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# Design of an Open Channel for Flood and Gully Erosion Control: A Case Study of Amakohia-Uratta in Imo State, Nigeria

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Authors MIC and ENRE designed the study and wrote the first draft of the manuscript, and the design protocols. Authors NRN and VCO managed the literature searches, discussion of the study and final editing. All authors read and approved the final manuscript.*

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## ABSTRACT

Flooding and gully erosion constitute a major problem associated with urbanization in the underlying watershed of an area. In this study, a trapezoidal channel hydraulic system was designed for flood and erosion control in Amakohia-Uratta, Owerri North, Imo state, Nigeria. A topographical survey of the study area was done. The result shows that the maximum elevation is 81.03 m, the minimum elevation is 78.21 m, the bed slope of the area is 0.02%, the area of the watershed is 1.061ha, and the maximum length of flow is 140m. Also, the results from the hydrological analysis using the rational method indicated that the rainfall intensity of 10 years

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duration was 105.3 mm/h with a peak discharge $Q_p$ of 0.17 $m^3/s$, causing the flood and erosion, while the channel design capacity (discharge) $Q_d$ is 0.17 $m^3/s$, calculated using trial and error methods. Finally, design parameters for the trapezoidal open channel were calculated. The result indicated that the channel width is 0.3 m, the design depth is 0.5 m, the freeboard is 0.1m, the total channel depth is 0.6m, the top width of the channel is 2.1 m and the side slope is 1.5:1. In all the design is appropriate to capture, carry and discharge the peak runoff to *Nworie* River a natural outlet.

*Keywords: Erosion; rainfall; hydraulic structure; topography; discharge.*

## 1. INTRODUCTION

The United Nations Development Programme in 1994 identified the causes of erosion and flood in Imo state as a result of intensive rainfall and resultant concentrated runoffs. If the intensity of rainfall exceeds the holding capacity of the soil, there will be an increase in surface runoff which can cause massive gully erosion. A major problem associated with urbanization is the increase in the volume of stormwater and rainfall generated within the underlying watershed in that particular urban area. The amount of water generated in emerging urban areas usually increases due to the available natural land being covered by buildings, such as residential, and commercial, roadways, concrete pavements, and parking lots, and covered land surface impervious for water infiltration and deep percolation. The large volumes of water generated from these activities need to be channelled to an appropriate and efficient outlet to prevent damage to buildings and properties, loss of lives, and damage to culverts and other drainage structures. There is also a need to decrease the outbreak of waterborne diseases occasioned by the increase in flood water.

An open channel is a structural passage in which liquid flows with its upper surface exposed to the atmosphere [1]. Open channel flow occurs in natural water courses, channels, diversions, and culverts. Gravity is the major energy source or factor that causes the movement of the water body as it flows downhill. The target is to determine the storm peak discharge from the given watershed and provide a control structure for the control of flooding and erosion to prevent environmental degradation.

Flood is a condition by which a dry land is covered with water for a given period, which may be as a result of rainfall and runoff, an overflow from the streams, rivers and seas underground seepages or discharges from domestic pipes and reservoirs [2]. Flood problems are common in low-lying areas and flood plains of the world [3]. Generally, floods are caused due to the existence of poor drainage facilities, blocked drains, improper road construction, and poor maintenance, culture and the various activities of humans on flood plains. A situation where there is no provision of drains to convey flood waters to suitable outlets induces flooding or the drainage facilities are poorly designed and installed. In many urban areas, some of the existing drains on the roads have been turned to refuse dumps. This indiscriminate dumping of refuse and obstructive materials has in no small measure contributed to the flooding of the roads and adjourning areas [4].

Flooding in our environment affects the economy, lives and property of the area, causing some rural communities to be cut off from the rest of the urban areas making transportation of farm products to areas they are highly needed almost impossible. Also, as a result of the perennial flooding of our highways, potholes are covered with water and motorist experience difficulties moving from one point to another. Flooding submerges building infrastructures displaces homes, covers farmlands, and weakens the base and sub-base of roads leading to failures. Erosion is the wearing away of the earth’s surface by agents of erosion such as water and wind under the force of gravity. The removal of soil particles involves three processes detachment, transportation and deposition [5]. Gully erosion is the movement of soil particles detached/eroded in a defined line or pattern thereby creating a well-defined V or U–shaped channel by the action of runoff or overland flow [5]. It occurs as a result of rainfall events which generate runoff that moves along the channel enlarging the channel's depth and width. Gully erosion is common in the rainforest region of Nigeria [6]. It is more destructive than the other control [7]. Gullies are permanently steep–sided and are characterised by head cuts and various steps along their courses [5].

UNDP [4] reported that approximately forty per cent (40%) of world agricultural land is adversely degraded. There are also reports of loss of lives in some parts of south-eastern Nigeria due to gully erosion [8]. Gully erosion affects food production in such areas as well as the destruction of properties, landslides, a threat to lives and hunger due to the removal of the soil's nutrients [9]. There are various ways to mitigate flood and erosion-related problems. One of the ways to address this is by providing roadsides drains, and culverts of adequate capacity to evacuate the excess water to the safest outlets. The channels should be well-designed to carry the peak runoffs generated from a given catchment area. These open channels should be adequately maintained to check floods in the environment. Indiscriminate dumping of refuse along the roads tends to obstruct the free flow of runoff which encourages flooding of roads and adjoining areas, this should be avoided. Adoption of proper refuse disposal practices and prevention of the blockage of open drains should be encouraged. Amakohia-Uratta is generally flooded during the rainy season (April – October) each year giving rise to the gully erosion phenomenon. This flooding is a result of excessive and constant rainfall in the area. This rainfall and flooding must find an outlet for safe discharge since rainfall is a natural event which cannot be controlled. The runoff or floods and gully erosion arising from the natural rainfall have subjected the community to perennial flooding and washing away of farmlands, residential and commercial buildings as well as the popular *Orie-Onumiri* market.

This colossal loss of property and lives within this community has prompted this research work, which aimed at designing a hydraulically and environmentally safe and efficient open channel structure to capture, collect and discharge the maximum/peak runoffs causing flooding and gully erosion in the study area to a nearby river (*Nworie* River), to prevent and control the destruction of lives and property and the outbreak of water-borne diseases in Amakohia-Uratta community and its environs. The objective of this study focuses on designing an open-channel hydraulic structure for flood and gully erosion checks. This, however, will specifically involve: conducting a topographical survey of the study area, obtaining the rainfall data of the area from the Nigeria Meteorological Agency (NIMET), using the rainfall intensity formula to determine the maximum rainfall intensity, with Manning's formula to estimate the permissible velocity of the flow and the rational technique in calculating peak discharge causing the flood/erosion and finally with the assumed depth and width of the channel through trial and error approach and using trapezoidal open channel design equations to estimate the channel design flow, which must be greater than the flow causing the flood/erosion.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

Amakohia-Uratta (5°30' to 5°34'N and 7°00' to 7°10'E) in Owerri North local government area of Imo State. It has a distance of about 3km from Owerri the state capital. The busy Owerri-Orlu Federal Road divided the community into two with people living at both flanges of the road. The residents comprise both natives and non-natives cohabitating peacefully. Amakohia-Uratta has a land mass of about 2100 $km^2$ [2].

### 2.2 Climatology

Amakohia Urata lies within the rainforest belt of Nigeria with an annual rainfall depth of about 2500mm [10]. The peak rainfall event occurs in July and September every year with 100 rainfall days and events occurring in the month of January to December annually. The adequacy in rainfall events supports rain-fed agriculture and root crops are predominantly produced.

### 2.3 Geology

The area is underlaid by the sedimentary sequence of the Benin Formation and the underlying Ogwasuiukwu-asaba Formation. The formation is made up of friable strands of the coastal plain sands and minor interactions of clay, the sand units are mainly coarse-grained, pebble fine-grained sandy soils [11].

### 2.4 Soils

The soils are mainly sandy soils derived from the consolidated ferritic soils, these soils have less clay content hence they are less cohesive, they are mainly the coastal plain sands with escarpment dominated by the ferritic particles [11]. The soil belongs to the deep, porous, weak structured and light sandy clay texture in the subsoil with high porosity and higher percolation rates.

## 2.5 Topography

The topography of Amakohia-Uratta is undulating with some sections steep. The slope area runs with termination at the natural outlet, the *Nworie* River, the overland flow velocities are usually greater on these steep slopes than in the areas with flat terrains. The overland discharge increases along the length of the slope as well as the area of the watershed contributing to the runoffs. Most of the areas affected by floods have undulating terrains that encourage the rapid movement of the floods/runoffs until they are finally discharged into the *Nworie* River.

## 2.6 Vegetation

The vegetation is that of typical rainforest vegetation with trees appearing in three layers (lower, medium, and upper layers) the leaves are usually evergreen due to an adequate supply of rainfall and higher temperatures. Many parts of the watershed have been cleared due to the physical developments particularly buildings for both residential and commercial purposes.

## 2.7 Population and Occupation

Amakohia-Uratta is densely populated with about 5,402 people according to the national population census of 2006 the majority of the populace are civil /public servants the number of farmers in the community is low as most of the land has been used for the construction of residential apartments, the farmers are mainly the indigenes who farm on the remaining portion of lands producing cassava, yams, vegetable coco-yams and maize. Most of the good requirements of this community are obtained from the *Orie-Onumiri* market.

## 2.8 Topographical Survey of the Study Area

This was carried out to determine the extent of the catchment area, gully profile, cross-sectional area of the gully and main slope of the gully this was obtained using Equation (1) and Table 1.

$$S = \frac{H_u - H_d}{L_{max}} \quad (1)$$

Where S is the gully slope, $H_u$ is the upstream elevation (m), $H_u$ is the downstream elevation (m), and $L_{max}$ is the maximum length of flow (m).

Therefore, $\frac{81.03-78.21}{140} = 0.02$.

## 2.9 Hydrological Analysis

The hydrological characteristics of the area were used to determine the mean annual rainfall, the runoff characteristics and the time of concentration of the flow.

### 2.9.1 Rainfall analysis

The rainfall intensity for the duration of ten years was obtained from the Nigerian Metrological Agency (NIMET) Imo Airport Unit. Rainfall intensity was calculated using Eq. (2). The maximum rainfall amount during 10 years return period of 630.2 mm was used for the calculation.

$$I = \frac{P}{T} \quad (2)$$

Where, I = rainfall intensity (mm/h), P = maximum rainfall amount (mm), and T = average rainfall duration (6 h).

### 2.9.2 Time of concentration (Tc)

This is the time required to move surface runoff from the remotest point of the watershed to its outlet. In the rational method, the rainfall duration must at least be equal to the time of concentration for producing peak runoff (rate) from the watershed. The equation for calculating Tc was developed by [12] and is given in Eq. (3).

$$T_C = 0.0195 L^{0.77} S^{-0.385} \quad (3)$$

Where, Tc = Time of concentration, L = Maximum length of flow path or channel reach (140 m from Table 1), S = gully slope (channel reach) from Eq. (1).

## 2.10 Estimation of Runoff Rate using a Rational Technique

Hydrologic design involves the estimation of runoff rate which a channel structure can safely handle. In this study area, the runoff rate (period of highest rain) was calculated for a ten-year return period. The design of runoff rate computation adopted is the rational method.

**Table 1. Elevation differences of the gully length**

| **Chainage** | 0 + 000 | 0 + 020 | 0 + 040 | 0 + 060 | 0 + 080 | 0 + 100 | 0 + 120 | 0 + 140 |
|---|---|---|---|---|---|---|---|---|
| **Off-set** | 81.03 | 80.60 | 80.12 | 79.68 | 79.22 | 78.82 | 78.52 | 78.21 |

#### 2.10.1 Runoff coefficient

The runoff coefficient (C) is the fraction of rainfall converting into surface runoff. It is defined as the ratio of runoff to rainfall. It is a dimensionless property that depends on the land use and soil types. The value of C used in this design is 0.55 [5].

#### 2.10.2 Area of the catchment

The total area of the catchment was calculated using the Simpson's rule for eight strips of the gully profile from Table 1, Eq. (4) in hectares (ha):

$$A = \frac{D}{3}[\, Q_1 + Q_L + 2(Q_3 + Q_5 + Q_7) + 4(Q_2 + Q_4 + Q_6)] \qquad (4)$$

Where, $Q_1$ = first elevation (m), $Q_3 + Q_5 + Q_7$ = sum of even elevations, $Q_L$ = last elevation, A = area of the catchment in hectares (ha), D = chainage interval (m).

### 2.11 Peak Runoff Estimation

The peak runoff is the maximum runoff to be used as the carrying capacity for the design of a given flood/erosion control structure that must carry the runoff without any form of silting or scouring of the channel to the safe outlet (*Nworie* River).

The basic equation for computing design runoff by rational method [5] is given in Eq. (5):

$$Q_P = \frac{CIA}{360} \qquad (5)$$

Where, $Q_P$ =peak Runoff (m$^3$/s), C = Coefficient of runoff, I = Rainfall Intensity (mm/hr), A = Catchment area (ha).

### 2.12 Shape of the Open Channel

The trapezoidal open channel was selected for this design since it can stand and resist flood and erosion problems of the catchment area.

### 2.13 Design Considerations and Assumptions

The following design considerations were made to provide the greatest stability and hydraulic efficiency, as well as select the kind of lining materials for the channel that forms the basis for selecting Manning's roughness coefficient, n of value 0.015 [5]. The bed slope value, S = 0.0002 (Eq. (1)); a side slope, Z = 1.5:1 [5]; the freeboard of design depth, d (20%); a minimum permissible velocity to prevent siltation (V); and a maximum permissible velocity to prevent scouring (V).

### 2.14 Design Equations and Parameters for Trapezoidal Open Channel

The dimensions of the control structure were evaluated using Manning's expression:

$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \qquad (6)$$

Where, V = minimum permissible velocity of stormwater in the hydraulic structure, m/s; R = hydraulic radius of the hydraulic structure, m; S = bed or land slope of the catchment area, m; n = Manning's coefficient corresponding to the lining material used in the hydraulic structure in this research, concrete material is used.

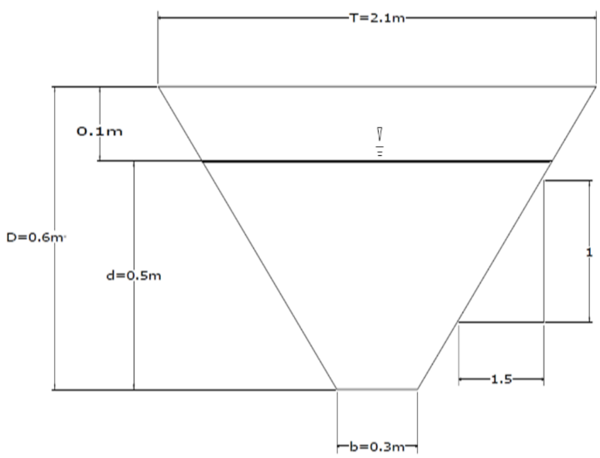


**Fig. 1. Schematics of the designed trapezoidal open channel hydraulic structure**

The hydraulic radius of the channel, R is given as:

$$R = \frac{A}{P} \quad (7)$$

Where, A= channel cross-sectional area, $m^2$; P= channel wetted perimeter, m.

The area of the trapezoidal open channel is given as:

$$A = bd + zd^2 \quad (8)$$

Where, b= the bottom width of the open channel, m; d = the design depth of the open channel, m; z = the channel side slope.

For a trapezoidal channel, the wetted perimeter is given as:

$$P = b + 2d\sqrt{Z^2 + 1} \quad (9)$$

The design discharge (run-off) capacity of the channel $Q_D$ is given as:

$$Q_D = AV \quad (10)$$

Where, $Q_D$= design discharge (run-off) capacity of the channel, $m^3$/s; V = velocity of flow, m/s; A = channel cross-sectional area, $m^2$.

The channel top width before the freeboard is given as:

$$t = b + 2dZ \quad (11)$$

Where, t = the channel top width before the addition of freeboard, m; d = channel design depth, m.

The channel top width after the freeboard is given as:

$$T = b + 2DZ \quad (12)$$

Where, T = Channel top width after addition of freeboard to avoid storm overtopping, m; D = the channel design depth plus freeboard i.e., the channel total depth (maximum depth), m.

For this design, a 20% freeboard is chosen, which is expressed as:

$$\text{Freeboard of } 20\% = \frac{20 \times d}{100} = D \quad (13)$$

Hence, D = d + freeboard

The design is a trial-and-error method where the channel width and depth are assumed as 0.3m and 0.5m respectively and 20% of the designed depth is added as a freeboard to check against overtopping of the channel by flood and wave action during active flows.

## 3. RESULTS AND DISCUSSION

The results of the hydrological analysis of the watershed, the peak/maximum discharge (runoff) causing the flood and erosion within Amakohia-Uratta, the channel design capacity and the size dimension of the trapezoidal open channel as obtained from the design calculations are presented in Table 2.

**Table 2. Summary of channel design parameters and outputs obtained in the study**

| Design Parameters | Unit | Output | Reference |
|---|---|---|---|
| Bed slope, S. | % | 0.02 | Eq. (1) |
| Rainfall intensity, I. | mm/h | 105 | Eq. (2) |
| Runoff coefficient, C. | | 0.55 | [5] |
| Area of the catchment, A. | ha | 1.069 | Eq. (4) |
| Peak/maximum runoff, Qp. | $m^3$/s | 0.170 | Eq. (5) |
| Design channel permissible velocity, V. | m/s | 0.375 | Eq. (6) |
| Channel hydraulic radius, R. | m | 0.25 | Eq. (7) |
| Manning’s coefficient, n. | | 0.015 | [5] |
| Lining material. | $m^3$ | concrete | - |
| Area of the channel, A. | $m^2$ | 0.525 | Eq. (8) |
| The wetted perimeter of the channel, P. | m | 2.10 | Eq. (9) |
| Channel side slope, Z. | | 1.5:1 | [5] |
| Channel Design depth, d. | m | 0.5 | Assumed |
| Channel design width, b. | m | 0.3 | Assumed |
| Freeboard. | m | 0.1 | Eq. (13) |
| Channel total depth, D. | m | 0.6 | Eq. (14) |
| The top width of the channel before the freeboard, t. | m | 1.8 | Eq. (11) |
| The top width of the channel after freeboard, T. | m | 2.1 | Eq. (12) |
| Channel design capacity, Qd. | $m^3$/s | 0.196 | Eq. (10) |

From the design calculations and assumptions, the following major technical information of the hydraulic structure was obtained for optimal discharge of surface water: at a total depth of 0.6 m, channel width, b of 0.3 m, bed slope, B of 0.02 and side slope, Z of 1:1.5, all the peak/maximum runoff Qp causing the flood/erosion within the study area can be conveniently emptied into the designed trapezoidal open channel (Fig. 1), which has a design capacity Qd of 0.196 $m/s^3$. From Table 2, the channel free-board is 0.1 m (i.e., 20 % of the designed depth) which was added to the design depth to give the channel total depth, D of 0.6 m. This is to avoid over-topping of the channel during periods of peak flow. It is evident that the channel should be lined with concrete material for easy maintenance and sustainability. The channel top width was increased from 1.8 m to 2.1 m by the addition of the freeboard. This also is to accommodate the peak flow during times of high-intensity rainfall.

It is, therefore, imperative that the design runoff capacity of 0.196 $m^3/s$ is well above the peak/maximum runoff capacity (0.170 $m^3/s$) causing the incessant flood and erosion at the Amakohia-Uratta catchment area and thus, the capacity (size) of the designed trapezoidal open-channel will be able to adequately capture, carry and discharge the runoff at peak/maximum runoff to the *Nworie* River, a natural outlet.

## 4. CONCLUSION

The design of a trapezoidal channel hydraulic system for flood and erosion control in Amakohia-Uratta, Owerri North, Imo state, Nigeria has been investigated in detail through field study, data collection, and design calculations. The objective of the study was primarily to design a trapezoidal open channel system that will capture, carry and discharge the peak/maximum runoff to a nearby stream which is the *Nworie* River.

Poor waste management combined with an inadequate drainage system has been identified as a major factor in the frequent flooding and erosion problems of the Amakohia-Uratta community. Also, the climate of this region cannot be overlooked as it greatly influences the high probability of flooding and erosion menace in the region. Amakohia-Uratta is located in the rainforest zone of Nigeria and as a result, witnesses an annual rainy season that lasts up to nine months, with the highest intensity rainfall occurring from June to September, this in combination with refuse accumulation, indiscriminate erection of residential and commercial buildings, concrete pavement of land areas and non-existent drainage system within this community, results in the generation of a large volume of runoff water discharging into homes, farms, markets, schools, churches causing both economic, environmental, and health-related effects to the inhabitants and their environment.

If a proper waste disposal system, and regulation in the citing and erection of buildings, planting and keeping green areas are not implemented in conjunction with the channelization project, there will be little likelihood of success in the prevention and control of flooding and erosion problems in this community. In general, the topographical survey of the catchment area shows that the maximum elevation is 81.03 m, the minimum elevation is 78.21 m, the mean slope of the area is 0.02 %, the area of the catchment is 1.061 ha and the maximum length of flow is 140 m. The hydrological analysis of the station was used to determine the rainfall intensity of 10 years duration to be 105.3 mm/h, with peak discharge Qp of 0.17 $m^3/s$ and design discharge is 0.196 $m^3/s$ which is both hydraulically and environmentally safe.

The design parameters for the trapezoidal open-channel hydraulic structure were calculated using the trial-and-error approach to obtain a channel width of 0.3m, a total depth of 0.6m, a bed slope of 0.0002, and a side slope of 1.5:1. This research generally seeks to present to the consulting firms: engineers and environmentalists who are in the business of designing and building of hydraulic structures for flood/erosion control in the urban and rural areas, a step-wise and efficient approach on the design and implement an of open-channel hydraulic systems. This will help to reduce the amount of unplanned and collapsed drainage systems that litter the streets of Owerri and the rest of Imo State Nigeria. This design approach, however, is most appropriate for locations within the tropical rainforest belt of Nigeria with consolidated ferritic soils of deep, porous, weak-structured, high porosity and percolation rate characteristics.

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## COMPETING INTERESTS

The authors have declared that no competing interests exist.

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