TERMINATION OF GULLY PROCESSES, SOUTHEASTERN NIGERIA

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Abstract: In southeastern Nigeria, gully erosion is responsible for the widespread destruction of transportation and communication systems, degradation of arable land, contamination of water supply, isolation of settlements and migration of communities. This account presents some of the results of a study of gully erosion, carried out during a period of eight years, in partnership with the rural people of twelve villages in Abia, Anambra, Enugu and Imo States.

The textural properties of the surficial deposits and horizontal to gently inclined bedrock make them susceptible to erosion. They are among the defining elements of a sensitive ecosystem, which undergoes rapid degradation, in response to surface runoff and human disruption. Gully processes are localized in the fine- to medium-grained Coastal Plain Sands (Pliocene-Recent) and Nanka Sands (Eocene) and the medium- to coarse-grained Nsukka Sandstone and Ajali Sandstone (Cretaceous) of the Anambra-Imo basin region. The most affected deposits are unconsolidated to poorly consolidated and with short dispersion times. The cleaner, more porous and weakly cemented sands are the most prone to gully advance, which increases directly with an increase in the proportion of grains, more than 1 mm. in diameter. Gully formation is enhanced by sliding, associated with a paleosol in the Nanka Sand, and by the rapid dispersion of clays in the interbedded shales.

Gully initiation is the result of localized erosion by surface runoff, associated with rainfall events of high intensity. Erosion is frequently focused, where the forest cover has been removed for agricultural purposes and also at the sites of uneven compaction of surface soils by foot (human and livestock) and wheeled traffic, in off-road locations. It also takes place, where soils and sediments abut against artificial materials, notably at poorly designed road culverts and roadside gutters. Gullies also occur, where springs issue from permeable sands, at contacts with less permeable deposits beneath. In general, the propagation of gullies is by sapping, caving and sliding at the gully head and sliding along the sides, accompanied by the down-slope transportation of gully-floor debris by storm runoff.

Termination of gully processes requires the integration of water-resource management, soil conservation and revegetation on the scale of a drainage basin. The technologies of water harvesting and spreading are necessary on hillsides, cleared for agricultural production. Some water harvesting technologies, such as roofwater harvesting, contribute to the control of runoff in settlements under threat. Spillways, diversion channels, culverts and gutters must be designed to accommodate runoff amounts at particular locations. For wider acceptance, termination strategies might take as their starting point design elements of indigenous technologies (terraces, barriers, diversion ditches, catchment ponds), which fell into disrepair as rural populations

increased. Public education is essential to a sustainable termination strategy. Different levels of government, donors, the private sector and the rural people must work together on solutions.

INTRODUCTION

In southeastern Nigeria, catastrophic gullies are formed by surface runoff from localized rainfall events of high intensity in the fine- to coarse-grained sands and sandstones of the Anambra-Imo basin region. Localized removal of soils, sediments and poorly consolidated sedimentary rocks by running water is augmented by processes of mass movement to form steep-sided ravines. The gully-forming processes ultimately yield a degraded “badlands” terrain, comprising knife-edge ridges, separated by deep ravines, and no longer amenable to agricultural use.

The World Bank (1990) recognized three main, environmental problems, facing Nigeria: soil degradation and loss, water contamination and deforestation. In addition, six other problem areas were specified: gully erosion, fishery loss, coastal erosion, wildlife and biodiversity losses, air pollution and the spread of the water hyacinth. Gully erosion contributes to each of the three main problems and causes damage with an annual cost to the nation, estimated at $100 million in 1990. In southeastern Nigeria, gully erosion is responsible for the destruction of transportation and communication systems, degradation of arable land, contamination of water supply, isolation of settlements and migration of communities. More than 2,500 gullies are active (Egboka, 2004).

The Food and Agriculture Organization of the United Nations summarized attempts to check gully erosion in southeastern Nigeria, from the establishment of the Udi Forest Reserve in 1918 to the formation of the Anambra State Task Force on Soil Erosion Control in 1990 (FAO, 1990). In general, these initiatives were “top down” in design and yielded some successful, mainly vegetative solutions, as well as largely unsuccessful, though expensive, engineered solutions. The FAO (1990) made reference to the “inherently unstable situation”, in which gullying results from the action of heavy rainfall on surface Earth materials under a reduced or altered vegetation cover and proposed a number of vegetative and inorganic technologies as solutions.

The present account presents the view that the textural properties of the soils, sediments and sedimentary rocks are among the defining elements of a sensitive ecosystem, which undergoes rapid degradation, in response to surface runoff and human disruption. Simple, geotechnical tests, such as gradation analysis and soil dispersion rate, provide an indication of the susceptibility of Earth materials to gully erosion and also the rates and probable, preferred directions of gully enlargement. The results of such tests are essential to the safe and effective selection and siting of technologies to control and prevent gully erosion in southeastern Nigeria. Hudec (project leader) and Simpson were the Canadian project team; Akpokodje and Umenweke were the Nigerian project leaders at Port Harcourt and Awka, respectively. Umenweke died in a tragic automobile accident in March 2000.

PROJECT OUTLINE

The research project, Gully Erosion, Nigeria, involved the University of Windsor, Ontario, Canada, and the two Nigerian universities, the Nnamdi Azikiwe University, Awka, Anambra

State, and the University of Port Harcourt, Port Harcourt, Rivers State, working in partnership with villagers in Abia, Anambra, Enugu and Imo States, southeastern Nigeria. Twelve villages collaborated: Umenekwu and Uturu (Abia State); Ekwulobia, Oraukwu and Umuchu (Anambra State); Ngwo and Obufinia/Ndiono (Enugu State) and Amucha, Umuaka/Okwudor and Umuchima (Imo State). Participatory management and evaluation were essential elements of the research. The project goal was to reduce gully erosion in southeastern Nigeria. The purpose was (1) to explain the widespread occurrence of gullies in the area and (2) to design a strategy for the prevention and control of gully erosion. The project ran from 1992 to 2000; the joint work was interrupted during a hiatus in the democratic process in Nigeria from 1996 to 1999. The funding agency was the International Development Research Centre (IDRC), Ottawa.

The project research included detailed mapping of the gully systems at selected locations and revision of existing maps of surficial deposits and the solid geology at and around the main sites of gully erosion. These systematic observations yielded information on the mechanisms of gully formation and data on the rate and configuration of gully advance. Selected geotechnical tests were carried out on samples of soils, sediments and sedimentary rocks at Port Harcourt and Windsor. Close to the start of the project term, the people of several partner villages and outlying areas began emergency measures to halt the advance of gullies, which threatened parts of their settlements, as well as highways and communications systems. Collaboration of the research teams with the people produced improvements in the local approaches to remediation. The project outcomes were controlled runoff at the observation sites, sustainable control of gully erosion at the sites of emergency intervention, empowered village partners and pluralism in environmental awareness in the partner villages.

GEOTECHNICAL SYNTHESIS

In the project area, the bedrock consists of mainly siliciclastic strata, which exhibit different degrees of lithification. Upper Cretaceous sandstones and shales in the north and east give way to Tertiary clastic rocks and sediments in the south and west and Quaternary sands farther south, beneath a soil cover of variable thickness. Gully processes are localized in the fine- to medium-grained Coastal Plain Sands (Pliocene to Recent) and Nanka Sands (Eocene) and the medium- to coarse-grained Nsukka Sandstone and Ajali Sandstone (Cretaceous) of the Anambra-Imo basin region. Kogbe and Mehes (1986) summarized the age relations of these deposits. Laterite development is widespread in the surface materials, extending to depths of 2 to 20 m

The textural properties of these deposits to a large extent determine their responses to the erosive action of surface runoff. Hudec et al. (1998) described the results of gradation analysis and measurements of the dry bulk density, dispersivity and moisture content of samples from the main geological units, which are susceptible to gullying. Gradation analysis of the Nanka Sand, Ajali Sandstone and Nsukka Sandstone shows that they are all strikingly uniform. The combined percent passing curves for size analyses of the units follow closely similar trends. The coefficient of uniformity (d60/d10) shows relatively minor variation in size distribution, in the size range of fine to medium sand. A plot of changes in gully dimensions (length, depth and breadth) against the proportion of particles smaller than 1 mm. shows that gully advance in all three directions increases with the amount of coarse sand.

The degree of consolidation and the presence of interstitial and intercalated mudstone of the main sand and sandstone units also have a bearing on their susceptibility to gully erosion (Hudec et al., 1998). The amount and type of mineral cement, expressed as the oxides of Ca, Mg, Mn, Na and K, show negative correlations with the rate of gully growth: the smaller the amount of cement (decreasing consolidation), the greater the rate of gully advance. The iron oxide cements of the laterites show a reverse trend, with the rate of gully enlargement increasing with increases in the amount of iron cement. Rates of gully erosion also increase with decreases in the dispersion time of detrital materials, which is the time taken for a sample to disperse (disaggregate) in water. The Ajali Sandstone and the Nsukka Sandstone show the shortest dispersion times among the units, affected by gully erosion. The relationship between dispersion time and proportions of the finer size grades, passing through 0.15 and 0.075 mm. sieves, indicates that dispersion time increases with increasing proportions of fines. The cleaner sands show rapid dispersion and therefore are more susceptible to erosion.

The Nanka Sand contains subordinate shales. There is also a local development of a paleosol at Nanka, where it is responsible for landslides. The leaching of cements from the sands and the dispersion of the clays in the interbedded shales are regarded as the main factors, controlling localized erosion and gully formation. The underlying Imo Shale was not studied, but contains expanding clays, which are likely to show strong dispersion effects. The Nsukka Sandstone contains subordinate carbonaceous shales, sandy shales and coal seams. Dispersion of clays in the argillaceous layers probably also contributes to differential erosion of the unit.

GULLY INITIATION AND PROPAGATION

Grove (1951a, 1951b) recognized two main types of gully on the scarp slopes of the Udi plateau and the Awka-Orlu uplands: (1) spring gullies, where permeable sands and sandstones rest on less permeable deposits and (2) slope gullies, which originate as channels (for example, sunken footpaths) in bottom-of-slope locations. Spring gullies are enlarged by sapping, caving and landslips and slope gullies by pot-holing; both types are further enlarged by waterfall action at the rim and undercutting of the sides promotes earthfalls and landslips. Intensive rainfall clears the debris from the gully bottom and the more continuous rains saturate the bank materials and cause the slumping of larger blocks. Grove (1951b) noted a possible connection between gully erosion and the increased runoff, associated with the clearing of woodland and road-building. Nearly forty years later, the FAO (1990) concluded that most of the gully erosion in southeastern Nigeria is caused by badly designed roads and the clearance of vegetation from building sites.

These types of gully were observed during the present study. As well, it was noted that some gullies originate as narrow rills with a down-slope orientation, which undergo progressive widening and deepening, with successive rainfall events (Hudec et al., 2005). These features tend to occur on bare soil surfaces, created by human and animal foot traffic and wheeled traffic in off-road locations and also by the grading of soil along the sides of roads. A special case is provided by lateritic deposits, in which narrow, relatively deep gullies are eroded downwards to the more friable materials beneath the laterite layer, leading to caverning in the more easily eroded material and collapse. Measured rates of gully erosion in two to three months of a single rainy season were up to 157 m. in length, 50 m. in width and 4 m. in depth.

The largest rainfall events, observed in the region during the project term, were 250 to more than 350 mm. of rain, with intensities of more than 0.25 mm. per minute. Rainfall data, collected for the Nigerian researchers by area schools, and observations on the performance of road culverts and roadside gutters during periods of heavy rainfall revealed major flaws in the design of highway drainage throughout the four states. Gullies tend to form, where the concrete-lined drains and culverts are too small to accommodate peak surface runoff, are not terminated at base-of-slope locations and are allowed to decay and become clogged with debris. The overflowing water erodes beneath the roadside gutter or culvert, which eventually falls away to provide a site of localized erosion. Highway development and construction projects account for the erosion of up to 90 percent of the gully systems in southeastern Nigeria.

GULLY TERMINATION

The textural controls of rate and direction of gully erosion demand an important place in planning for the reduction of risks, associated with gully processes. Hudec et al. (2001) noted that risk reduction planning for gully erosion must take into account the management of large volumes of water in a setting of slope instability. Many of the risk reduction strategies, designed for floods (UNHDA, 1996) and different types of mass movement (Miller, 1997) are applicable to the formation of gullies. Indeed, landslides and related phenomena contribute to gully enlargement in southeastern Nigeria, while floods commonly occur at lower elevations, where river channels are choked with the sand from gullies in the adjacent uplands. Simpson et al. (2002) commented on the need to incorporate gully prevention and control into policies for the strategic management of water resources, in view of the threat posed by gully erosion to the fabric of rural society. .

The selection and siting of technologies for the prevention and control of gully erosion ideally would combine the analysis of satellite imagery with geotechnical and related investigations on the ground and in the laboratory. Simpson and Sohani (2001) outlined the relationships between straight-line ground features (lineaments), drainage and introduced measures for water conservation in a dryland region of Maharashtra, India. The lineaments are the surface traces of deep-seated fractures, seen on satellite imagery, which are conduits for ground water. In Nigeria, the wrench faults with east-northeasterly (dextral) and north-northwesterly (sinistral) orientations, described by Black and Girod (1970) over a wider area of West Africa, hold promise as a starting point for the understanding of possible, deep-seated controls of the surface processes, shaping the landscape. Sites of incipient gully formation in southeastern Nigeria are likely to have distinctive signatures for satellite observation, comparable to those presented by Hidalgo (2000) for landslides in northern South America. As noted by Grove (1951b), to be most effective, anti-erosion measures must be applied in the early stages of gully formation.

The termination of gully processes requires the integration of water-resource management, soil conservation and revegetation on the scale of a drainage basin. The technologies of water harvesting and spreading are necessary to reduce the velocity and erosive power of the runoff on hillsides, cleared for agricultural development. Water harvesting is the use of technologies for the capture at and near ground level and eventual extraction of fresh water, obtained from a particular catchment area. The catchment may be natural or artificial. Technologies for water spreading involve the diversion of water underground, into the interconnected pore systems of shallow Earth materials. In general, water spreading requires the excavation of ridges and trenches, oriented parallel to contours of elevation above mean sea level; these are particularly effective on terraced hillsides. For example, water held at a particular terrace level by a terrace-margin ridge (bund) of soil infiltrates into the soil and this process may be accelerated through the additional use of trenches and infiltration pits. The FAO (1990) drew attention to the advantages, associated with the use of gabions (barriers comprising bundles of stones in galvanized iron chainlnk), strips of the grass Vetiver and alley cropping as approaches to the reduction of soil erosion on hillsides. Gabions are particularly suited to use on hillsides, composed of unstable materials, because of their flexibility.

In southeastern Nigeria, the rural people have a history of controlling surface runoff by means of minor hill-slope modifications, barriers and catchment basins. Hill farmers in the Mmaku area of the Udi plateau edge have traditionally used stone-faced terraces (FAO, 1990), though this practice appears to be isolated in extent. Barriers of interwoven branches and low walls of dried mud were used widely to control the movement of surface runoff around settlements and remain at many locations. These structures fell into disrepair, as a result of larger numbers of people crossing the hillsides, and for the most part are no longer maintained. Runoff is directed away from small roads and pathways in many parts of the project area by means of shallow diversion ditches, connected to catchment basins, located down-slope. These structures are generally effective in minimizing erosion along the roads.

The emergency measures for gully prevention and control, initiated by some of the partner villages and maintained by them, on the basis of consultations with the research teams, were effective over a period of eight years (Simpson et al., 2002). At the Okigwe-Uturu-Isiukwuato road junction, Uturu, near Abia State University, Abia State, the collapse of a roadside drain led to the formation of a deep gully that threatened the highway and disrupted the related telecommunication systems. A soil fill was introduced and then graded and a concrete drain diverted runoff down-slope, away from the highway. A dense cover of grasses and shrubs was established. At Ekwulobia, in Anambra State, the village and adjacent highway were at risk from a gully, resulting from a collapsed, concrete drain. The villagers constructed a concrete spillway at the gully head, leading to a concrete drain, which diverted the runoff away from the gully. Roofwater harvesting reduced the amount of surface runoff in the settlement, in the vicinity of the gully. At Amucha, in Imo State, the Nigerian researchers designed and constructed modifications to roadside drains, taking into account the volumes of runoff, received from local rainfall. There was no undercutting of the new section of gutter, even though the road itself previously had been eroded below the level of the drain in places.

The termination of gully erosion also may take place under entirely natural circumstances (Grove, 1951b). The headward erosion of deep ravines, associated with entrenched spring heads, is slowed down by the root systems of forested slopes and by slipped material, accumulated at lower levels. The erosion of slope gullies leads to the formation of badlands, in which erosion at an individual gully head slows, as it approaches the local water divide. Spring and slope systems commonly are stabilized by algal growth around the gully heads and the spread of ferns and mosses and later trees at lower levels. Recent observations of gullies at Ngwo, Enugu State, near the Enugu-Onitsha Expressway, showed that they had become inactive, as a result of the combined effects of lateritization and the growth of new vegetation.

The termination of gully processes on a significant scale in southeastern Nigeria will require unparalleled adjustments to lifestyle and professional outlook, encompassing such wide-ranging activities as highway construction and maintenance, agricultural practice and off-road movement of rural people and their livestock. This can be achieved only through close interaction of the affected communities, state and federal authorities, donors and private industry, working on the scale of a drainage basin. The project addressed this issue in an end-of-project workshop, held in Owerri, Imo State, on September 2, 1999. It brought together members of village erosion committees, traditional chiefs, government officials from each of the four states, individuals from private companies and the Canadian and Nigerian project teams, with faculty members and graduate students from each of the Nigerian partner universities.

CONCLUSIONS

In southeastern Nigeria, the textural properties of surficial deposits and the horizontal to gently inclined sands and sandstone, forming the bedrock, make them susceptible to gully erosion. Grain size, the distribution of mineral cements and dispersion rates are among the defining elements of a sensitive ecosystem, which undergoes rapid degradation, in response to surface runoff and human disruption. Localized erosion, leading to gully initiation and propagation, tends to occur at (1) textural heterogeneities and interruptions to the vegetation cover of granular surface materials; and (2) the unlined interfaces between such materials and artificial structures.

Trends in increasing proportion of well washed sands and of grains, exceeding 1 mm. in diameter, indicate where accelerated gully enlargement is most likely to occur and should be employed in the selection and siting of technologies for the termination of gully erosion. Success in gully prevention and control requires the careful integration of water-resource management, soil conservation and revegetation on the scale of a drainage basin. In particular, the technologies of water harvesting and spreading are essential to the control of surface runoff. Roofwater harvesting to reduce the surface runoff near dwellings and gabions, strips of Vetiver grass and alley cropping applications to arrest soil erosion on hill slopes are technologies that would make an immediate difference. Improvements to roadside drainage should have the highest priority.

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