THE APPLICATION OF CIVIL 3D HYDRAFLOW AND NIGERIAN FMW SPECIFICATIONS IN THE DRAINAGE DESIGN OF MODIBBO ADAMA UNIVERSITY, YOLA

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ABSTRACT

Stormwater accumulation on roadways at Modibbo Adama University, Yola, presents significant threats to road users and may cause pavement failure, and is particularly inherent between the Education and Life Science faculties. This issue is intensified by climate change, that influence weather conditions, as well as deficient drainage facilities to manage runoffs. This research developed an efficient roadside drainage system, based on hydrologic and hydraulic analyses, to eliminate flooding within the affected facilities. The design process employed AutoCAD Civil 3D with the HydraFlow Extension, incorporating Nigerian Federal Ministry of Works specifications. The results show that the composite runoff coefficient is 0.25, and the rainfall intensity is recorded at 157.32 mm/hr, corresponding to a time of concentration of 12 minutes. The catchment area was 27.4 hectares, and peak runoff was 3.03 m^3/sec, with a peak discharge of 3.64 m^3/sec. A trapezoidal channel was designed with a velocity of 4.37 m/s and a critical depth of 0.73 m. The channel area is 0.4 m^2, the wetted perimeter is 2.23 m, and the top width is 1.33 m. Using AutoCAD Civil 3D with the Hydraflow Extension, drainage designers can manage a wide range of hydrologic and hydraulic tasks. The software efficiently delineates drainage areas, computes the time of concentration, and performs other rainfall-runoff analyses. This research recommends the need to integrate aspects of climate change impacts into the planning, design, construction, and maintenance of drainage systems.

Keywords: Civil3D, Drainage design, FMW Manual, Safety

1 INTRODUCTION

Drainage infrastructure in urban areas is necessary for maintaining environmental hygiene and protecting public health. A drainage system is an essential facility for urban growth and development. Its main objective is to effectively transport liquid waste, including wastewater, stormwater, and domestic sewage, from problem areas to disposal or treatment locations. The impact of drainage systems is clear in their role in linear transport infrastructure, as seen in road and railway designs. Problems with drainage can cause negative effects on road pavement. The removal of stormwater and wastewater in residential areas is an essential public health measure that greatly improves individual well-being. Efforts should mainly focus on reducing water-related diseases caused by pathogens that multiply in standing water due to poor drainage. These vector-borne diseases include waterborne illnesses, infections linked to water scarcity, and diseases transmitted by waterborne vectors. Research shows that water-related diseases are a major cause of increased death and hospitalization rates worldwide [1, 2]. In road design, adequate drainage is of the greatest significance and cannot be overemphasized. The presence of a significant quantity of water or moisture within a roadway degrades the mechanical properties of the materials used to construct it. It is necessary to prevent runoff from adjacent land from infiltrating the roadway. The side drainage should have sufficient capacity and an appropriate longitudinal gradient that conveys all collected surface water away [3, 4]. Establishing a drainage system to capture stormwater runoff is a long-term objective for society, especially in urban areas for sustainability [5]. Flowing water's destructive potential increases exponentially with its velocity. Highway drainage design ensures road safety, the management of pollutants, and cost-effective maintenance by removing stormwater originating on or near a road and directing it into culverts and channels to deliver the water to a location where it will not compromise the road's stability and safety [4, 5, 6]. The fundamental goal of stormwater drainage system design is to limit flooding and minimize pollution by establishing the physical storage volume of structures. To achieve its goal, the design of a stormwater drainage system should be supported by appropriate information; therefore, the necessary data should be collected for the design [7, 8, 9]. Thus, the objective of the research work was to conduct a hydrologic survey and hydraulic design of roadside drainage at MAU, Yola, for the deterrence of flooding, ponding, and waterlogging of the road surface and to prevent the failure of the pavement.

2 MATERIALS AND METHODS

Data was collected using survey equipment such as a measuring tape, a dumpy level, a total station, and a hand GPS. Secondary data such as topographical data, rainfall data etc. were collected and analyzed. Drainage design criteria were according to the Nigerian Federal Ministry of Works Highway (FMW) Manual [10].

2.1 Study Area

The "Study area" is located centrally within the main campus (see Fig. 1a and 1b) beginning at the west side of the University Library and heading North east between the Faculty of Medical Sciences and Faculty of Life Sciences with coordinates (start point 9°21'04"N, 12°29'33"E and end point 9°21'02"N, 12°29'27"E), There are two primary seasons in this region: the rainy season and the dry season. The precipitation season spans from the start of May to the end of October, whereas the drier season primarily lasts from November to April. January and February represent the driest months, with an average minimum relative humidity of 13%. This is primarily attributable to the prevalent arid and dehydrating northeast trade winds. August and September, with a mean annual precipitation of 972 mm, are the months with the most precipitation. The warmest month is April, with an average maximum temperature of 39.7ºC, while the coldest times of year are the months of December and January, with average minimum temperatures of 16ºC [11, 12]. In the design of drainage systems, the determination of the peak discharge and flow behavior is the main task, which is a result of runoff from the catchment area. Furthermore, the flow Q is calculated based on the discharge coefficient, the catchment area, as well as the intensity of the precipitation, employing Lloyd Davies' rational formula. [13, 14]. Rational Method was employed in finding the peak discharge of the total catchment, which is given by equation 1.

$$Q = {}^{CIA}\!/_{360} \qquad (1)$$

Where: Quantity of runoff (m^3/s), C = Coefficient of runoff, I = Intensity or rate of rainfall (mm/h), and A = Area of the watershed (Hectares). The design of the side drainages is based on the concept of flow through open channels. If Q is the amount of surface water (m^3/sec) to be removed by the side drainage and V is the allowable flow velocity (m/s) on the side drainage, then A (m^2) is the area of the cross-section of flow, which can be represented by equation 2.

$$Q = A \times V \qquad (2)$$

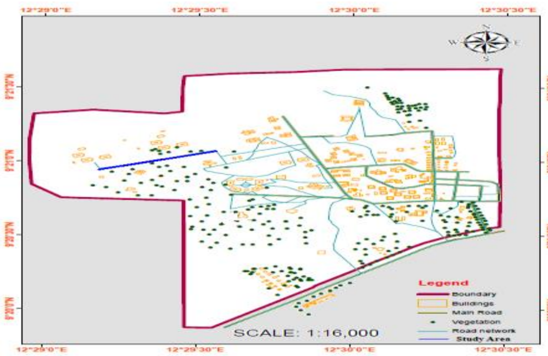


Figure 1a. Map of MAU showing the Study area

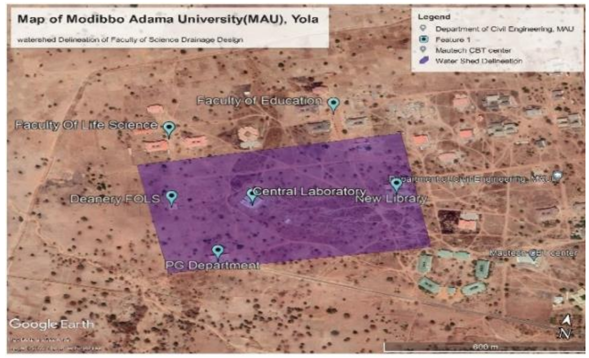


Figure 1b. Watershed delineation of the drainage design

In designing the open channel's cross sections, the channel's velocity must be sufficient to prevent siltation and assure self-cleaning, but not so high as to cause erosion [14, 15, 16]. Therefore, the section of the channel is considered to be trapezoidal (Figure 2). For a trapezoidal channel, the side slope is assumed to be 1:1.

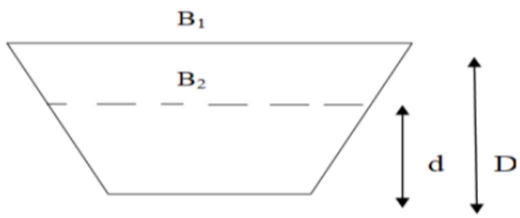


Figure 2. Trapezoidal section of channel

Where, B1 = top width of channel section (m), B2 = top width of flow of channel section (m), b = bottom width of channel (m), d = depth of water in channel (m), D = depth of channel (m). Using Manning's formula for the values of flow velocity V, roughness coefficients n, and hydraulic radius R, the slope S of the longitudinal drainage cross-section and the flow depth [8, 17, 18] can be calculated using equation 3.

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

3 RESULT AND DISCUSSION

3.1 Survey

Following the hydrologic design requirements, a topographic survey of the corridor was conducted Fig. 3 shows the longitudinal profile along the centre line from the topographic survey conducted, and contains the highest elevation of 216.75m and the lowest elevation of 210.98m with a chainage of 754.92m. The precision of the data obtained during the survey had an immediate influence on the majority of the design activities engaged in hydraulic design. Topographic investigations were planned with topographic sheets and maps or images of the study area [19].

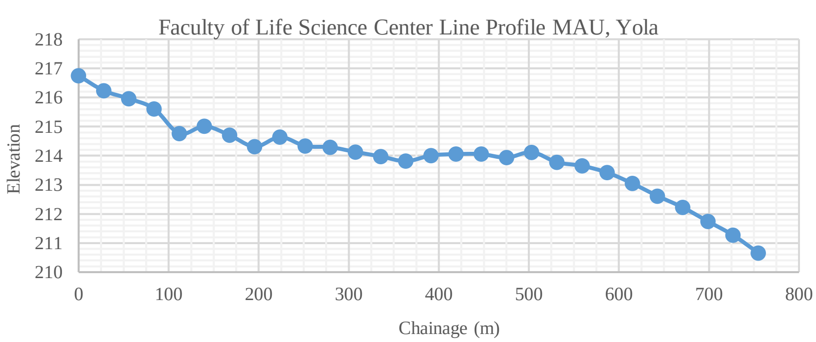


Figure 3. Surveyed profile of the study area

3.2 Drainage Design

The drainage design adheres to the guidelines and specifications of the Ministry of Works and Highway Drainage Manual [10]. The Rational Method was utilized, and it was assumed that rainfall intensity was uniform across the complete catchment area, considered an adequate assumption for relatively small catchments. The average annual rainfall data of the area was used to obtain the rainfall intensity. The drainage area's slope of 5% was determined from the designed contour map. Using a bed slope of 1.5%, the catchment peak discharge of the entire catchment was computed as 3.032 m3/sec using a rainfall intensity of 157.32 mm/h. A topographic map was designed to provide a picture of the terrain and features through the use of contour lines, colors, and symbols, Contour lines on the designed topographic map show topography or changes in elevation (Fig. 4). They reveal the location of slopes, depressions, ridges, cliffs, height of mountains and hills, and other topographical features. It was plotted on a Scale of 1:500 with a contour interval of 20m, Minimum Elevation (194.000m) and Maximum Elevation (252.006m).

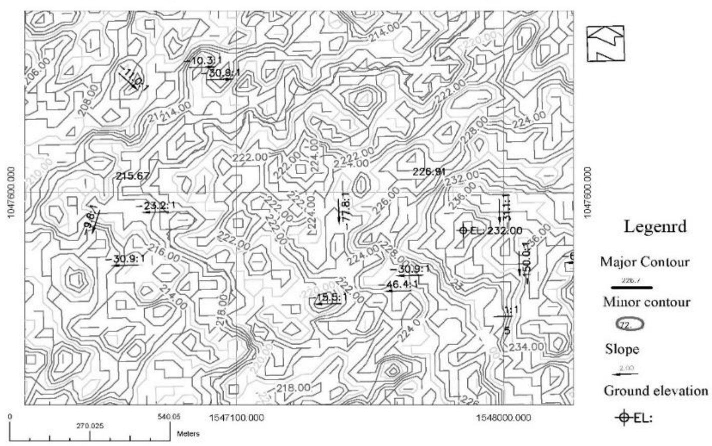


Figure 4. Contour map of the area

3.3 Efficiency of Channel Drainage System

Channel efficiency is the ability of water and sediments to pass through a channel. The amount of water in the cross-section of a channel is vast relative to the bed and banks of the channel; this may be measured using hydraulic radius, R, which is the ratio of cross-sectional area, A, to wetted perimeter, P. The hydraulic radius of a channel determines its efficiency and the amount of water it can carry. The larger the hydraulic radius, the more efficient the channel is and the more water it can carry [20, 21, 22, 23]. The bottom width of the channel is 600mm, and the side slope is set to 0.5:0.5 for the economical section to derive an acceptable compromise between top width and maximum discharge. The hydraulic radius is computed after all of the parameters have been calculated. When the cross-section of a channel contains a large amount of water compared to the length of the bed and banks, the channel is said to be more efficient. Efficiency is calculated using the hydraulic radius equation 4.

$$R = {}^{A}\!/_{P} \tag{4}$$

where, A = cross-sectional area (m^2), $= \frac{1}{2}(0.6 + 0.4)0.8 = 0.4$. A channel is more efficient if there is a large area of water in the cross-section compared with the length of the bed and banks.

3.4 Determination of Rainfall Intensity

From MAU rainfall data (2010-2021) for the study area, rainfall intensity was found to be 157.32 mm/hr corresponding to a time of concentration of 12minutes. t = 12 minutes, Where t = Time of Concentration. Design Recurrence Interval is taken as 10years, Thus, use the rainfall duration of 12 minutes for a return period of 10 years. Intensity of Rainfall, I = 157.32 mm/hr. Where T= Recurrence Period interval (return period), in this case 10 years.

3.5 Determination of Runoff Coefficient

According to the (FMWH) Manual (2013). Part 1: Design, Volume V: Drainage Design. The selection of the appropriate value of C for a particular catchment requires inspection of the site and should be based upon experience and engineering judgement of the prevailing conditions in the catchment area. And gives the recommended values of coefficient of run off (C) for Heavy Soil steep as (0.25 - 0.35) in urban area. From the above, the assumed runoff coefficient C = 0.25. Determination of Peak Discharge (Q, in m/s) using equation 6.

$$Q = Cf \times C \times i \times A \quad (5)$$

Where C_f = 1 (for Design recurrence interval of 10years), C= Runoff coefficient, dimensionless, in this case 0.25, I = intensity in mm/hr. A= Basin area in Ha, in this case 27.4 Ha.

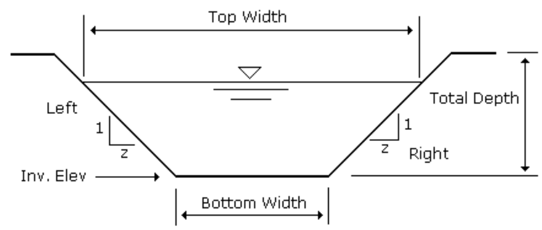
3.6 Design of Drainage Channel

The direct solution of Manning's equation consisted of solving for any of the variables in Manning's formula through an iterative procedure utilizing Civil 3D's built-in functions (specifically, the Hydraflow Express Extension for Autodesk Civil 3D). This method was used to determine the appropriate channel size for discharging the flow, and the resulting data are presented in Table 2. The drainage channel was designed for the roadside drainage of the Faculty of Life Sciences. The results are appended below for a bottom width of 0.5m by using known discharge Q to produce a rating curve. Trapezoidal Channel Inputs:

Bottom Width (m) = 0.6000
Side Slopes (z:1) = 0.500, 0.500
Total Depth (m) = 0.730
Invert Elevation (m) = 215.969
Slope (%) = 1.500
N-Value (Concrete) = 0.013
Length (m) = 755

Calculations

Compute by: Discharge (Q) vs Depth
No. of Increments = 6
Discharge Q = 3.03m^3



Trapezoidal Section

Table 2. Trapezoidal Channel Design

Serial No.	Depth (m)	Q (m3/s)	Area (m2)	Velocity (m/s)	Wp (m)	Yc (m)	Top Width (m)	Energy (m)
1	0.1217	0.155	0.080	1.9221	0.8721	0.1798	0.7217	0.3101
2	0.2433	0.474	0.176	2.7003	1.1441	0.3597	0.8433	0.6153
3	0.3650	0.925	0.286	3.2397	1.4162	0.5364	0.9650	0.9004
4	0.4867	1.506	0.410	3.6697	1.6882	0.7071	1.0867	1.1736
5	0.6083	2.221	0.550	4.0380	1.9603	0.7300	1.2083	1.4400
6	0.7300	3.076	0.704	4.3671	2.2323	0.7300	1.3300	1.7028
7	0.8000	3.635	0.800	4.5437	2.3889	0.8000	1.4000	1.8531

Wp = Wetted perimeter, Yc = Critical Depth

Designed Output (see Table 2.), Depth (m) 0.73, Discharge Q (m^3/s) = 3.076, Area (m^2) = 0.704. Velocity (m/s) = 4.3671, Wetted Perimeter (m) = 2.2323, Critical Depth, Y_c (m) = 0.7300, Top Width (m) = 1.33, EGL (m) = 1.7028. A trapezoidal channel with base width 0.6m side slope of ½, critical depth of 0.8 and top width of 1.85m was proposed to convey a maximum discharge of 3.635 m^3/s thus providing a freeboard of (0.8m - 0.73m = 0.07m = 70mm). i. e. Required discharge = 3.03 m^3/s; designed drainage maximum discharge capacity = 3.635 m^3/s, therefore ok (Figure 5).

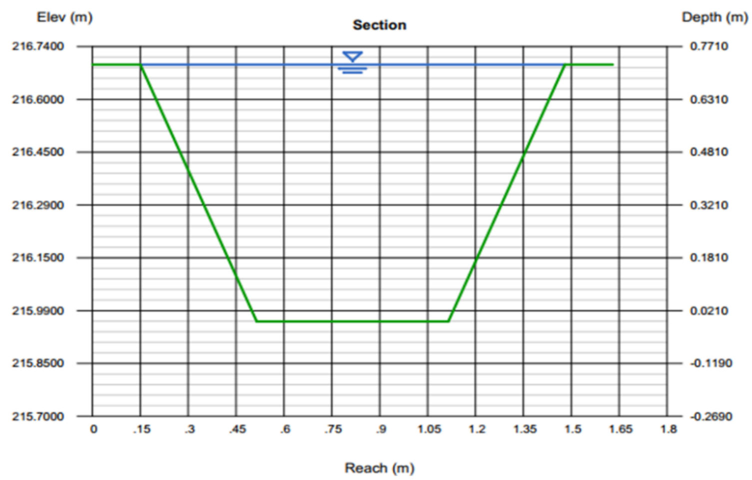


Figure 5. Roadside Drainage Design

3.7 Culvert Design

Within the designated research area, culverts must cross the drainage channel to make connectivity to nearby developments easier. Designing highway culverts involves determining flow, hydraulic performance, economy, type of structure and location (position and spacing). The selection of the most appropriate type of culvert for this study depends on a range of factors, including economics, site conditions, and environmental considerations. While the present study consists mainly of concrete pipes culvert proposed (see Table 3).

Table 3. Culvert Design Input

Culvert length (m)	10.00	Slope (%)	3.64
Invert elevation entrance(m)	208.12	Invert elevation exit(m)	207.69
Size	0.60(m)	shape	circular
No of barrels	1.0	Manning's n	0.13
Culvert material	concrete	Inlet configuration	Square edge with headwall

There are two main types of culvert flows: inlet-regulated and outlet-regulated flows. A different combination of factors governs the hydraulic capacity of a culvert for each form of control [15, 24]. Actual flow conditions can be difficult to ascertain. Consequently, a check for both forms of flow was performed during the design phase, and the structure was built to withstand the most severe conditions. A culvert functions with inlet regulation when the flow capacity at the entrance is controlled by culvert type (barrel shape), culvert inlet type, and culvert sectional area (see Table 4).

Table 4. Culvert Design output data generated by hydraflow software

Design flow(m^3)	0.50	Flow per barrel(m3)	0.50
Tail water condition	Normal	Tailwater elevation(m)	208.23
Velocity Up(m/s)	2.11	Velocity down(m/s)	3.51
Hydraulic Gradient line (HGL) up(m)	208.58	Hydraulic Gradient line (HGL) down(m)	207.99
Head water elevation(m)	208.58	HW/D	1.16
Flow Regime	Inlet control	Rise	600mm

4 CONCLUSIONS

Using visualisation, simulation, and water analysis linked with the design process for stormwater management, AutoCAD Civil 3D assists in improving project delivery and making better-informed decisions. For the direct solution of Manning's equation, the use of software applications to solve for any of the variables in Manning's formula is done by a process of iteration. This was undertaken by means of an iteration procedure using the in-built functions available in Civil 3D (Hydra Flow Express Extension for

Autodesk Civil 3D). Drainage systems were designed to dispose of stormwater and were environmentally beneficial, causing minimal or no long-term detrimental damage. Stormwater drainage in the study area (MAU, Yola) was successfully designed using the Rational Method. The Rational Method's chosen runoff coefficient considers several factors, including the catchment basin, land use pattern, soil cover, infiltration details, and so on. Great effort was made to estimate these components to arrive at the runoff value, and the runoff coefficient 'C' value was determined with great care. A trapezoidal channel with a maximum width of 1 m, a depth of 0.5 m, and a free board of 0.070 m with a slope of 1:1 was designed. Consequently, besides collecting, guiding, and transporting excess surface water resulting from rainfall, stormwater drainage facilities selected for this study seek to reduce flood damage to properties and improve usability by removing excess water susceptible to pollution and insect breeding. The use of the MAU average rainfall data for 10 years to find the intensity of rainfall used in determining discharge provides average data with sufficient accuracy to reflect climate change. This proposal for drainage design using the software on the university campus will serve as a model for other campuses in humid regions as well as other local, regional, national, and international drainage infrastructure systems. As a result, it will assist in achieving stormwater management environments that are resilient and sustainable, including aesthetically enhanced areas that provide greater opportunities.

REFERENCES

1. Fayomi, G.U., Onyari, E.K. and Jaiyeola, A.T. (2024). Quantitative assessment of open drainage and storm water runoff capacity in Nigeria: *Consequences and way forward. Case Studies in Chemical and Environmental Engineering*, vol. 9, pp. 100766.

2. Ojo, B. and Emmanuel, E.O. (2024). Evaluating highway drainage systems for flood mitigation: A case study of the Benin-Auchi Expressway in Esan West, Edo State. *J. Sci. Eng. Res*, vol. 11, no. 4, pp. 133-153.

3. Jayasree, P.K., Balan, K. and Rani, V. (2021). Water Resources Engineering. *John Wiley & Sons*, doi: 10.1201/9780429094811-14.

4. Teshome, M. and Devi, A.R. (2020). A Review of Recent Studies on Urban Stormwater Drainage System for Urban Flood Management. *Preprint*, pp. 1-15.

5. Monachese, A.P., Gómez-Villarino, M.T., López-Santiago, J., Sanz, E., Almeida-Ñauñay, A.F. and Zubelzu, S. (2024). Challenges and innovations in urban drainage systems: sustainable drainage systems focus. *Water (Basel)*, vol. 17, no. 1, pp. 76.

6. Ashley, R. and Smith, B. (2024). Urban drainage. *ICE Handbook of Urban Drainage Practice, Emerald Publishing*, pp. 1-20.

7. Sohn, W., Brody, S.D., Kim, J.H. and Li, M.H. (2020). How effective are drainage systems in mitigating flood losses. *Cities*, vol. 107, pp. 102917.

8. Amadasun, C.V.O. (2019). Integrated Geophysical Techniques: A Viable Tool for Accentuating the Needed Importance of Side-Drains to Paved Road Networks. *FUPRE Journal of Scientific and Industrial Research*, vol. 3, no. 3, pp. 35-51.

9. Kang, M.S., Koo, J.H., Chun, J.A., Her, Y.G., Park, S.W. and Yoo, K. (2009). Design of drainage culverts considering critical storm duration. *Biosyst Eng*, vol. 104, no. 3, pp. 425-434.

10. Federal Ministry of Works (2013). Highway Manual Part 1: Drainage Design, vol. 4, no. 1., pp. 1-20.

11. Saka, M.G., Kenan, T. and Yakubu, M. (2021). Juvenile height equations for plantation-grown date palm (Phoenix Dactylifera L.). *International Journal of Research and Innovation in Applied Science*, pp. 91-96.

12. Tya, T.S.K. and Akoh, E. (2020). Hydraulic Evaluation Of Road Side Drainage System in Modibbo Adama University of Technology Yola, Adamawa State, Nigeria. *Nigeria Journal of Engineering Science and Technology Research*, vol. 6, no. 1, pp. 51-57.

13. Yusuf, Y.M., Tukur, A.L., Gadzama, E.W. and Abubakar, A.U. (2022). Customized Design of a Proposed Alignment at MAU Yola Campus in Civil 3D Using Nigerian Federal Ministry of Works Highway (FMWH) Manual. *Journal of Advanced Industrial Technology and Application*, vol. 3, no. 2, pp. 78-95.

14. Ezugwu, M.O. and Eze, A.B. (2019). A Basic Design Approach of Drainage Facilities for Efficient Prevention and Control of Flooding. *Nigerian Journal of Engineering Science research*, vol. 2, no. 1, pp. 1-12.

15. Guyer, J.P., Asce, F. and Aei, F. (2013). An Introduction to Seepage and Drainage, no. 877. *Guyer Partners*.

16. Shafan, T. (2024). Design of a Stormwater Management System in Lady Irene Campus. *East African Journal of Engineering*, vol. 7, no. 1, pp. 199-216.

17. Biancardo, S.A., Intignano, M., Abbondati, F., Di Fonzo, F., Gualtieri, C. and Dell'Acqua, G. (2025). Rainwater drainage systems solutions for safer transport infrastructures. *Transportation Research Procedia*, vol. 90, pp. 304-311.

18. Teshome, M. and Devi, A.R. (2020). A Review of Recent Studies on Urban Stormwater Drainage System for Urban Flood Management. *Preprint*, pp. 1-15.

19. Pooja, N.P. (2020). Design of Storm Water Drainage System in A Metropolitan Area. *International Journal of Engineering Research*, vol. 9, no. 6, doi: 10.17577/ijertv9is060757.

20. Ferguson, R. and Recking, A. (2025). Flow resistance and hydraulic geometry in gravel-and boulder-bed rivers. *Water Resour Res*, vol. 61, no. 3, p. e2024WR038852.

21. Tamanna, N., Tuladhar, R. and Sivakugan, N. (2020). Performance of recycled waste glass sand as partial replacement of sand in concrete. *Constr Build Mater*, vol. 239, pp. 117804.

22. El-Hazek, A.N. (2019). Design Charts and Design Equations for Trapezoidal Earthen Open Channels. *Sumerianz Journal of Scientific Research*, vol. 2, no. 12, pp. 166-182.

23. Umar, N. and Gray, A. (2023). Flooding in Nigeria: a review of its occurrence and impacts and approaches to modelling flood data. *International Journal of Environmental Studies*, vol. 80, no. 3, pp. 540-561.

24. Bazarov, D., Norkulov, B., Umarov, S., Artikbekova, F., Kurbanov, A. and Salimbayev, M. (2023). Experimental evaluation of the throughput of the supply channel of pumping stations. *E3S Web of Conferences*, 5033p.