Research Article

Spatial distribution of soil erosion and sediment yield in the Pra River Basin

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Abstract
This study demonstrates the application of Revised Universal Soil Loss Equation (RUSLE) and Sediment Distributed Delivery (SEDD) models integrated with Geographic Information System (GIS) to estimate gross soil loss and the sediment delivery of the Pra River Basin in Ghana. Digital Elevation Model, land use map, rainfall data and soil map were input to the model to display the spatial distribution of soil erosion and sediment in the basin. The model estimated an annual soil erosion of 1.28×10^6 t/year and an average sediment yield of 2.70 t/ha/year in the basin. Results showed that about 21.3% of the basin is susceptible to severe and very severe erosion. The model results showed that soil erosion rate varied with land use types. It also showed that the Lower Ofin sub-basin has the highest erosion rate. The study demonstrates that the RUSLE and SEDD model integrated with GIS provides relatively easy, cost-effective and fast approach in the estimation of spatially distributed soil erosion and sediment yield of river basins. The results will help in the planning and management of natural resources to ensure sustainable development of the Pra River Basin.

Keywords Revised Universal Soil Loss Equation (RUSLE) · Sediment Delivery Distributed (SEDD) · Soil erosion · Sediment yield

1 Introduction

Soil erosion in river basins continue to be one of the critical environmental problems affecting agricultural productivity [1], water quality and quantity [2, 3] and reservoir/dam operations [4]. It involves the detachment of soil particles, transport and deposition under the influence of rain droppings, runoffs and wind [5]. Sediment yield of a basin results from soil erosion and transport processes taking place in a whole contributory area [6, 7]. Its severity is often enhanced by anthropogenic activities such as mining, urbanization, deforestation and climate change [8–10]. Vanmaercke et al. [11] indicated that sediment yield observations of African catchments range between 0.002 and 157 t/ha/year. Quansah et al. [12] reported that 29.5%, 43.3% and 23% of Ghana's land area is vulnerable to slight to moderate erosion, severe sheet and gully erosion and very severe sheet and gully erosion respectively. In Ghana, surface water bodies and reservoirs/dams continue to suffer the threat of soil erosion leading to siltation of rivers, deterioration in water quality and the reduction in reservoir capacities [13–15]. As a result, the lifespan of reservoirs/dams are drastically reduced. Subsequently, water supply for both domestic and commercial uses, as well as for the generation of hydropower, for the growing energy demand is negatively affected [16]. Thus, effective catchment management is needed to ensure the sustainability of natural resources both for the current and future generation [17, 18]. This will require timely information on the rate and amount of soil loss and delineation of degraded areas [19, 20].

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Conventional soil erosion and sediment yield measurement methods have had their challenges such as cost, time and technology [21] leading to inadequate or sometimes unavailability of reliable data, especially in developing countries for planning and project implementation purposes [22]. As such empirical and physically-based models have been developed for soil loss estimations and predictions [23–25]. The Revised Universal Soil Loss Equation (RUSLE) [26] which is the updated form of Universal Soil Loss Equation (USLE) [5] is one of the widely utilized empirical models for the estimation of soil loss [19, 27, 28]. RUSLE was firstly developed in the USA to forecast long-term average erosion under different management systems [1, 26]. Unlike other models, RUSLE is relatively simple, easy to parameterize and does not require complex data to operate with. Thus, it is very appropriate for data deficient countries like Ghana. The integration of the RUSLE with Geographic Information Systems (GIS) and Remote Sensing makes it suitable for the assessment of the heterogeneous nature of the basin's topographic and drainage features [7, 29]. The spatial display and analytic functions of GIS allows the RUSLE model to be applied to individual cells to spatially exhibit the pattern of soil erosion in a catchment [7, 30, 31]. Hence its application in soil loss estimation and prediction has been catalogued in literatures [7, 9, 32, 33]. Zerihun et al. [34] evaluated soil loss severity in the Dembecha Northern District, Ethiopia, using RUSLE integrated with GIS and Remote Sensing. Their model evaluated the mean yearly soil loss in the District to be 49 t/ha/year. Tossic et al. [28] utilized the RUSLE to appraise the normal yearly soil loss and gave regionalization in the territory of republic of SRPSKA-BiH according to the level of erosion risk. Ayalew [35] adopted RUSLE to Ethiopian conditions to estimate soil loss and identified severity areas in Gerdi for conservation measures. His study demonstrated that RUSLE integrated with GIS provides a good estimate of soil loss over areas. Ashiagbor et al. [36] likewise modelled the spatial distribution of soil erosion in the Densu River Basin of Ghana using RUSLE and GIS tools, and used the model to explore the connection between the catchment's soil erosion and the contributory factors. El Jazouli et al. [19] evaluated soil erosion susceptibility in the Middle Atlas Mountain-Morocco using the USLE and the spectral index approach and realized an agreement between the two. Kayet et al. [37] used the RUSLE and Soil Conservation Service (SCS) curve number (CN) to estimate soil loss in the Kiruburu and Meghahatuburuu mining sites. Their results indicated a solid connection between the soil loss with runoff. Again, Fernandez et al. [6] combined GIS with RUSLE model to evaluate the spatial distribution of soil erosion and sediment delivery of a catchment and concluded that the coordinated approach enables relatively simple and cost-efficient way of estimating soil erosion and sediment delivery.

In spite of the fact that the RUSLE and its integration with Geospatial technologies have gotten acknowledgment among hydrologist and erosion researchers, its application in Ghana is exceptionally low. Considering the unavailability of soil loss and sediment yield data, and the need to monitor soil erosion, there is the need to adopt appropriate models to demonstrate the spatial distribution of soil erosion and sediment yield, especially in basins experiencing drastic land use and cover changes. One of such important basins is the Pra River Basin (PRB) in Ghana. It is the second largest basin in Ghana with an average discharge of 4174 Mm^3/year [38]. The climatic environment makes the basin susceptible to rainfall erosion [39, 40]. Previous sediment yield studies and estimates by Akrasi [22] and Akrasi and Ansa-Asare [39] indicated that the sediment yield of the basin was low by world's standard. However, the rise in the activities and operations of illegal miners known as Galamseyers in the basin and alluvial mining within the river bed [41, 42], and the increasing urbanization since then, can significantly alter the erosion regime of the basin. It is therefore likely that the estimates might not be reflecting the current situation, knowledge of which is important for basin management to ensure sustainability of the ecosystem.

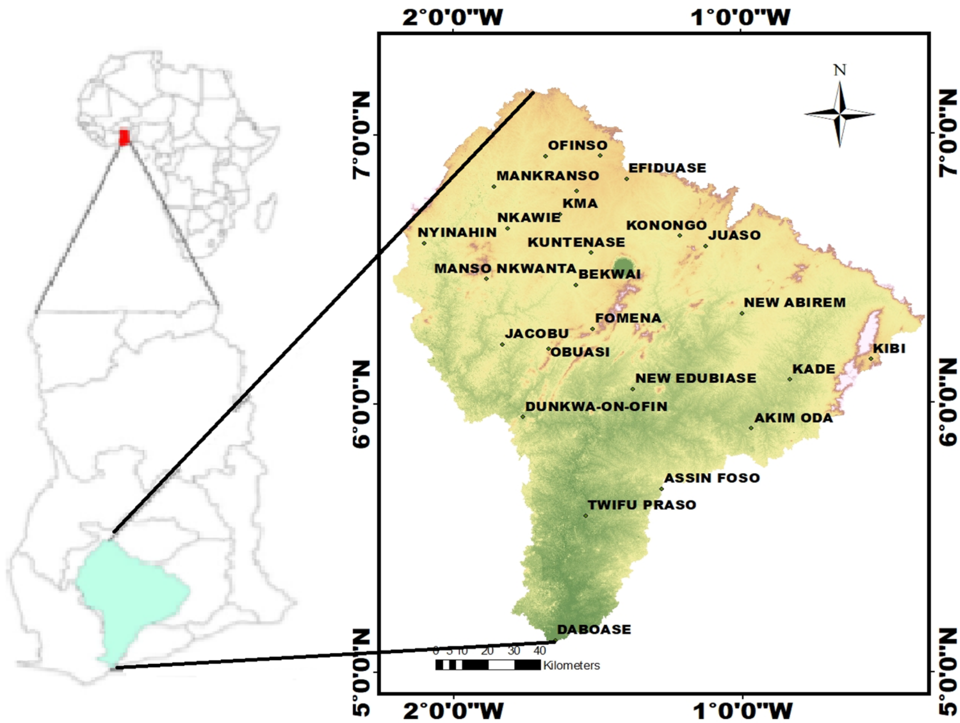
In view of this, the study applies the RUSLE model to display the spatial distribution of soil erosion and the sediment yield of PRB. The study integrated the RUSLE and SEDD model with GIS and Remote Sensing to identify the sediment generating areas for prioritized attention. This is important for effective catchment management to reduce the soil loss rate and the amount of sediment yield in the Pra River system, thereby ensuring the sustainability of the ecosystem, longevity of reservoirs/dams and an improved agricultural productivity.

2 Materials and methods

2.1 Study area

Pra River Basin (Fig. 1) covering a total land area of 23,200 km^2 is situated within Latitudes 5° N and 7° 30′ N, and Longitudes 2° 30′ W, and 0° 30′ W, in Ghana. It has an average discharge of about 4174 Mm^3/year. The main tributaries of the basin are Anum, Birim, Ofin and Oda River, which takes it source from the Mampong-Kwahu plateau and flows southwards for about 240 km before joining the Gulf of Guinea [38]. The terrain is relatively level and undulating with most astounding heights of up to 870 m

Fig. 1 Map of Pra River Basin



above ocean level situated in the northern segments and the edges of the eastern parts.

The basin falls within the sub-tropical wet climatic zone, with double rainfall seasons (May–July and September–November). The mean annual rainfall ranges between 1300 and 1900 mm increasing westwards and south-westwards. Relative humidity is very high averaging between 70 and 80% throughout the year. The average minimum and maximum temperatures are 26 °C in August and 30 °C in March respectively.

The basin is underlain with forest ochrosols and pre-Cambrian rocks (delegated Birimian and Tarkwaian) [41]. The principal vegetation of the basin consists of moist semi-deciduous forest type. The basin is richly endowed with water and mineral resources.

2.2 Methods and dataset

The Revised Universal Soil Loss Equation (RUSLE) is an empirically-based model used to estimate long-term average annual soil loss resulting from rainfall and runoff [5, 26] given as

$$A = R \times \boldsymbol{K} \times LS \times C \times P \quad (1)$$

where A is the average soil loss/erosion (t/ha/year); R is the rainfall-runoff erosivity factor (MJ mm ha/h/year); K is the soil erodibility factor (t ha MJ^{-1} mm^{-1}); LS is the slope length and steepness factor (dimensionless); C is the cover management factor (dimensionless) and P is the support practice factor. The annual soil loss (A), the sediment delivery ratio (SDR) and the sediment yield of the basin were obtained on a grid-by grid basis by integrating the respective data (Fig. 2) with GIS.

2.3 Rainfall erosivity factor, R

The rainfall erosivity factor (R) characterizes the impact of rain to cause erosion [43]. The rain drop size, distribution, frequency, intensity and velocity determines the amount of soil erosion detached and transported. Therefore, greater rainstorm intensity and duration results in higher erosion potential [7]. Thus high R value indicates high

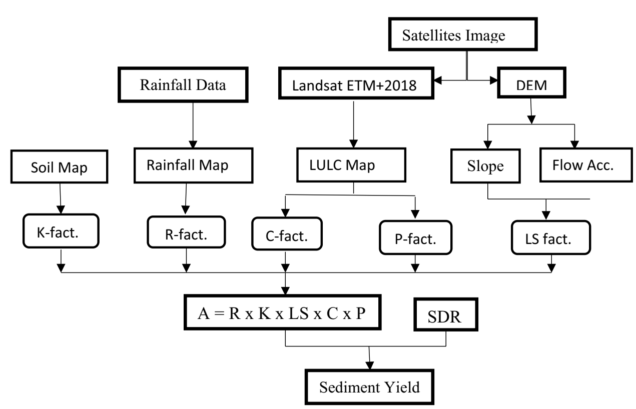


Fig. 2 Flow chart of methodology

potential of soil detachment and transport. The annual R factor is an element of the aggregate tempest vitality (E) and the most extreme 30-min force (I_{30}) [44]. It is determined through the summation of every rainstorm, the result of the aggregate vitality and the greatest 30 min force, I_{30}. Be that as it may, these figures are not really accessible at standard meteorological stations [36, 45] yet since long-term normal R-values are regularly related with all the more promptly accessible precipitation information, the yearly precipitation and the modified Fournier Index [46] was utilized in building up the mean yearly precipitation map and the average yearly erosivity map in ArcGIS separately. The Modified Fournier Index (MFI) is more important for the investigation of precipitation forcefulness since it considers the estimation of precipitation in various long periods of the year and the variety amid a particular year or period.

The R-factor was then computed from [46] equation developed for West Africa expressed as

$$R = 5.444\text{MFI}-416 \tag{2}$$

MFI is the modified Fournier index expressed as

$$\text{MFI} = \sum_{i=1}^{12} \frac{P_i^2}{P} \tag{3}$$

P_i is the monthly average amount of precipitation for month i (mm) and P is the average annual quantity of precipitation (mm). In this study, daily rainfall records from twenty-two (22) meteorological stations within and around the basin, from 1986 to 2018 were used to calculate the mean annual rainfall. Then the rainfall map (Fig. 3a**)** and the rainfall erosivity (R) map was produced by interpolation using the Kriging tool in ArcGIS. And since the constant mean of the data across the basin is unknown, ordinary Kriging method using the spherical semivariogram model was adopted for the interpolation process

2.4 Soil erodibility factor, K

The soil erodibility factor represents the soil's vulnerability to disintegration by precipitation and overflow [26]. Morgan [44] defines it as "the mean annual loss per unit of rainfall erosivity for a standard condition of bare soil, recently tilled up and down slope with no conservation practice". It is influenced by the soil's inherent properties such as texture, structure, organic matter, permeability etc. High K-value implies the soil is highly susceptible to detachment whilst low K-value indicates the soil's resistance to detachment or erosion during storm event [46]. In this investigation, the K-factors (Table 1) was obtained from [36]. He estimated the soil erodibility factor for soils in Ghana using the erodibility monograph by Wischmeier and Smith [5].

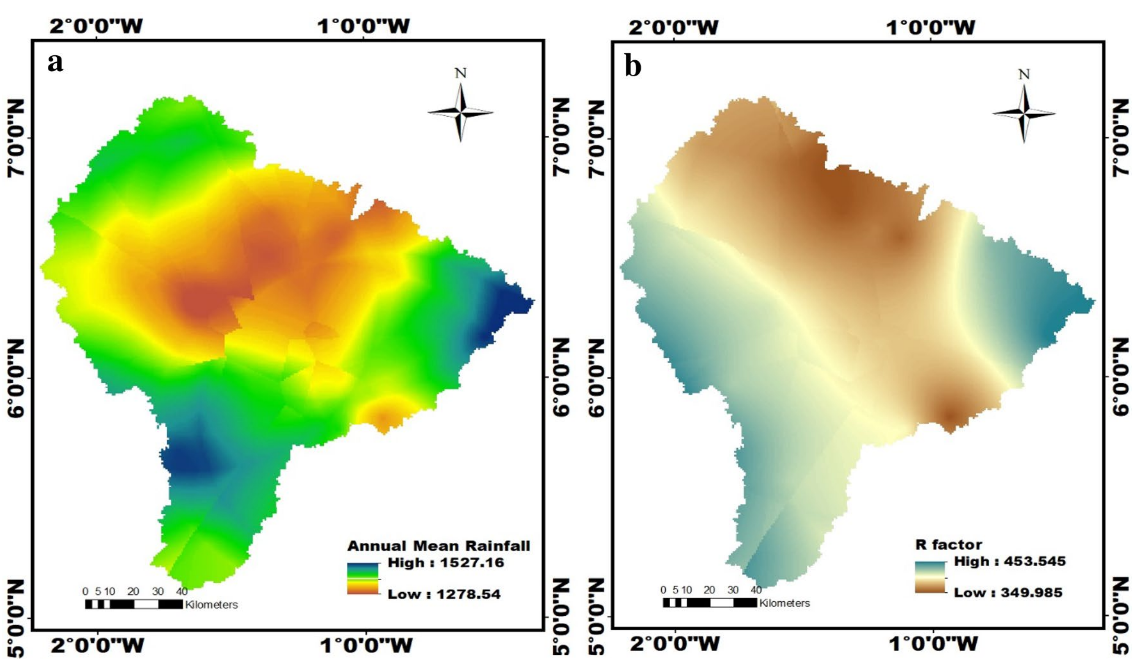


Fig. 3 **a** Annual mean rainfall map, **b** rainfall erosivity (R) map

Table 1 K-factor of soils in the PRB

Soil type	K-factor
Acrisols	0.253
Lixisols	0.234
Leptosols	0.275
Fuvisols	0.295
Luvisols	0.234
Alisols	0.250

Table 2 C-factors of land use and land cover classes in the basin

Land use and land cover class	C factor
Closed forest	0.001
Open forest	0.003
Farm/grassland	0.5429
Settlement	0.35
Mining	1
Water	0.000

The K-factors were allotted to the various soil classifications in the basin and used to generate K-factor map in ArcGIS.

2.5 Cover management factor, C

The cover management factor C explains the proportion of soil loss under determined conditions to that from persistent fallow and tilled land [5]. The C factor reflects the effect of cropping and management practices on erosion. The value of C indicates the soil's exposure to rain drops. High C-value indicate low vegetative cover, hence higher rate of erosion during rainfall, whiles low C-value indicates good vegetative cover, resulting in low erosion rate. In this study, the C-factor map was developed from Landsat ETM + 2018 covering the PRB. The Landsat imagery was classified with the supervised classification technique using the spectral angle mapping technique. Hence, Land use/Land cover (LULC) map (Fig. 6a) was produced. Six LULC classes were identified and classified, namely closed/dense forest, open/degraded forest, farm/grassland, settlement, mining and water bodies. The details of the classification and the accuracy assessment is published in [52]. The C-factor estimates corresponding to the different LULC classes suggested by Kusimi et al. [32] and Wischmeier and Smith [5] (Table 2) were allotted to their individual classes to produce the C-factor map.

2.6 Slope length and steepness factor (LS)

The LS factor depicts the impact of topography on soil erosion. It is the combination of slope length (L) and slope steepness (S) in relation to a unit cell (grid). The slope length (L) is characterized as the separation from the source of runoff to the point where settlement begins or runoff enters a well-defined channel which is part of the drainage system, whilst the steepness factor (s) demonstrates the impact of incline steepness on disintegration. For the determination of LS factor, hypothetical relationship in light of unit stream control hypothesis has been received from [9] as this connection is most appropriate for integration with GIS. The relation is given as

$$LS = \left[\frac{As}{22.13}\right]^{n}\left[\frac{sin\beta}{0.0896}\right]^{m} \quad (4)$$

As is the specific area (A/b), characterized as the upslope contributing zone for overland lattice (A) per unit width typical to stream heading (b), β is the incline angle in degrees, n = 0.4 and m = 1.3. However, in this study, LS factor was determined from the DEM of the basin integrated into the GIS environment. The GIS technology enables relatively easy calculation of the L and S factors through the estimation of upslope contributing areas and the inclined slope individually. The overland flow length and the slope map were used as input in the derivation of LS factor map using Eq. 5 stated by Mitasova et al. [47] and Ashiagbor et al. [36].

$$LS = \mathrm{Pow}\left(Flowaccumulation * \frac{Cell\ resolution}{22.1, 0.4}\right) * \mathrm{Pow}\left(\sin\left(\frac{slope\ of\ DEM}{0.09, 1.4}\right)1.4\right) \quad (5)$$

2.7 Conservation support practice, P

The support practice factor (P) describes the effect of practices like contouring, strip-cropping, terraces and contour furrows on the rate of runoff and erosion. The P-factor ranges between 1 and 0.01 for bare soils with no erosion measures and fully protected land surface respectively [48].

In this study, field observation as well as the classification results showed that the basin is well protected by forest, grassland and crops. Accordingly, as demonstrated by Kusimi et al. [32] P-factor of 1 was allocated to settlement and mining territories, and zero (0) to water. With regard to forest and farm/grassland reference was made to [49] and [33].Thus, *P* values of 0.31 and 0.05 were assigned to farm/grassland and forest respectively to generate P-factor map in ArcGIS.

Hence, raster maps of R, K, LS, C and P were coordinated in ArcGIS environment utilizing the RUSLE model to produce the annual soil loss map.

2.8 Sediment yield

If A_i is the measure of soil erosion created inside the ith cell of the basin, then according to [7] the sediment yield of the cell, SY is

$$SY = A_i * SDR_i \quad (6)$$

where SDR is the sediment delivery ratio

2.9 Sediment delivery ratio (SDR)

SDR explains the portion of the gross soil loss from the ith cell that really reaches a stream system [6]. It is assessed as a component of movement time [50] given as

$$SDR_i = \exp\left(-\beta t_i\right) \quad (7)$$

where t_i is travel time (h) for cell i and β is basin specific parameter.

The movement time for every cell, t_i along a stream path as stated by Jain and Kothyari [7] is

$$t_i = \sum_{i=1}^{m} \frac{l_i}{V_i} \quad (8)$$

l_i is the length of fragment l (flow length) in the stream way and is equivalent to the length of the side or askew relying upon the stream heading in the cell, and Vi is the stream speed for the cell (m/s). The flow length was derived from the DEM of the basin whilst the flow velocity is a function of the land surface slope and the land cover characteristics [45].

$$V_i = a_i \sqrt{s_i} \quad (9)$$

where s_i—slope of the ith cell and a_i—coefficient dependent on land use.

Introducing Eqs. 8 and 9 into Eq. 7 gives Eq. 10

Table 3 Land cover types and their coefficients, a_i

Land cover type	Coefficient, a_i
Closed forest	0.7600
Open forest	0.6401
Built up/bare lands	6.3398
Farm/grassland	0.4572
Water	0.1250

$$SDR_i = \exp\left(-\beta \sum_{i=1}^{m} \frac{l_i}{a_{i\sqrt{s_i}}}\right) \quad (10)$$

The land use coefficients (Table 3) of the individual land cover classes adopted from [32] was used.

The basin specific parameter β is related to the morphology of the basin. For β, [32] found that the sediment yield of the basin was insensitive to β-value, hence β-value of 1 was chosen.

3 Results and discussion

The MFI of the basin ranged between 130 and 163 signifying that the basin is susceptible to severe rainfall erosion [39, 40]. The rainfall erosivity factor, R (Fig. 3b) obtained ranges from 349 to 455 MJ mm/ha/h.

The basin is underlain with wood ochrosols: Acrisols, Lixisols, Alisols, fluvisols, leptosols and luvisols. Their corresponding erodibility factors (K) showing the basin's susceptibility to erosion under the influence of rain droppings were assigned to produce the K-factor map (Fig. 4), with values ranging from 0 to 0.295. This implies all the soils in the basin have low erodibility.

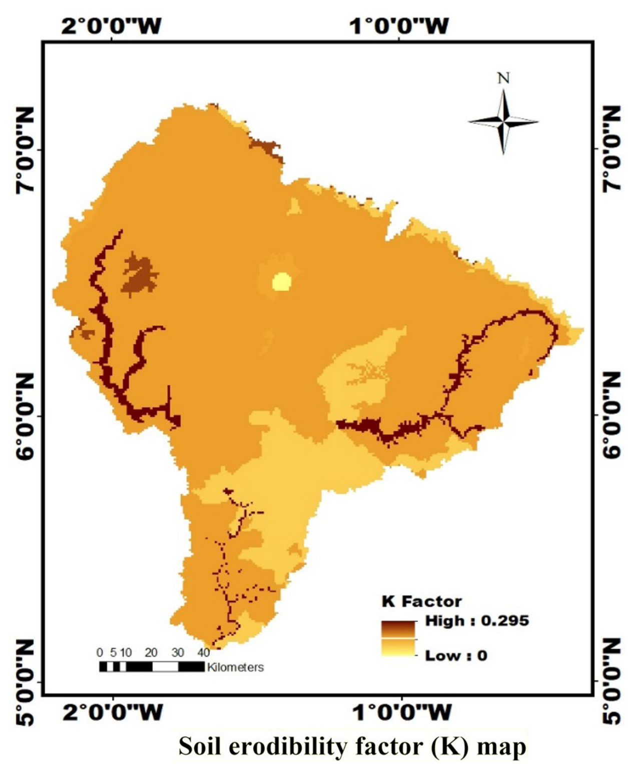


Fig. 4 Soil erodibility factor (K) map

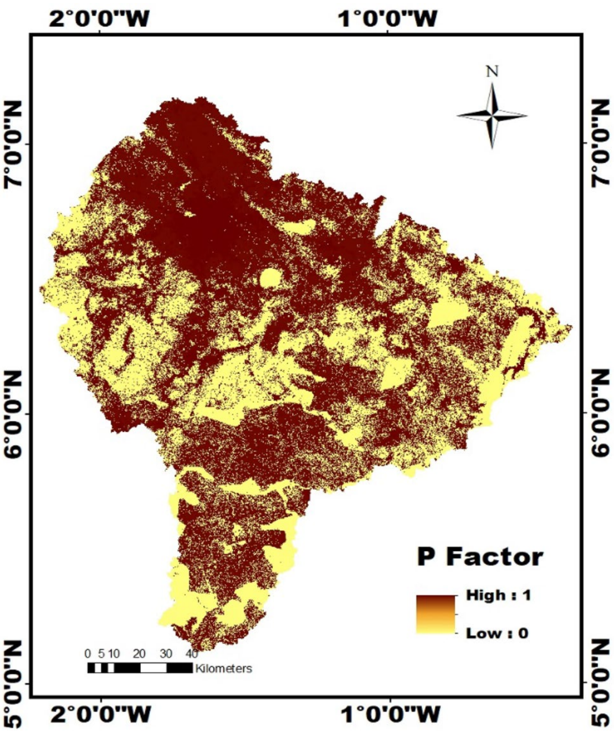


Fig. 5 P factor map of PRB

The conservation support practice factor (P) of the basin ranged between 0 and 1 (Fig. 5) with the mean of 0.17. P factor describes management practices that either enhanced or minimize soil erosion in the basin.

The cover management factor (C) map produced (Fig. 6b) shows the C factors of the basin ranges from 0 to 1 with a mean of 0.32. The 2018 land use/cover (LULC) map of PRB (Fig. 6a) showed that 21.63%, 18.39%, 51.81%, 6.46%, 1.12% and 0.59% of the basin is covered with Closed forest, Open forest, Farm/grassland, Settlement, Mining and water respectively. Hence, spatial distribution of the C factor is heterogeneous. Low C values are associated with Forest covers while high values are associated with Mining, Farmlands and Settlement.

The LS factor values (Fig. 7) were within the range of 0–1955.36, with an average of 0.62. The low values correspond mostly to the plain areas, thus transport of eroded sediment is limited while high values correspond to the mountainous and hilly areas such as the Ashanti Mampong-Kwahu scarps, around Lake Bosomtwi and Atewa mountain.

3.1 Soil erosion

The RUSLE factors, R, K, LS, C and P were combined to depict the spatial distribution of the soil erosion in the basin (Fig. 8). The estimated gross soil erosion of the basin

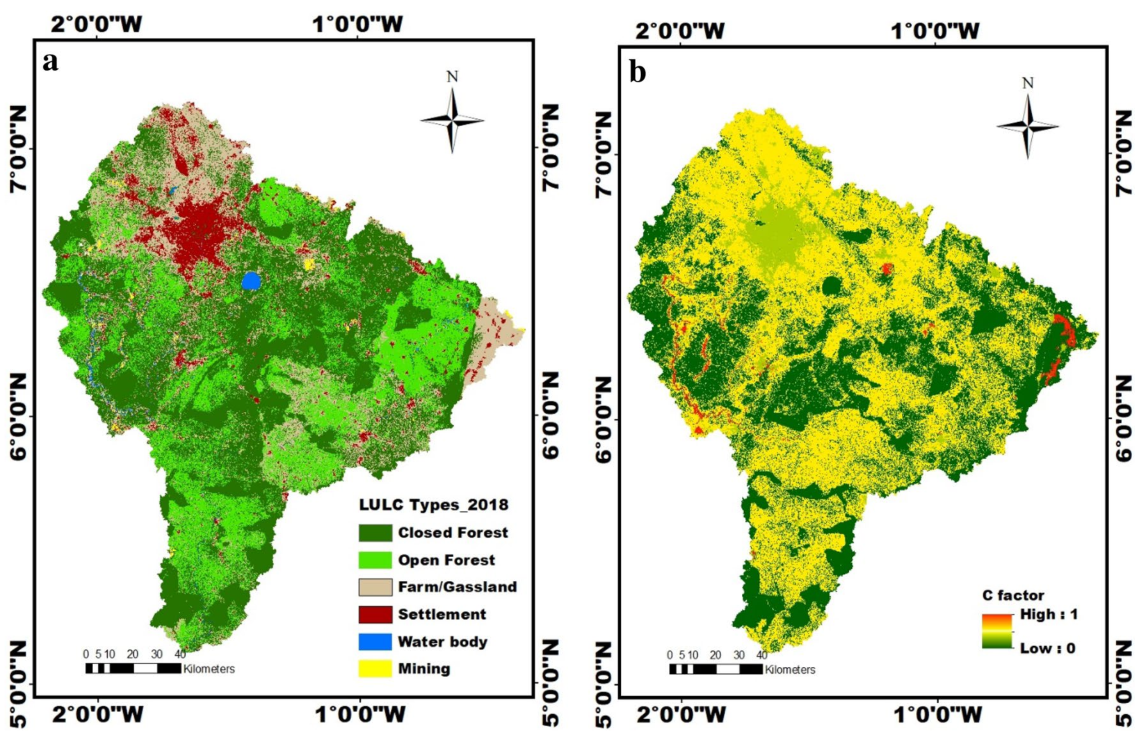


Fig. 6 **a** LULC map (2018), **b** cover management factor (C) map

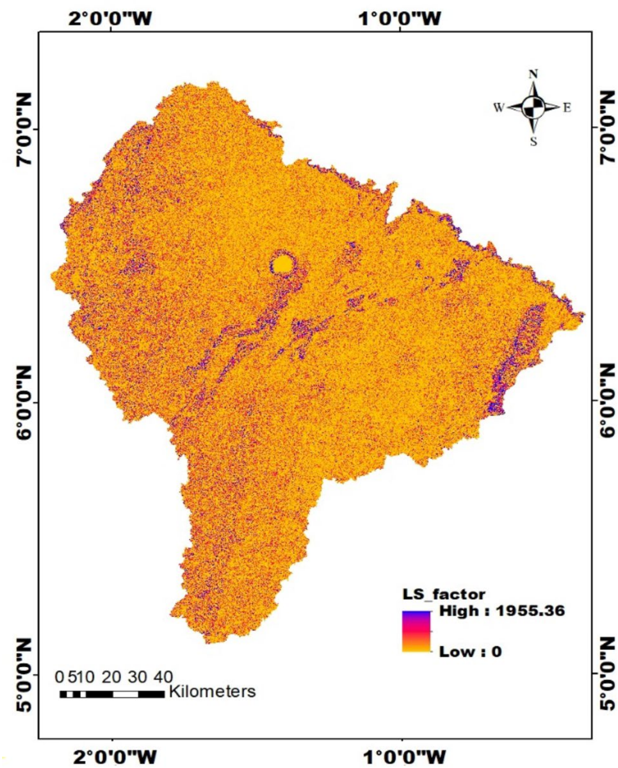


Fig. 7 LS factor map of the PRB

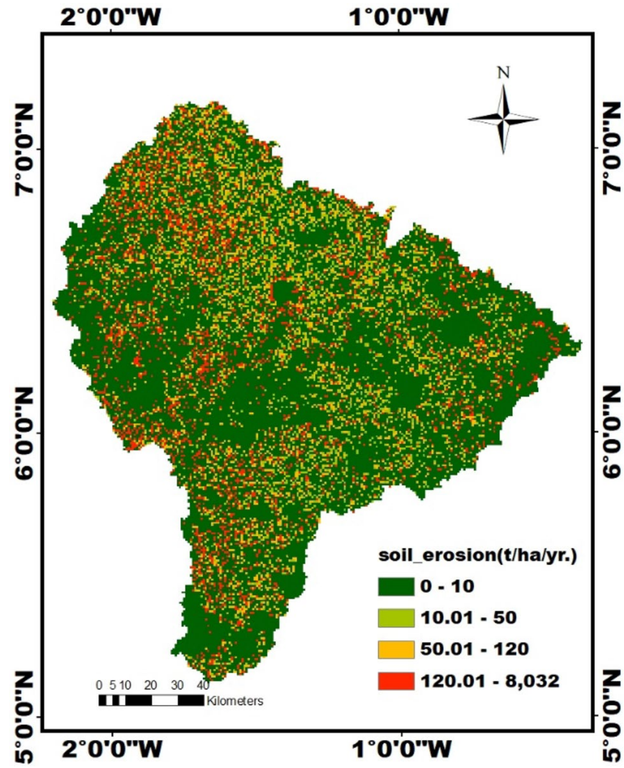


Fig. 8 Spatial distribution of soil loss of PRB

was 1.28×10^6 tons/year. The soil loss ranges from 0 to 8032 tons/ha/year with an average value of 38.3 tons/ha/year and a standard deviation of 116.87. Comparing the mean soil erosion value to the [51] classification scheme, the basin is classified as moderate risk. The soil erosion susceptibility zones in the basin is categorized into four types namely; low, moderate, severe and very severe erosion (Table 4). The range obtained shows that about 78.7% of the basin experiences Low to moderate erosion whilst about 21.30% experiences severe to very severe erosion risk. The severe and very severe risk zones were basically Farmlands along steep slopes and exposed land areas due to illegal mining (galamsey) whilst the low risk zones are dominated with forest and crop cover as found by Kusimi et al. [32].

The soil erosion rate was categorized with respect to the sub-basins of the Pra River viz: Upper Ofin, Oda, Anum, Lower Ofin, Upper Pra, Twifu Praso, Birim, Assin Praso and Lower Pra by overlaying the shapefile and the soil loss map. This helped to prioritize the sub-basins for conservation measures with respect to their risk levels. The results (Table 5) show that the Lower Ofin sub-basin experiences the most soil loss of averagely 59.88 tons/ha/year ranging from 0 to 8032 tons/ha/year. This is due to the fact that

Table 4 Categories of erosion risk, area and the amount of soil loss

Erosion risk categories	Severity class	Area (%)	Soil loss (tons/year)
0–10	Low	71.8	1938.61
10–50	Moderate	6.9	73,142.67
50–120	Severe	11	298,099.51
> 120	Very severe	10.30	907,731.4
–	Total		1,280,912.19

this sub-basin suffers greatly from the illegal gold mining activities both on land and in the river [17, 52].

The model results (Table 6) also shows that soil erosion rate varied with land use types in a decreasing order from Mining > Settlement > Farmland/grassland > Open forest > Closed forest. Hence for effective catchment management, there is the need to adopt support management practices such as terracing and contouring on farmlands to control the rate of soil loss. Also, the buffer zone policy which prevents the execution of anthropogenic activities within the buffer zones of water bodies must be enforced. Illegal mining (galamsey) and alluvial mining must as a matter of urgency be stopped.

Table 5 Sub-basins of the Pra River and their corresponding soil loss

Sub-basin	Area (ha)	Soil loss (tons/ha/year)			Conservation priority
		Range	Mean	Gross	
Upper Ofin	306,185	0–1647	55.60	247,581.9	Second
Oda	93,515	0–736	43.22	60,072.5	Third
Anum	69,031	0–850	37.94	37,830.7	Fourth
Birim (Kade)	212,185	0–3218	29.90	92,636	Eight
Assin Praso	308,645	0–1507	22.11	100,077.7	Ninth
Lower Ofin	383,913	0–8032	59.88	294,951.3	First
Upper Pra	366,076	0–1888	31.39	169,449.5	Seventh
Twifu Praso	337,521	0–927	35.54	176,575.1	Fifth
Lower Pra	210,061	0–1303	33.57	101,737.2	Six

3.2 Sediment delivery ratio (SDR)

The SDR value (Fig. 9) describes the fraction of the eroded sediment delivered to the point in question. Thus, it's an index of the sediment transport efficiency. The SDR values ranged from 0 to 1. Generally, the SDR values of the basin were low except around the mountainous areas and hill slopes such as Mampong and Kwahu scarps, where the river takes it source, and around Lake Bosomtwe. Besides, river channels exhibit relatively high SDR values. This implies erosion occurring in the mining, farm and settlement areas [33] are entrained into the river channels and transported downstream.

3.3 Sediment yield

The model estimated the sediment yield of the PRB (Fig. 10) ranging from 0 to 520.772 tons/ha/year, with a mean of 2.70 tons/ha/year as opposed to [39] estimate of 0.508 tons/ha/year. Even though the mean obtained appears relatively lower than that for African catchment of 4.93 tons/ha/year. [11], the erosion rate and sediment delivery in the basin is increasingly being worsened. The increase in the sediment yield can be attributed to the significant land use/cover changes resulting from increasing urbanization, illegal mining and alluvial mining in the basin since 2008 [17, 42, 52]. It is observed that the mean sediment yield (Table 6) in water is higher than that of other cover types. This is because high run-offs generated during rainfall causes erosion from especially farmlands, settlement and mining areas, and entrains the sediment into the streams and rivers. This means the water bodies serves as the major recipients of the sediment generated in the catchment, making it vulnerable to siltation, pollution and destruction of aquatic life [3]. Besides, the activities of the alluvial gold mining as well as sand winning in the river bed increased the sediment production in the rivers and streams in the basin.

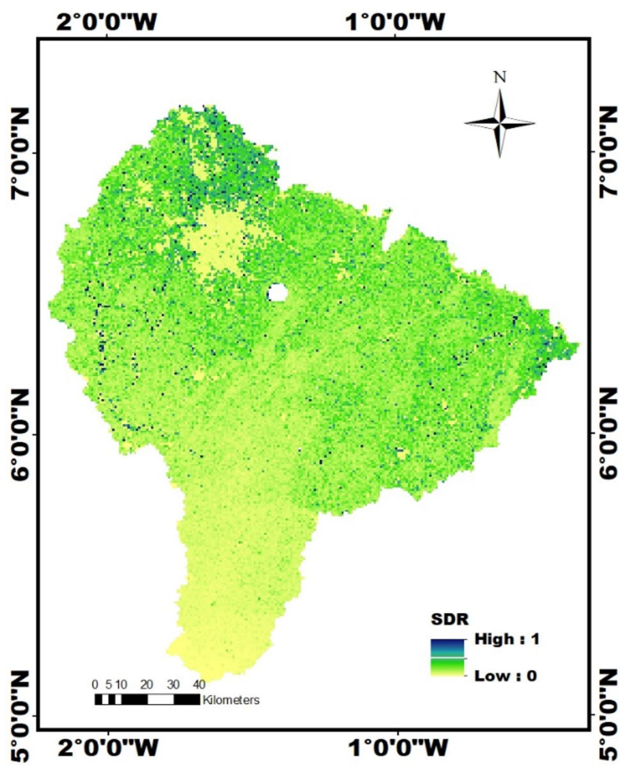


Fig. 9 Sediment delivery ratio of PRB

Table 6 LULC types and their corresponding soil loss and sediment yield

LULC class	Area (%)	Soil loss (tons/ha/year)			Sediment yield (tons/ha/year)		
		Range	Mean	Gross	Range	Mean	Total
Closed forest	21.63	0–322	19.96	142,590.39	0–335	1.37	974.18
Open forest	18.39	0–1981	23.87	147,851.12	0–137	1.66	1078.52
Farm/grassland	51.81	0–5089	43.49	756,559.45	0–521	3.53	6482.9
Settlement	6.46	0–1642	63.73	140,386.88	0–106	1.67	3658.57
Water	0.59	0–2936	87.47	18,456.38	0–440	14.1	2969.68
Mining	1.12	0–8032	192.98	75,067.91	0–309	6.77	2632.65

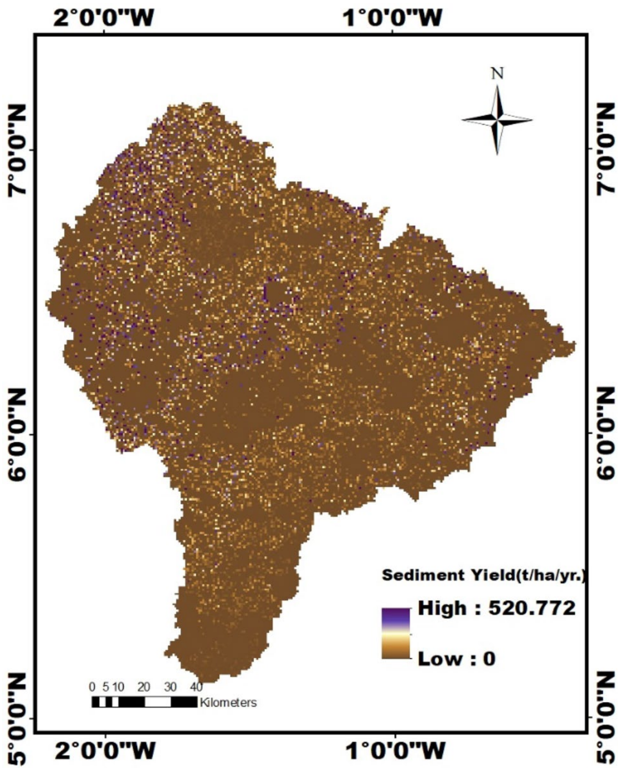


Fig. 10 Sediment yield in PRB-2018

4 Conclusion and recommendations

The RUSLE and the SEDD model integrated with GIS is adopted to estimate the annual soil loss in a grid basis and the sediment yield of the PRB. The model estimated annual soil loss of 1.28×10^6 t/year in the basin. The erosion map showed that about 21.3% of the basin comes under severe to very severe erosion category. High soil erosion occurs mostly in the farmlands, mining and settlement areas. An average of 2.70 t/ha/year of sediment yield was also predicted by the model.

Most of the sediments eroded from the catchment are entrained into the rivers and streams causing siltation and pollution. Areas characterized **with** severe to very severe soil loss should be given special and immediate conservation priority to reduce or control the rate of soil erosion whilst low to moderate prone areas should be protected from further erosion.

The study demonstrates that the RUSLE model integrated with GIS is an important tool in estimating soil loss of basins and their spatial distribution especially for surface erosion. Thus, it can be effectively adopted to monitor soil erosion and sediment delivery in basins where erosion and sediment data is virtually non-existent. However, there is the need to painstakingly and consistently determine the soil erodibility factors for soils in the basin's, especially in the changing environment. This is important because the accuracy of the results from the RUSLE model depends largely on the accuracy of the factors used.

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Compliance with ethical standards

Conflict of interest Authors have no conflict of interest.

References

1. Fadlalla ARE, Ouerghi S, Rahim EA (2015) Soil erosion risk map based on Geographic Information System and Universal Soil Loss Equation (case study: Terengganu, Malaysia). Indian J Sci Technol 3(2):38–43
2. Amegashie BK, Quansah C, Agyare WA, Tamene L, Vlek PL (2011) Sediment-bound nutrient export from five small reservoir catchments and its implications for the Sudan savanna zone of Ghana. Lakes Reserv Res Manag 16:61–76. https://doi.org/10.1111/j.1440-1770.2011.00459.x
3. Mensah AM (2009) The influence of land-use activities on nutrient inputs into upland catchment streams, Ghana. Ph.D. thesis, Rheinischen Friedrich-Wilhelms-Universität Bonn
4. Akuffo SB (2003) The imminent water supply crisis in Accra: the silting up of the Weija Lake, Accra Mail—Accra
5. Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses—a guide to conservation. Agricultural handbook 537. US Department of Agriculture, Washington, DC, pp 21–22
6. Fernandez C, Wu JQ, McCool DK, Stockle CO (2003) Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. J Soil Water Conserv 58(3):128–136
7. Jain MK, Kothyari UC (2000) Estimation of soil erosion and sediment yield using GIS. Hydrol Sci J 45(5):771–786. https://doi.org/10.1080/02626660009492376
8. Amsalu T, Mengaw A (2014) GIS based soil loss estimation using RUSLE model: the case of Jabi Tehinan Woreda, ANRS, Ethiopia. Nat Resour. https://doi.org/10.4236/nr.2014.511054
9. Jain MK, Mishra SK, Shah RB (2010) Estimation of sediment yield and areas vulnerable to soil erosion and deposition in a Himalayan watershed using GIS. Curr Sci 98(2):213–221
10. Adornado HA, Yoshida M, Apolinares H (2009) Erosion vulnerability assessment in REINA, Quezon Province, Philippines with Raster-based tool built within GIS environment. Agric Inf Res 18(1):24–31. https://doi.org/10.3173/air.18.24
11. Vanmaercke M, Poesen J, Broeckx J, Nyssen J (2014) Sediment yield in Africa. Earth Sci Rev 136:350–368. https://doi.org/10.1016/j.earscirev.2014.06.004 **(+Appendix)**
12. Quansah C, Baffoe-Bonnie E, Asiamah RD (1989) Soil erosion in Ghana and strategies for conservation. A paper presented at the African Ministerial conference on the environment (RCU/

SOFERNET) and soil conservation strategy for Africa. Accra, Ghana, 28–30 August, 1989
13. Asante-Sasu CK (2016) Estimation of the rate of sediment transport into Bui hydropower reservoir. Thesis submitted to the Dept. of Civil Engineering in partial fulfillments of the requirement for the degree of Master of Science in Water Resources Engineering and Mgt, KNUST, pp 40–56
14. Kusimi J (2008) Analysis of sedimentation rates in the Densu River channel: the result of erosion and anthropogenic activities in the Densu Basin. West Afr J Appl Ecol 14:1–14
15. Ayivor JS, Gordon C (2012) Impact of land use on river systems in Ghana. West Afr J Appl Ecol 20(3):83–95
16. Boakye E, Bentil J (2011) Access to potable water in Sekondi-Takoradi and its environs. Takoradi Polytech J Technol 1(1):1–82
17. Awotwi A, Anornu GK, Quaye-Ballard J, Annor T, Forkuo EK (2017) Analysis of climate and anthropogenic impacts on runoff in the Lower Pra River Basin of Ghana. Heliyon 3(12):1–27. https://doi.org/10.1016/j.heliyon.2017.e00477
18. Abroampah MP, Boakye E, Yalley PP (2015) The impact of Sofokrom quarry on River Anankwari. Int J Sci Res (IJSR) 4(11):1057–1062
19. El Jazouli A, Barakat A et al (2017) Soil erosion modeled with USLE, GIS, and remote sensing: a case study of Ikkour watershed in Middle Atlas (Morocco). Geosci Lett. https://doi.org/10.1186/s40562-017-0091-6
20. Yadav RP, Sidhu GS (2010) Assessment of soil erosion in Himachal Pradesh. J Indian Soc Soil Sci 58(2):212–220
21. Silva RM, Santos CAG, Montenegro SMGL, Silva LPE (2010) Spatial analysis of vegetal cover and sediment yield in Tapacurá River Catchment based on remote sensing and GIS. Ann Wars Univ Life Sci Land Reclam 42(1):5–16. https://doi.org/10.2478/v10060-008-0059-5
22. Akrasi SA (2005) The assessment of suspended sediment inputs to Volta Lake. Lakes Reserv Res Manag 10:179–186
23. Aksoy H, Kavvas ML (2005) A review of hillslope and watershed scale erosion and sediment transport models. CATENA 64(2–3):247–274. https://doi.org/10.1016/j.catena2005.08.008
24. Amore E, Modica C, Nearing MA, Santoro VC (2004) Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. J Hydrol 293:100–114. https://doi.org/10.1016/j.jhydrol.2004.01.018
25. Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Styczen ME (1998) The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surf Proc Land 23(6):527–544. https://doi.org/10.1007/978-3-642-58913-3_29
26. Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting soil erosion by water—a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Handbook No. 703, Washington, DC
27. Napoli M, Cecchi S, Orlandini S, Mugnai G, Zanchi CA (2016) Simulation of field-measured soil loss in Mediterranean hilly areas (Chianti, Italy) with RUSLE. CATENA 145:246–256
28. Tossic R, Dragicevic S, Kostadinov S, Dragovic N (2011) Assessment of soil erosion potential by the USLE method: case study, republic of Srpska—Bih. Fresenius Environ Bull 20(8):1910–1917
29. Jain MK, Das D (2010) Estimation of sediment yield and areas of soil erosion and deposition for watershed prioritization using GIS and remote sensing. Water Resour Manag 24(10):2091–2112. https://doi.org/10.1007/s11269-009-9540-0
30. Dabral PP, Baithuri N, Pandey A (2008) Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. Water Resour Manag 22(12):1783–1798. https://doi.org/10.1007/s11269-008-9253-9
31. Pandey A, Chowdary VM, Mal BC (2007) Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. Water Res Manag 21(4):729–746. https://doi.org/10.1007/s11269-006-9061-z
32. Kusimi JM, Yiran GA, Attua EM (2015) soil erosion and sediment yield modeling in the Pra River Basin of Ghana using the Revised Universal Soil Loss Equation (RUSLE). Ghana J Geogr 7(2):38–57
33. Yan R, Zhanga X, Yan S, Chen H (2018) Estimating soil erosion response to land use/cover change in a catchment of the Loess Plateau, China. Int Soil Water Conserv Res 6(1):13–22. https://doi.org/10.1016/j.iswcr.2017.12.002
34. Zerihun M, Mohammed SM, Sewneta D, Adem AA, Lakew M (2018) Assessment of soil erosion using RUSLE, GIS and remote sensing in NW Ethiopia. Geoderma Reg 12:83–90. https://doi.org/10.1016/j.geodrs.2018.01.002
35. Ayalew G (2014) A geographic information system based soil loss and sediment estimation in Gerdi Watershed, Highlands of Ethiopia. J Environ Earth Sci 4(19):62–75. https://doi.org/10.11648/j.ijsts.20150301.14
36. Ashiagbor G, Forkuo EK, Laari P, Aabeyir R (2016) Modeling soil erosion using RUSLE and GIS tools. Int J Remote Sens Geosci 2(4):7–17
37. Kayet N, Pathak K, Chakrabarty A, Sahoo S (2018) Evaluation of soil loss estimation using the RUSLE model and SCS-CN method in hill slope mining areas. Int Soil Water Conserv Res 6(1):31–42. https://doi.org/10.1016/j.iswcr.2017.11.002
38. Water Resources Commission (2012) Pra River Basin—integrated water resources management plan. Water Resources Commission, Ghana, pp 6–15
39. Akrasi SA, Ansa-Asare OD (2008) Assessing sediment and nutrient transport in the Pra basin of Ghana. West Afr J Appl Ecol 13:45–54
40. Oduro-Afriyie K (1996) Rainfall erosivity map for Ghana. Geoderma 74:161–166
41. Awotwi A, Anornu GK, Quaye-Ballard J, Annor T (2018) Monitoring land use/cover changes due to extensive gold mining, urban expansion and agriculture in the Pra River Basin of Ghana, 1986–2025. Land Degrad Dev. https://doi.org/10.1002/idr.3093
42. Kusimi JM, Amisigo BA, Banoeng-Yakubo BK (2014) Sediment yield of a forest river basin in Ghana. CATENA 123:225–235. https://doi.org/10.1016/j.catena.2014.08.001
43. Hudson NW (1995) Soil conservation, 3rd edn. BT Batsford Ltd., London
44. Morgan RPC (2005) Soil erosion and conservation. National Soil Resources Institute, Cranfield University, Oxford. https://doi.org/10.1002/9781118351475.ch22
45. Mbugua WE (2009) Using GIS techniques to determine RUSLE'S 'R' AND 'LS' factors for Kapingazi River Catchment. Master of Science Research Project Report submitted to the Department of Geomatic Engineering and Geospatial Information Systems, Jomo Kenyatta University of Agriculture and Technology, pp 9–11
46. Arnoldus HMJ (1980) An approximation of the rainfall factor in the USLE. In: De Boodt M, Gabriels D (eds) Assessment of erosion. Wiley, Chichester, pp 127–132
47. Mitasova H, Hofierka J, Zlocha M, Iverson LR (1996) Modeling topographic potential for erosion and deposition using GIS. Int J Geogr Inf Sci 10:629–641
48. Arekhi S (2008) Evaluating long-term annual sediment yield estimating potential of GIS interfaced MUSLE model on two

micro-watersheds. Pak J Biol Sci 11(2):270–274. https://doi.org/10.3923/pjbs.2008.270.274
49. Sun WY, Shao QQ, Liu JY (2013) Soil erosion and its response to the changes of precipitation and vegetation cover on the Loess Plateau. J Geogr Sci 23:1091–1106. https://doi.org/10.1007/s11442-013-1065-z
50. Ferro V, Minacapilli M (1995) Sediment delivery processes at basin-scale. Hydrol Sci J 40:703–717. https://doi.org/10.1080/02626669509491460
51. Food and Agriculture Organization (FAO) (1997) "AFRICOVER land cover classification". Technical document on the AFRICOVER land cover classification scheme: a dichotomous, modular-hierarchical approach
52. Boakye E, Anyemedu FOK, Quaye-Ballard JA, Donkor EA (2019) Spatio-temporal analysis of land use/cover changes in the Pra River Basin, Ghana. Appl Geom. https://doi.org/10.1007/s12518-019-00278-3