MONITORING GULLY FORMATION AND DEVELOPMENT FOR EFFECTIVE REMEDIATION AND CONTROL

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INTRODUCTION

Recent research and field studies have shown that gully erosion is one of the most soil degradation processes in most states of the South East and South South zones of Nigeria as it causes considerable soil loss and produces larger volume of sediment.

One of the main causes of gully erosion in the study area, Edo State includes road construction with inappropriately terminated drainage network. While damages, by surface run off to the road may be limited, off site effects can be severe as witnessed in the study area (Ehiorobo and Izinyon 2011). Although gullies are visually striking, their small spatial extent generally renders them undetectable in most generally available topographical maps and low resolution satellite imageries.

As a result, it is necessary to carryout ground monitoring and modeling of the gully erosion phenomenon in order to predict their environmental impact and take remedial measures.

Short term monitoring of gully head or gully wall retreat has been conducted by measuring the change in distance between the edge of the gully head or wall and bench mark points installed on the gully walls (Vandekerekhova et al 2001). Some other researchers have used aerial photographic methods to determine the volume of soil loss by concentrated flow erosion.

This study involves the integration of GPS with Total Stations, remote sensing and GIS for the monitoring and experimental studies of gully morphology for the planning of land reclamation and control of the gully in order to prevent further land degradation in the study area.
THE STUDY AREAS

The gully area is bounded by UTM coordinates 700800mN to 702500mN and 795800mE to 79600mE. The gully runs in a south-easterly direction down to Ikpoba river. The elevation of the study area ranges from 16m to 110m above sea level (fig1). The average temperature in this area is 28°C. The raining season commences usually from April to October with a break during the month of August, commonly referred to as August break. Maximum recorded rainfall 2001–2011 was 439mm with a minimum of 3.75mm. There is however a sharp deviation this year 2012, probably as a result of climate change, as heavy rains have been experienced from January to date. Humidity is generally high about 98% for most of the year. The area lies within the tropical rain forest zone of Nigeria.
BACKGROUND TO THE PROBLEM

The Queen Ede problem is said to have started sometime in the 1990’s as a result of abrupt termination of the drainage channel along the Benin-Asaba road in front of the current location of the gully.

A gully of length 200m and 2m wide and almost 5m deep run along Edobor street to join another gully of the same width and depth and about 400m long along Pogha road.

This gully continues for about 60m along Igunbor street carrying along its part sediment and waste, which are dumped along Ogunbor street. As the run off in this area continue towards the highway with very high velocity it joins the storm generated along the Benin Asaba highway, crosses the highway at almost a right angle and with increase velocity of flow, continue down slope to cause more devastating damage around the Queen Ede secondary school.

Fig 2: Layout of Existing Drainage Infrastructure
DATA ACQUISITION

- The surveys carried out for gully control and remediation included:
  - Mapping of catchment basin and location of secondary gullies contributing run off to the main gully
  - Detailed surveys of existing control infrastructure including gutters, culverts, catch pits, drainage channels e.t.c
  - Longitudinal bed profile from head to outlet of the main gully.
  - Planimetric survey of the gully head at large scale
  - Cross sectional surveys of the gully to determine the nature of the stage of gully development i.e whether V or U shaped.

Two field observation sessions were carried out within the gully area, the first in December 2010 and the second in November 2011. Each observation session consisted of detailed topographical surveys of the gully site with the associated catchment basins using a total station instrument. The total station instrument was used to capture XY and Z coordinates covering the entire gully site at about 10m interval as well as other points of significant changes in slope along the bank, gully walls and gully floor.

During the topographical surveys, the average point density in some areas such as the gully head, gully floor and terraces were more intense than in other parts of the gully.
The total station measurements in each epoch were collected at centimeter level resolution to capture break in slope and other topographic features necessary for producing accurate Digital Elevation Model (DEM). The gully cross sections along with topographical profile of the gully bed from head to outlet was carried out using Automatic level with Telescopic staff. Ikonos imagery was acquired to measure and monitor the extent of the eroded area as well as providing a quantifiable estimate of the landed area and in the analysis of physical structures that have been affected or endangered by the gully (See Fig 3).

**Fig 3: Ikonos Imagery of Queen Ede Gully Site**

**DATA PROCESSING**

The morphological data and cross sectional data were used to determine the cross sectional areas and the volume of soil loss in each case.

The eroded volume of each gully segment was calculated using the cross sectional area and the distance between cross section as:

\[
V = \sum L_i A_i
\]

Where \( L_i \) is length of gully section in meters \( A_i \) is crosssectional area in m²

Short term erosion rates (t ha⁻¹ yr⁻¹) \((E_s)\) were calculated in order to determine the rate of erosion over the period of study using the equation given as (Nyssen et al 2006).
Typical cross sections of Queen Ede gully are shown below

\[ E_t = \frac{(V_{38.0} - V_{20.0}) \rho_s}{T A} \]  

(2)

Where:

- \( E_t \) - Erosion rate
- \( \rho_s \) - Bulk density of soil occurring in the contributing area
- \( T \) - Period of gully development in years
- \( A \) - Watershed area in hectares

Erosion per unit gully surface (t.m\(^{-2}\)) was estimated using the equation

\[ E_p = \frac{V \rho_s}{A_p} \]  

(3)

Where:

- \( V \) - Current volume of soil loss in the gully
- \( A_p \) - Plan area of gully (m\(^2\))
- \( E_p \) - Erosion per unit gully surface
- \( \rho_s \) - Bulk density
From the cross sections above, it can be seen that the gully is U-shaped, thus; we can conclude:

- The run-off contributing catchment area is large and therefore the discharge passing through the gully is also large.
- The longitudinal slope of the gully bottom is parallel to the land slope.
- The run off enters the gully from the head and from the sides at points where adjacent land is slightly lower than the surrounding.
- The gully have been formed by under cutting and collapse of the bank walls.
- The gully continue to expand towards the head as active erosion action occurs mainly from side walls near the head as a result of under cutting of the base and walls.
The longitudinal profile of the gully from head to the outlet at Ikpoba river is shown in Fig 6 while a planimetric survey plan of the gully head at large scale is shown in Fig 7.
Satellite imagery delineation and field measurement of the gully growth indicated that the planimetric area of the gully has increased from 9.48 Hectares to 10.44 Hectares. From Table I, it can be shown that the value of soil loss increased from 375,322m³ in 2010 to 393070m³ in 2011.

Short term erosion rates was calculated using equation (2), to be 0.541 t ha⁻¹ yr⁻¹.

The average was based on measured gully volume and the average soil bulk density. This indicate the severity of soil loss due to gully erosion in the Queen ede catchment basin.

During the period of observation, the top and bottom width of the gully experienced increase between ch 00+40 – ch 00 +100, between ch00+220 - ch00+280 and between ch00+940 and 00+980 respectively (See Table I). It is however expected that with heavy rain in Benin city since January 2012, slumping in various part of the gully walls will occur as a result of ground water exerting pressure on the overlaying saturated soil profile. This in turn will cause the soil to loose its stability and consequently causing the slumping of gully walls with consequent further widening of the gully and deposition of higher volume of sediment at the down stream of the gully. This will create further environmental degradation and loss of valuable properties and land resources.
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CONCLUSIONS

This paper examined the use of GPS, Total Station Instrument, Remote Sensing and GIS in monitoring Gully formation and development. Results of the topographical surveys of the catchment basin revealed that the gully is at a low point which serves as a receptor for all the run off coming from the entire catchment basin.

The cross sectional surveys revealed that the Gully is U shaped which show that the run off contributing catchment area is large and therefore the discharge passing through the gully is also large.

The recent increase in the growth and expansion of the gully can be attributed to the change in rainfall pattern in the region caused by climatic change.

The use of high resolution satellite imagery in combination with ground survey methods using GPS and Total station enables us to produce different types of maps and develop models, and accurately design structures needed to control the gully process.

The Geo information provided, will enable the Engineer carry out control measures including redesign and upgrading of existing drainage infrastructure, provision of gully control measures at the head region and other remediation measures necessary for healing of the gully and its prevention from further expansion to protect the environment from further degredation.