Performance of gully erosion control measures in southeastern Nigeria

C. O. OKAGBUE & K. O. UMA
Department of Geology, University of Nigeria, Nsukka, Nigeria

ABSTRACT The performance of gully erosion control measures in some parts of southeastern Nigeria is presented. The measures include tree planting, hydraulic regulation works that integrate a drainage network with storage ponds to cut off flood crests and lower hydraulic loads of interceptor canals, and stabilization works such as check dams on the main channels of gullies and wicker-work fences and hedges at the inner gully slopes. There is evidence that tree planting and surface regulation of surface waters is effective in controlling only shallow (<15 m deep) gullies that have not cut through a saturated zone. These measures tend to fail when used for deep gullies that are greatly affected by groundwater especially when such gully floors are located in non cohesive and very permeable sands.

INTRODUCTION

In the last quarter of the nineteenth century channels in some parts of Nigeria were noticed to have entrenched their valleys. These channels generally eroded into red-earth and unconsolidated geologic materials establishing prominent gullies with near vertical slopes. Increased erosional activities in the vicinity of the early gullies have continued to expand these gullies into a complex system. Some
of the gullies especially those in southeastern Nigeria are now of canyon proportion, and constitute the most threatening environmental hazard in this part of Nigeria.

Fig. 1 Location of gullies in southeastern Nigeria.

Fig. 1 shows the location of the catastrophic gully areas. The most active and dangerous spots occur at Agulu, Nanka, Alor, Oraukwu, Oko and parts of Udi, Enugu and Ukehe in Anambra State. Other catastrophic gullies occur at Amucha, Isuikwuato, Ohafia, Abriba and Arochukwu in Imo State, and in parts of Uyo and Calabar in Cross River State. In all these places, with similar stratigraphic sequences of thick cohesionless sand strata overlain by a red clayey sand stratum and surface earth of either sandy loam or
silty loam, intense gullying involving sudden and often catastrophic movements of large earth masses, has sent villages packing, wrecked homes, swept crops and washed roads away.

The incidents of gullying have caused much concern to successive governments of Nigeria and have generated much attention among institutional and private researchers. Studies have been conducted and seminars and workshops held on the immediate and remote causes of the gullies. Based on some of the results of these studies, a number of control measures have been designed and constructed in some of the affected areas. Some of these measures have been fully or partially successful while others have woefully failed.

This paper critically assesses the performance of the control measures and discusses the factors that have contributed to their success and/or failure. It is hoped that the results presented herein would be of interest to planners and designers of gully control measures in Nigeria and elsewhere where similar gully problems occur.

CAUSES OF THE GULLIES

The causes of the intense gullying are evident from the results of the studies so far conducted in the area. From the much that has been postulated and written on the origin and development of the gullies, there appear to be a considerable measure of agreement. Table 1 summarises the opinions of the main workers.

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<th>Author(s)</th>
<th>Causes of Gullying</th>
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<td>Floyd (1965)</td>
<td>Soil characteristics and human activities.</td>
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<td>Ofomata (1965)</td>
<td>Mainly soil characteristics, less of human activities.</td>
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<tr>
<td>Ogbukagu (1976)</td>
<td>Mostly geologic set up and soil characteristics.</td>
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<td>Nwajide &amp; Hoque (1979)</td>
<td>Topography, climate and soil characteristics.</td>
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The earlier workers (Floyd, 1965; Ofomata, 1965; Ogbukagu, 1976; Technosynesis, 1978; Nwajide & Hoque, 1979) have emphasised the importance of the soil and geologic materials exposed by the removal of vegetation cover and the impact of heavy rainfall on such materials. The consensus of these earlier workers is that the high intensity rainfall in the area produces high volumes of overland flow.
with high erosive energy. The action of the highly erosive floods on the unusually susceptible geological and soil materials produces the complex gullies. Floyd (1965) had suggested a six-stage evolution of the gullies:

(a) Intense agricultural activity leading to soil degradation and destruction
(b) Rain splash and removal of soil particles
(c) Leaching and eluviation
(d) Sheet and rill erosion
(e) Accelerated erosion and formation of gullies
(f) Mass earth movements through slumping, sliding and downhill creep leading to the complex badlands.

More recently, the effects of groundwater and hydrogeotechnical factors have been highlighted as possible additional factors especially in the most dangerous spots where mass earth movement is the dominant mechanism. Egboka & Okpoko (1984) and Egboka & Nwankwor (1985) indicated that the active gullies are located mostly at the discharge areas of groundwater systems. The high pore-water pressures especially during the peak recharge times of the rainy season reduce the effective strength of the unconsolidated materials along the seepage faces. It has also been shown (Uma & Onuoha, 1986) that, in some areas, the high seepage forces due to the near critical exit hydraulic gradients at the various levels of seepage on the gully walls produce boiling conditions, piping and internal erosion that undermine the bases and partial bases of the gullies.

One fact is clear from the several studies and from a close field inspection of the affected areas; the development of the gullies is progressive through at least four main stages of:

(a) Formation of rills,
(b) Development of incipient gullies,
(c) Formation of shallow gullies (<15 m deep), and
(d) Development of deep gullies (>15 m deep).

The main erosional activity at the first three stages involves the surficial removal of soil grains and small chunks of earth by rain splash, concentrated flood run-off along the rills and existing gullies and minor undercutting at the toe of the channels.

Some of the gullies tend to stabilize at or before the third stage. Those that develop up to the fourth stage constitute the most catastrophic cases. They frequently contain groundwater seepages and springs at several horizons of their slope and their bases are formed by a thick stratum of very cohesionless and permeable white sands. The dominant mechanism at this fourth stage is sliding, slumping and soil flow involving movement of large soil masses. The mass movements are associated with groundwater fluxes and other hydrogeotechnical factors as is evident by the seepage faces and springs at the bases and partial bases of the gullies.

CONTROL MEASURES APPLIED

The description and interpretation of the works of earlier researchers on the general erosive processes have constituted the bases for the design and construction of the remedial measures so far adopted. Generally actions have been based on techniques cap-
able of reducing the erosive capacity of the flood water (i.e. those measures that either reduce the quantity of the flood water flowing in the drainage network or reduce their velocity) and those capable of increasing the resistance of the soil relative to the erosive capacity of the flood waters.

To reduce the erosive capacity of the flood water, two types of protection measures have been adopted. The first involves the construction of hydraulic regulation works that integrate a drainage network with storage ponds to cut off flood crest and lower hydraulic loads of interceptor canals. The interceptor canals, which are commonly located at the head of the advancing gully channels, drain runoff from areas adjacent to the gullies into artificial reservoirs (ponds) constructed where deep infiltration can occur. Fig.2 is a sketch of the hydraulic regulation work at Agulu, one of the dangerously gullied areas. The size of such hydraulic regulation work is
based on the size of the zone that is adduced to contribute flood water to the main gully trunk. The contributing area is demarcated from a detailed elevation survey of the area. When an isolated area is too large for one set of regulation work, it is broken up into smaller units.

Within the hydraulic regulation structures are stabilization works such as check dams on the main channels of gullies and revetments and hedges at the inner gully slopes. The check dams (Fig. 3) consist of a series of woods (sometimes timbers) firmly affixed in the gully bed at close spacing and connected by fairly strong horizontal woods or planks. Sometimes the wooden poles are driven into the ground across the gully to form a 2-sided framework resembling crib dams. The two sides are interconnected by cross members and braces and the intervening space is filled with compacted earth. The framework is held together with iron wire or rope.

![Fig. 3 Schematic section showing arrangement of check dams along the gully channel.](image)

The revetments are in the form of wicker-work fences used as stabilization work to reduce surface flows on the inner slopes of gully walls. The fences (Fig. 4) are formed by stakes about 10 cm thick driven into the ground close together (about 0.5 m - 1.0 m apart) and interwoven with braces and the like. The wicker-work fences are sometimes accompanied by tree planting to help strengthen the soil.

Tree planting is perhaps the oldest form of control measure adopted and is based on the recommendations of colonial workers. It is still used extensively in an attempt to increase the erosive resistance of the soils and to exert protection control. The trees used are those that have deep and abundant roots which are thought to be capable of binding the soil particles together. The more common ones are Cashew trees and Bamboos.

**PERFORMANCE OF THE MEASURES**

Varied degrees of success have been achieved with the remedial measures so far adopted. In some areas, gullying has apparently
stabilized after two years of the construction of the remedial measures, in some the gullying has continued but at a reduced rate while at others gullying has continued unabated despite the measures. The areas with apparent success include some gully spots around Oraukwu, Alor and Awo in Anambra State and some parts of Amuchia in Imo State (Fig.1). In these areas the gullying is still shallow (i.e. less than 15 m deep) and have not cut into the cohesionless and very permeable white sands. The groundwater table is also far beyond the gully bottom as no springs or seepages are seen on the gully walls. Apparently, the effect of groundwater on the gully advancement is minimal. No recent gully activity has been observed and vegetation has started thriving on the gully slopes.

![Diagram of timber-type wicker works.](image)

FIG. 4 Schematic sections of the timber-type wicker works.

In the areas of partial success which include some upslope gully spots around Nanka and Oko, gully activities have been significantly reduced. The erosion activities are confined to surficial removal of grains and small chunks of soil at the upslope side of the hydraulic regulation structures and at the banks of the main gully trunks. Intense gully sliding appears to have subsided as indicated by the absence of large volumes of recent debris at the gully floors in these areas. These partially stabilized gullies have cut into the cohesionless and very permeable sands but the groundwater level rises above the gully bottom only during the rainy season (April to September). The areas are classed as partially successful because they appear to work well only during periods of non-saturation of the sandy horizon. For example, some spots that were assumed relatively safe during the authors' inspection visit at the end of the
1985 rainy season were beginning to show signs of yielding to gully-formation during the 1986 rainy season. As the surface waters appear to be well controlled, groundwater apparently has some effect on the gully propagation.

In the most dangerous spots around Agulu, Nanka, Oko and Amucha where the gullies have cut deep into the cohesionless sand and the sand horizon remains perpetually saturated, the control measures appear to have totally failed to stop the development and advancement of the gullies. Sliding and slumping have continued despite the control measures. Some of the structural framework of the remedial measures such as remnants of check dams, wicker-work fences and concrete structures of interceptor channels can be seen lying at the bottom of the new gullies in the failed mass of earth materials. Tree planting has not helped, as surviving trees and shrubs are constantly uprooted, carried down and buried in large masses of earth materials. In these areas, gully walls are indented with springs and seepage faces; boiling spots depicting quick conditions are widespread, all showing effects of groundwater.

DISCUSSION

The control measures so far adopted in the gullied areas have been concentrated on regulation of surface waters (their volume and velocity), and planting of trees to strengthen the soil. These measures appear to have been successful in the shallow (<15 m deep) gullies cut mainly into red clayey earth; they have failed in deep gullies cut into very permeable and cohesionless sand where the gully walls are indented with springs and seepages at various horizons. This implies that the remedial measures take care of only the surface run-off, and fail to accommodate the disastrous effects of groundwater. Field inspection of the failed or failing structures reveal that most of them fail after undercutting and piping in the foundations. Piping results from uncontrolled seepage of groundwater along with seepage forces. Uncontrolled seepage pattern leads to saturation, internal erosion, excessive uplift and seepage forces to the extent that soil particles migrate to an escape exit and cause piping and erosional failure.

Also affecting success/failure of the concrete channel structures is the termination point of such channels. In areas where the channels have been terminated into the gullies, undercutting arising from channel deepening and scouring has led to the failure of the measure. Channels terminated at the local base level of rivers tend to be free from this type of failure.

Tree planting as a stabilizing measure has been effective only on minor gullies i.e. those that have not reached considerable depths (less than 5 m). The reason appears to be explained by the fact that the disturbances in deeper gullies originate several meters below the zone of influence of tree roots. In the deep gullies whose slopes are constantly undermined by flood and internal erosion the trees close to the gully edge usually find their ways down the gully floor as soon as the slope is undermined. Also the vegetation species (Cashew and Bamboo) used so far on the gully floors have
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failed to thrive on saturated and sometimes running sand that characterize the floors of the deep gullies.

FIG. 5 An example of failed water channel structure (note remnants of structure down the deep gully).

CONCLUSIONS

The following conclusions can be drawn from the present study:

(a) The success of any gully control measure doubtlessly depends on the stage of gully development, the local geological setting (stratigraphy and groundwater conditions), the characteristics and hydrogeotechnical properties of the eroded soils and their response to varying meteorological and hydrological conditions. Gullies cut into young and recent riverine alluvial deposits can be controlled by proper regulation of flood waters in conjunction with the use of vegetation. The use of only these measures may not be effective in controlling gullies cut deeply into non-cohesive sands.

(b) The rate of expansion and the mode of bank failures in gullies depend on the influence of not only surface flows but also groundwater conditions. Gullies that are not seriously affected by groundwater advance slowly by surficial removal of soil grains and small chunks of earth masses, whereas sliding and slumping involving large soil masses characterize gullies seriously affected by groundwater. Effective control of the second category of gullies involves not only controlling surface waters but also controlling groundwater effects.

(c) Gullies cut into very permeable and non-cohesive sands are more difficult to control than those cut into slightly cohesive soils. This is because high seepage forces in very permeable sands lead to internal erosion of the soils thus undermining structures that are constructed to control surface runoff. Channel structures that are terminated into gullies rather than at the local base.
levels of rivers also suffer undermining.

(d) Design and construction of gully erosion control structures should be based not on the general factors adduced to be responsible for gully problems but on the site specific factors (such as geology and hydrogeology) of the gullying areas.

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