Optimizing Locations for Best Management Practices in Watershed Zones in Developing Societies (A Case Study of Edim Otop Area in Calabar, Nigeria).

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Keywords: Erosion, Flooding, Watershed, Conservation.

Summary

Land degradation from Erosion and Flooding poses cut-throat challenges to maintaining healthy habitats for both man and animal especially in developing societies. Watersheds have remained the immediate relatable environment to local communities within areas of these hazardous phenomena yet the understanding of these watersheds and their components remain relatively unknown to the indigenes whose activities contribute to the depreciation in soil and water properties. This paper is aimed at addressing the use of Hydrological and Terrain Geo-spatial analysis in mapping sub-watershed Zones in Edim Otop Area in Calabar, Nigeria by determining best suited locations for implementing selected Best Management Practices (BMPs). The BMPs considered for this study include flowpath identification, open space selection, Riparian Buffer, Rainwater harvesting, Bioswales and Tree planting. The methodology involved creating watershed zones from Digital Elevation Models (DEM) and Land Cover information derived from available open source data. The community centered watersheds were categorised into upper, middle and lower watershed zones by classifying localised elevations using threshold values and then in combination with the other factors which were analysed to choose optimal locations for the various BMPs by considering proximity to existing hazards and their relative positions in the sub watershed zones. The overall output was in line with achieving enhanced soil and underground water conservation by integrating spontaneous community understanding of the composition of the watersheds and the its effective management. The final products were the BMP maps that were used to communicate and enhance community involvement in effective and inclusive management of the watershed.

1. INTRODUCTION

The persistent devastation caused by Erosion and Flooding continues to engulf several communities in Cross River State and specifically Calabar. Calabar, being the Capital city, boasts of an ever growing population and an expanding infrastructural development which directly implies that there is pressure on the eco-system especially in soil and water resources(Amah et al, 2008). Moore & Smith (1963) stressed on the economic loss caused by erosion and further stressed on the adaptation of small watershed zones as an effective approach towards controlling erosion and improving on water quality. In Nigeria, the cost of managing these hazards has been enormous on the government with the World Bank estimating a total of 9.7 billion dollars in 2018 as the total cost of managing environmental hazards. Not surprisingly, this estimate projects Cross River State alone to require a total of 413 million dollars on degradation related to water, erosion and flooding factors. It further highlights that the State holds the record of having the highest rate of erosion at a 169 ha per year of all the coastal States in the study(Croitoru et al, 2020).

The inability of government to meet these high numbers in battling degradation requires that alternative solutions to managing these menaces are explored. The poorest people in the community become the most vulnerable in these situations as the cycle of poverty, ignorance, degradation in soil and water quality stares at them directly. This implies that solutions to these local and immediate challenges will require community engagement.

The watershed and sub watershed zones become the immediate environment for communities to manage these problems; however, a fair grasp of these concepts will require their understanding. Best Management Practices (BMPs) within watershed are consistently being applied in recent times as a means to conserve soil and water quality. The approaches to mapping, delineating and choosing locations for BMPs have been dependent on mostly manual interpretations of historic watershed maps (thereby limiting their efficiency in reality) as well as isolated implementation by experts of these solutions without sufficient engagements from community agents and occupants as highlighted by Fulcher et al(1992).

This study bridges these gaps by using several Terrain and Morphometric tools to identify best locations for implementing BMPs in watershed zones and creating community centered maps by adding community inputs to the products derived.

2. STUDY AREA

Edim Otop Community in Calabar Municipality is one of the pilot communities of the Nigerian Erosion and Watershed Management Practice (NEWMAP) intervention. The community is located close to the Great Qua River and possesses one of the biggest Gully Erosion Sites in Calabar, Cross River State, Nigeria. The community is located approximately on Latitude 4°57'50.74''N and Longitude 8°21'8.17''E.

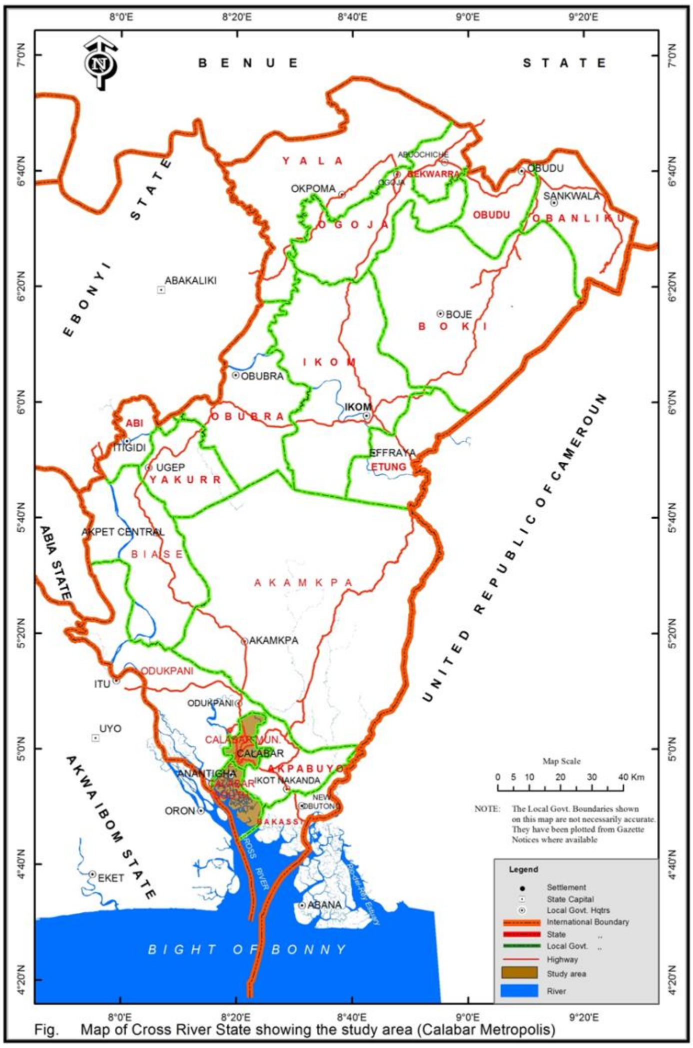

Figure 1: Study Area

3. METHODOLOGY

3.1 Data Sources

The main data source for this study comprised of Worldview 10m Digital Elevation Model which forms the basis for generating all other terrain, hydrology and morphometric data for interpretation and analysis. Other sources are discussed in the subsections where necessary. The data were manipulated in the ArcGIS and QGIS (Saga) environment. Field data acquired using a Garmin Handheld GPS was also used. The field data included records to show notable landmarks and critical activities in the watershed zones.

3.2 Optimizing Locations for BMPs Using GIS Tools

3.2.1. Identifying sub watershed zones

Utilizing the concept of sub watershed zones allows for the overall planning of watershed activities. This forms the first aspect optimization of BMPs by providing a holistic view for effective planning.For ease of managing watershed zones, the basic practice involves dividing a particular community centered watershed into Upper, Middle and Lower watersheds. These subzones are characterised by land forms that exist within. The Upper watershed is often located in the highest sectors of the watershed and comprises a stable terrain with relatively gentle slopes, while the Middle Watershed Sector comprises of relatively high slopes and has the greatest potential for runoff and the Lower Watershed Sector is characterised as the depositional areas which in most cases is susceptible to flooding.

The first approach was to derive the Watershed delineations for the entire Calabar Metropolis using Hydrological GIS analysis, from which the Watershed Boundary intersecting the Edim Otop Community was extracted for further evaluation. The traditional method for such sub-division of the watershed involved inspecting contours on the map and manually categorising them based on the slope values. This approach allows for too much generalisation since it is based on the operators appreciation of the terrain thereby reducing the effectiveness of the BMPs placements(Liang-Jun Zhu, Zhu, Qin, & Liu, 2018).

Hence, given the characteristics of the sub watershed zones, analytical comparisons of height variations provided the best interpretation of the terrain for sub-delineations. This was achieved in two (2) steps: i) by identifying the local height differences relative to the lowest point in the watershed using the *Valley Depth* analysis, which intuitively reveals the directional order for the sub watershed zones; ii) where the delineations of the sub-watershed zones are further delineated by classifying the *Relative Slope Position* into three (3) distinct categories, in this case, the *Geometric Interval* classification method was adopted having created a balanced distribution as compared to the other methods.

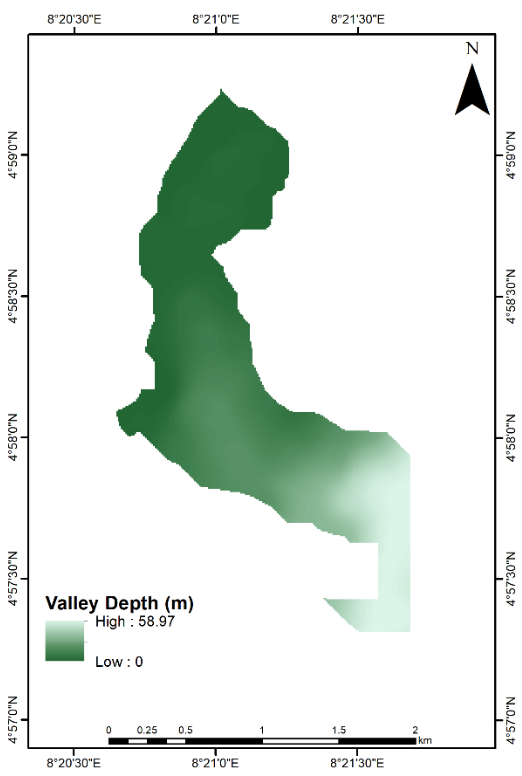

Figure 2: Valley Depth measured relative to the lowest terrain Point

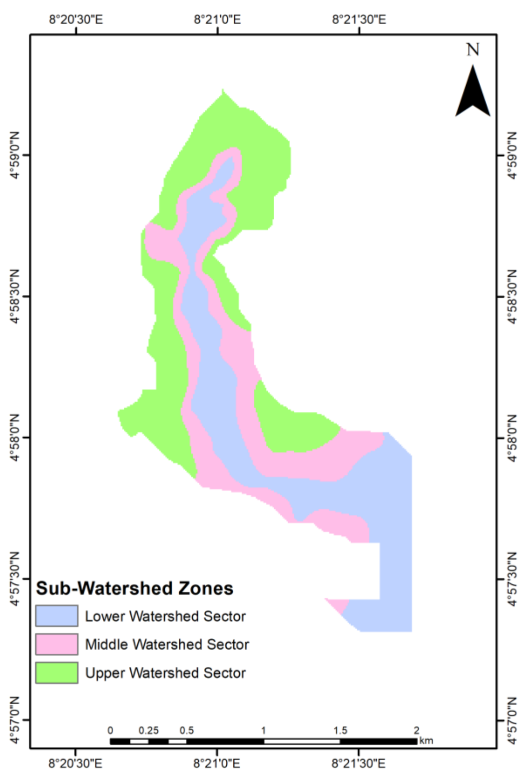

Figure 3: Sub-watershed zones derived from Relative Slope Position

Having the three (3) sub-watershed zones provides the major platform for positioning BMPs on a watershed. This forms the basis for effective planning and distribution of watershed activities as they align with the characteristics of each watershed zone. As a rule-of-thumb, the table below shows the distribution of such activities according to their priorities in the watershed zone:

Table 1.Sub-watershed zones with suitable BMPs.

Sub-Watershed zone	**BMPs**	**Remarks**
Upper Watershed Sector	Rainwater Harvesting, Waste Management	Areas with the highest concentration of buildings. Storm water gathers its momentum at this sector hence the need to prioritise harvesting of rainwater.
Middle Watershed Sector	Soil Stabilisation using bio-remediation strategies, for example tree and grass planting; landscaping etc.	Areas with highest run-off capacity.

Lower Watershed Sector	Open Spaces for water bio infiltration measures; Impervious area reduction; flood reduction.	Depositional area with emerging landscape due to settling of soil.

3.2.2 Flowpath Identification

Flowpath Identification often is categorised as a planning process BMP which allows for controlling drainage network and building placements. In most cases like in Edim Otop, building regulations are not often adhered to and as such the flow paths are obstructed. This now serves as priority areas for response to cases of emergencies as a result of severe rainfall and flooding.

Using the Hydrology tool, the major flowpath(s) identified within a watershed highlights the zone that requires a planning process BMP, the importance being that flow patterns of surface water and collection points are spatially identified.

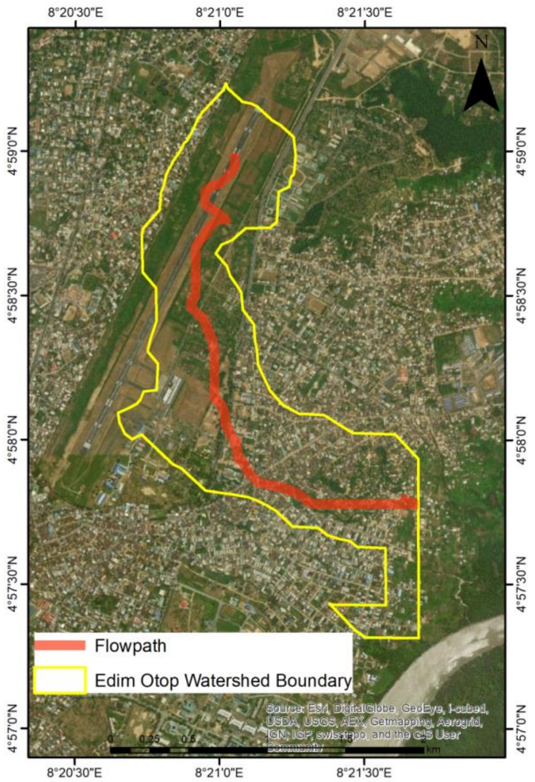

Figure 4: Flowpath Analysis (Planning Process BMP)

3.2.3 Open Space Selection

Open Spaces allow for conservation of water quality as well as providing recreational space within the watershed. Such spaces further improve watershed zones by their ability to accommodate other BMPs such as Rain Garden, Storm Water Tree Planting, Native Vegetation (including grasses of erosion resistant characteristics), etc.

The Land Cover classification of the Edim Otop watershed highlights those areas suitable for the selection of open spaces. Areas classified as Grass Lands and Bare Lands formed the main classes for Open Space Selection. For Bare Lands, complete reclamation and planting/bio-based BMPs are required while the Grass Land will require re-configuration of the uses to enhance soil and water quality. This is informed by the peculiar practice within this region where Open Spaces i.e grass lands are often used for growing staple vegetables. For the purpose of soil conservation where such agricultural activities may not be suitable, Alternative Livelihoods are recommended for the Locals of that region.

For the Edim Otop watershed zone, the portions grass lands are filtered by separating those whose area are less than a hectare for small scale interventions while those larger than 1 hectare will require full blown planning BMPs to be implemented.

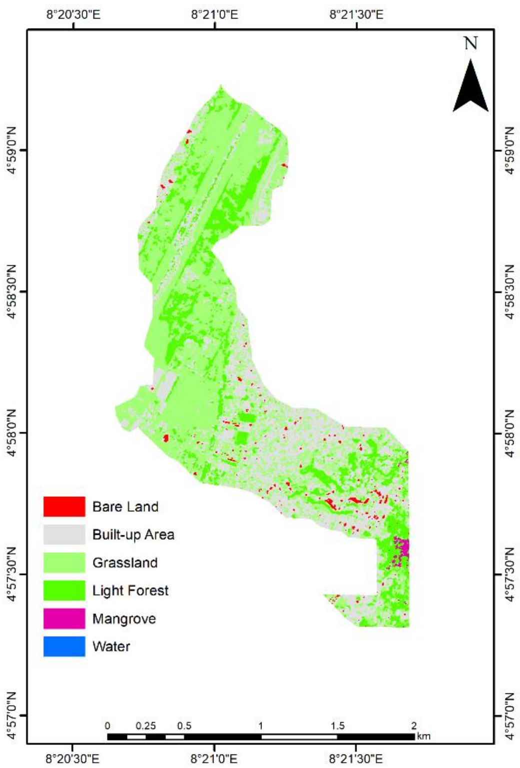

Figure 5: Land Cover of Edim Otop Watershed (2016)

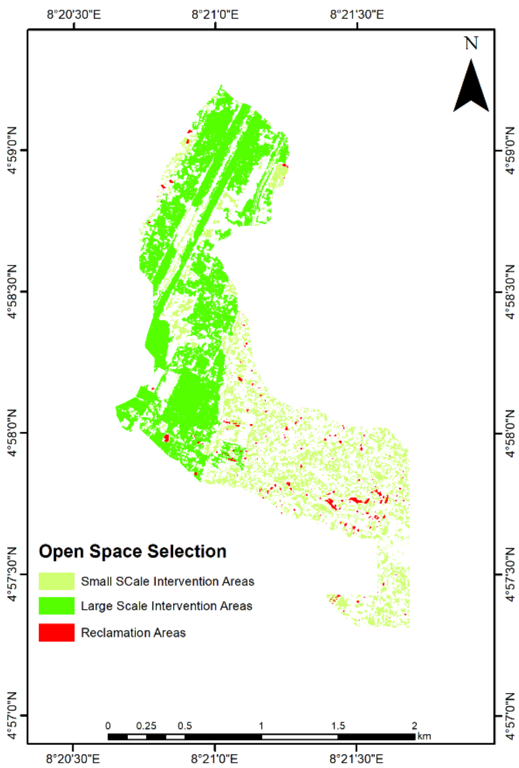

Figure 6: Open Space Selection based on Prioritization of Bare Lands and Grass Lands

3.2.4 Riparian Buffer

Riparian buffers comprise of vegetation positioned along stream, river or channel banks for the purpose of stabilizing the banks, filtering pollution substances as well as providing a diverse habitat for wildlife. Riparian buffers help to maintain soil and water quality even as they add aesthetic quality to the landscape.

The mapping of the Riparian buffer was adapted from Tomer et al(2003) by classifying values derived fromWetness Index and Erosion Index. These two (2) indices are dependent on the upslope contributing area and per unit grid cell width and the land slope in degrees. The Erosion index is said to be equivalent to the LS factor in the Revised Universal Soil Loss Equation (RUSLE).

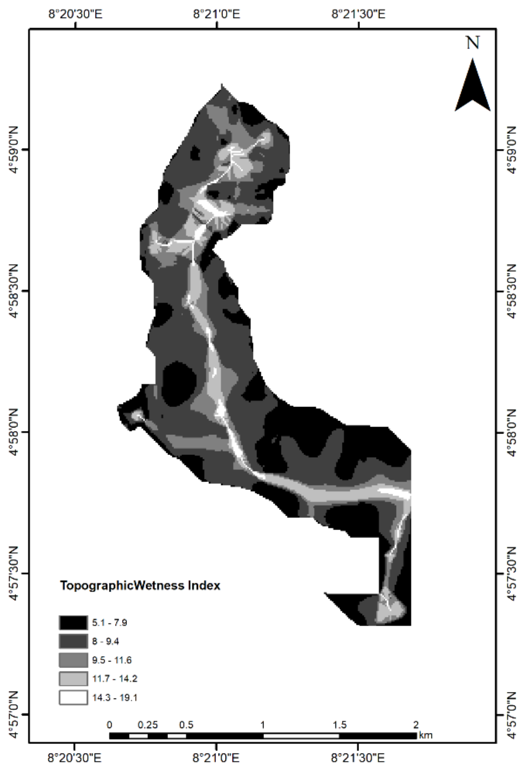

Figure 7: Wetness Index of the Watershed Zone

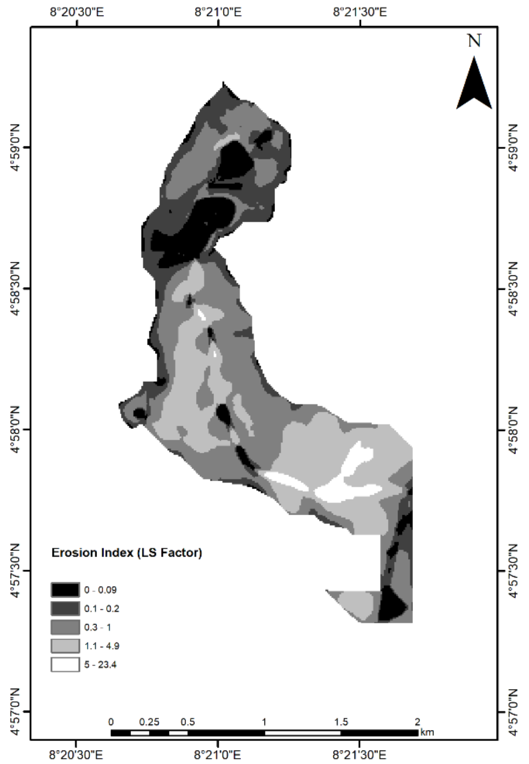

Figure 8: Erosion Index of the Watershed Zone

From the adaptation from Tomer et al., 2003, the regions of highest correlation of the indices represent regions best suited for Riparian Zones. A re-classification of the indices was implemented to highlight the impact zones, which are then overlaid to derive the Riparian Zones.

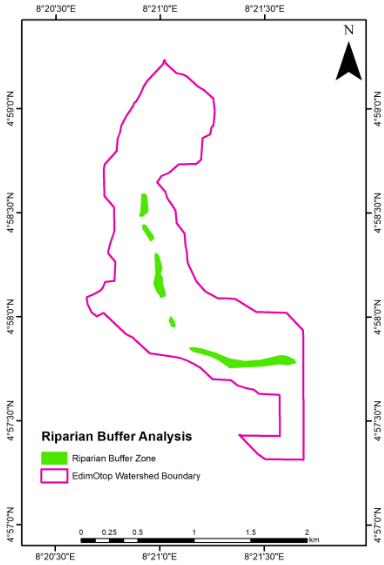

Figure 9: Riparian Buffer derived from Erosion and Wetness Indices

3.2.5 Rainwater Harvesting

Rainwater harvesting in Calabar Metropolis was relatively unknown until the NEWMAP project. Water from roofs is openly dispersed thereby increasing surface runoff during peak flow/heavy rainfall. Rainwater harvesting helps tackle this by the use of Rain Barrels to channel roof water and storing them for more controlled use. This practice conserves water and reduces soil erosion.

The Upper watershed sector is reckoned with the highest potential for gathering water force which then gains kinetic characteristics in the middle watershed. Based on this, Rainwater Harvesting is critical in these sub sectors of the watershed. Community dwellers and other Stakeholders are sensitized to adopt these measures to help maintain soil stability over longer periods.

To map the buildings within these sub-watersheds a *spatial join* was carried out on the Google Building Open Dataset (Sirko et al., 2021) overlaid on the sub-watershed zones. The buildings are then categorised as high, medium or low priority areas based on their location on the sub sectors.

One other advantage of adopting this BMP is that it can be implemented at household level thereby reducing burden on government's intervention.

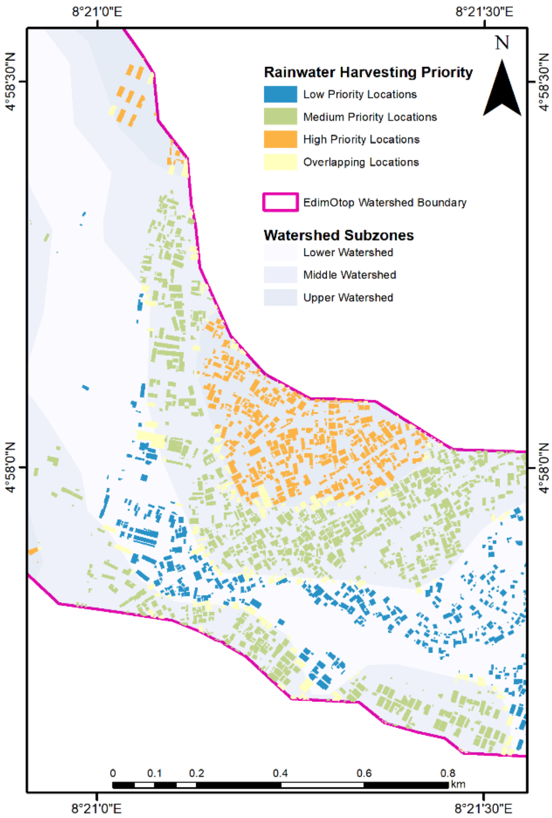

Figure 10: A Sector of Priority Households for Rainwater Harvesting in Edim Otop Watershed

3.2.6 Bioswales and TreePlanting

Tree Planting and Bioswales are best suited along roads in the watershed. Tree Planting is effective in every desired BMP as specie adaptation can be applied based on the needs of the ecosystem. Having them beside roads improve on aesthetics, provides infiltration points and serve as wind breakers hence reducing pollution and erosion from wind factor. These functions improve on both water and soil quality. Bioswales reduce surface runoff with the adaptation to store storm water for some hours. They also add to aesthetics on the watershed landscape.

The locations of Tree Planting and Bioswale BMPs have been optimised to lie along access roads for ease of implementation and effectiveness. Regions marked for Bioswales are selected in areas where the roads intersect regions of Positive *Profile Curvature* values; as these regions are characterised by accelerated flows during heavy rainfall and the concave nature allows for easy implementation of the Bioswale design.

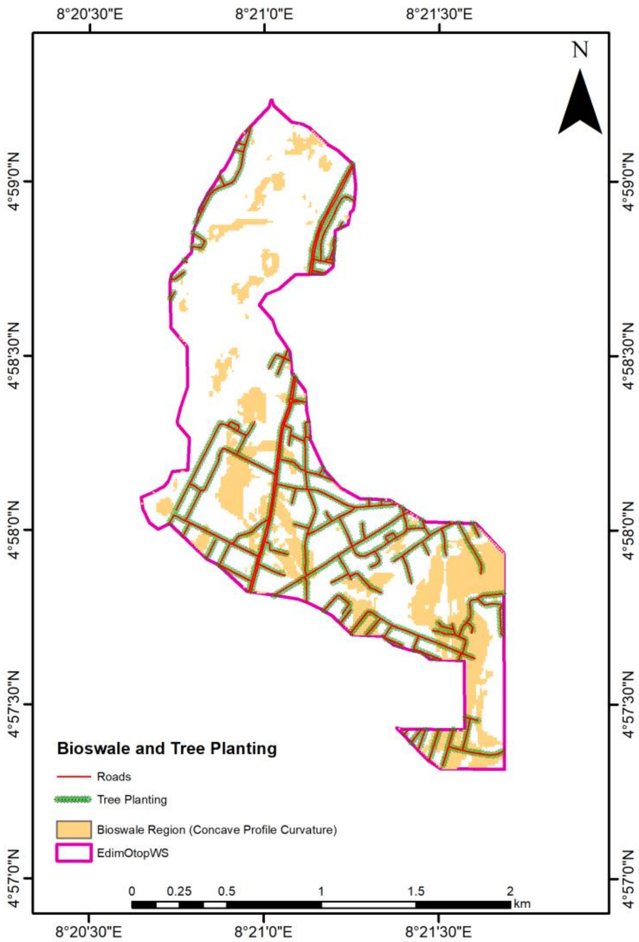

Figure 11. Tree Planting and BioswaleBMPs optimised from street locations and Profile Curvature analysis.

3.3 Community and Stakeholders Input

After deriving all the BMP maps, a catalogue of the raw maps was produced and presented before community locals and relevant Stakeholders. In order to improve understanding of the watershed maps and the solutions therein, the Community and Stakeholders were coordinated to include all notable landmarks and relevant activities with the watershed zone. To achieve this, field visitations were required where the landmarks were spatially registered with handheld GPS. Some of the land marks were mapped using the local semantics to facilitate quick recognition of the details by the locals. The sub-watershed zones were also used as references on the map to reduce the spatial ambiguity by the users. This means, some activities are restricted to inhabitants within a certain watershed sub-delineation.

4. RESULTS

Given the results from the terrain analysis and an integration of community and Stakeholders input, the derived locations for BMPs in the Edim Otop watershed transcended from typical manual selection of sites to a more scientifically informed process. The need to translate the results to the grassroots where implementation was to be done brought in Stakeholders contribution to mapping. This approach was tested by allowing the stakeholder to describe likely locations of proposed and implemented BMPs and the responses improved by about 50% after the landmarks were added to the maps. In this simple test, fifty (50) persons were randomly selected from the area to carry out the sensitization activity. The test improved from eighteen (18) to thirty nine (39) persons after mapping with the locals was done.

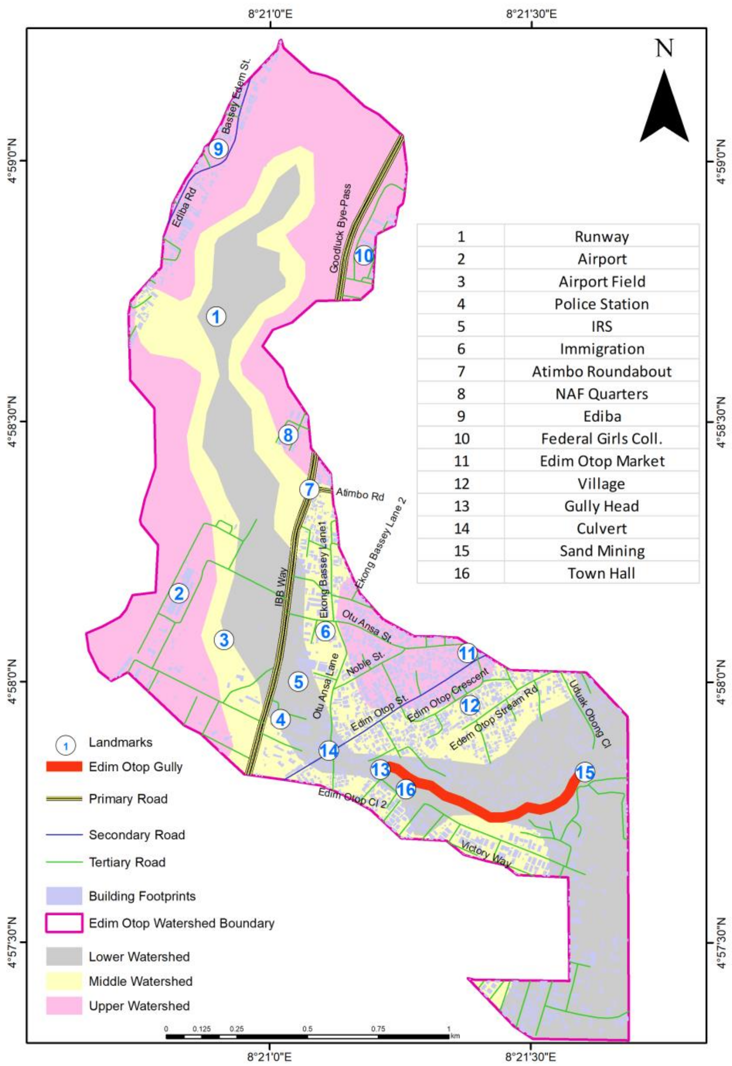

Figure 12: Map showing Edim Otop Watershed and sub-watershed delineations with landmark inputs from Stakeholders as an aid to map interpretation.

5. CONCLUSION

The purpose of this study is to showcase improved approaches in selecting and optimising the locations of certain BMPs within a watershed zone in order to minimise challenges faced from Erosion and Flooding within the Edim Otop area. Terrain based analysis was used to interpret landforms and find suitable indicators that align with the characteristics of certain BMPs. The BMPs were community centered such that their implementation can be achieved with grass root effort and contributions. In that sense, the Community/Stakeholders were involved in making relevant inputs to the mapping process and their understanding of the concepts of watershed and the relevance of implementing the BMPs. In testing the effectiveness of the community centered approach, a success rate of 50% was achieved with a test group of fifty (50) persons just within a period of two (2) weeks. This shows that the approach can be sustainable. The approach of optimising BMP locations is promising and the methods adopted herein will need to be further tested on other watershed zones to ascertain the adaptability and scalability of the processes. Furtherance to this, it is believed that community understanding of these processes can be further improved by creating pictorial diagrams/maps to improve relatability of the concepts to reality.

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Biographical Notes

IDU Emmanuel Yahaya, MNIS, is a seasoned Geoinformatician with over 15 years of expertise in Land Surveying, Geographic Information System (GIS), Remote Sensing, and Statistics. Emmanuel has served as a consultant for the Nigerian Erosion and Watershed Management Project (World Bank Assisted), specializing in GIS and Mapping. In his current role as Chief Land Surveyor at the Federal Housing Authority, Emmanuel excels in training and mentoringand managing geospatial data for Federal Housing Authority Estates. His prior experience as Assistant Director Survey and Surveyor II at the Office of the Surveyor-General, Cross River State, involved monitoring geodetic networks, database updating, and conducting technical evaluations using GIS and statistical analysis.Emmanuel's extensive career also includes roles as a Part-Time Lecturer in GIS and Remote Sensing at the University of Calabar. He holds a Master's degree in Geo-Information Science and Earth Observation from the University of Twente, Netherlands, and a Bachelor's degree in Surveying and Geoinformatics from the University of Nigeria. Emmanuel is an active member of the Nigerian Institution of Surveyors and the Surveyors Council of Nigeria. His diverse skill set includes proficiency in GIS software, remote sensing and data quality control.

AGBONIKA Unekwuojo Pamela is a Geospatial Expert who has served with Nigeria's Regulatory body for Surveyors (SURCON) diligently for over fourteen (14) years rising from Higher Technical Officer to Principal Technical Officer. As a staff of SURCON, she was dedicated in assisting the Council achieve its mandate which is to regulate, control and uphold Professional Ethics and continually develop professionals that compare with their peers globally; particularly in coordinating matters that relate to the training of persons seeking to become registered as Surveyors as well as the enrolment and examination processes. Unekwuojo has passion for climate conservation and environmental protection and has been actively involved in community oriented programmes toward achieving sustainable development goals (SDGs). She is currently a Technical expert with the Federal Housing Authority on Survey and Land management. She was the first vice Chair for YSN, Nigeria and is currently an active member of Women in Surveying (WIS) and the Nigerian Institution of Surveyors (NIS). She is a registered Surveyor with Surveyors Council of Nigeria.