Gully Erosion Control In Nigeria: World Bank / Newmap Perspective on Hydrological Data Analysis

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Abstract- **This paper presents World Bank / NEWMAP hydrological data acquisition method for hydraulic channel provision in mitigation / control of gully erosion in Nigeria. Ogane-Aji gully erosion site in Anyigba, Dekina Local Government Area of Kogi State, Nigeria is a case study of this novelty approach. The gully lies within the geographical coordinates of Latitude 7°31′ 7.9″N and Longitude 7°10′ 21.017″E. Daily rainfall data from thirty – four (34) gauge stations in Nigeria were obtained. Maximum monthly rainfall MMR and the mean annual rainfall MAR were deduced. Others are 24 h, 6 h, 3 h, 1 h, 0.75 h, 0.5 h, 0.25 h and 0.1 h rainfall intensities; their corresponding mean and standard deviations; and frequency factors k_T for different return periods using Gumbels distribution models. The 24 h rainfall intensities extreme value (EV) distribution for the 2-Year, 5-Year, 10-Year, 25-Year, 50-Year and 100-Year return periods of all the flood events in the 34 stations in Nigeria were exported into ArcGIS 10.6.1 software. Local x, y, and z coordinate in decimal degrees of the World Geodetic System 1984 (WGS 84) for the most devasted location at the project site was also inputted in the software. This automatically generated the Ogane-Aji – Dekina gully erosion site adjusted intensities for the respective return periods. These values were inputted into the developed NEWMAP empirical excel template that allows 20% increase in rainfall and account for the extreme climatic variability in the future, to plot the intensity – duration – frequency IDF curve for the project site. The Coefficient of runoff c for the sub-catchments was obtained based on the land-use / vegetation-cover of the watershed. Data acquired from Geodetic survey and orthophoto were used to establish the time of concentration, t_c of the sub-catchments according to Kerby-Kirpich models. With the t_c and IDF curve, the specific sub-catchments rainfall intensities were determined. Rational, Manning's and continuity formulae were used to obtain the sub-catchment discharges for the entire watershed.**

Keywords: **Guage stations, Arc GIS software, Return Period, IDF curve, Global Mapper, Design discharge**

1.0 Introduction

Gully erosion is the erosion process whereby water concentrates in narrow channels and over short periods removes the soil. Gully formation is one of the major disasters in Nigeria. Nigeria has over 3000 active gullies. Most of the gullies are formed due to human activities.

In 2010, Mr. President made a request for assistance to the World Bank Nigeria office, to support the country in addressing severe challenging erosion and its impacts, emerging Land degradation and environmental insecurity, especially in south-eastern Nigeria. That request was responded to.

The Government of Nigeria / Federal Ministry of Environment in concert with the World Bank and its partner agencies: Food and Agricultural Organization of United Nations, Global

Environment Facility, the Special Climate Change Fund, came up with an outfit called "Nigeria Erosion and Watershed Management Project" (NEWMAP) to address the multi-dimensional scale the menace of gully erosion in the south-east, as well as land degradation in the North. The project (NEWMAP) is in line with the growth and resilience goals of Nigeria's Vision 20:2020.
Part of the objectives of NEWMAP, includes to reduce vulnerability to soil erosion in targeted sub-catchments. It is an eight-(8) year innovative, multi-sectoral project, which is a State-led interventions to prevent and reverse land degradation, initially focusing on gully erosion sites that threaten infrastructure and livelihoods in seven States: Abia, Anambra, Cross River, Ebonyi, Edo, Enugu and Imo. The Project has further scaled out to other twelve states in Nigeria including: Delta, Oyo, Sokoto, Gombe, Plateau, Kogi, Kano, Akwa Ibom, Borno, Nasarrawa, Katsina and Niger states.
World bank / Nigeria Erosion and Watershed Management Project (NEWMAP) approach for erosion control in Nigeria have proved successful in the last eight years of their intervention. The approach hinges on accurate geodetic and hydrologic study of gully erosion flood catchment, which encompasses the analysis of the available cumulative historical rainfall data in Nigeria.
Ogane-Aji Gully Erosion project area is located in Ogane-Aji, Anyigba, Dekina Local Government Area of Kogi State, Nigeria. The study area, lies within the geographical coordinates of Latitude 7°31′ 7.9″N and Longitude 7°10′ 21.017″E, North Central geo-political zone also referred to as the middle belt of Nigeria, as shown in Figure 1. It is a semi-urban environment and it is densely populated.

In the 2006 Nigerian census, Ogane-Aji had an estimated population of 260,312. The gully head is located within the semi-urban area of Ogane-Aji, while the tail end is within the rural area of the site and is located in the lowest point discharging runoff directly into the Ofu River. The main gully is located at Dekina road. This gully erosion was caused by the abrupt termination of a major concrete channel receiving flow from the upstream (Plate 1).

2.0 Topographical Survey

Reconnaissance survey of the site was conducted, during which, handheld global positioning system GPS was used to pick geographical coordinate points of different watershed divides, gully head, end -gully, gully fingers, etc., reachable within the study area. These coordinates were inputted into google earth pro application and processed to obtain the entire watershed polygon. The polygon helped in the drone flight planning for detailed aerial photogrammetry and topographical survey. The established polygon area shown in Figure 2, is 2,583,860 km^2.

The aerial survey was carried out using the DJI Phantom 4 pro V.2 UAV and Trimble DGPS field drone equipment. A total of 17 flights were executed at flying altitude of 160 m in relatively good weather condition. 9,965 images were captured having 803,448 densified points. High resolution digital ortho-photos (DOP) shown in Figure 3 was created from the images.

Processing of image data was done on workstation using Agisoft Photoscan photogrammetric software, version 1.4.1 build 5925, on Windows 64 bit operating system. With the DOP, land cover / land use analysis was conducted automatically from the orthophoto, utilizing the ArcGIS software. The DOP was also imported into the Civil 3D and its digitization carried out.
The aerial photogrammetry and terrestrial survey points were combined to produce a layout map. That is, acquired spot heights (x,y,z) (x,y,z) created from the aerial photogrammetry and

210,994 spot heights (x, y and z) at 5 meters interval from the terrestrial survey were imported

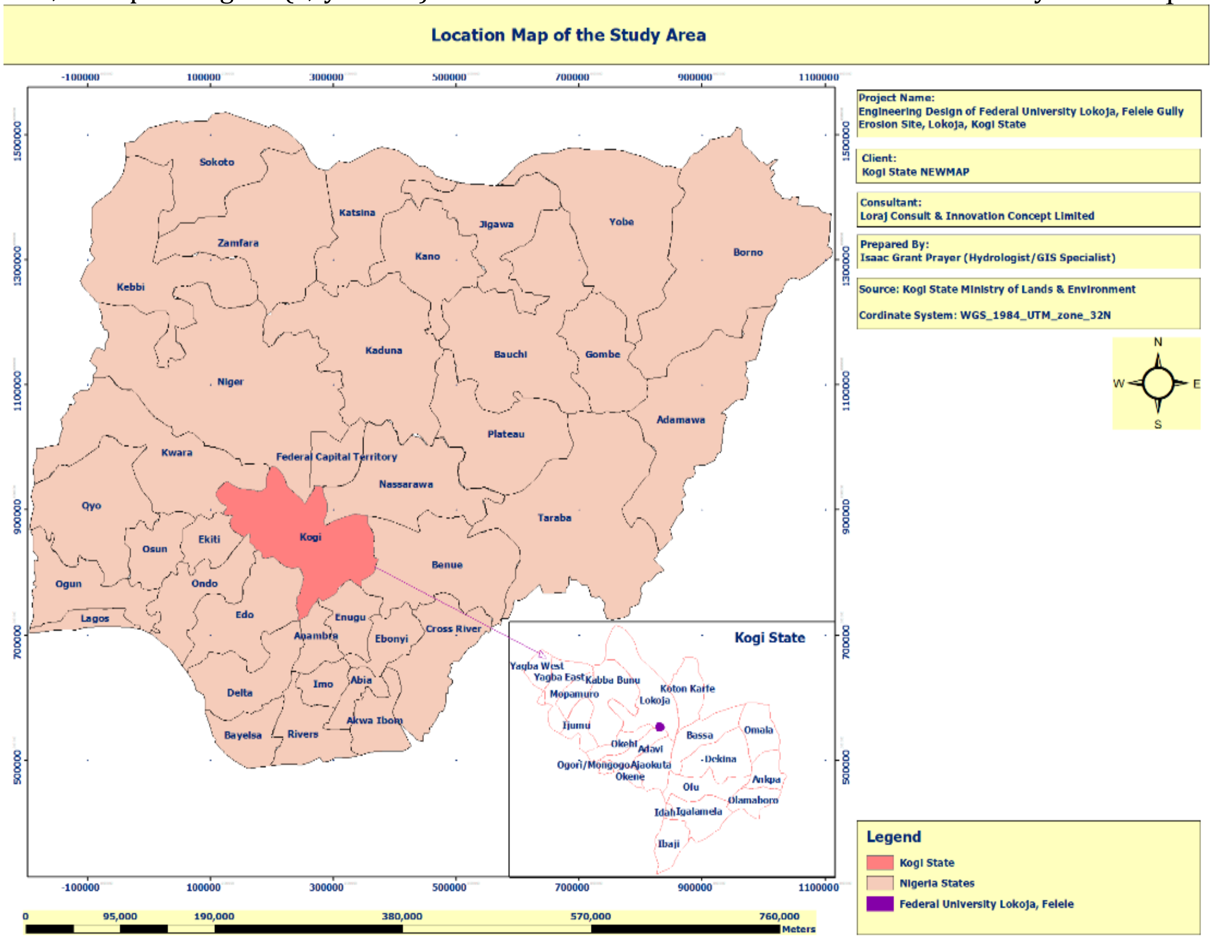


Figure 1: Map of Nigeria showing Kogi State and the study area

into the Global Mapper 20.0 GIS software, as well as the Civil 3D Autodesk Software (2018 version) for the establishment of the digital elevation model (DEM) and contour generation at 1 m interval for the project site. Using the DEM in the Global Mapper, the natural runoff flow path needed for hydrological analysis and design phase of gully remediation structures; while the DEM imported in the Civil 3D is used to produce the sections and profiles of the gullies, gully fingers, roads, etc.

3.0 Hydrological Design Consideration / Analysis and IDF Curve Development

The rainfall records used in the analysis were obtained from 34 rainfall gauge stations in Nigeria from the Nigeria Meteorological Agency (NIMET). The maximum monthly rainfall MMR, mean annual rainfall MAR, which is the yearly 24 hour duration rainfall intensity derived from each year for the gauge stations were determined. Then, they were converted to the hourly rainfall intensity. Gumbels statistical distribution approach was used to obtain the 2-year, 5-year, 10-year, 50-year and 100-year return periods of the rainfall intensity for the various gauge station.

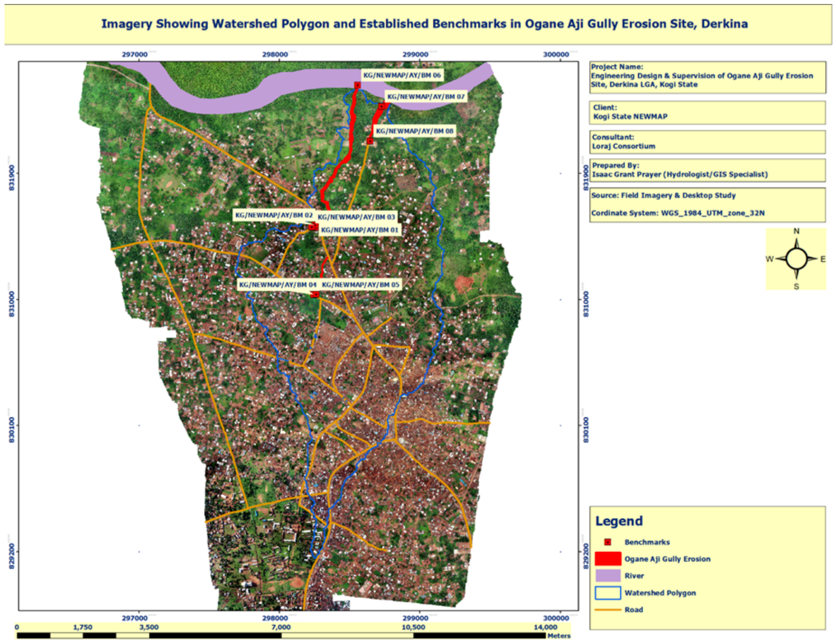


Figure 2: Google earth imagery showing the polygon area of the project site

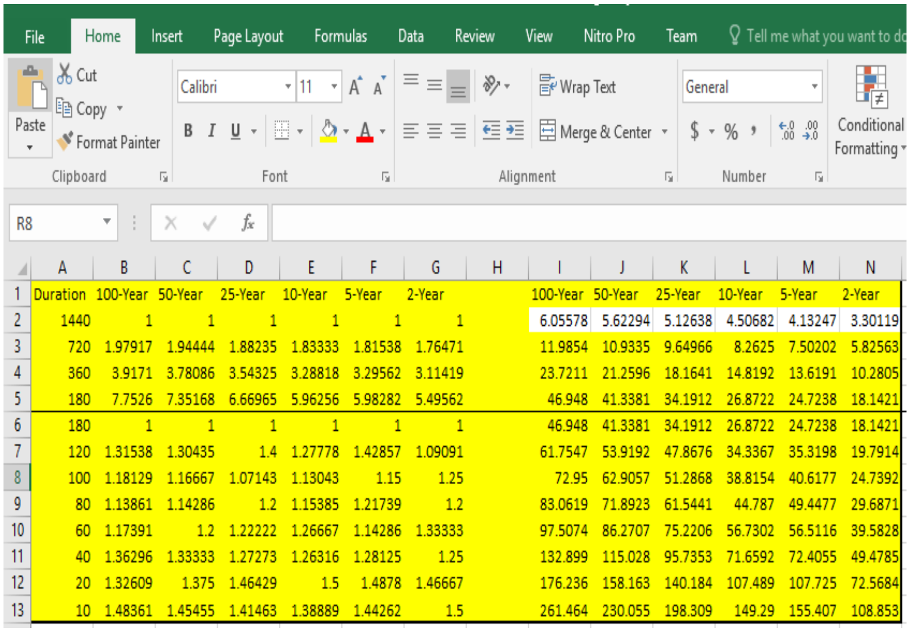
With these data, ArcGIS 10.6.1 software was used to generate a map encompassing the different rainfall locations. The software uses “inverse distance weighting method” for the interpolation of the stations’ values to generate the mean annual rainfall map for Nigeria.

Then, inputting the coordinates of the most devasted point (gully head) at the Ogane-Aji gully erosion site, into this generated ArcGIS map, the site-specific station values for the respective return periods were generated, as shown in Table 1.

Table 1: Ogane-Aji gully site station’s value for 24-hr duration as derived

Return Period (yr)	**100-Year**	**50-Year**	**25-Year**	**10-Year**	**5-Year**	**2-Year**
Station value (mm/hr)	6.05578	5.62294	5.12638	4.50682	4.13247	3.30119

These site-specific station values were inputted into the NEWMAP empirical excel template, as shown in Figure 3 to generate variables with which the IDF Curve (Figure 4) for the project site is plotted. The NEWMAP excel template modifies the rainfall intensity by safety factor of 1.2. This accommodates for extreme climatic variability in the future. Table 2 is the summary of the statistical analysis (2-year, 5-year, 10-year, 50-year and 100-year return periods of the rainfall intensity for the various gauge stations) of the rainfall data obtained from different parts of Nigeria.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Duration	100-Year	50-Year	25-Year	10-Year	5-Year	2-Year		100-Year	50-Year	25-Year	10-Year	5-Year	2-Year
2	1440	1	1	1	1	1	1		6.05578	5.62294	5.12638	4.50682	4.13247	3.30119
3	720	1.97917	1.94444	1.88235	1.83333	1.81538	1.76471		11.9854	10.9335	9.64966	8.2625	7.50202	5.82563
4	360	3.9171	3.78086	3.54325	3.28818	3.29562	3.11419		23.7211	21.2596	18.1641	14.8192	13.6191	10.2805
5	180	7.7526	7.35168	6.66965	5.96256	5.98282	5.49562		46.948	41.3381	34.1912	26.8722	24.7238	18.1421
6	180	1	1	1	1	1	1		46.948	41.3381	34.1912	26.8722	24.7238	18.1421
7	120	1.31538	1.30435	1.4	1.27778	1.42857	1.09091		61.7547	53.9192	47.8676	34.3367	35.3198	19.7914
8	100	1.18129	1.16667	1.07143	1.13043	1.15	1.25		72.95	62.9057	51.2868	38.8154	40.6177	24.7392
9	80	1.13861	1.14286	1.2	1.15385	1.21739	1.2		83.0619	71.8923	61.5441	44.787	49.4477	29.6871
10	60	1.17391	1.2	1.22222	1.26667	1.14286	1.33333		97.5074	86.2707	75.2206	56.7302	56.5116	39.5828
11	40	1.36296	1.33333	1.27273	1.26316	1.28125	1.25		132.899	115.028	95.7353	71.6592	72.4055	49.4785
12	20	1.32609	1.375	1.46429	1.5	1.4878	1.46667		176.236	158.163	140.184	107.489	107.725	72.5684
13	10	1.48361	1.45455	1.41463	1.38889	1.44262	1.5		261.464	230.055	198.309	149.29	155.407	108.853

Figure 3: NEWMAP empirical excel template for generating variables with which the site specific IDF Curve is plotted

Table 2: Summary of analysis of the rainfall data obtained from different parts of Nigeria

No	Location	Longitude (°)	Latitude (°)	Elevation (m)	Period (yrs)	Years (No)	MAR (mm)	24-hr Intensity (mm/hr)					
								2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
1	Abuja	7	9.25	343	1982-2006; 2008 & 2009	27	1,388	4.6	6.4	7.4	8.6	9.5	10.4
2	Akure	5.3	7.28	375	1986-2005; 2008 & 2009	22	1,413	4	5.3	6.2	7.2	8	8.7
3	Bauchi	9.82	10.28	609	1971-2006; 2008 & 2009	38	980	3.5	4.3	4.8	5.4	5.8	6.1
4	Benin	5.1	6.32	77	1986-2004; 2008 & 2009	21	2,195	5.2	6.2	6.8	7.4	7.8	8.1
5	Benin Airport	5.68	6.34		1991-2010	20	2,300	5.3	6.2	6.7	7.4	7.8	8.2
6	Bida	6.02	9.1	144	1971-2009	39	1,061	3.6	5.1	6.3	8	9.4	10.7
7	Calabar	8.35	4.97	61	1970-2010	46	2,730	6	7.5	8.5	9.5	10.3	11
8	Enugu	7.55	6.47	141	1971-1999; 2001-2006; 2008 & 2009	37	1,761	4.6	6	6.8	7.8	8.5	9.2
9	Gusau	6.7	12.17	463	1971-2006 & 2008	37	897	3	4.1	5.1	6.4	7.5	8.5
10	Ibadan	3.9	7.6	227	1971-1980; 1986-2003; 2005; 2008 & 2009	27	1,344	3.6	5.4	7.2	9.6	11.7	13.8
11	Ikeja Lagos	3.33	6.58	39	1981-2010	30	1,438	5	6.8	8.2	9.6	10.6	11.7
12	Ikom	8.7	5.97	119	1972-2005; 2008 & 2009	36	2,247	5	6.4	7.2	8.1	8.8	9.5
13	Ilorin	4.58	8.48	307	1971-2006; 2008 & 2009	38	1,185	4.1	5.2	5.9	6.8	7.4	8
14	Jos	8.85	9.63	1,285	1971-2005; 2008 & 2009	37	1,253	3.1	3.7	4.1	4.6	5	5.4
15	Kaduna	7.45	10.6	645	1971-2006; 2008 & 2009	38	1,136	3.2	4.2	4.8	5.6	6.2	6.7
16	Kano	8.2	12.05	472	1971-2006; 2008 & 2009	38	897	3.6	4.8	5.6	6.8	7.6	8.4
17	Katsina	7.63	13.02	517	1971-2009	39	529	2	3.4	5	5.2	9	11
18	Lokoja	6.73	7.78	62	1971-2018	48	1181	3.3	4.1	4.48	5.1	5.5	5.9
19	Maiduguri	13.08	11.85	353	1986-2005; 2008 & 2009	22	593	3.2	4.2	4.8	5.5	6.1	6.7

20	Makurdi	8.53	7.73	112	1971-1977; 1979-2005; 2008 & 2009	36	1,145	4.1	5.1	5.7	6.4	7	7.5
21	Minna	6.53	9.62	256	1971-2006; 2008 & 2009	38	1,199	3.8	4.7	5.1	5.6	6	6.4
22	Ogoja	8.8	6.67	117	1976-2006; 2008 & 2009	33	1,805	4.3	5.7	6.6	7.7	8.6	9.4
23	Onitsha	6.78	6.15		1986-2005	20	1,930	5.2	6.3	7	7.8	8.3	8.9
24	Owerri	7	5.48	19	1974-2006; 2008 & 2009	35	2,355	5.4	7.2	7.9	8.9	9.6	10.3
25	Port Harcourt	7.02	4.85	19	1971-2009	39	2,243	5.4	6.8	7.6	8.5	9.2	9.8
26	Sokoto	5.25	13.02	350	1971-2006; 2008 & 2009	38	622	3.1	4.2	4.9	5.8	6.5	7.1
27	Uyo	7.92	5.5	38	1981-2006; 2008 & 2009	28	2,191	4.9	5.9	6.4	7	7.4	7.8
28	Warri	5.73	5.52	6	1986-2005; 2008; 2009	22	2,746	6.1	7.6	8.4	9.5	10.2	10.8
29	Yelwa	4.75	10.88	244	1971-2006; 2008 & 2009	38	936	3.6	4.4	4.9	5.3	5.6	5.9
30	Zaria	7.68	11.1	110	1971-2006; 2008 & 2009	38	1,009	3.3	4	4.4	4.8	5.1	5.4
31	Anambra-Imo RBDA	7.19	5.66	81	1976-2001	26	2,270	6.2	7.4	8	8.6	9.1	9.6
32	Upper Benue RBDA, Dadin Kowa	10.05	11.09		2001-2017	17	913	3.3	4.15	4.6	5.25	5.65	5.8
33	Lafia	8.53	8.55		1987-2017	31	1300	3.5	5.2	5.85	6.8	7.4	7.6
34	Awka	7.07	6.2		1998-2018	21		3.9	5.58	6.7	8.1	8.9	9.3

where: MAR - Mean Annual Rainfall; RBDA - River Basin Development Authority

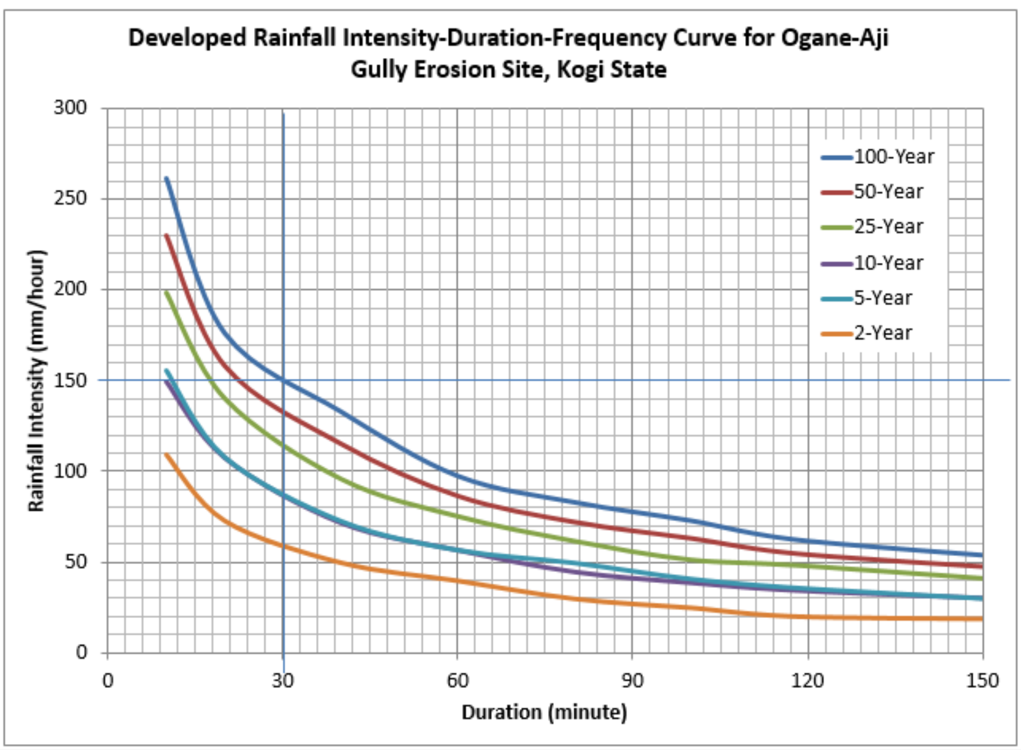


Figure 4: Developed rainfall intensity-duration-frequency (IDF) curve for Ogane-Aji gully site

3.0 Estimation of Runoff Coefficient

The watershed features of the project area, land use map was automatically generated with the aid of ArcGIS 10.6.1 software using the Ortho-photo from the photogrammetric survey map of the project site. The characteristic features of the land use in terms of vegetation cover, bare lands, built-up areas etc., are presented in Table 3. Using Equation 1, according to the Highway-Manual (2013), the runoff coefficient c of the project site was calculated.

$$\text{Runoff coefficient, c} = \frac{\sum_{i=1}^{n} A_i c_i}{\sum_{i=1}^{n} A_i} \qquad (1)$$

where A_i are the surface areas in hectare for the various land use types of the project area, and c_i are the runoff coefficients for the various land use types.

Table 3: Defined land use of the project area

n	Land use	Area Covered, A_i (ha)	% Area Covered	Land use factor, c_i	Weighted Run-off Coefficient	Computed Run-off Coefficient, c
	Col. 1	**Col. 2**	**Col. 3**	**Col. 4**	**Col. 5 = Col. 2 × Col. 4**	**Col. 6**
1	Bare land	78.146	30.219	0.30	23.444	$\frac{104.617}{258.600} = 0.41$
2	Built-up areas	90.176	34.871	0.75	67.632	
3	Vegetation	90.278	34.910	0.15	13.541	
4	Water bodies	0.000	0.000	0.00	0.000	
	Total	258.600	100		104.617	

From the computation in Table 3, the runoff coefficient c of project site is 0.41.

4.0 Sub-Catchment Delineation, Time of Concentration and Discharge Computation

The catchment area was delineated into sub-catchments using the developed DEM in Figure 5 of the Global Mapper 20.0 GIS software. The areas of sub-watersheds were defined as SC1, SC2, SC3, SC4, etc.

The concept of the time of concentration of a catchment is the basis for estimating an appropriate time scale for rainfall duration in the Rational method for estimating peak flows. International Glossary of Hydrology (1974); Johansson (1984) defined it as the period of time required for storm runoff to flow from the most remote part of a drainage basin to the outlet.

The Kerby-Kirpich model for the estimation of sub-watershed total time of concentration given as in Equation 2 was used (Roussel, et. al, 2005).

$$\text{The total time of concentration } T_c = T_{ov} + T_{ch} \qquad (2)$$

where T_{ov} (mins) is the time of overland flow in minutes, T_{ch} = Time of concentration for channel flow (mins).

The Kerby equation (Kerby, 1959) determines the time of concentration for the overland flow. It has the form:

$$T_{ov} = K_{kb}(L_{ov} \times N)^{0.467} \times S_{ov}{}^{-0.235} \quad (3)$$

where K_{kb}=1.44, is the Kerby unit conversion coefficient; L_{ov} = overland flow length in meters; N = Dimensionless retardance coefficient = 0.3; S_{ov} = Dimensionless slope of terrain conveying the overland flow (%) expressed as:

$$S_{ov} = \frac{\text{subwatershed upstream elevation } (H_1) - \text{subwatershed downstream elevation} (H_2)}{\text{subwatershed overland flow length } (L_{OV})}$$

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(4)

The Kirpich equation for time of channel flow T_{ch} (mins) has the form (Kirpich, 1940):

$$T_{ch} = K_{kp} L_{ch}{}^{0.77} \times S_{ch}{}^{0.385} \quad (5)$$

where K_{kp}=0.0195, is the Kirpich unit conversion coefficient; L_{ch} is channel flow length (m); and S_{ch} is the dimensionless channel slope expressed as:

$$S_{ch} = \frac{\text{subwatershed upstream elevation } (H_2) - \text{subwatershed downstream elevation} (H_3)}{\text{subwatershed channel flow length } (L_{ch})}$$

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(6)

The sub-catchment (or sub-watershed) upstream and downstream elevations, channel flow length, channel flow length and overland flow length were determined using the Digital Elevation Model (DEM) aided by the Global Mapper 20.0 GIS software.

Rational formular (Equation 4) was used for discharge computation in each sub-watershed:

$$Q = \frac{CIA}{Z} \quad (7)$$

where Q (m^3/s) is the sub-watershed discharge for the respective return period; A (ha) is the sub-catchment area; I (mm/hr) is the sub-catchment (or sub-watershed) rainfall intensity for the respective return period and c is the runoff coefficient for the entire water – shed of the project site. Z is conversion coefficient, which is 360.

The rainfall intensities, II (mm/hr) for the sub-catchments for the respective return periods were obtained from IDF curve (Figures 4) for the corresponding time of concentration t_c, while the area (ha) of each sub-watershed (Table 4) was obtained from the DEM with the aid Global Mapper 20.0 GIS software.

Table 4, shows the summary of design discharge computation for the sub-watershed areas for 25, 50 and 100-year return periods.

The obtained discharges for the different return periods were integrated into the hydraulics design phase for sizing of hydraulic structures to safely convey flow to the flood plain (Ofu

Stream). For all structures lined along the gully, a 100-year return period discharge was used, 25-year return period discharge was used for channels lined along roads; 50-year return period used for culverts and man-holes along the roads. The gully structures included chute channel, stilling basin, transition channel, gabion check dams, gabion channel, rip-rap, reno mattress, etc.

HEC 14 in Thompson & Kilgore (2006) was used as design standards for the hydraulic design of energy dissipators for culverts and channels. it presents among other formulas, the Manning's and Continuity equations given in Equations (8) and (9):

$$V = \frac{1}{n} R^{2/3} S^{1/2} \tag{8}$$

$$Q = AV \tag{9}$$

where V is the velocity, m/s, n is the Manning's roughness coefficient R is the hydraulic radius = A/P (m), P is the wetted perimeter (m), S is the slope of the energy grade line (m/m) (note: for steady uniform flow, S = channel slope, (m/m); Q is the discharge (m^3/s), A is the cross-sectional area of flow (m^2), V is the mean cross-sectional velocity (m/s) (which is perpendicular to the cross section).

With the value of Q obtained from Equation (7) and velocity v obtained from Equation (8), the cross- sectional area of the channel is obtained using Equation (9).

5.0 Conclusions

The analytical approach of the World bank / NEWMAP in hydrological data acquisition for hydraulic structures provision in mitigating / controlling gully erosions in Nigeria have been successfully discussed. The novel approach has been applied in over 40 erosions sites in Nigeria; and the success stories are unprecedented.

The approach is initiated from the onset by recognizance survey of the gully area and then to aerial photogrammetry and terrestrial surveys. Survey spot heights (x,y,z), Google earth Pro imagery showing the polygon area of the project site, DEM and orthophotos are the acquired data. Also acquired data is the historic daily rainfall data from NIMET for the 34 gauge stations in Nigeria.

Equipment for some of the data acquisition includes hand-held GPS, field drone equipment and field survey equipment (which included total station). Agisoft Photoscan photogrammetric software, version 1.4.1 build 5925, on Windows 64 bit operating system was used for drone data processing into spot heights and orthophotos; ArcGIS 10.6.1 software was used to generate map encompassing the different rainfall locations; Global Mapper 20.0 GIS software was used for the establishment of the digital elevation model (DEM), catchment delineations, and contour generation respectively, Civil 3D Autodesk Software (2018 version) was used also for the establishment of the digital elevation model (DEM), sections and profiles of gullies and roads; and contour generation. Others are NEWMAP empirical excel template, Kerby-Kirpich models, Rational, Manning's and continuity formulae, Gumbel statistical analysis model, etc.

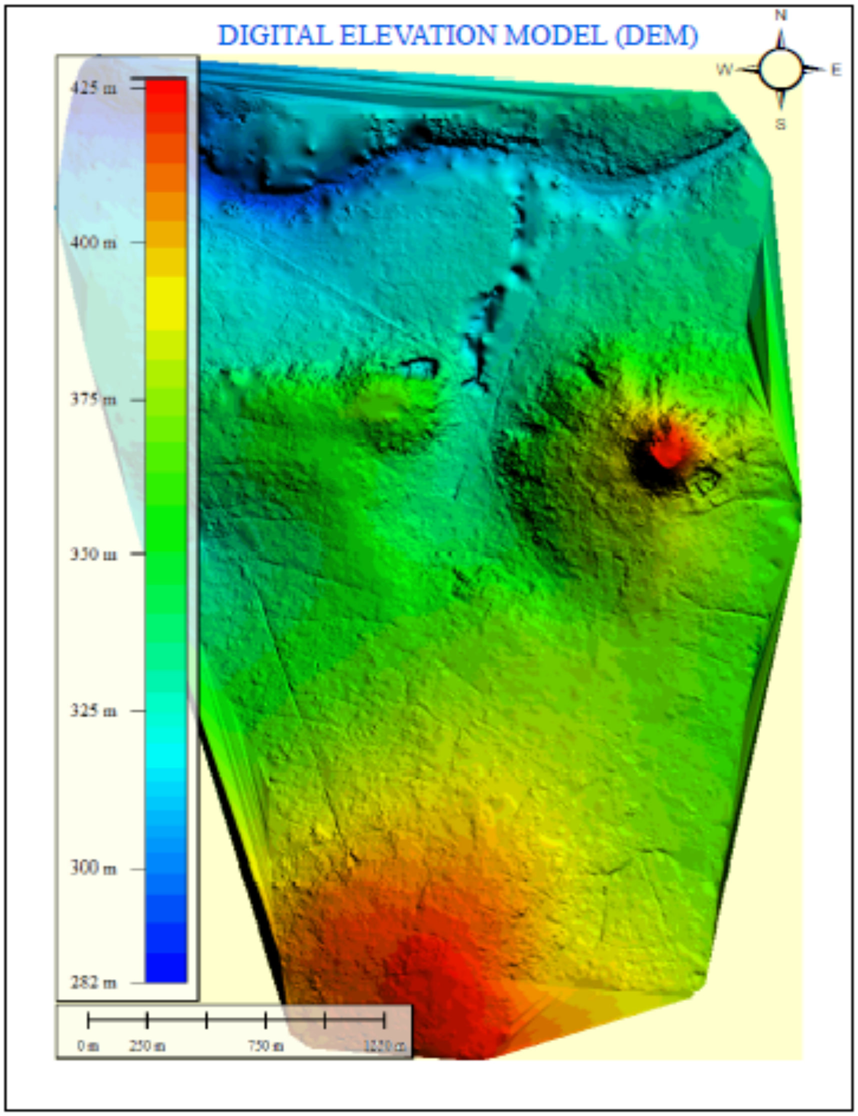

Figure 5: Digital elevation model (DEM) of the project site

Table 4: Summary of design discharge computation sheet

OGANE AJI GULLY EROSION REMEDIAL WORK, ANYIGBA, KOGI STATE, NIGERIA																	
DESIGN DISCHARGE ESTIMATION SHEET																	
Sub-catchment	Area	L_{ov}	L_{ch}	H1	H2	H3	Sov	Sch	Tov	Tch	Tc	C	I (mm/hr)		Q (m3/s)		
	(ha)	(m)	(m)	(m)	(m)	(m)							25 year	50 year	100 year	25 year	50 year	100 year
SC 1	12.188	52.554	668.410	325.425	322.249	313.166	0.060	0.014	10.095	15.277	25.372	**0.41**	**138**	**142**	**160**	**1.92**	**1.97**	**2.22**
SC 2	14.750	105.600	1374.000	425.127	420.278	313.816	0.046	0.077	14.916	13.613	28.529	**0.41**	**117**	**135**	**152**	**1.97**	**2.27**	**2.55**
SC 3A	10.307	103.160	587.520	367.889	352.083	321.926	0.153	0.051	11.116	8.293	19.408	**0.41**	**145**	**164**	**184**	**1.70**	**1.93**	**2.16**
SC 3B	5.4	84.842	492.520	376.566	365.728	324.980	0.128	0.083	10.589	6.024	16.613	**0.41**	**155**	**175**	**195**	**0.95**	**1.08**	**1.20**
SC 4A	9.553	90.499	399.760	340.902	330.470	315.690	0.115	0.037	11.180	6.995	18.175	**0.41**	**150**	**165**	**185**	**1.63**	**1.80**	**2.01**
SC 4B	10.322	89.029	702.600	422.185	399.375	327.647	0.256	0.102	9.196	7.304	16.499	**0.41**	**155**	**175**	**195**	**1.82**	**2.06**	**2.29**
SC 5	7.487	89.029	525.960	422.257	399.346	329.179	0.257	0.133	9.186	5.272	14.458	**0.41**	**165**	**190**	**210**	**1.41**	**1.62**	**1.79**
SC 6A	0.604	15.190	121.870	331.540	322.799	317.907	0.575	0.040	3.329	2.715	6.045	**0.41**	**200**	**230**	**260**	**0.14**	**0.16**	**0.18**
SC 6B	2.659	227.230	333.910	333.189	329.907	319.155	0.014	0.032	27.998	6.422	34.420	**0.41**	**108**	**125**	**145**	**0.33**	**0.38**	**0.44**
SC 6C	0.564	72.536	58.202	351.355	336.771	331.550	0.201	0.090	8.847	1.128	9.974	**0.41**	**190**	**230**	**262**	**0.12**	**0.15**	**0.17**
SC 6D	2.320	55.536	188.550	356.053	350.151	330.427	0.106	0.105	9.072	2.628	11.699	**0.41**	**180**	**215**	**245**	**0.48**	**0.57**	**0.65**
SC 6E	1.944	55.334	167.240	351.608	343.423	331.066	0.148	0.074	8.379	2.739	11.118	**0.41**	**190**	**220**	**250**	**0.42**	**0.49**	**0.55**
SC 6F	4.868	189.380	296.060	356.169	336.321	332.837	0.105	0.012	16.140	8.625	24.765	**0.41**	**138**	**142**	**160**	**0.77**	**0.79**	**0.89**
SC 6G	3.733	81.616	120.250	362.913	361.355	356.133	0.019	0.043	16.255	2.607	18.862	**0.41**	**145**	**164**	**184**	**0.62**	**0.70**	**0.78**
SC 7A	8.104	36.451	662.520	397.031	392.834	329.252	0.115	0.096	7.313	7.149	14.462	**0.41**	**165**	**190**	**210**	**1.52**	**1.75**	**1.94**
SC 7B	2.858	90.130	323.520	373.898	365.024	333.189	0.098	0.098	11.579	4.077	15.657	**0.41**	**155**	**175**	**195**	**0.50**	**0.57**	**0.63**
SC 7C	4.148	91.940	198.620	388.576	334.898	332.989	0.584	0.010	7.692	6.857	14.549	**0.41**	**165**	**190**	**210**	**0.78**	**0.90**	**0.99**

SC 8A	6.068	137.750	495.580	493.847	385.048	339.207	0.790	0.092	8.654	5.798	14.452	**0.41**	**165**	**190**	**210**	**1.14**	**1.31**	**1.45**
SC 8B	11.163	109.360	594.370	424.167	393.413	351.303	1.000	0.071	7.351	7.391	14.741	**0.41**	**165**	**190**	**210**	**2.10**	**2.42**	**2.67**
SC 8	13.493	262.010	811.410	424.604	379.994	333.824	0.000	0.057	0.000	10.219	10.219	**0.41**	**200**	**230**	**262**	**3.07**	**3.53**	**4.03**
SC 9A	3.460	52.236	176.150	361.943	359.889	347.907	0.039	0.068	11.136	2.943	14.079	**0.41**	**170**	**195**	**215**	**0.67**	**0.77**	**0.85**
SC 9B	2.532	221.250	157.900	346.126	336.695	333.286	0.043	0.022	21.442	4.208	25.650	**0.41**	**125**	**140**	**160**	**0.36**	**0.40**	**0.46**
SC 9C	24.45	201.300	578.190	357.328	354.964	336.921	0.012	0.031	27.776	9.921	37.697	**0.41**	**100**	**118**	**138**	**2.78**	**3.29**	**3.84**
SC 10	14.399	117.390	725.870	372.323	368.687	336.417	0.031	0.044	17.191	10.314	27.506	**0.41**	**120**	**135**	**155**	**1.97**	**2.21**	**2.54**
SC 11	16.693	193.660	697.820	425.943	385.158	354.064	0.211	0.045	13.842	9.997	23.840	**0.41**	**130**	**145**	**165**	**2.47**	**2.76**	**3.14**
SC 12	9.815	109.550	419.050	375.096	372.875	357.308	0.020	0.037	18.389	7.240	25.629	**0.41**	**125**	**140**	**160**	**1.40**	**1.56**	**1.79**
SC 13	16.413	89.006	1232.000	400.482	396.428	358.098	0.046	0.031	13.798	17.784	31.582	**0.41**	**110**	**130**	**150**	**2.06**	**2.43**	**2.80**
SC 14	8.19	124.590	585.870	390.310	384.567	370.304	0.046	0.024	16.099	11.027	27.127	**0.41**	**120**	**135**	**155**	**1.12**	**1.26**	**1.45**
SC 15	12.693	87.489	434.650	376.272	373.937	357.341	0.027	0.038	15.520	7.369	22.888	**0.41**	**132**	**150**	**165**	**1.91**	**2.17**	**2.39**
SC 16	17.283	100.160	1211.000	417.439	411.635	367.28	0.058	0.037	13.778	16.481	30.259	**0.41**	**115**	**132**	**152**	**2.26**	**2.60**	**2.99**
TOTAL	**258.476**										**596.303**					**40.35**	**45.83**	**51.80**

Results obtained from the hydrological study for use during the hydraulic structures provision in gully erosion sites included IDF curve for the project site, coefficient of runoff c for the sub-catchments obtained based on the land-use / vegetation-cover of the watershed, sub-catchment areas in hectare, sub-catchment discharges for the different return periods for the entire water-shed.

Other recommendations of World bank /NEWMAP empirical approach is for all structures lined along gullies to be designed for a 100-year return period discharge; 50-year return period recommendation for concrete culverts and man-holes along the roads; and 25-year return period discharge for channels lined along roads. Gully structures herein, included chute channel, stilling basin, transition channel, gabion check dams, gabion channel, rip-rap, reno mattress, etc.

References

El-Swaify, S. A., Dangler, E. W., & Armstrong, C. L. (1982). *Soil Erosion by Water in the Tropics.* University of Hawaii / HITAHRCTAHR Research and Extension Series 24.

Highway-Manual. (2013). *Part 1 - Design, Volume 4 - Drainage Design*. Federal Ministry of Works.

Hudson, N. W. (1995). *Soil Conservation* (3rd ed.). New York: Iowa State University Press.

Johansson, I. (1984). *Nordic Glossary of Hydrology*. Stockholm: Almqvist and Wiksell International.

Kerby, W. S. (1959). Time of Concentration for overland flow. *Civil Engineering*, 29.

Kirpich, Z. P. (1940). Time of concentration from small agricultural watersheds. *Civil Engineering*, 10(6), 362.

Morgan, R. P. (1986). *Soil Erosion and Conservation*. Harlow: Longman Group.

Roussel, M. C., Thompson, D. B., Fang, X., Cleveland, T. G., & and Garcia, C. A. (2005). *Time-parameter estimation for applicable Texas watersheds.* Texas: Texas Department of Transportation and the Federal Highway Administration, Department of Civil Engineering College of Engineering Lamar University Beaumont.

Schwab, G. O., Fangmeier, D. D., Elliot, W. J., & Frevert, R. K. (1981). *Soil and Water Conservation Engineering* (4th ed.). Chichester: John Wiley and Sons.

Thompson, P. T., & Kilgore, R. T. (2006). *Hydraulic Design of Energy Dissipators for Culverts and Channels* - Hydraulic Engineering Circular No. 14, Third Edition (Vols. Report No. FHWA-NHI-06-086 HEC 14). Virginia: National Highway Institute.

WMO. (1974). *International Glossary of Hydrology* - Report No. 385. Geneva.