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Geological and Erodibility Investigations of Rafin Gora area of Niger State, Northern Nigeria

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Abstract

Geological, geotechnical and geochemical studies were carried out in Rafi Gora area to ascertain the erodibility of the soils. Medium and coarse-grained sandstone and clay stone were mapped with structures like joints, cross bedding (120/18E and azimuth of 190S), Herringbone, clay clasts, lamina and bioturbation. The sand content of the soils is between 59% and 90%, silt ranges from 18% to 1% and clay constitutes between 9.9% and 32%). Using USDA textural classification, the soils were classified into sand (S), Loamy Sand (LM), Sandy Clay (SC) and Sandy Loam. The soil has a mean pH value of 4.73, average Organic Matter (OM) content of 2.72 and the Coefficient of permeability (K) of 0.90 cm/sec. This k is classified to be within moderately rapid flow (FAO, 2010), an indication of base flows which could result in the collapse of river bank and consequently advance the growth of gullies. Erodibility index (EI) ranges between 0.01 and 0.16 with a significant positive relationship with silt content (0.96), clay content (0.30) and organic matter content (0.20) but significant negative relationship with sand content, pH and permeability. It was advised that excavation of vulnerable claystones by the locals for building construction be totally discouraged.

Keywords: Geological, Geotechnical, Geochemical Erodibility index.

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1. Introduction

The causes of gully erosion with respect to the geologic settings as suggested by the earlier studies are numerous. Some of the identified natural causes include tectonic activities, uplift, climatic factors, geotechnical properties of soil, among others. Anthropogenic causes include farming and uncontrolled grazing practices, deforestation, and mining activities (Ezechi and Okagbue, 1989).

Ofomata (1981) indicated that areas of high susceptibility to gully erosion correspond to geological regions of weak unconsolidated sandy formations while least susceptible areas are within the consolidated tertiary to recent in areas they studied. Classical gullies are located in the False-bedded sandstone, Coastal Plain sands, Nanka Sands and the Bende-Ameki Formations of southeastern Nigeria. These are all sandy formations which have more gullies than their Shale formation counterparts. The geology therefore plays direct and indirect influence on the gully formation. The indirect effect is on the soil formation and the nature of soil which contribute significantly to erosion processes. Ezechi and Okagbue (1989) summarized the types of gully erosion with respect to their modes and conditions of formation and indicated that the nature of the underlying bed (or geology) has a bearing on the initiation and propagation of gullies.

The erodibility of the soil (EI) is an estimate of the ability of soil to resist erosion based on the physical characteristics of each soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved structure have a greater resistance to erosion (Wall *et al.*, 1987). Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Wall *et al.*, 1987). Silt dominated soil were found by Bobe (2004) to be more susceptible to particle detachment in terms of sediment yield than sandy soil. This he attributed to the relative transportability of fine and non aggregated silt particles. Early studies by Bennett (1926), Middleton (1930) and Baver (1933) demonstrated that erosion rates were influenced by soil properties. Igwe (2005) remarked that a number of factors such as the physical and the chemical properties of the soil influence erodibility. Higher erodibility value (K-factor) indicates the soil's higher susceptibility to soil erosion (Adornado *et al.*, 2009). Wischmeier and Smith (1978) and Renard and Demarsily (1997) used an equation that relates textural information, organic matter, information about the soil structure, and profile permeability with the K factor or soil erodibility factor.

The greatest threat to the environmental settings in Nigeria is the gradual but constant dissection of the landscape by soil erosion. Gullies have assumed a different dimension such that settlements and scarce arable land are threatened (Igwe, 2003). Therefore, gully erosion problems have become a subject of discussion among soil scientists, geographers, geologists, engineers, and social scientists. Rafin Gora is located in Northern Nigeria where desertification and aridity had been the major environmental problems that has been receiving global attention. Emergence of gully erosion as deep as 12m in the region has been reported by Gabriel and Jibril (2011), Mbaya *et al.* (2012) and Mahmud and Umaru (2018).

In order to mitigate these gullies, there is need for geological, geotechnical and chemical evaluation of the soil associated with gully.

2. Methodology

2.1 The Study Area

Rafin Gora is situated in Kontagora Local Government Area of Niger state and it lies within latitude of 10° 16ʹ N to 10°27ʹ N and longitude 5°23ʹ E and 5°26ʹ E (Figure 1). The area of a linear settlement covers about 30km^2. The area is accessed through major road that links Mokwa to Kontagora, which has been threatened by gully effects with foot paths linked to genesis of several rill gullies heads in the village. The studied area has a total annual rainfall of about 1100-1332mm with the highest mean monthly rainfall is in August with about 240-300mm (Nigeria Meteorological Agency, NIMET, 2012). The highest monthly temperature is March with temperature of about 37˚C and the lowest temperature is recorded in the month of August with temperature of about 23˚C. The vegetation comprises of shrubs, grasses and tall trees that are easily identified in the dry season compare to the wet season (NIMET, 2012). The area is characterized by long extensive ridges of hills and plain lands. The entire area has a good drainage network cutting across the community that discharges into river Kontagora. The contour values range from 225 to 370 and most houses built closer to the drainages are exposed to gully effects. The vast and fertile land is mostly used for rice, millet, and beans farming except in few places where houses structures are built. Both the structures and farms become more exposed to dangers associated with gully erosion during every raining season. Geologically**,** the area lies within the basal part of Bida Formation (Doko member). Much like its lateral equivalent (Lokoja Sandstone), the Bida Sandstone lies unconformably on the crystalline Basement complex and consists of a basal conglomerate with a succession of cross-bedded white to grey sandstones intercalated with kaolinitic clays believed to have been derived from nearby deeply weathered basement rocks (Rahaman *et al.*, 2019).

2.2 Geology Mapping and Soil sampling

The lithology of the area with various structures present was studied using metre rule to measure the thickness of the lithologies and geological compass to denote the strike, dip and azimuth of the structures (Figure 1). Eight soil samples were collected across the gully profiles and used in determining the geotechnical and geochemical influence of soil on formation and expansion of gully erosions and other 15 points offsite using hand trowel for a depth 50cm to generate the erodibility map of the area.

2.3 Geotechnical Investigation

Grain size distribution, organic matter content and pH of soils were determined using standard procedures (BS 1981, ASTM 1979) at the Civil Engineering laboratory of the Federal University of Technology, Minna, Nigeria. The cumulative percentage retained and passing through the sieve apparatus was used to determine the coefficient of uniformity (Cu) and coefficient of curvature (Cc) use in determining the grading of the soil (Equation 1 & 2).

$$\mathbf{Cu} = \frac{\mathbf{D_{60}}}{\boldsymbol{D_{10}}} \tag{1}$$

$$\mathbf{Cc} = \frac{(\boldsymbol{D_{30}})^{2}}{(\boldsymbol{D_{10}})(\boldsymbol{D_{60}})} \tag{2}$$

where Cu = Coefficient of Uniformity, Cc = Coefficient of Curvature, D_{60} = grain size value at 60% passing sieve apparatus, D_{10} = grain size value at 10% passing sieve apparatus, D_{30} = grain size value at 30% passing.

Erodibility index was calculated based on a multiple regression equation developed by David 1988 and adopted by Hernandez *et al.*, 2012.

$$\mathbf{K\ D = \{(0{:}043 * pH) + (.0{:}62\ /OM) + (00082 * S) - (0.0062 - C)\}\ x\ Si,} \tag{3}$$

where pH: acidity of the soil; OM: organic matter (%); S: Sand content (%); C: clay ratio = (% clay / % sand + % silt); Si: Silt content = % silt/100.

Finally hydraulic conductivity (K, cm/sec) of the soils was estimated empirically using grain size distribution data based on Hazen's equation.

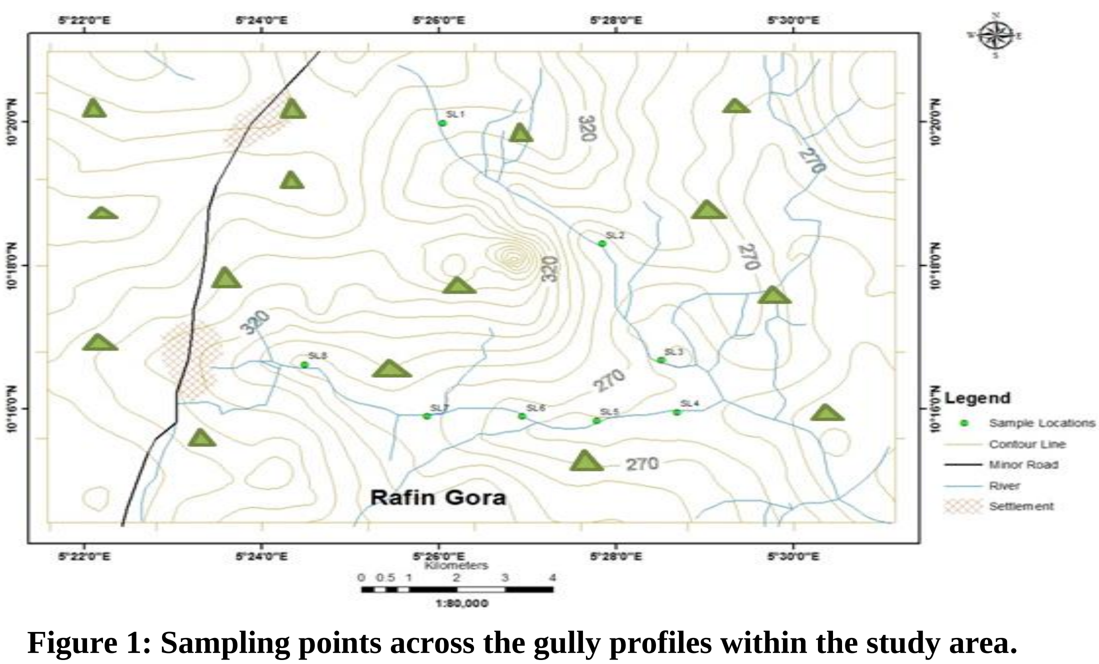

Figure 1: Sampling points across the gully profiles within the study area.

3. Results

3.1 Geology of the area

The study area is underlain by reddish, poorly sorted sandstone. Three different lithologies were identified which included light reddish medium grained sandstone, light brownish coarse-grained sandstone and yellowish clay stone (Figure 2). Geological structures like joint, cross bedding with strike and dip of 120/18E and dip direction of 190S, herringbone structures, clay clast, lamina and bioturbation were identified with their various implications in development of the gullies. The existence of the herringbone structures in Lokoja SST as lateral extension of Bida SST has been reported by Ojo and Akande in 2012, who attributed it to tidal lag processes.

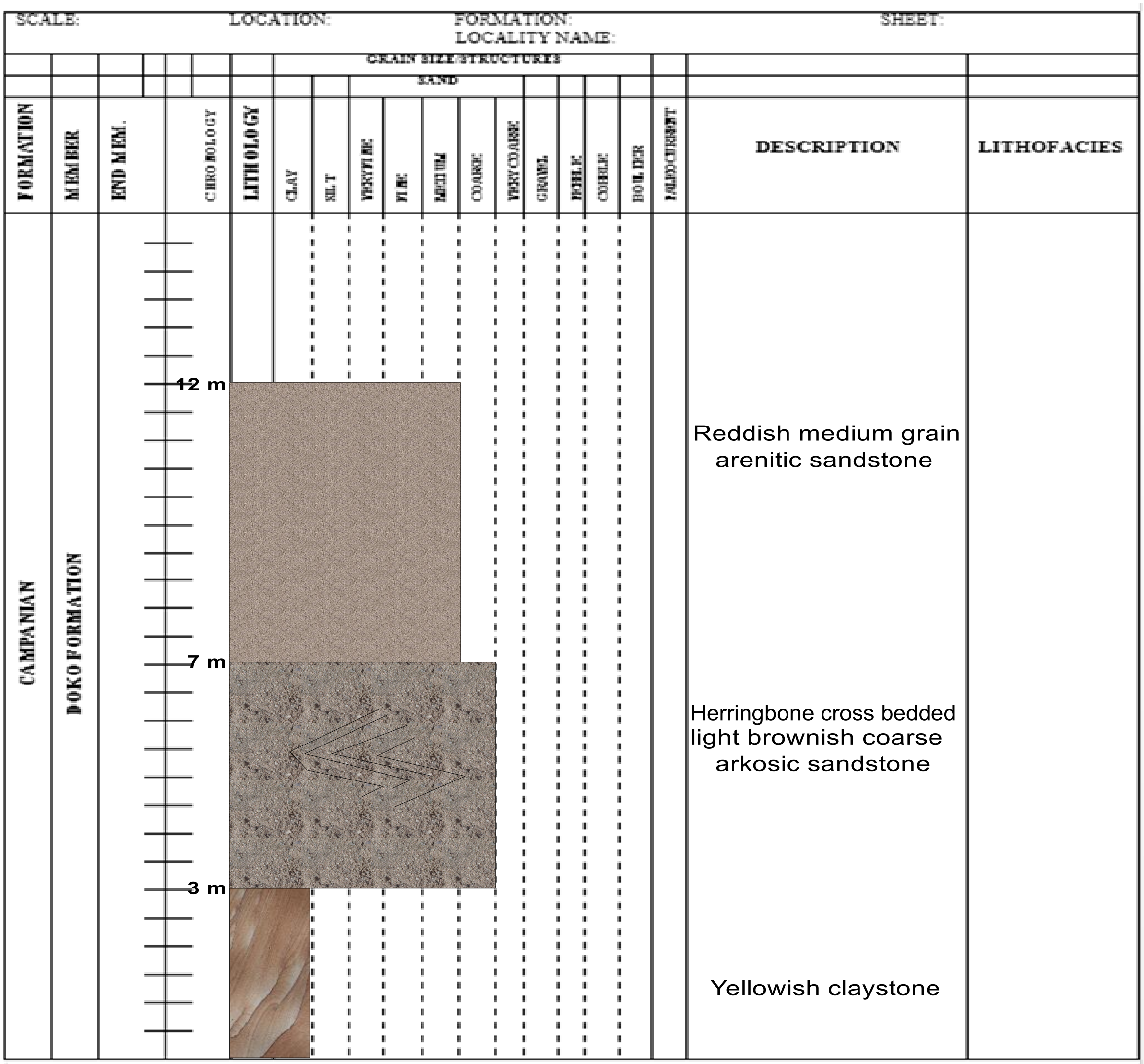

Figure 2: Lithological section of the study area.

3.2 Properties of the Soils and Erodibility Index

The sand content is between 90% in location 15 to 59% in location 11 with mean value of 71.2. Silt content ranges from 18% in location 4 to 1 % in location 15 with mean value of 6.40. Clay contents were observed to be highest in location 11(32 %) and lowest in location 15 (9.9 %) with mean value of 22.52 %. Based on these findings, the soils were classified into Sand (S), Loamy Sand (LM), Sandy Clay (SC) and Sandy Loam using USDA textural classification.

Table 1: Soil properties and erodibility index of the study area

Location	Longitude	Latitude	Sand	Silt	Clay	TC	OM	pH	K (cm/sec)	EI
L1	10 21 12	5 29 45	62	9	29	SCL	5.79	5.65	0.23	0.06
L2	10 17 33	5 28 55	71	5	24	SCL	1.07	4.61	0.35	0.06
L3	10 19 55	5 28 14	65	5	30	SCL	2.79	4.58	0.2	0.04
L4	10 21 6	5 27 15	64	18	18	SL	3.21	4.31	0.78	0.16
L5	10 16 45	5 27 32	61	11	28	SCL	4.71	4.39	0.25	0.09
L6	10 19 33	5 26 1	70	4	26	SCL	2.14	4.07	0.3	0.04
L7	10 20 42	5 22 52	81	8	11	LS	5.79	4.45	2.18	0.08
L8	10 18 16	5 22 14	73	6	21	SCL	2.36	4.53	0.51	0.06
L9	10 15 54	5 23 9	69	2	29	SCL	1.07	4.79	0.23	0.03
L10	10 16 12	5 25 3	90	1	9.9	S	1.5	5.16	2.81	0.01
L11	10 17 52	5 29 4	59	9	32	SCL	1.93	4.05	0.17	0.09
L12	10 16 22	5 28 12	63	7	30	SCL	2.57	4.38	0.2	0.06
L13	10 16 30	5 27 45	62	9	29	SCL	1.29	4.49	0.22	0.11
L14	10 16 33	5 25 54	89	1	11	LS	3.64	4.96	2.33	0.01
L15	10 16 34	5 23 45	90	1	9.9	S	1.71	6.5	2.81	0.01
		Mean	71.2	6.40	22.52		2.77	4.73	0.90	0.06

The pH value of the soil ranges from 4.31 in location 4 to 6.5 in location 15 and the Organic Matter content (OM) was as well observed to be highest in location 1 at 5.79 % and lowest at 1.07 in location 9 (Table 1). This indicates that the soil in the whole area is slightly acidic and may require lime to buffer the acidity. The coefficient of permeability was observed to be highest in location 15 at 2.81cm/s and lowest in locations 3, 12 and 13 at 0.2cm/sec each with mean value of 0.90cm/sec (Table 1). This K is classified to be moderately rapid flow (FAO, 2010), an indication of moderately rapid base flows which could result in the collapse of river bank and consequently advance the growth of gullies.

Table 1 further shows that the erodibility index (EI) of soil around locations 4 and 13 is high, with values of 0.16 and 0.11 respectively while EI is lowest in locations 14 and 15 with a value of 0.01. Pearson's correlation between soil properties and erodibility index shows a significant positive relationship with silt content (0.96), clay content (0.30) and organic matter content (0.20). But significant negative relationship was found between EI and sand content, pH and permeability (Table 2). Poesen *et al. (*2003) had reported that increasing rock content consistently correlated with decreasing erosion rates, at all slopes because presence of rocks affects surface processes, protecting the soil from raindrop impact and overland flow energy. It is also, important to note that as proportion of silt and very fine sand in the soil increases the erodibility increases (Baver, 2006). To buttress these results, clay/silt rich soil formed in between sandy walls was found intensively washing down the gully wall leaving the sandy walls hanging (Figure 3).

Table 2: Soil Erodibility Index (EI) Correlation with Soil Properties.

Soil	**Sand (%)**	**Silt (%)**	**Clay (%)**	**OM (%)**	**pH**	**K (cm/s)**	**EI**
Sand	1						
Silt	-0.671969471	1					
Clay	-0.912297081	0.310250923	1				
OM	-0.081749254	0.392935506	-0.114572019	1			
pH	0.558742817	-0.447380729	-0.462899112	0.032410031	1		
K (cm/s)	0.935591865	-0.452241874	-0.947797364	0.073080216	0.572893	1	
EI	-0.655565807	0.963344255	0.307680432	0.201743546	-0.54241	-0.464193222	1

Figure 3: Washing of clay and silt rich soil (Long10° 16 ‘33"; Lat5° 25’ 54’’).

4. Conclusion

The study area is underlain by reddish, poorly sorted sandstone with geological structures like joint, cross bedding, herringbones structures, clay clast, lamina and bioturbation. There is the possibility of structural control of the active gullies, with tendency of upstream expansion and greater impact on roads and houses. The acidic soil with low in organic matter content and high permeability in the study area classified into Sand (S), Loamy Sand (LM), Sandy Clay (SC) and Sandy Loam and concluded that soil around location 4 and 13 were highly erodible while the least erodible soil were located in 14 and 15. This EI show a significant positive relationship with Silt content, Clay content and Organic matter contents but significant negative relationship with Sand content, pH and permeability. The following recommendations are as advanced as possible control or mitigation measures against gully development and expansion in Rafin Gora and its environs.

1. Effective drainage system should be constructed within the community to reduce the impact of runoff in expansion of gullies.
2. The immediate stabilization of moderate sheet and rill erosion, and incipient gullies in the area by the community through vegetation or other mechanical means should be encouraged.

3. Excavation of vulnerable claystone by the residents for building construction should be totally discouraged as more erosional problems are created in an area where they are excavated.

References

[1] Adornado, H. A., Yoshida, M., &Apolinares, H. A. (2009). Erosion vulnerability assessment in REINA, Quezon Province, Philippines with raster-based tool built within GIS environment. Agricultural Information Research, 18(1), 24-31.
[2] ASTM 1979 (1979). A procedure for the determination of ductile fracture toughness values using J integral techniques. Journal of Testing and Evaluation 7, no. 1 (1979): 49-56.
[3] Baver, L. D. (1933). Soil porosity as an index of structure. Soil Science Society of America Journal, 14(2001), 83-85.
[4] Bennett, H. H. (1926). Some comparisons of the properties of humid-tropical and humid-temperate American soils; with special reference to indicated relations between chemical composition and physical properties. Soil Science, 21(5), 349-376.
[5] Bobe, B. W. (2004). Evaluation of soil erosion in the Harerge region of Ethiopia using soil loss models, rainfall simulation and field trials (Doctoral dissertation, University of Pretoria).
[6] British Standard (B.S. 1981). A procedure for the determination of ductile fracture toughness values using integral techniques.
[7] David, M. (1988). Soil erodibility factor (K) in soils under varying stages of truncation. Soil Science Annual, 72(1), 134621.
[8] Ezechi, J. I., & Okagbue, C. O. (1989). A genetic classification of gullies in Eastern Nigeria and its implications on control measures. Journal of African Earth Sciences (and the Middle East), 9(3-4), 711-718.
[9] Gabriel, H. & Jibril, S. (2011) Geotechnical evaluation of soils in Kafari and its environs, North East Nigeria. Continental Journal of Earth Sciences, 5(1), 20-31.
[10] Hernandez, M., Nichols, M. H., Nearing, M., & Polyakov, V. O. (2012). Monitoring channel head erosion processes in response to an artificially induced abrupt base level change using time-lapse photography. Geomorphology, 265, 107-116.
[11] Igwe, C. A. (2003). Erodibility of soils of the upper rainforest zone, southeastern Nigeria. Land Degradation & Development, 14(3), 323-334.
[12] Igwe, C. A., & Ejiofor, N. (2005). Structural stability of exposed gully wall in Central Eastern Nigeria as affected by soil properties. International agrophysics, 19(3), 215-222.
[13] Mahmud, H. L., & Umaru, E. T. (2018). Impact of Gully Erosion on Landuse/Land Cover in Bida Town Niger State, Nigeria. Intl. J. of Geography and Environmental Management, 4(2), 7-15.

[14] Mbaya, L. A., Ayuba, H. K., &Abdullahi, J. (2012). An assessment of gully erosion in Gombe town, Gombe state, Nigeria. Journal of Geography and Geology, 4(3), 110.

[15] Middleton, H. E. (1930). Properties of soils which influence soil erosion (No. 178). US Department of Agriculture.

[16] Nigerian Meteorological Agency (NIMET, 2012). Agro-meteorological Bulletin, Quarterly Compilation Decadal, April-June, 2012, pp: 1-27.

[17] Ofomata, G. E. K. (1981). Impact of road building, urbanisation and general infrastructural development on the Nigerian rainforest ecosystem. Landscape Planning, 8(1), 21-29.

[18] Ojo, O. J. &Akande, S. O. (2012). Hydrocarbon potential of Cretaceous sediments in the Lower and Middle Benue Trough, Nigeria: Insights from new source rock facies evaluation. Journal of African Earth Sciences, 64, 34-47.

[19] Poesen, J., Nachtergaele, J., Verstraeten, G. &. Valentin, C., (2003). Gully erosion and environmental change: importance and research needs, Catena, 50 (2-4), pp. 91-133.

[20] Rahaman, M. A. O., Fadiya, S. L., Adekola, S. A., Coker, S. J., Bale, R. B., Olawoki, O. A., & Akande, W. G. (2019). A revised stratigraphy of the Bida Basin, Nigeria. Journal of African Earth Sciences, 151, 67-81.

[21] Renard, P., & De Marsily, G. (1997). Calculating equivalent permeability: a review. Advances in water resources, 20(5-6), 253-278.

[22] Wall, W., Bergonse, R. V., & Reis, E. J. (1987). Theoretical constraints to gully erosion research: time for a re-evaluation of concepts and assumptions? Earth Surface Processes and Landforms, 36(11), 1554-1557.

[23] Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: a guide to conservation planning (No. 537). Department of Agriculture, Science and Education Administration.