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ARTICLE

Evaluation of Sediment Yield Predicting Models of Ghana

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ABSTRACT

Fluvial sediment transport data is a very important data for effective water resource management. However, acquiring this data is expensive and tedious hence sediment yield modeling has become an alternative approach in estimating river sediment yields. In Ghana, several sediment yield predicting models have been developed to estimate the sediment yields of ungauged rivers including the Pra River Basin. In this paper, 10 months sediment yield data of the Pra River Basin was used to evaluate the existing sediment yield predicting models of Ghana. A regression analysis between predicted sediment yield data derived from the models and the observed suspended sediment yields of the Pra Basin was done to determine the extent of estimation of observed sediment yields. The prediction of suspended sediment yield was done for 4 out of 5 existing sediment yield predicting models in Ghana. There were variations in sediment yield between observed and predicted suspended sediments. All predicted sediment yields were lower than observed data except for equation 3 where the results were mixed. All models were found to be good estimators of fluvial sediments with the best model being equation 4. Sediment yield tends to increase with drainage basin area.

1. Introduction

Sediment yield (SY) of a basin refers to the total amount of sediments delivered from the catchment expressed as (t yr^{-1}) whilst the annual specific sediment yield (SSY) is obtained by dividing annual suspended sediment yield by catchment area (t km^{-2} $year^{-1}$) [1-4]. It is a useful measure of the sediment delivery ratio of the basin. Sediment yield from a catchment is a function of several anthropogenic and physical factors that influence erosion and sediment transport in the basin. The factors include farming, mining, construction, basin slope, basin area, geology and rainfall intensity and the natural drainage network [1]. The effects of these factors on sediment load vary in time and in space. In most cases, several of these factors may control sediment load of rivers in an area [5-7]. Fluvial sediment transport data is a very important data for effective water resource management [8]. However, acquiring fluvial sediment data in-situ is quite expensive and challenging [9-10], consequently sediment yield modeling has become an imperative alternative. Many authors in the past have used varied methodologies to estimate sediment yield of rivers that have no direct measured data [6, 11, 12, 13]. These sediment yield estimation methods among others

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are the erosion rate method, catchment-based method, rating curve method and regression method [6].

In Ghana there exist scanty sediment data on the country's water bodies [8]. Early sediment studies undertaken in the country were mainly of short duration and were associated with specific projects such as hydro-power, potable water supply, irrigation among others [14-18,12]. In the 1980s and 1990s, attempts were made to implement systematic collection of sediment data in Ghana by Water Research Institute of Ghana [12,19,20], but the initiative was unsustainable as the sampling programmes proved too expensive to maintain [12]. In recent times however, there have been academic studies on fluvial sediment transport in the country [21-25].

Sediment budgets typically require estimates of (1) basin-wide sediment yield, (2) erosion rates from upland, channel, and floodplain sources, and (3) changes to the volume and residence time of material in downslope storages [26-27]. Quantifying these variables is usually more practicable in small catchments [27-29] where direct measurements of erosion rates and storage terms can be made. However, budgets are difficult to construct in very large catchments because the delivery of eroded material from slopes and its storage in channels become more complex, and its measurements are subject to greater uncertainties, with increasing scale [27]. Therefore, quantifying these processes typically requires careful measurements within the framework of long-term monitoring programs [30-32, 26-27].

A complementary approach is the use of models to predict sediment budgets/sediment yields especially in wider river basins. This is because local or regional rivers often show similar characteristics; hence reliable estimates of sediment yields could be obtained from a regression equation that is derived from data on regional rivers that have broadly similar characteristics [6]. Catchment sediment yield modelling has become imperative because population growth causes increases in land use and land cover changes and coupled with threats of climate change, water resources will be threatened, and this will have dire consequences on economic activities and livelihoods in the country [33].

Based on factors that influence sediment yields and geographical conditions several sediment yield predictive models have been developed across the world to estimate fluvial sediment transport. A few examples [34-38] centred on annual specific sediment yield (SSY) are outlined in Table 1. Reference can be made to other models in the following literature [39-41] and many others. Though these models are convenient means of estimating sediment yields, they are however saddled with some degree of uncertainties and must be used with some caution especially in developing countries where such models were developed base on insignificant data.

Sediment yield predictive models for ungauged rivers have been developed for the southwestern river basins in Ghana [9], the Volta basin system [12], and the Pra River Basin [42] using runoff and catchment area as determinant factors. Boateng et al. 2012 [6] have also used only drainage catchment area as a parameter to estimate fluvial sediment input of Ghanaian rivers to the coastal sediment budget of Ghana. In this paper, 10 months sediment yield data of the Pra River Basin [2] is being used to evaluate the existing sediment yield predicting models of Ghana. A regression analysis between predicted data derived from the models and the observed suspended sediment yields of the Pra Basin was done to determine the degree of over/under estimation of sediment yields base on the co-efficient of determinations of the regression models.

Table 1. Examples of sediment yield predictive models

Model	Location	Reference
$SSY = 1.49 \times e^{1.24PGA} \times MLR^{0.66} \times e^{-0.05TreeCover} \times Ro^{0.24}$	Africa	Vanmaercke et al., 2014 [38]
$SSY = 0.86 \times S - 0.269 \times SWC + 10$	Ethiopia	Haregeweyn et al., (2008) [36]
$SSY = 114.54 + 1.567 \times A - 5.023 \times PER + 116.14 \times L_{em}$	Italy	Grauso et al., (2008) [35]
$\log SYY = -0.8838 + 0.8140 \log R - 0.3906 \log Q_{max}$	Colombia	Restrepo et al.,2006[37]
$SSY = 654 + 38.4\ LCs + 10.2P_{max} - 3787\ HI + 0.815\ EL_{ch} - 5711R_{pk}$	Asia	Ali and de Boer 2008 [34]

Note:
SSY: predicted annual specific suspended sediment yield (t km^{-2} y^{-1}); e: exponential fit; PGA: average expected Peak Ground Acceleration with an exceedance probability of 10% in 50 years; MLR: average height difference within a radius of 5 km; TreeCover: estimated percentage of the catchment covered by trees; Ro: estimated average annual runoff depth; S: slope gradient (%); SWC: areal coverage of soil and water conservation measures (%); A: catchment area (km^2); PER: catchment perimeter (km); L_{em}: erodibility index; R: mean annual runoff (mm yr^{-1}); Q_{max}:,maximum water discharge (m^3s^{-1}); LCs: % snow/ice cover; EL_{ch}: upstream channel elevation; HI: hypsometric integral; P_{max}: maximum monthly precipitation; Rpk: relief peakedness.

2. Study Area

The drainage system of Ghana is divided into three main units: the Volta Basin, South-western Basin and Coastal Basin (Figure 1). The Volta River Basin drains about three-fourths of the total land area of Ghana and consists of the following major catchments; Black Volta, White Volta, Daka, Oti, Afram, Pru, Sene, Kalurakuni and

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Lower Volta. The South-western Basin consists of the Pra,

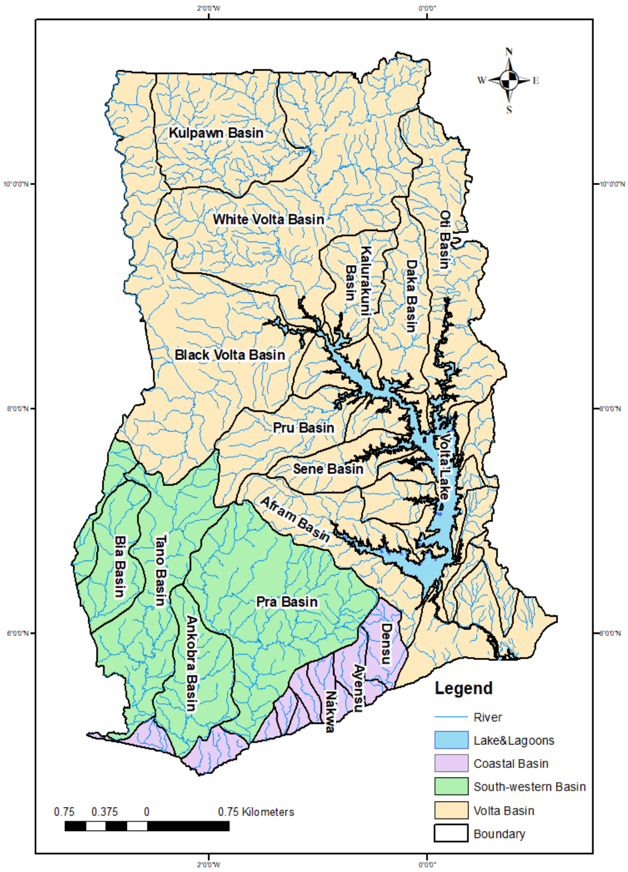

Figure 1. Map of Ghana showing the main drainage basins

Ankobra, Tano and the Bia rivers. The coastal rivers include the Densu, Ayensu and Nakwa. The northern and coastal zones of the country are characterised by flat and undulating topography of a denuded landscape with isolated peaks of plateau surfaces/inselbergs which rise to 180 meters a.s.l. The middle belt of the country is however of folded mountain ranges of elevations between 240 - 300 meters a.s.l [43]. Ghana is located within the equatorial zone hence its climate is tropical; hot and humid in the south whiles the northern part is hot and dry. The rainfall regime in the north is unimodal with an annual mean of about 100 cm and bimodal in the south with an annual rainfall of about 180 cm [43]. Generally, the vegetation in northern part is grassland, middle belt is tropical forest and shrubs cover the coastal landscape.

Sediment yield analysis was carried out in the Pra River Basin which is part of the south-western basin Ghana (Figure 1) with the following geographical coordinates; latitudes 5°00'N and 7°15'N and longitudes 0°03'W and 2°80'W. The basin consists of three major sub-basins; Ofin, Oda and the Birim (Figure 2). The drainage basin area is 23,188 km^2 with a mean annual discharge of 214 m^3s^{-1} [42]. The basin is generally of low relief characterised by undulating topography with an average elevation of about 450 m above sea level.

The soils are forest ochrosols which are alkaline and forest oxysols which are acidic. The soils are derived from the Tarkwaian and Birrimian geological formations of sandstones, granites and metamorphosed rocks such as phyllites and schists [43].

The climate of the basin is the wet semi-equatorial climatic system which is characterized by two rainfall maxima, the first season being April - July and the second rainy season is from September - November. The rains are brought by the moist south-west monsoons with high annual rainfall amounts of between 125 and 200 cm. The rainy season could be characterised by high flows which can cause bank erosion at certain sections of the river channel. Dry seasons are well marked and span from November to March [43]. The Pra Basin is covered by the moist semi-deciduous forest vegetation which consists of trees, lianas, climbers, and shrubs/bushes which protect the soil from erosion by rain drops and run-off. Most corridors of the river channels are covered by shrubs which protects them against bank erosion [43].

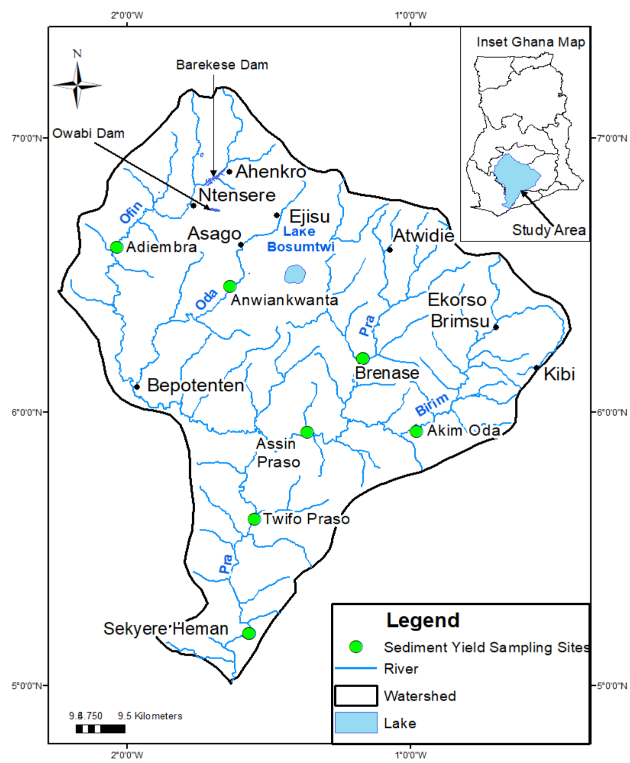

Figure 2. Pra River Basin showing sediment yield sampling sites

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3. Research Materials and Methods

3.1 A Review of Sediment Yield Predictive Models in Ghana

Base on measured suspended sediment yield and discharge data on certain forested river basins in Ghana, Amisigo and Akrasi (2000) [9] derived three empirical equations (eqns. 1-3) of least square regression for the prediction of specific suspended sediment yields of catchments in the southwestern basin system for which no sediment measurements are known:

$$SSY = 9.92A^{0.062} \quad (1)$$

$$SSY = 44.9S_R^{0.773} \quad (2)$$

$$SSY = 0.24Q^{0.84}A^{0.26} \quad (3)$$

Where SSY = the mean annual specific suspended sediment yield (t km^{-2} $year^{-1}$), S_R = total annual stream flow per basin area (Q × 3600s/h × 24h/day × 365days/yr × 1/(A × $10^6 m^2/km^2$) = 31.536 km^2 s/yr.m^2 × Q/A), Q = mean daily stream discharge (m^3/s) and A = catchment area (km^2). Equation 1 had a co-efficient of determination (R^2) of 0.02, that of eqn. 2 is 0.65 and eqn. 3 is 0.95. Later Akrasi (2005) [12] again used eqn. (3) based on observed data of specific suspended sediment yield obtained for eight measuring stations in six river basins of the Volta River Basin to develop a simple empirical prediction model for estimating the specific suspended sediment yields of catchments in the Volta basin system for which no sediment measurements are available. The adjusted coefficient of determination (R^2) for the relationship was 0.92, indicating that the parameters selected by the regression analysis (mean daily stream discharge and catchment area) accounted for a large proportion of the variance of the sediment yield data and both exponents were statistically significant at 5% level. Also, the ability of eqn. 1 to predict the specific suspended sediment yields of Volta River sub-basins was further demonstrated by a plot of predicted versus observed specific suspended sediment yield for eight gauged catchments in the Volta Basin. The coefficient of determination of the observed versus predicted values was 94%. This model was later used to estimate the specific suspended sediment yields in other catchments such as the Pra, Ankobra, Tano among others in southern Ghana.

The model of Boateng et al., (2012) [6] was derived by establishing a relationship between catchment area and sediment yield to estimate fluvial sediment inputs into the coastal sediment budget in Ghana, using suspended sediment discharge data of 11 stations sampled for an average period of 12 years [20]. Two sets of equations were used: one for smaller catchments (Ss) (i.e. catchment less than 5,000km^2) eqn.4 and for large catchments (SL) (i.e. catchment more than 5,000km^2), eqn.5. This is because small catchments are often recorded as having proportionally large yields [44]. Linear regression equation was applied to large rivers because it provided the best fitted curves of graphical plot (a correlation coefficient R^2 of 0.98) and quadratic regression relationships for smaller catchments because it offered the best fit with a correlation coefficient R^2 of 0.61.

The regression equation for smaller catchments (Ss): Suspended sediment yield (SY) (t/yr) = 20722−1.127 × a + 0.001422 × a^2 … (R^2 = 0.98), ... (4) and for large catchments (SL): Suspended sediment yield (SY) (t/yr) = -108+15.80 × a.................... (R^2 = 0.61), ... (5) where A = catchment area (km^2) and t = tonnes.

3.2 Suspended Sediment Yield Measurements in the Pra River Basin

Suspended sediment concentration measurements were taken for 10 months on the Pra River and major sub-catchments of the Pra catchment (i.e Ofin, Oda and Birim) (Figure 2). Samples were taken using dip and integrated sampling approaches. Samples were analyzed using the evaporation method. Daily mean suspended sediment concentration was calculated from which monthly and annual suspended sediment yields were derived. The sampling procedure at the various stations, laboratory analysis and the method used to compute the suspended sediment yields of the sampled rivers have been well explained in Kusimi et al., (2014) [2]. Sediment rating curves using the rating techniques of Walling 1977 [45] were derived by plotting suspended sediment discharges against water discharges for each of the stations [2]. Rating curves of the stations are illustrated in Table 2. The best fit curve was that of Twifo Praso with a co-efficient of determination (R^2) of 98%.

Table 2. Suspended sediment rating curves in the Pra River Basin

No.	Station	River	Equation	R^2
1	Sekyere Hemang	Pra	$Qs = 429.48Q^{0.67}$	0.66
2	Twifo Praso	Pra	$Qs = 100.38Q^{0.90}$	0.98
3	Assin Praso	Pra	$Qs = 14.638Q^{1.12}$	0.92
4	Akim Oda	Birim	$Qs = 31.626Q^{0.95}$	0.73
5	Adiembra	Offin	$Qs = 10.914Q^{0.97}$	0.86
6	Brenase	Pra	$Qs = 31.608Q^{0.97}$	0.73
7	Anwiankwanta	Oda	$Qs = 13.676Q^{1.15}$	0.86

Note: Qs = suspended sediment discharge

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3.3 Evaluation of Existing Sediment Yield Models

Predicted sediment yields from equations 1, 3, 4, & 5 were compared with the 10 months observed sediment yields of the Pra Basin [2]. The performance of the equations was evaluated for levels of predictability base on R^2 and the root mean square errors (RMSEs) of the models. Since equation 1- 3 predict specific annual suspended sediment yield (SSY), the predicted specific annual suspended sediment yield data were converted to annual suspended sediment yield (SY) by multiplying each predicted specific annual suspended sediment yield (SSY) by the basin area (see Tables 3 - 6). Equation 2 was not used in this analysis because of the incompatibility of data format, i.e. mean daily stream discharge (m^3/s) could not be converted to total annual stream flow per basin area km^2 s/m^2. A linear regression between predicted sediment yield data derived from the models and the observed suspended sediment yields of the Pra Basin was done to determine the extent of prediction of the observed sediment yields. The co-efficient of determination (R^2) and RSMEs were derived for each model to ascertain their predictive levels (Figs.3 - 6 and Tables 3 - 6).

4. Results and Discussion

4.1 Evaluation of Sediment Yield Prediction Models

Table 3 shows catchment areas, observed sediment yields of the rivers, predicted annual specific suspended sediment yield as well as the predicted total sediment yields derived from equation 1. The predicted annual specific suspended sediment yield (SSY) ranged from 15.5 t km^{-2} y^{-1} in the Oda Basin to about 18.5 t km^{-2} y^{-1} in the Pra main catchment. Predicted sediment yields (SY) are between 19,912.9 t/yr and 420,521 t/yr. Predicted sedi-

Table 3. Sediment yields derived from equation 1

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield (t km^{-2}/yr)	Predicted annual suspended sediment yield (t/yr)	Observed annual suspended sediment yield (t/yr)	Percentage of sediment under estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	15.5	19,912.9	66,094.1	69.9	30.1	2,808,070.6
Offin	Adiembra	3,101.1	16.3	50,640.7	115,372.1	56.1	43.9	3,031,046.5
Birim	Akim Oda	3,104.2	16.3	50,694.3	290,775.6	82.6	17.4	3,320,045
Pra	Brenase	2,167.8	16.0	34,622.8	150,455.4	76.9	23.1	3,711,915.2
Pra	Assin Praso	9,234.8	17.5	161,359	220,907.1	26.9	73.1	4,285,896.9
Pra	Twifo Praso	20,625.3	18.4	378,795.1	2,645,002.1	85.7	14.3	5248961.4
Pra	Sekyere Heman	22,7578	18.5	420,521	7,489,290.1	94.4	5.6	7,068,769.1
	Mean			159506.5	1,568,270.9			4,210,672.1

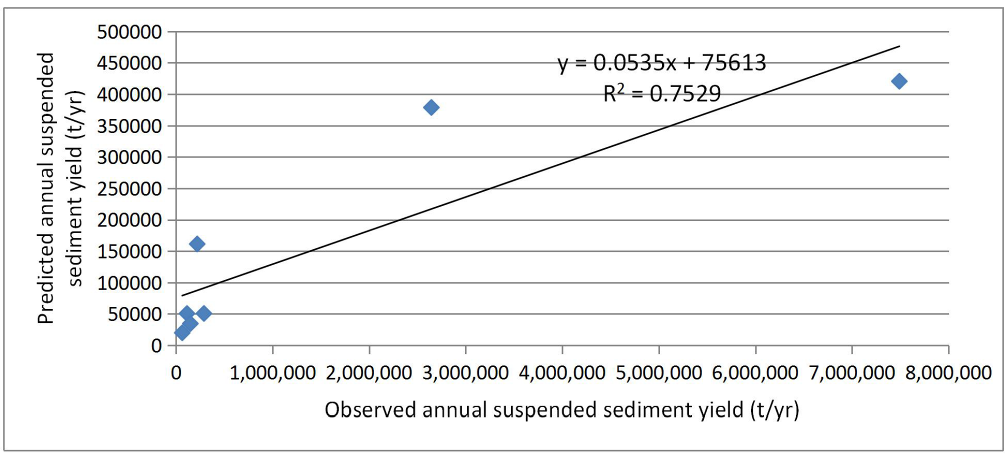

Figure 3. A plot of predicted and observed suspended sediment yields for equation 1

ment yields are lower than the observed sediment yields in all basins. The predicted suspended sediment yield was lowest 19,912.9 t/yr as against 66,094 t/yr observed in the Oda Basin at Anwiankwata and the highest predicted was 420,521 t/yr as against 7,489,290 t/yr observed in the Pra Basin at Sekyere Heman (Table 3). Equation 1 grossly underestimates sediment yields in the river basins. The percentage of under estimation of sediment yield ranges between 27-94% across the basins. The model can predict sediment yield of between 6-73% of observed sediment yield with RMSE range of 2.8-7.1 million and a mean of 4.2 million. Apart from Assin Praso where sediment yield predicted is over 70%, the percentage of sediments predicted in other basins is insignificant (Table 3). Figure 3 shows a scatter plot of predicted suspended sediment yield (t/yr) against observed suspended sedimentyield (SY) for equation 1 with a linear equation y = 0.0535x + 75613; R^2 = 0.75. Based on the co-efficient of determination, equation 1 is a good predictive model of sediment yield in the Pra River.

Estimating sediment yield using basin area in this model will result in the estimation of over 70% of annual sediment yields in the watershed.

Predicted annual specific suspended sediment yield (SSY) and predicted suspended sediment yield (SY) results derived from equation 3 is presented in Table 4. Predicted annual specific suspended sediment yield is between 14 and 660 t km^{-2} $year^{-1}$ and annual suspended sediment yield is between 17,604 and 15 million t/yr. For equation 3, predicted sediment yields were lower than observed sediment yields in four stations whiles in the other three stations, predicted sediment yields were higher than observed sediment yields. Under estimation of sediments were at Akim Oda on the Birim River, Brenase on the Pra River, Twifo Praso on the Pra River and Adiembra on the Ofin River (Figure 2). Percentage of under estimation of sediment yield is between 13 and 94%, thus equation 3 could predict between 6 and 84% of observed sediment

Table 4. Sediment yields derived from equation 3

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield (t km^{-2} $year^{-1}$)	Predicted annual suspended sediment yield (t/yr)	Observed annual suspended sediment yield (t/yr)	Percentage of sediment under/ over estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	40.9	126,858.4	66,094.1	-91.91	191.9	3,326,568.1
Offin	Adiembra	3,101.09	22.6	49,064.4	115,372.1	57.5	42.5	3,593,018.5
Birim	Akim Oda	3,104.18	13.7	17,604.3	290,775.6	93.9	6.1	3,935,842.9
Pra	Brenase	2,167.79	42.2	130,733.7	150,455.4	13.1	86.9	4,398,285.8
Pra	Assin Praso	9,234.75	206.5	4,259,705.3	220,907.1	-1828.3	1928.3	5,078,690.3
Pra	Twifo Praso	20,625.28	58.2	537,091.5	2,645,002.1	79.7	20.3	5,525,730.4
Pra	Sekyere Heman	22,757.98	659.7	15,014,189.2	7,489,290.1	-100.5	200.5	7,524,899.1
	Total			2876463.8	1,568,270.9			4,769,005

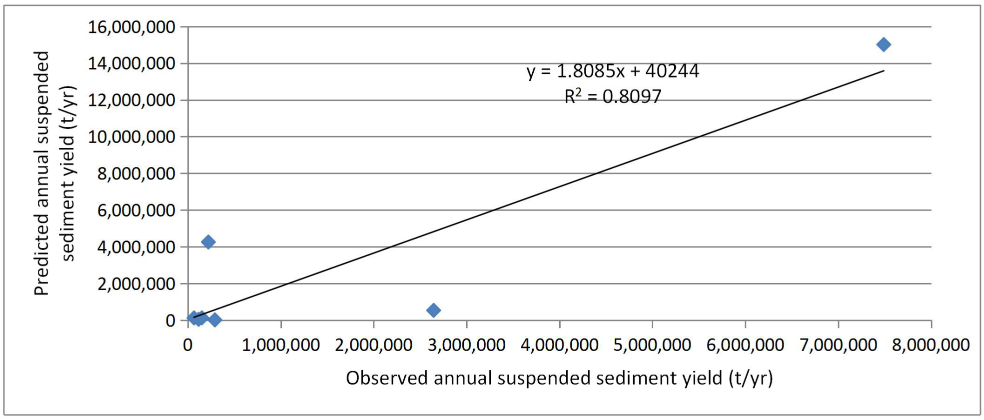

Figure 4. A plot of predicted and observed suspended sediment yields for equations 3

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yields of the respective catchments (Table 4). Predicted annual suspended sediment yields were greater than the observed yields at Anwiankwanta on the Oda River, Assin Praso and Sekyere Heman all on the Pra River (Table 4 and Figure 2). Over prediction of fluvial sediments ranges from 92 to over - 1,800% of observed data (Table 4).

Linear regression curve derived from a plot of the predicted suspended sediment yield (t/yr) against observed suspended sediment yield are shown in Figure 4. The predictive model and co-efficient of determination are y = 1.8085x + 40244 and R^2 = 0.80 with RMSEs range of 3.3 to 7.5 million. The co-efficient of determination of the curve show that the linear regression model is a good predictive model for suspended sediment yield in the Pra Basin. Equation 3 is therefore a good equation for estimating sediment yield in the Pra Basin and base on findings of Amisigo and Akrasi (2000)[9] and Akrasi (2005)[12], this model is a good estimator of sediment yield in Ghanaian rivers. Thus, basin area and water discharge are key factors to coupled in predicting river sediment load and transport in Ghanaian rivers.

Table 5 shows the suspended sediment yields predicted base on equation 4 and observed yields for each station. The lowest predicted sediment yield was 20,237 t/yr as against observed value of 66,094 t/yr at Anwiankwanta in the Oda River Basin whiles the highest values are 731,564 t/yr and 7,489,290 t/yr for predicted and observed respectively at Sekyere Heman. For equation 4, all predicted suspended sediment yields were lower than observed sediment yields. Predicted fluvial sediments are under predicted with percentage under estimation ranging from 40 - 90%. The difference between the observed and predicted ranged between 45,857 t/yr at Anwiankwanta on the Oda River to about 6.8 million t/yr at Sekyere Heman (Figure 2). Except at Assin Praso on the Pra River, fluvial sediment yields predicted are all lower than 50% of ob-

Table 5. Sediment yields derived from equation 4

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield ($t\ km^{-2}\ year^{-1}$)	Predicted suspended sediment yield (t/yr)	Observed suspended sediment yield (t/yr)	Percentage of sediment under estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	15.7	20,237.7	66,094.1	69.4	30.6	2,835,926.9
Offin	Adiembra	3,101.1	15.8	48,889.2	115,372.1	57.6	42.4	3,063,093.9
Birim	Akim Oda	3,104.2	15.8	48,938	290,775.6	83.2	16.8	3,355,319.6
Pra	Brenase	2,167.8	15.8	34,143.1	150,455.4	77.3	22.7	3,749,412
Pra	Assin Praso	9,234.8	14.3	131,583.5	220,907.1	40.4	59.6	4,328,927.2
Pra	Twifo Praso	20,625.4	29.2	602,399.2	2,645,002.1	77.2	22.8	5,301,565.5
Pra	Sekyere Heman	227,578	32.2	731,564	7,489,290.1	90.2	9.8	7,129,822.1
				140464.1	1,568,270.9			4,252,009.6

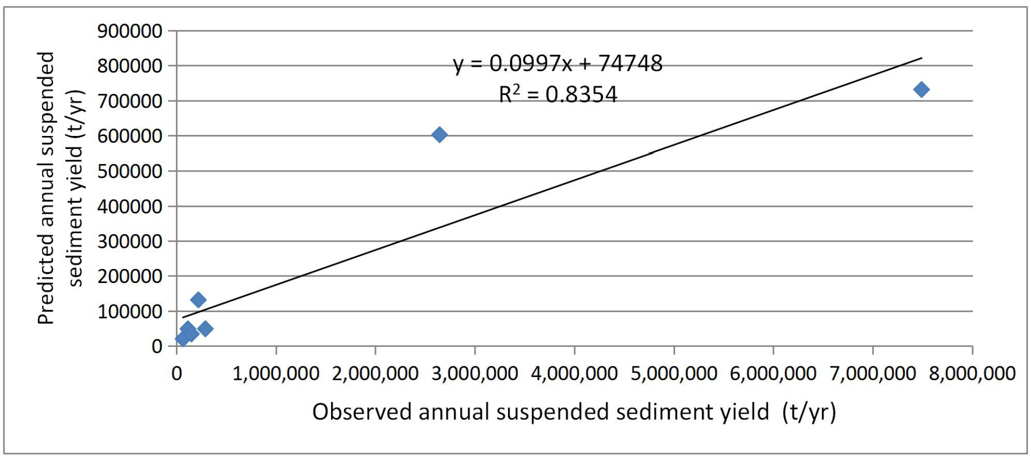

Figure 5. A plot of predicted and observed suspended sediment yields for equation 4

served sediment yield data in all other sub- basins (Table 5). Similarly, the RMSE of sediment prediction is between 2.8 and 7.1 million with average of 4.2 million. Figure 5 shows the best fit line and the co-efficient of determination between predicted and observed data of sediment yields. The co-efficient of determination of the best fit line is $R^2 = 0.84$. Equation 4 is also a good model in sediment yield estimation base on catchment area, but it is a better model than equation 1 where R^2 is 0.75 which is also base on watershed area.

Results of predicted sediment yield and the annual specific sediment yield of equation 5 are illustrated in Table 6. Predicted sediment yield ranges between 20,237 t/yr as the lowest at Anwiankwanta in Oda Basin to 3.5 million t/yr at Sekyere Heman in the Pra River Basin with an average annual specific sediment yield of about 15.8 t km^{-2} year^{-1} across all basins. Like equation 4, observed suspended sediment yields were higher than all predicted suspended sediment yields. For instance, observed sediment yield was 290,775 t/yr as compared to 48,938 t/yr predicted in Akim Oda (Table 6). The level of under prediction of fluvial sediment transport was high. The difference in sediment yield between predicted and observed data is between 45,857 t/yr at Anwiankwanta and 7.1 million t/yr at Sekyere Heman (Figure 2). Equation 5 predicts between 5 and 66% of observed fluvial sediment transport and just like equation 4, the amount of fluvial sediments predicted are all less than 50% of observed data except at Assin Praso (Table 6). Also, the RMSEs are equally like results of equation 4. A plot of predicted annual suspended sediment yield for equation 5 against observed annual suspended sediment yield in the Pra River Basin is shown in Figure 6. The co-efficient of determination of the linear regression is $R^2 = 0.75$. For Boateng et al., (2012) [6] equations; equation 4 is a better estimator of sediment yield compared to equation 5 since the co-efficient of determination of equation 4 is higher (0.84%). Equation 5 also produces similar RMSEs as other equations (Table 6).

For all the sediment yield predictive models, the lowest results were obtained in the Oda Basin and the highest

Table 6. Sediment yields derived from equation 5

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield (t km^{-2} year^{-1})	Predicted suspended sediment yield (t/yr)	Observed suspended sediment yield (t/yr)	Percentage of sediment under estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	15.7	20,237.7	66,094.1	69.4	30.6	2,835,926.9
Offin	Adiembra	3,101.1	15.8	48,889.2	115,372.1	57.6	42.4	3,063,093.9
Birim	Akim Oda	3,104.2	15.8	48,938	290,775.6	83.2	16.8	3,355,319.6
Pra	Brenase	2,167.8	15.8	34,143.1	150,455.4	77.3	22.7	3,749,412
Pra	Assin Praso	9,234.8	15.8	145,801.1	220,907.1	34	66	4,328,927.3
Pra	Twifo Praso	20,625.4	15.8	325,771.4	2,645,002.1	87.7	12.3	5,301,565.5
Pra	Sekyere Heman	227,578	15.8	3,594,68.1	7,489,290.1	95.2	4.8	7,129,822
	Mean			140464.1	1,568,270.9			4,252,009.6

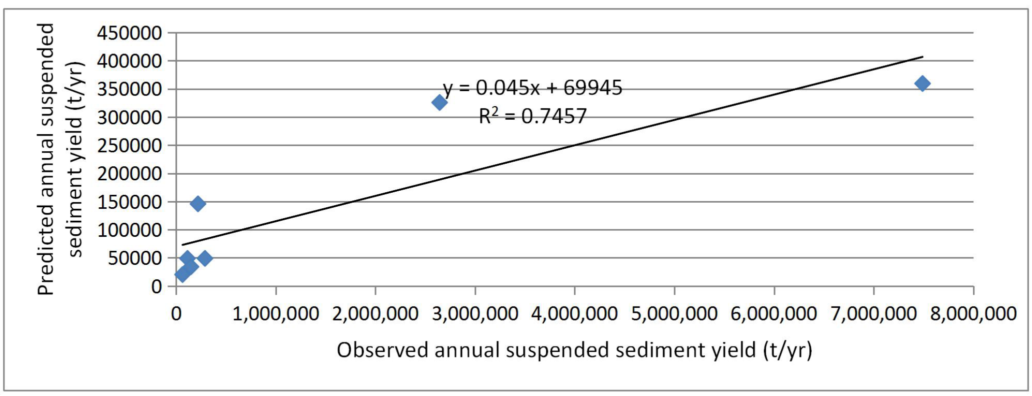

Figure 6. A plot of predicted and observed suspended sediment yields for equation 5

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Table 7. Sediment yields of equation 3 base on only water discharge

River	Station	Water Discharge (m^3/s)	Predicted annual suspended sediment yield (t/yr) with discharge and area	Predicted suspended sediment yield (t/yr) with on only discharge	Percentage of water discharge sediments
Oda	Anwiankwanta	37.61	17,604.3	5.1	0.004
Offin	Adiembra	20.8	130,733.7	3.1	0.006
Birim	Akim Oda	13.41	126,858.4	2.1	0.012
Pra	Brenase	39.04	49,064.4	5.2	0.004
Pra	Assin Praso	144	537,091.5	15.6	0.0004
Pra	Twifo Praso	40.85	4,259,705.3	5.4	0.001
Pra	Sekyere Heman	556.67	15,014,189.2	48.6	0.0003

values in the Pra main catchment at Sekyere Heman for both annual specific suspended sediment yield and annual suspended sediment yield. It is observed that sediment yield tends to increase as the drainage basin increases, thus basins of larger areas yield higher sediments. Estimating the sediment yield of equation 3 with only water discharge (Table 7) shows that, water discharge accounts for less than 0.1% of predicted sediment yields of the equation. Thus over 99.9% of the sediments estimated by equation 3 in Table 4 are attributable to catchment area. Catchment area is therefore a key independent predictive variable in sediment yield estimation in the Pra Basin. This finding is however at variance with other studies where sediment yield decreases with catchment area [2, 4, 38, 46-48]. The explanation to this phenomenon is that an increase in catchment area increases the probability of sediment deposition owing to decreasing slope and channel gradients. Comparing R^2 and RMSEs of the models, the best sediment yield predictive equation is equation 4 which had R^2 of 0.84 followed by equation 3 ($R^2 = 0.80$) with equations 1 and 5 being the least having R^2 of 0.75. Generally, most predicted values of fluvial sediment yields are lower than observed sediment yields in all the catchments. The RMSEs are equally similar for all models except that of eqn.3.

5. Conclusion

The prediction of suspended sediment yield was done for 4 out of the 5 known sediment yield predictive models in Ghana. There were variations in sediment yield between observed and predicted suspended sediments. Predicted sediment yields of equation 3 were found to be higher and lower than the observed sediment yields in certain basins; however predicted sediment yields of equations 1, 4 and 5 were all lower than that of observed suspended sediment yields. For all the sediment yield predictive models, the lowest results were obtained in the Oda Basin and the highest values in the Pra main catchment at Sekyere Heman for both annual specific suspended sediment yield and annual suspended sediment yield. The analyses showed that sediment yield increases with drainage basin area, thus basins of larger drainage areas yield higher sediments. Based on co-efficient of determination (R^2), all the sediment yield models evaluated can be said to be good estimators of sediment yield for river basins in Ghana.

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