Monitoring of Soil Loss from Erosion Using Geoinformatics and Geotechnical Engineering Methods

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KEY WORDS: GPS, Gully Erosion, rill Erosion, Monitoring

ABSTRACT:

Soil erosion has become one of the most serious environmental problems all over the world. This is as a result of the fact that a large volume of land area which would have been used for development of infrastructure and residential area is lost in urban areas while large agricultural land is lost in rural environment. Gully erosion removes large volumes of soil from an area. Gully erosion is attracting great interest by scientific communities.

In this study the position of all major rill and gully sites were located and Georeferenced using Hand held GPS receiver. Based on severity rating and geopolitical considerations, six of the erosion gully sites were selected for monitoring and Control points were established around each of the gully sites by method of Differential GPS (DGPS) surveys and detailed topographical survey of gully sites carried out using reflectorless total station instruments. Using SPOT imageries in combination with GIS and total station data, the location maps, contoured maps along with DEM were generated using ARCGIS 9.2 software. The morphological parameters of the gullies including depth, width, length and areas of the gullies were then determined. Volumetric estimate of the amount of soil loss from gully erosion was also carried out. Soil samples were recovered from the gully sites to determine their erodisivity and other properties to be used for soil loss modeling.

The result of the studies was used as an indicator for determining the gully initiation point slope-Area relationship, and threshold of gully initiation was also established. The maximum volume of soil loss occurred in gully No 2 (Queen Ede College). The minimum AS^2 value was 345 while the maximum was 3,267. This shows that the results lie within the two boundary layers of 41 and 814 (m^2) and 500-4000 m^2 established by Poesen et al , Montomery and Dietrich respectively.

1. INTRODUCTION

Erosion is the detachment and transportation of soil particles on the earth's surface from one point to the other by erosive agents such as wind and water (Aghayedo 1996). The two most common types of water erosion are sheet and gully erosion. A less common type of erosion is rill erosion. In sheet erosion, soil is removed in sheet form by the influence of flowing water from a given area on a sloping terrain. In sheet erosion, maximum movement of the soil takes place when the depth of flow equal to the diameter of soil particle. In rill erosion, the erosive effect of flowing water leads to the movement of large amount of soil particles from the sides and bottom of the flow path which are mixed in the flowing water. These surface flows contain soil particles in suspension and form micro channel called rills (Tech report Vol I, flood and erosion profile in Edo state 2010). The last stage of rill erosion is usually classified as gully. Gully erosion is said to take place when excessive surface run-off flowing with high velocity and force detach and carry soil particles down slope. They may also occur when runoff volume from sloppy terrain increases sufficiently or increase in flow velocity as to cut deep holes along its path (Ehiorobo and Izinyon 2011). Gullies may also develop on traces formed by the movement of machineries down slope.

Poesen et al 2003, defined gully erosion as the erosion process whereby run off water accumulates and also receives in narrow channels and over short periods removes the soil from this narrow area to considerable depths.

Shumun et al (1984),Stabulluoglu, Tarboton and Pack (2003) on the other hand defined gullies as unstable eroding channels formed at or close to valley heads, sides and floors. Of recent, gully erosion has attracted great interest by researchers. It is now well known that increase exploitation and exploration of land resources in upper parts of catchments results in increased sediment yield and elevated nutrients loss in run off that reduced water quality and availability to down stream users (Valantin, Poesin and Li 2005). Gully processes are usually the main source of sedimentation (Hum et al 2005). Gully erosion has for some time been neglected because gully processes are difficult to study and difficult to control. Gullies have three-dimensional nature affected by varied factors and processes including surface hydrology, soils, topography, Land use etc. Many gullies grow initially rapidly to large dimensions (Thomas et al 2004, Valentin, Poesen and Li

2005), making effective control technically difficult or prohibitively expensive. This is why studies on gully processes (Gomez et al 2003) and their modeling (Siderchuk 2005) are scarce. Recent research and field studies have shown that gully erosion is one of the most soil degradation processes in most states of Nigeria as it causes considerable soil loss and produces large volume of sediment. Gullies are also catalyst for transferring surface run off and sediment from uplands to valley bottoms and creation of channels that aggravate the problem of flooding and water pollution. Field measurements and research findings in various countries have shown that the development of gullies increases the connectivity in the Landscape and hence also the sediment delivery to low lands and water courses. Many cases of damage to water courses and properties by runoff from agricultural land relate to the occurrence of gully erosion (Verstraeten and Poesen, 1999, Bourdman 2001, Poessen et al 2003) .

Many studies have investigated the susceptibility of soil to inter rill and rill erosion but very few studies exist on the susceptibility of soils to gully erosion. Substantial efforts have been invested in developing soil erosion models resulting in a variety of empirical and more so publicized models, such as the universal soil loss equation USLE, its revised version the RUSLE, the water prediction project WEPP and Coordination of Information on the Environment (CORINE). The prediction of gully development using mathematical model is difficult as the different factors involved in the prediction are not so easy to determine. Soil type and in particular the vertical distribution of the erosion resistance of the various soil horizons largely controls, the size, the depth and cross sectional morphology of the gullies (Poesen et al 2003). Poesen (1993) found that soil shear strength at saturation of the various losses-derived soils horizon is a good indicator of their resistance against concentrated flow erosion.
In Nigeria, high land use pressure particularly in the South East and South South regions render the Landscape more Vulnerable to gully erosion. Land use changes have also caused the development of bank gullies along some river banks.

Gully represent some of the most destructive form of erosion, destroying soil, undermining infrastructure, damaging farm lands, altering transportation corridors and lowering water tables (Valentin et al 2005). Gully erosion affects sediment budgets and flux rates, and influences stream dynamics as evidenced from data on hydrograph (Costa and Bacellar, 2007, Perroy et al 2010). Although gullies are visually striking, their small spatial extent generally renders them undetectable in most generally available topographical maps and low resolution imageries. The use of GPS and Total station data along with high resolution satellite imageries and GIS offers the potential to effectively measure gully volume at the landscape scale. Monitoring and experimental studies of the initiation and development of gullies at various temporal and spatial scales need to be carried out. The critical thresholds for the initiation, development and in filling of gullies in different environments in terms of flow hydraulics, rainfall, topography, soils and land use need to be identified.

Pattern and rates of gully networks development as well as network geometric configuration are highly controlled by soil properties (Bryan 2004). One of the main causes of rill and gully erosion in 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 very severe. The road is said to induce a concentration of surface run off with a concentrated diversion of concentrated run off to other catchments and an increase in catchment size which enhances gully development after road construction (Nyssen et al 2002). Changes in drainage pattern associated with urbanization results in gully particularly where illegal settlements without urban infrastructure exist.

At the moment existing predictive models are unsuitable for use in soil loss assessment from gully erosion as soil loss caused by gully erosion are rarely accounted for by use of these models. As a result of the above it is necessary to carryout monitoring and modeling of gully erosion in order to predict the environmental impacts and take remedial measures.

However, contrary to sheet and rill erosion, where standardized procedures for the assessment of erosion rates exist eg RUSLE, no standard procedures are available for measuring gully erosion rates and controlling factors. In the past, both ground based and airborne techniques have been used to assess gully erosion rates at a time scale. 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 point, installed on the gully walls (Vandekerekhova et al 2001, Oostwood, Wijdenes and Bryan 2001). Some other studies have used aerial photographic methods to determine the volume of soil loss by concentrated flow erosion (Thomas et al 1986, Ries and Marzolff 2003). One of the most common methods in use lately is by integration of GPS, GIS and remote sensing technologies. In the current study GPS was used to establish 3-D controls for each gully site while total station instrument was used to measure the morphological parameters of the gullies.

2. THE STUDY AREA

Edo State is one of the thirty six states of Nigeria and lies within the oil rich Niger Delta region. It has a population of 3.2 million with a land mass of 19,635 square kilometers. The State lies between Latitude $05^{0}44'$ to $07^{0}34'$ N and Longitude $05^{0}04'$ to $06^{0}45'$E

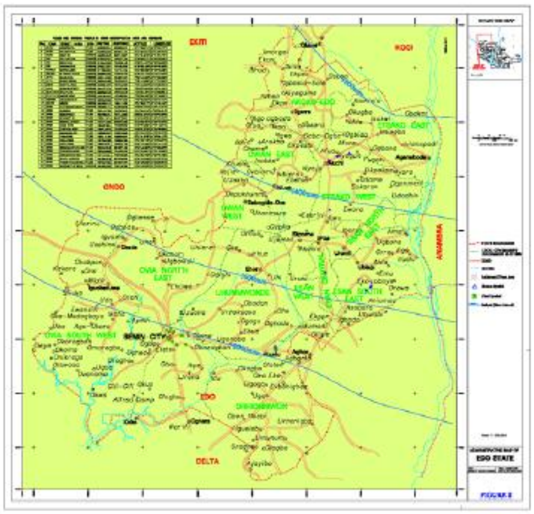


Figure 1. Edo State Map

The land mass of Edo State is undulating with intermittent valleys and flat terrains from the Southern part of the State, with height above sea level varying from 15m in the southern boundary with Delta State up to about 300m above sea level in the northern part of the state. This along with the relatively flat terrain in the south and dissecting plateau and hills in the Northern parts of the State, along with steep slopes in various parts of the central and Northern parts of the State along with high rainfall and lateritic soils consisting of medium to coarse sands and clayed deposits account for the problem of gulling in this State. The average annual rainfall ranges from 1400mm in the northern part of the State to 2000 mm in the South. In 2011 an average rainfall of 2500 mm has been recorded as at September 2011 (NIMET 2011). Gulling which is rapidly developing in many parts of the State mainly due to urbanization has been identified in terrains covered by friable and highly erodible A-3 soil deposits. Examples of such gullies include the ones at the University of Benin and Queen Ede secondary school both in Benin City, the State capital, the Ibore and Emu gully sites in Edo Central, Oshiobugie-Auchi and Ikabigbo gullies in Edo North. In the State, an estimated land area of 2,000 sq km is degraded land. About 30% of this area is degraded by gulling and rill erosion while 70% is estimated to be area under sheet erosion.

3. METHODOLOGY

The overall methodology involves the use of Geographic information system GIS, Remote sensing, Global positioning system GPS and Electronic total station in acquiring the necessary data for assessment of soil erosion particularly gully erosion, study the spatial temporal distribution pattern of gully erosion initiation and the effect of land use on gulling erosion.

3.1 Desk studies and field measurements

The first phase of this study included acquisition of information and report on erosion in Edo State from the State Ministry of Environment. Thereafter, topographical maps at scale 1: 25000 were acquired from the office of the Surveyor General of the Federation. The position of the major rill and Gully erosion sites were then located and Georeferenced on the ground using Hand held GPS receivers.

Control points were established around each gully site by method of Differential GPS (DGPS) survey. Detailed topographical surveys of the gully sites together with the flood basin were carried out using reflectorless total station instruments. During the topographical survey, the average points density in some areas such as the gully heads, gully edges and terraces were more intensive then in the other parts of the flood basin. The total station data were geo referenced using the DGPS control points. Measurements were collected in six gully sites cross sections along with topographic profile running along the gully channels. The morphological parameters of the gullies including depth, width, length and the area of the gullies were measured. The total station measurements were collected at centimeter-level resolution to capture breaks in slope and other topographic features important for producing accurate DEMS.

Hand auger soil samples were collected both within the catchment basins and on each encroaching layers of the gullies. The samples were taken to the Geotechnical Engineering laboratory for Standard classification and other tests which included particle size distribution, Natural moisture content, specific gravity, Atterberg limits test, compaction, consolidation, permeability, etc. Of these the most important for gully erosion modeling include particles size, moisture content and specific gravity.

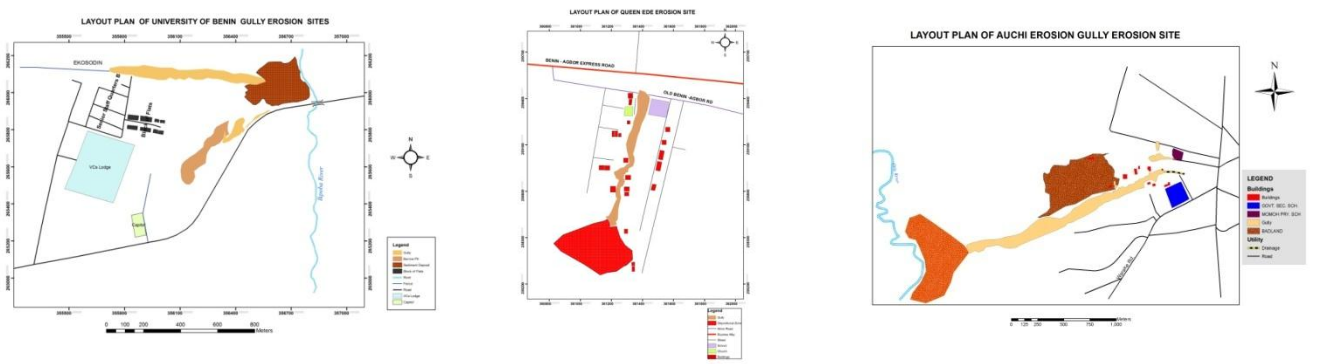
4. DATA PROCESSING AND RESULTS

Spot elevation along with points coordinates of the gullies where obtain from the DGPS and Total station surveys using the in-built software in the total station system with the DGPS derived coordinates as control/ reference points. Based on the computed points coordinates and elevations, the morphology parameters including length, width, depth, and areas of the gullies along with total soil loss were determined. Next, the project coordinates for each erosion site were exported into personal Geo database as shape files in Arc GIS environment.

The shape files created for the elevation data were then added and a Triangulated Irregular Network (TIN) created using the Z coordinates. Digital Elevation Models DEM were then generated by converting the TIN into Raster. Contour lines were generated using the created TIN to interpolate for the contours with the aid of 3D analyst extension. Arc Scene was then used for the visualization of the 3D model generated. From the contours, the slopes were generated as necessary. The pixel size of the DEM was 1m. The morphological parameters for the six gullies are presented in Table I. Figure 2a, b and c show the location maps while figure 3 a, b and c show the contour maps for the University of Benin, Queen Ede and Auchi erosion gully sites respectively. Figure 4 a, b and c presents the triangulated Irregular Network for the same sites.

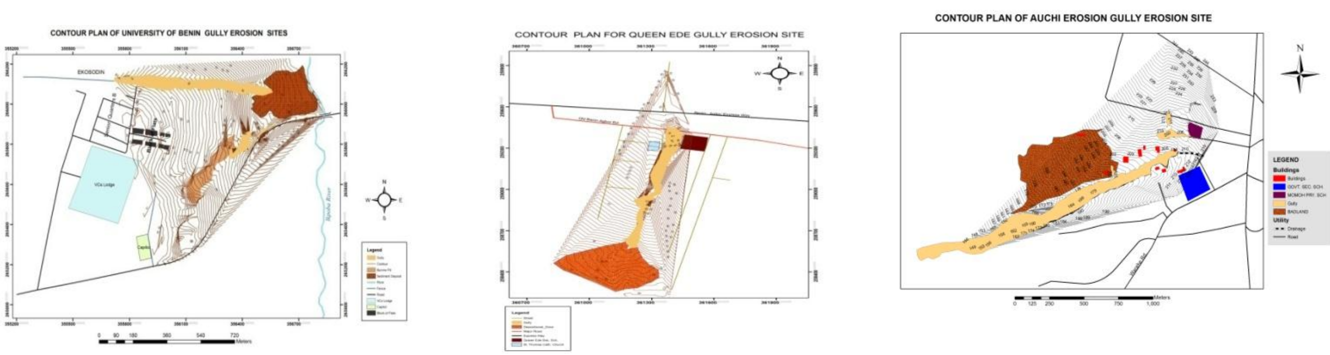
No of Gully	Name of Gully	L(m)	W(m)	D(m)	A(m^2)	S(m)	AS^2(m^2)	WDR	V (m^3)
1	University of Benin	1020.232	44.165	26.575	44,880	0.022	2,172	1.661	358336.085
2	Queen Edo College	12.5	54.0315	11.83	67,480	0.010	675	4.567	385113.568
3	Oshiobugie Auchi	2,200	62.755	25.330	127,600	0.160	3,267	2.479	129085.00
4	Ikabigbo	467.66	22.975	7.768	11,675	0.172	345	2.958	57901.108
5	Ibore	1,300	45.00	12.00	56,680	0.151	1,279	3.750	208800.00
6	Emu	1,700	22.50	10.00	38,760	0.254	2,500	2.250	103625.449

Table 1. The morphological parameters for the six gullies sites



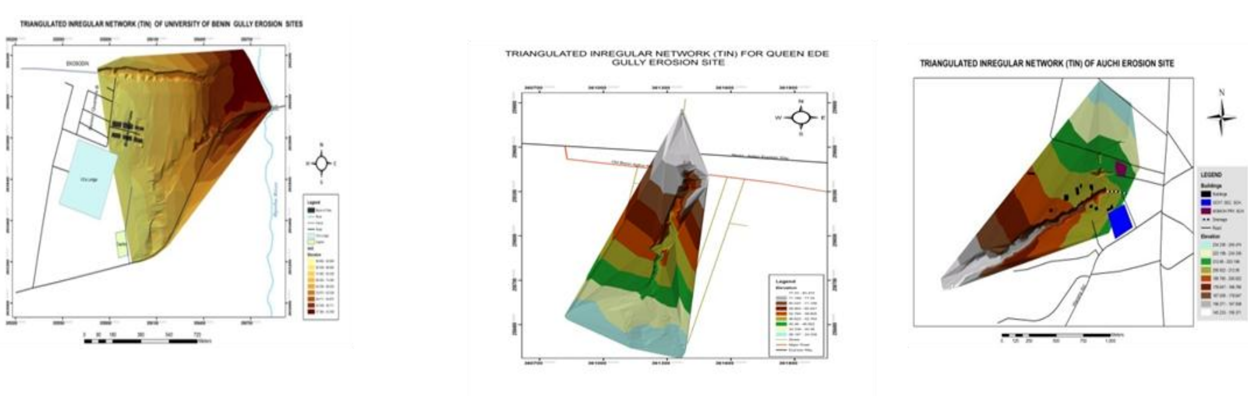
(a) (b) (c)

Figure 1. Layout of University of Benin, Queen Ede and Auchi gully Esion sites



(a) (b) (c)

Figure 2. Contour plan of University of Benin, Queen Ede and Auchi gully Esion sites



(a) (b) (c)

Figure 3. Triangulated Irregular Network (TIN) of University of Benin, Queen Ede and Auchi gully Esion sites

Where L- Length, W- Average width of gully, D- Average Depth of gully, A-Gully area, S- Critical slope gradients ,WDR – Width-Depth Ratio V- volume of soil loss.

5. ANALYSIS AND DISCUSSION OF RESULTS

The results of field observation showed that the erosion rates in the selected gullies for detailed studies are intense. If the position of the gully heads can be predicted and if erosion rates of the gullies are measured, measures can be take to protect the areas from further gullying. The areas of the gullies ranged from 11,675 (m^2) to127,600(m^2), depth ranged from 7.768m to 26.575m, and width from 22.50m to 62.785m. The longest of the gullies studied was Auchi gully with a total length of 2.2km. The Width to depth ratio WDR varied from 1.661 to 4.567. The volume of soil loss varied from 57,901.11(m^3) at Ikabigbo gully to 385,113.57 (m^3) at Queen Ede gully, in the six gullies studied. Measurement results in December 2010 and September, 2011 showed that the University of Benin gully witnessed a retreat of 66m within the 9 month period. This was found to be as a result of improper channeling of storm runoff from different directions into the gully head along with the unprecedented intensity of rain fall in 2011 which was the highest experienced in the area for the past 30 years. The values of AS^2 considered as an indicator for the gully initiation point ranged between 345 and 3,267. The lower limit conform to poesen et al (1998) range of between 41 and 814(m^2) while the upper limit comform to Montgomery and Dietrich (1992) range of between 500 and 4000(m^2).

6. CONCLUSION

In this study, attempt were made to assess gully erosion based on an integration of remote sensing, GIS, GPS with total station technology. Using these technologies, the spatial distribution patterns of gully erosion, the topographical threshold for gully erosion, initiation, and the effect of land use were studied.

The result of the study showed that gully volume has significant relationship with both the gully length and areas and also with the depth and width of the gully. The study established a relationship between the drainage basin area A and the critical slope (S) for entrenchment. Montgomery and Dietrich (1992) proposed that there is a threshold between the contributing area and the critical slope and that the value of AS^2 of 500-4000(m^2) was an indicator for determining the gully initiation point slope-Area relationship, and threshold of gully initiation was established.

The results in this study showed that the gullies No 1,2,3,4,5 and 6 satisfied Montgomery and Dietrich (1992) proposal that the values of AS^2 of 500-400 (m^2) is an indication for determining the gully initiation point slope-Area relationship while gully No 4 satisfied the (Poesen et al 1998) relationship of range between 41 and 814m^2.

Reference

1 Aghayedo (1996), “ Erosion and Flooding in Edo State” Consensus Building workshop for state Environmental action plan by FEPA/EDSEPA, Benin City, 5th Nov., 1996.

2 Niger Delta Development Commission (NDDC) (2010), “ Flood and Erosion Research profile in Niger Delta region (Edo State)” Tech Report Vol I.www.fig.net/pub/fig2011/papers/ts07e/ts07e_ehiorobo_Izinyon_5126.pdf

3 Ehiorobo, J.O and Izinyon C.O, (2011), “ Measurement and documentation for Flood and Erosion Monitoring and control in the Niger Delta States of Nigeria, FIG working week 2011.

4 Poessen, J. Ngchtergaele, J. Verstraeten,G. and Valentin,C. (2003) “ Gully erosion and environmental change; importance and research needs”.Catena Vol 50 pp91-133.

5 Schumm,S.A, Harvey,M.D and Watson, C.C, (1984), “ Incised channels: Morphology Dynamics and control” 200pp, Water resources public. Highlands Ranch. Colorado.

6 Istanbulluoghi,E, Tarboton, D.G, Pack, R.T, and Luce,C (2003), “A sediment transport model for incision of gullies on steep topography”. Water resources research vol 39 (4) ES9-6-1.-ESG 6-5.

7 Valentin,C. Poesen J and Young Li (2005), “ Gully erosion: impacts, factors and control” Catena Vol 63 pp 132-153.

8 Hum S, Bellanger, B., Borite, Ph., Podwojewski, P., Valentin, C, Velasquez, F,. Bricquet J.P, de-Rouw, A., and Girandin C, (2005), “ Monitoring soil organic carbon erosion with isotopic tracers: two case studies on cultivated tropical catchments with steep slopes CRC press, Bocaraton, Florida, USA.

9 Thomas,J. T, Iverson, N.R, Burkert, M.R, Kramer L.A (2004), “ Long term growth of a valley-both gully” ,Western Iowa. Earth surface process and Land forms Vol 29 pp 995-1009.

10 Gomez, B. Banbury,K. Marden, M.Trustum,N.A, Peacock, D.H and Hoskin, P.J (2003), “ Gully erosion and sediment production”, TC weraroa strem, New Zealand, Water resources. Vol 39(7) pp1187.

11 Sidorchuk A (2005), “Stochastic component in the gully erosion modeling” , Catena Vol 63 pp299-317.

12 Verstraeten, G. and Poesen, J (1999), “ The nature of small-scale flooding, muddy floods and retention pond sedimentation in central Belgium” Geomorphology 29: 275-292.

13 Boardman J (2001), “ Storms, floods and soil erosion in the South Douns, East Sussex”, Antum and winter 2000-1, Geography Vol 86(4) pp 346-355.

14 Poesen, J, (1993), “ Gully Topology and gully control measures in the European loss belt. In: Farm Land Erosion in Temperate Plains and Hills” (ed. By S. Wicherek), Elsevier, Amsterdam,221-239.

15 Costa, F.M, Bacellar, L. de. Almeido Pwado (2007), “Analysis of the influence of gully erosion in the flow pattern of catchment streams, South eastern Brazil”. Catena Vol 69 pp230-238.

16 Perroy,R.L., Bookhagen, B., Asner, G.P, Chadwick, O.A (2010), “ Comparision of gully erosion estimates using air borne and ground-based LIDAR on Santa Cruz” Island, California.

17 Bryan, R B (2004), “ Gully-scale implication of rill network and confluence process, In: Valentin C, Poesen, J and Young Li (Eds) Gully erosion under global change.” Sichuan Science and Technology Press, Chengdu, China pp 73-95.

18 Nyssen. J, Poesen, J, Moeyersun, J., Luyten, E., Veyret-Picot, M, Deckers, J., Haole, M., and Govers, G (2002), “ Impact of road building on gully erosion risk: a case study from the Northern Ethiopean highland”. Earth surface process and Land forms.

19 Vandekerckhove, L. Muys, B. Poesen J, Deweardo B and Coppe O, (2001), “ A method for dendrochronological assessment of medium term gully erosion rates”. Catena Vol 45(2) pp 123-161.

20 Oostwoud D.J, W and Bryan R. (2001), “ Gully-head erosion processes on semi-arid valley floor in Kenya: a case study into temporal valuation and sediment budgeting” earth surface process and Land forms, Vol (26) pp 911-933.

21 Ries, J.B, and Marzolff L (2003), “ Monitoring of gully erosion in the central Ebro basin by large scale aerial photograph taken from a remotely controlled blimp”. Catena Vol 50 pp 309-328.

22 Vandekerchova, L, Poesen, J, Govers G (2003), “ Medium-term gully headcut retreat in South east Spain determined from aerial photographs and ground measurements” Catena Vol 50 pp329-352.

23 Wu, Y, and Cheng, H (2005), “Monitoring of gully erosion in the loess plateau of China using a Global positioning system”. Catena Vol 63(2-3) pp 154-166.

24 Poesen,J.W., Van Wesemael,B., Bunte,K., Sole-Benet, A, (1998), “Variation of rock fragment cover and size along semi arid hill slopes: a case study from Southeast Spain”. Geomorphology Vol 23. Pp323-335

25 Montgomery, D.R, and W.E. Dietrich, (1992), “Channel initiation and the problem of landscape scale”. Science, V.255, pp826-830.

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