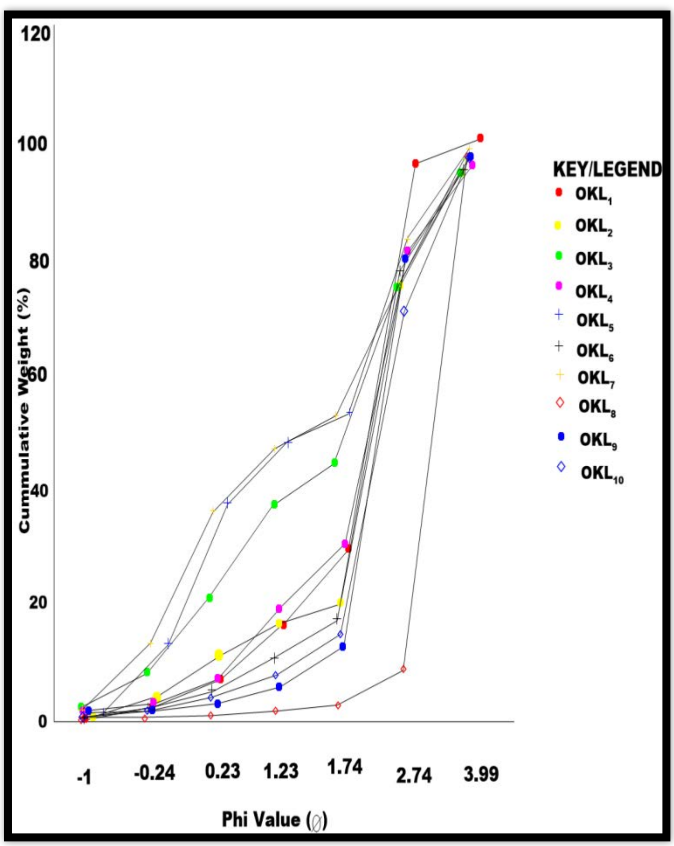

Figure 3 : Cumulative curves showing the trends of all the samples

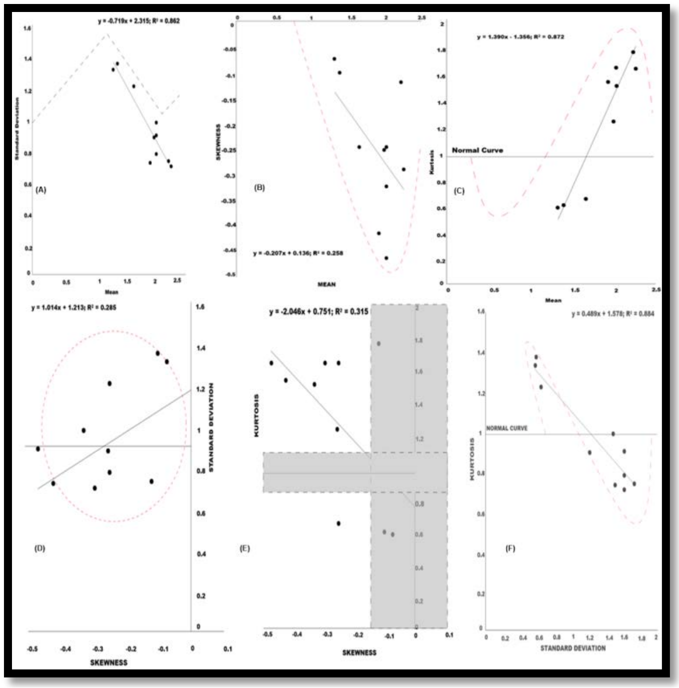

Figure 4 : Bivariate plots showing the placement of present samples in the model plot as proposed by Folk and Ward (1957). (A) Mean versus standard deviation, (B) mean versus skewness, (C) mean versus kurtosis, (D) skewness versus standard deviation, (E) skewness versus kurtosis and (F) standard deviation versus kurtosis

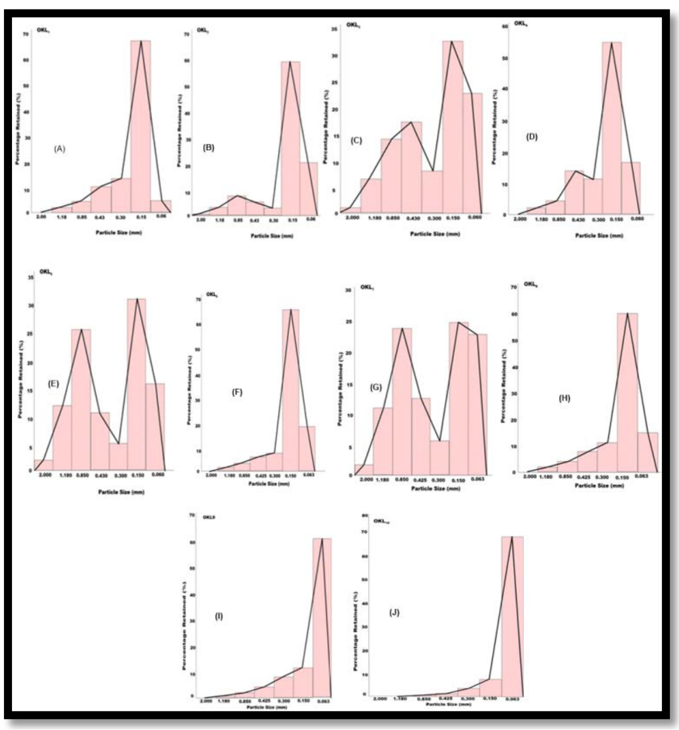

Figure 5 : Histogram of sediment distribution in the study area

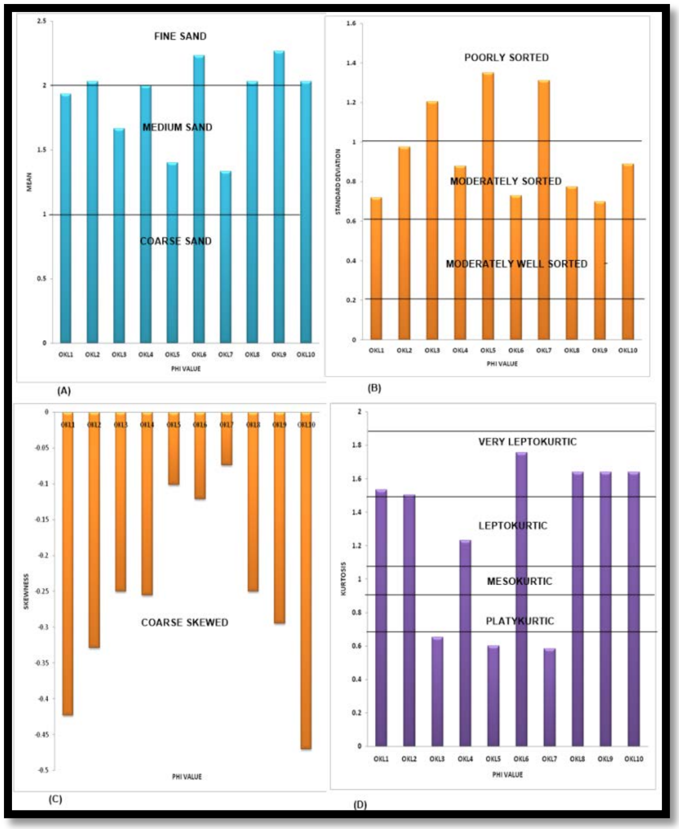

Figure 6 : Comparative histograms of all samples showing (A) mean, (B) standard deviation, (C) skewness and (D) kurtosis values.

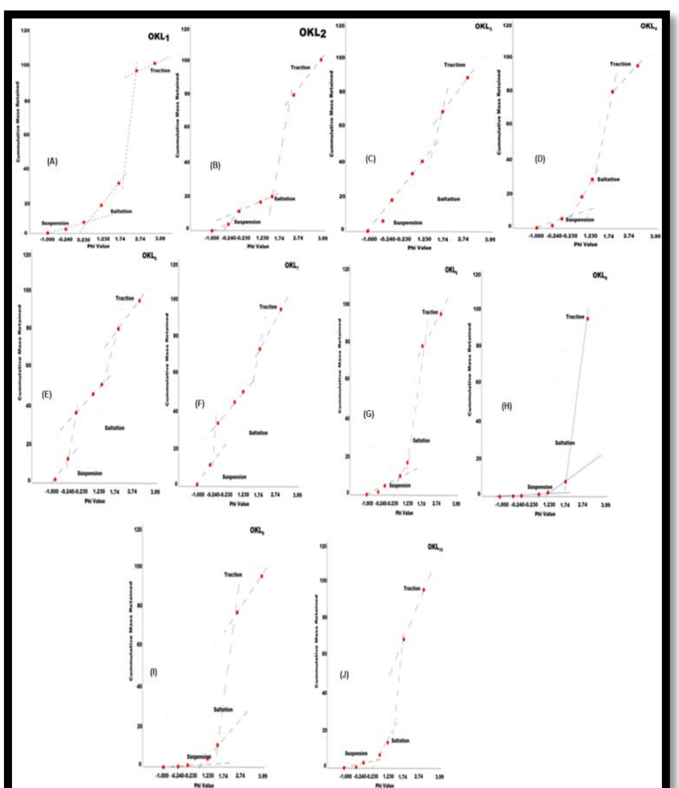

Figure 7 : Arithmetic probability curves (A to F) showing the trend of traction, saltation and suspension populations of all the samples.

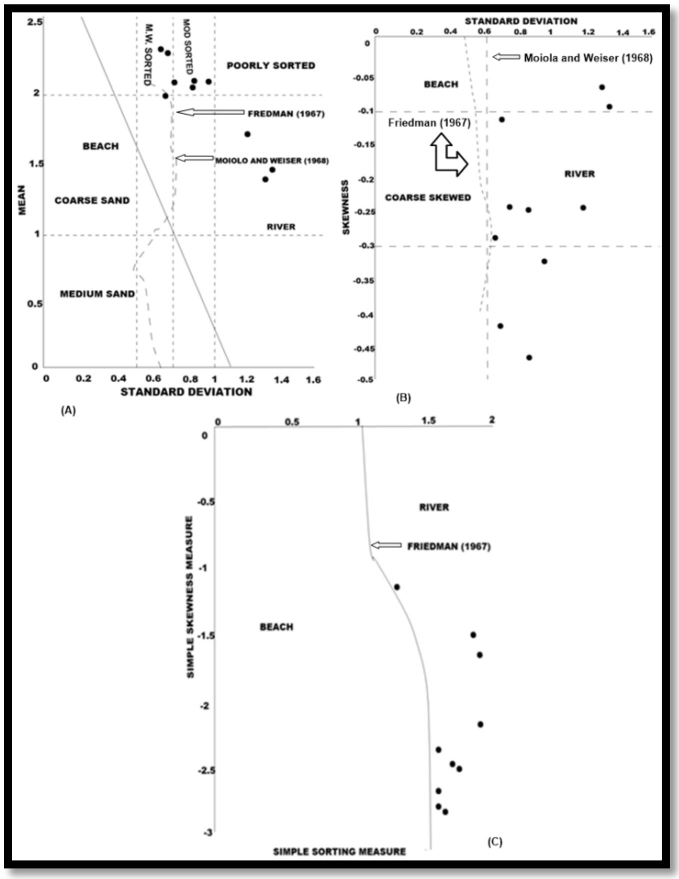

Figure 8 : Bivariate plots depicting environment of deposition (A) standard deviation versus mean, (B) standard deviation versus skewness and (C) simple sorting measure (SOS) versus simple skewness measure (SKS).

Table 1: Particle Size Distribution in the study area is of the samples.

(A) OKL_1

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retaine d (%)	Cummulative Mass Retaine d	Cummulaive Mass Passing (%)
2.000	-1.000	1.00	0.21	0.21	99.79
1.180	-0.240	9.89	2.04	2.24	97.76
0.850	0.230	21.42	4.42	6.66	93.34
0.425	1.230	48.53	10.01	16.67	83.33
0.300	1.74	62.68	12.92	29.59	70.41
0.150	2.74	319.35	65.85	95.44	4.56
0.063	3.99	22.13	4.56	100.00	0.00
Base Pan		0.00	0.00		
	Total = 484.98g				

(B) OKL_2

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retaine d (%)	Cummulative Mass Retaine d	Cummulaive Mass Passing (%)
2.000	-1.000	2.00	0.42	0.42	99.58
1.180	-0.240	16.91	3.51	3.92	96.08

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0.850	0.230	36.63	7.60	11.52	88.48
0.425	1.230	26.73	5.55	17.07	82.93
0.300	1.74	14.88	3.09	20.16	79.84
0.150	2.74	286.08	59.37	79.52	20.48
0.063	3.99	98.68	20.48	100.00	0.00
Base Pan		0.00	0.00		
	Total = 481.88g				

(C) OKL_3

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retained (%)	Cummulative Mass Retained	Cummulaive Mass Passing (%)
2.000	-1.000	4.00	0.85	0.85	99.15
1.180	-0.240	29.82	6.35	7.20	92.80
0.850	0.230	64.61	13.76	20.97	79.03
0.425	1.230	79.43	16.92	37.89	62.11
0.300	1.74	36.53	7.78	45.67	54.33
0.150	2.74	150.05	31.97	77.64	22.36
0.063	3.99	104.98	22.36	100.00	0.00
Base Pan		0.00	0.00		
	Total = 469.41g				

(D) OKL_4

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retained (%)	Cummulative Mass Retained	Cummulaive Mass Passing (%)
2.000	-1.000	1.00	0.22	0.22	99.78
1.180	-0.240	8.21	1.78	2.00	98.00
0.850	0.230	17.79	3.86	5.87	94.13
0.425	1.230	62.00	13.47	19.33	80.67
0.300	1.74	49.55	10.76	30.09	69.91
0.150	2.74	247.80	53.82	83.91	16.09
0.063	3.99	74.08	16.09	100.00	0.00
Base Pan		0.00	0.00		
	Total = 460.43g				

(E) OKL_5

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retained (%)	Cummulative Mass Retained	Cummulaive Mass Passing (%)
2.000	-1.000	9.00	1.92	1.92	98.08
1.180	-0.240	54.38	11.62	13.54	86.46
0.850	0.230	117.83	25.17	38.70	61.30
0.425	1.230	47.88	10.23	48.93	51.07
0.300	1.74	23.08	4.93	53.86	46.14
0.150	2.74	143.88	30.73	84.59	15.41
0.063	3.99	72.15	15.41	100.00	0.00
Base Pan		0.00	0.00		
	Total = 468.91g				

(F) OKL_6

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retained (%)	Cummulative Mass Retained	Cummulaive Mass Passing (%)
2.000	-1.000	1.00	0.21	0.21	99.79

1.180	-0.240	7.16	1.48	1.69	98.31
0.850	0.230	15.50	3.21	4.90	95.10
0.425	1.230	27.20	5.63	10.52	89.48
0.300	1.74	35.15	7.27	17.80	82.20
0.150	2.74	310.98	64.35	82.14	17.86
0.063	3.99	86.80	17.86	100.00	0.00
Base Pan		0.00	0.00		
	Total = 483.28g				

(G) OKL$_7$

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retaine d (%)	Cummulative Mass Retaine d	Cummulaive Mass Passing (%)
2.000	-1.000	7.00	1.60	1.60	98.40
1.180	-0.240	47.20	10.77	12.37	87.63
0.850	0.230	102.26	23.34	35.71	64.29
0.425	1.230	53.28	12.16	47.87	52.13
0.300	1.74	25.25	5.42	53.29	46.71
0.150	2.74	106.58	24.32	77.62	22.38
0.063	3.99	98.08	22.38	100.00	0.00
Base Pan		0.00	0.00		
	Total = 438.13g				

(H) OKL$_8$

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retaine d (%)	Cummulative Mass Retaine d	Cummulaive Mass Passing (%)
2.000	-1.000	1.00	0.21	0.21	99.79
1.180	-0.240	9.15	1.88	2.08	97.01
0.850	0.230	19.83	4.06	6.15	93.85
0.425	1.230	38.50	7.89	14.04	85.96
0.300	1.74	54.78	11.23	25.27	74.73
0.150	2.74	291.30	59.73	85.00	15.00
0.063	3.99	73.15	15.00	1000.00	0.00
Base Pan		0.00	0.00		
	Total = 487.70g				

(I) OKL$_9$

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retaine d (%)	Cummulative Mass Retaine d	Cummulaive Mass Passing (%)
2.000	-1.000	0.00	0.00	0.00	100.00
1.180	-0.240	2.06	0.44	0.44	99.56
0.850	0.230	4.45	0.95	1.39	98.61
0.425	1.230	15.43	3.29	4.68	95.32
0.300	1.74	33.60	7.18	11.86	88.14
0.150	2.74	325.30	69.47	81.33	18.67
0.063	3.99	87.40	18.67	100.00	0.00
Base Pan		0.00	0.00		
	Total = 468.23g				

(J) OKL$_{10}$

Particle Size (mm)	Particle Size (Phi)	Mass Retained (g)	Percent Retaine d (%)	Cummulative Mass Retaine d	Cummulaive Mass Passing (%)

2.000	-1.000	0.00	0.00	0.00	100.00
1.180	-0.240	4.95	1.03	1.03	98.97
0.850	0.230	10.73	2.23	3.25	96.75
0.425	1.230	20.63	4.28	7.54	92.46
0.300	1.74	33.15	6.88	14.42	85.58
0.150	2.74	279.48	58.03	72.45	27.55
0.063	3.99	132.68	27.55	100.00	0.00
Base Pan		0.00	0.00		
	Total = 481.60g				

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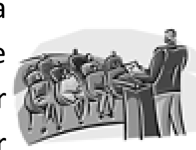
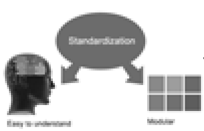


You may join as member of the Editorial Board of Global Journals Incorporation (USA) after successful completion of three years as Fellow and as Peer Reviewer. In addition, it is also desirable that you should organize seminar/symposium/conference at least once.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The FARSS can go through standards of OARS. You can also play vital role if you have any suggestions so that proper amendment can take place to improve the same for the benefit of entire research community.

As FARSS, you will be given a renowned, secure and free professional email address with 100 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.



The FARSS will be eligible for a free application of standardization of their researches. Standardization of research will be subject to acceptability within stipulated norms as the next step after publishing in a journal. We shall depute a team of specialized research professionals who will render their services for elevating your researches to next higher level, which is worldwide open standardization.

The FARSS member can apply for grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A. Once you are designated as FARSS, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria. After certification of all your credentials by OARS, they will be published on your Fellow Profile link on website https://associationofresearch.org which will be helpful to upgrade the dignity.

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The ' MARSS ' title is accorded to a selected professional after the approval of the Editor-in-Chief / Editorial Board Members/Dean.

The “MARSS” is a dignified ornament which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., MARSS or William Walldroff, M.S., MARSS.

MARSS accrediting is an honor. It authenticates your research activities. After becoming MARSS, you can add 'MARSS' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, Visiting Card and Name Plate etc.

The following benefitscan be availed by you only for next three years from the date of certification.

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We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The MARSS member can apply for approval, grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A.

Once you are designated as MARSS, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria.

It is mandatory to read all terms and conditions carefully.

Auxiliary Memberships

Institutional Fellow of Global Journals Incorporation (USA)-OARS (USA)

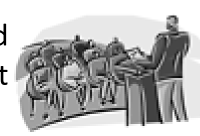
Global Journals Incorporation (USA) is accredited by Open Association of Research Society, U.S.A (OARS) and in turn, affiliates research institutions as "Institutional Fellow of Open Association of Research Society" (IFOARS).

The "FARSC" is a dignified title which is accorded to a person's name viz. Dr. John E. Hall, Ph.D., FARSC or William Walldroff, M.S., FARSC.

The IFOARS institution is entitled to form a Board comprised of one Chairperson and three to five board members preferably from different streams. The Board will be recognized as "Institutional Board of Open Association of Research Society"-(IBOARS).

The Institute will be entitled to following benefits:

The IBOARS can initially review research papers of their institute and recommend them to publish with respective journal of Global Journals. It can also review the papers of other institutions after obtaining our consent. The second review will be done by peer reviewer of Global Journals Incorporation (USA) The Board is at liberty to appoint a peer reviewer with the approval of chairperson after consulting us.
The author fees of such paper may be waived off up to 40%.



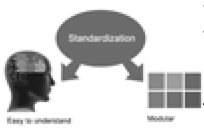
The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.

The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of "Open Association of Research Society, U.S.A (OARS)" so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.



After nomination of your institution as “Institutional Fellow” and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.
The board can also take up the additional allied activities for betterment after our consultation.

The following entitlements are applicable to individual Fellows:

Open Association of Research Society, U.S.A (OARS) By-laws states that an individual Fellow may use the designations as applicable, or the corresponding initials. The Credentials of individual Fellow and Associate designations signify that the individual has gained knowledge of the fundamental concepts. One is magnanimous and proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice.

Open Association of Research Society (US)/ Global Journals Incorporation (USA), as described in Corporate Statements, are educational, research publishing and professional membership organizations. Achieving our individual Fellow or Associate status is based mainly on meeting stated educational research requirements.

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We shall provide print version of 12 issues of any three journals [as per your requirement] out of our 38 journals worth $ 2376 USD.

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- The professional accredited with Fellow honor, is entitled to various benefits viz. name, fame, honor, regular flow of income, secured bright future, social status etc.

- In addition to above, if one is single author, then entitled to 40% discount on publishing research paper and can get 10%discount if one is co-author or main author among group of authors.
- The Fellow can organize symposium/seminar/conference on behalf of Global Journals Incorporation (USA) and he/she can also attend the same organized by other institutes on behalf of Global Journals.
- The Fellow can become member of Editorial Board Member after completing 3yrs.
- The Fellow can earn 60% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.
- Fellow can also join as paid peer reviewer and earn 15% remuneration of author charges and can also get an opportunity to join as member of the Editorial Board of Global Journals Incorporation (USA)
- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

Note :

"

- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone.

"

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The paper should be in proper format. The format can be downloaded from first page of 'Author Guideline' Menu. The Author is expected to follow the general rules as mentioned in this menu. The paper should be written in MS-Word Format (*.DOC,*.DOCX).

The Author can submit the paper either online or offline. The authors should prefer online submission.Online Submission: There are three ways to submit your paper:

(A) (I) First, register yourself using top right corner of Home page then Login. If you are already registered, then login using your username and password.

(II) Choose corresponding Journal.

(III) Click 'Submit Manuscript'. Fill required information and Upload the paper.

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(C) If these two are not conveninet , and then email the paper directly to dean@globaljournals.org.

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- Font type of all text should be Swis 721 Lt BT.
- Paper Title should be of Font Size 24 with one Column section.
- Author Name in Font Size of 11 with one column as of Title.
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- Main Text: Font size 10 with justified two columns section
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- First Character must be three lines Drop capped.
- Paragraph before Spacing of 1 pt and After of 0 pt.
- Line Spacing of 1 pt
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- Numbering of First Main Headings (Heading 1) must be in Roman Letters, Capital Letter, and Font Size of 10.
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You can use your own standard format also.
Author Guidelines:

1. General,

2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript’s Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

1. GENERAL

Before submitting your research paper, one is advised to go through the details as mentioned in following heads. It will be beneficial, while peer reviewer justify your paper for publication.

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The Global Journals Inc. (US) welcome the submission of original paper, review paper, survey article relevant to the all the streams of Philosophy and knowledge. The Global Journals Inc. (US) is parental platform for Global Journal of Computer Science and Technology, Researches in Engineering, Medical Research, Science Frontier Research, Human Social Science, Management, and Business organization. The choice of specific field can be done otherwise as following in Abstracting and Indexing Page on this Website. As the all Global

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2) Drafting the paper and revising it critically regarding important academic content.

3) Final approval of the version of the paper to be published.

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Appeal of Decision: The Editorial Board's decision on publication of the paper is final and cannot be appealed elsewhere.

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Manuscript submission is a systematic procedure and little preparation is required beyond having all parts of your manuscript in a given format and a computer with an Internet connection and a Web browser. Full help and instructions are provided on-screen. As an author, you will be prompted for login and manuscript details as Field of Paper and then to upload your manuscript file(s) according to the instructions.

To avoid postal delays, all transaction is preferred by e-mail. A finished manuscript submission is confirmed by e-mail immediately and your paper enters the editorial process with no postal delays. When a conclusion is made about the publication of your paper by our Editorial Board, revisions can be submitted online with the same procedure, with an occasion to view and respond to all comments.

Complete support for both authors and co-author is provided.

4. MANUSCRIPT'S CATEGORY

Based on potential and nature, the manuscript can be categorized under the following heads:

Original research paper: Such papers are reports of high-level significant original research work.

Review papers: These are concise, significant but helpful and decisive topics for young researchers.

Research articles: These are handled with small investigation and applications

Research letters: The letters are small and concise comments on previously published matters.

5.STRUCTURE AND FORMAT OF MANUSCRIPT

The recommended size of original research paper is less than seven thousand words, review papers fewer than seven thousands words also.Preparation of research paper or how to write research paper, are major hurdle, while writing manuscript. The research articles and research letters should be fewer than three thousand words, the structure original research paper; sometime review paper should be as follows:

Papers: These are reports of significant research (typically less than 7000 words equivalent, including tables, figures, references), and comprise:

(a)Title should be relevant and commensurate with the theme of the paper.

(b) A brief Summary, "Abstract" (less than 150 words) containing the major results and conclusions.

(c) Up to ten keywords, that precisely identifies the paper's subject, purpose, and focus.

(d) An Introduction, giving necessary background excluding subheadings; objectives must be clearly declared.

(e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition; sources of information must be given and numerical methods must be specified by reference, unless non-standard.

(f) Results should be presented concisely, by well-designed tables and/or figures; the same data may not be used in both; suitable statistical data should be given. All data must be obtained with attention to numerical detail in the planning stage. As reproduced design has been recognized to be important to experiments for a considerable time, the Editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned un-refereed;

(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

(h) Brief Acknowledgements.

(i) References in the proper form.

Authors should very cautiously consider the preparation of papers to ensure that they communicate efficiently. Papers are much more likely to be accepted, if they are cautiously designed and laid out, contain few or no errors, are summarizing, and be conventional to the approach and instructions. They will in addition, be published with much less delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and to make suggestions to improve briefness.

It is vital, that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

Format

Language: The language of publication is UK English. Authors, for whom English is a second language, must have their manuscript efficiently edited by an English-speaking person before submission to make sure that, the English is of high excellence. It is preferable, that manuscripts should be professionally edited.

Standard Usage, Abbreviations, and Units: Spelling and hyphenation should be conventional to The Concise Oxford English Dictionary. Statistics and measurements should at all times be given in figures, e.g. 16 min, except for when the number begins a sentence. When the number does not refer to a unit of measurement it should be spelt in full unless, it is 160 or greater.

Abbreviations supposed to be used carefully. The abbreviated name or expression is supposed to be cited in full at first usage, followed by the conventional abbreviation in parentheses.

Metric SI units are supposed to generally be used excluding where they conflict with current practice or are confusing. For illustration, 1.4 l rather than 1.4 × 10-3 m3, or 4 mm somewhat than 4 × 10-3 m. Chemical formula and solutions must identify the form used, e.g. anhydrous or hydrated, and the concentration must be in clearly defined units. Common species names should be followed by underlines at the first mention. For following use the generic name should be constricted to a single letter, if it is clear.

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Many researchers searching for information online will use search engines such as Google, Yahoo or similar. By optimizing your paper for search engines, you will amplify the chance of someone finding it. This in turn will make it more likely to be viewed and/or cited in a further work. Global Journals Inc. (US) have compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

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A major linchpin in research work for the writing research paper is the keyword search, which one will employ to find both library and Internet resources.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy and planning a list of possible keywords and phrases to try.

Search engines for most searches, use Boolean searching, which is somewhat different from Internet searches. The Boolean search uses "operators," words (and, or, not, and near) that enable you to expand or narrow your affords. Tips for research paper while preparing research paper are very helpful guideline of research paper.

Choice of key words is first tool of tips to write research paper. Research paper writing is an art.A few tips for deciding as strategically as possible about keyword search:

- One should start brainstorming lists of possible keywords before even begin searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in research paper?" Then consider synonyms for the important words.
- It may take the discovery of only one relevant paper to let steer in the right keyword direction because in most databases, the keywords under which a research paper is abstracted are listed with the paper.
- One should avoid outdated words.

Keywords are the key that opens a door to research work sources. Keyword searching is an art in which researcher's skills are bound to improve with experience and time.

Numerical Methods: Numerical methods used should be clear and, where appropriate, supported by references.

Acknowledgements: Please make these as concise as possible.

References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

References to information on the World Wide Web can be given, but only if the information is available without charge to readers on an official site. Wikipedia and Similar websites are not allowed where anyone can change the information. Authors will be asked to make available electronic copies of the cited information for inclusion on the Global Journals Inc. (US) homepage at the judgment of the Editorial Board.

The Editorial Board and Global Journals Inc. (US) recommend that, citation of online-published papers and other material should be done via a DOI (digital object identifier). If an author cites anything, which does not have a DOI, they run the risk of the cited material not being noticeable.

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Before start writing a good quality Computer Science Research Paper, let us first understand what is Computer Science Research Paper? So, Computer Science Research Paper is the paper which is written by professionals or scientists who are associated to Computer Science and Information Technology, or doing research study in these areas. If you are novel to this field then you can consult about this field from your supervisor or guide.

TECHNIQUES FOR WRITING A GOOD QUALITY RESEARCH PAPER:

1. Choosing the topic: In most cases, the topic is searched by the interest of author but it can be also suggested by the guides. You can have several topics and then you can judge that in which topic or subject you are finding yourself most comfortable. This can be done by asking several questions to yourself, like Will I be able to carry our search in this area? Will I find all necessary recourses to accomplish the search? Will I be able to find all information in this field area? If the answer of these types of questions will be "Yes" then you can choose that topic. In most of the cases, you may have to conduct the surveys and have to visit several places because this field is related to Computer Science and Information Technology. Also, you may have to do a lot of work to find all rise and falls regarding the various data of that subject. Sometimes, detailed information plays a vital role, instead of short information.

2. Evaluators are human: First thing to remember that evaluators are also human being. They are not only meant for rejecting a paper. They are here to evaluate your paper. So, present your Best.

3. Think Like Evaluators: If you are in a confusion or getting demotivated that your paper will be accepted by evaluators or not, then think and try to evaluate your paper like an Evaluator. Try to understand that what an evaluator wants in your research paper and automatically you will have your answer.

4. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

5. Ask your Guides: If you are having any difficulty in your research, then do not hesitate to share your difficulty to your guide (if you have any). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work then ask the supervisor to help you with the alternative. He might also provide you the list of essential readings.

6. Use of computer is recommended: As you are doing research in the field of Computer Science, then this point is quite obvious.

7. Use right software: Always use good quality software packages. If you are not capable to judge good software then you can lose quality of your paper unknowingly. There are various software programs available to help you, which you can get through Internet.

8. Use the Internet for help: An excellent start for your paper can be by using the Google. It is an excellent search engine, where you can have your doubts resolved. You may also read some answers for the frequent question how to write my research paper or find model research paper. From the internet library you can download books. If you have all required books make important reading selecting and analyzing the specified information. Then put together research paper sketch out.

9. Use and get big pictures: Always use encyclopedias, Wikipedia to get pictures so that you can go into the depth.

10. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right! It is a good habit, which helps to not to lose your continuity. You should always use bookmarks while searching on Internet also, which will make your search easier.

11. Revise what you wrote: When you write anything, always read it, summarize it and then finalize it.

12. Make all efforts: Make all efforts to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in introduction, that what is the need of a particular research paper. Polish your work by good skill of writing and always give an evaluator, what he wants.

13. Have backups: When you are going to do any important thing like making research paper, you should always have backup copies of it either in your computer or in paper. This will help you to not to lose any of your important.

14. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several and unnecessary diagrams will degrade the quality of your paper by creating "hotchpotch." So always, try to make and include those diagrams, which are made by your own to improve readability and understandability of your paper.

15. Use of direct quotes: When you do research relevant to literature, history or current affairs then use of quotes become essential but if study is relevant to science then use of quotes is not preferable.

16. Use proper verb tense: Use proper verb tenses in your paper. Use past tense, to present those events that happened. Use present tense to indicate events that are going on. Use future tense to indicate future happening events. Use of improper and wrong tenses will confuse the evaluator. Avoid the sentences that are incomplete.

17. Never use online paper: If you are getting any paper on Internet, then never use it as your research paper because it might be possible that evaluator has already seen it or maybe it is outdated version.

18. Pick a good study spot: To do your research studies always try to pick a spot, which is quiet. Every spot is not for studies. Spot that suits you choose it and proceed further.

19. Know what you know: Always try to know, what you know by making objectives. Else, you will be confused and cannot achieve your target.

20. Use good quality grammar: Always use a good quality grammar and use words that will throw positive impact on evaluator. Use of good quality grammar does not mean to use tough words, that for each word the evaluator has to go through dictionary. Do not start sentence with a conjunction. Do not fragment sentences. Eliminate one-word sentences. Ignore passive voice. Do not ever use a big word when a diminutive one would suffice. Verbs have to be in agreement with their subjects. Prepositions are not expressions to finish sentences with. It is incorrect to ever divide an infinitive. Avoid clichés like the disease. Also, always shun irritating alliteration. Use language that is simple and straight forward. put together a neat summary.

21. Arrangement of information: Each section of the main body should start with an opening sentence and there should be a changeover at the end of the section. Give only valid and powerful arguments to your topic. You may also maintain your arguments with records.

22. Never start in last minute: Always start at right time and give enough time to research work. Leaving everything to the last minute will degrade your paper and spoil your work.

23. Multitasking in research is not good: Doing several things at the same time proves bad habit in case of research activity. Research is an area, where everything has a particular time slot. Divide your research work in parts and do particular part in particular time slot.

24. Never copy others' work: Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

25. Take proper rest and food: No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

26. Go for seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

28. Make colleagues: Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

29. Think technically: Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

31. Adding unnecessary information: Do not add unnecessary information, like, I have used MS Excel to draw graph. Do not add irrelevant and inappropriate material. These all will create superfluous. Foreign terminology and phrases are not apropos. One should NEVER take a broad view. Analogy in script is like feathers on a snake. Not at all use a large word when a very small one would be sufficient. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Amplification is a billion times of inferior quality than sarcasm.

32. Never oversimplify everything: To add material in your research paper, never go for oversimplification. This will definitely irritate the evaluator. Be more or less specific. Also too, by no means, ever use rhythmic redundancies. Contractions aren't essential and shouldn't be there used. Comparisons are as terrible as clichés. Give up ampersands and abbreviations, and so on. Remove commas, that are, not necessary. Parenthetical words however should be together with this in commas. Understatement is all the time the complete best way to put onward earth-shaking thoughts. Give a detailed literary review.

33. Report concluded results: Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

34. After conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print to the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects in your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

Title Page:

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

Abstract:

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

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- Do not give permission to anyone else to "PROOFREAD" your manuscript.

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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ISSN 9755896