PROPOSED BIOENGINEERING METHOD FOR PROTECTING ROADSIDE SLOPE EROSION IN SUDAN BY APPLYING LOCAL PLANTS

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Abstract

The employ of plants for topsoil corrosion defense and ramp stabilized have an extended custom. Older techniques with astounding vegetation and construction of wood applied in the earlier period. Lately, these older soil preservation and stabilize methods rediscovered and better. Bioengineering—prevention techniques that turn into element of roadway manufacturing and building, it has assisted viaduct the missing knowledge among traditional technical fields, earth employs administration, scenery structural design, and environmental discipline. In this study, the study illustrating the opportunity of applying local plants to prevent the pavement ramp edge bank by employing diverse sorts of vegetation suggested. Local plants are capable of applying like an environmental technique be able to keep the roadside ramp bank corrosion in Sudan. The central part of this statement is a complete outline of the mainly significant Bioengineering prevention techniques that be able to employ and used for roadside bank corrosion defense and slope stabilizing. Engineering testing, reporting of soil experimentation, measures and the important compensation of employing local life spices and plants bio-prevention of the state highway ramp, and reconsider of employing plants the same as the botanicals. The methods discussed based on the results of the study. In considerations about the importance of Environmental-prevention and stabilizing of the public highway ramp soil at stating the study. The research concluded that some native vegetation could in protecting the highway embankment slope, and prevents the soil erosion due to intense rainfall in Sudan.

Keywords
Soil erosion, Bioengineering protection, Biotechnical, Vegetation, Local Species, Slope Stabilization.
Introduction
The most cost-effective and easy way of preventing soil erosion and developing slope stabilization is to apply of vegetation and species. The purpose of the methods in the stabilizing of the soil surface is establishing plant cover as rapidly as possible. The method can be accomplished by using vegetation with dense roots for sediment sources, minimizing soil erosion when it is available. Also, the preference is in the use of native vegetation. The local indigenous plant is usually cheap during the maintenance process. Also, it provides a harmonious and pleasing view of the surrounding natural landscape [1]. Searching and using the native species whenever possible is essential. The water conserved occurs naturally by cultivating the use of native species and plants. Native vegetation does not need supplemental irrigation because it can adapt to the intense local rainfall after it has established. The local grasses and other wildflowers are easy to maintain, and it adds seasonal colors to the landscape. Increasing biodiversity, reducing maintenance costs, natural resources conservation and helping benefit wildlife, by using the native vegetation in slope protection aids as a bioengineering method to prevent soil erosion for highway embankments [2]. It is essential to find and apply new techniques of avoiding the decay of the highway in Sudan. It can help reduce the victim’s numbers in highway accidents. These reasons above strongly encourage and suggest that this study is carried out. Protecting soil erosion due to wind and rainfall, by using vegetation [3], Roots reinforce the soil and add shear strength [4]. Enhancing stabilization of the slope, minimize runoff of surface water, decreases the risk of deep and shallow landslides [5]. Lately, native species can be employed to manage soil attrition in build highway bank [6]. Cover of vegetation provides a sustainable bio-prevention and natural eco-protection for slope and soil erosion due to an increase of rainfall intensity. Considerable attention is given to using native plants and species in applying on the roadside as optimal for controlling soil erosion nowadays. Plants have turned out to be an instrument in restoring the ramp material situation and increase the strength soil through the plant's roots [7]. It is essential this information put forth as plans for using vegetation as a sustainable bioengineering for covering highway slopes against erosion due to rainfall intensity. The core of this research paper based on focusing and studying the native vegetation in Sudan that can use for roadside embankment erosion. Study the site conditions such as environmental, characteristics of native vegetation, selecting the local plants and vegetation along with the diversity of soil erosion levels of the embankment slope for highways in Sudan at Gezira State. Next, make a comparison of roadside erosion between natural vegetation and non-vegetated slopes.

1 Materials and Techniques
2.1 Examine Site
The Studied roadside slope was situated in the middle of Sudan at the Gezira State, which it one of the central states in Sudan, is
the study site. This road is a part of the national highway. Linking between all the big cities and the capital city of Sudan: Khartoum. And it is the dangerous part of the federal road connection between Wad Medani (Capital of Gezira State) and Al Hag Abdullah. The importance of this road is transporting crops, products, and passengers; Figure 1 demonstrates the road site.

![Fig. 1 A: The general Sudan map. B: Location of the road in Sudan Gezira state.](image)

2.2. Description of the Site

The slope type of roadside embankment filled slope. Constructed of several selected materials to meet the design formation on the road, the road passing an agricultural area has a slope. The problem of this road is that there is no drainage system. Thus, it did not provide a site ditch to discharge the asphalt surface. And the height of the slope between 3.5 to 4.75 meters, slope angle in a range of 26 to 47 degrees. Figure 2 illustrates the geography of eroded road part of the road, a picture created by Google Earth.

![Figure 2 Shows the topography of road site](image)

2.3. The Problems of the National Roadside Slope

Based on the highway authority and the administration of traffic police in the Gezira State, during the autumn season makes parking on the roadside shoulder very dangerous. Embankment side slope materials affected by the rainfall intensity contribute to the problem of slope erosion. The victims of traffic accidents based on the records of the police administration are (7-8) people per year. The number of accident victims shows the essentials and the significance of the study. Solving and treating the slope side erosion is encouraged from doing this research. The study focused on the most eroded slope-longitudinal section 630 meters. Control erosion soils of
roadside embankment slope minimize the traffic accidents and reduce the number of victims. This study hopes to find the suitable native vegetation that can apply for controlling the slope soil erosion as a bioengineering method in Sudan. The eroded slope is shown in Fig. 2.

2.4. The Climate of the Site

The site, located in the Gezira State, the climate there is tropical. The characteristics of this environment are (Sudan Seasonal Monitor Evaluation Report 2012) [8]:

Monitoring of rainfall (percent of average) by 30 Jun 2017 illustrated in figure 4 in Gezira State based on readings from different as shown in Fig. 3. Months of rainy seasons (July to September), dry periods are short (December to January). The intensity of rainfall is raised in some state parts. Average of rainfall intensity is (360 to 380 mm) as in Sudan Meteorological authority 2012 report, which published on the website: www.tamsat.org.uk/bulletins/2012, Fig. 5 shows the diagram precipitation in mm and Average rainfall days. Detail of meteorological of Gezira state is shown in Fig. 6 as:

- Gezira rainfall intensity calculates from the monitor station to measure the precipitation analysis.
- Temperature: regular yearly greatest and lowest are 37°, 24°.
- Sun brilliance 7.6 to 11 hours /daylight.
- Dampness proportion 76 to 182%, reduced in the dried out period and arrives at 24-19%.
- Airstream: route of the storm as of south to southwest gust in hot time, in wintry weather blow from north to northeast and affect the decreased visibility the majority throughout the due to dust.

Fig. 3 Map of Gezira State shows the location of rainfall reading stations.

Table 1 Average of maximum (a) and minimum temperature degrees (b).

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree</th>
<th>Month</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>32.3</td>
<td>July</td>
<td>35.2</td>
</tr>
<tr>
<td>February</td>
<td>38.4</td>
<td>August</td>
<td>36.5</td>
</tr>
</tbody>
</table>

(a)

<table>
<thead>
<tr>
<th>Month</th>
<th>Degree</th>
</tr>
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<tbody>
<tr>
<td>January</td>
<td>14.6</td>
</tr>
<tr>
<td>February</td>
<td>16.1</td>
</tr>
<tr>
<td>March</td>
<td>14.2</td>
</tr>
<tr>
<td>April</td>
<td>22.2</td>
</tr>
<tr>
<td>May</td>
<td>24.8</td>
</tr>
<tr>
<td>June</td>
<td>25.3</td>
</tr>
</tbody>
</table>

(b)

Fig. 4 Total Rainfall (percent of average) by 30 Jun 2017

Average Rainfall (mm Graph for El Gezira)
Mohammed et al.,

Fig. 5 The diagram shows precipitation (mm) and average rainfall days, a: Average rainfall, (b): High and low temperatures, (c): Minimum temperature, (d): maximum temperature forecast for Thursday 23.11.2017

Fig. 6 Gezira state meteorological and climate data in Sudan is at the location 14°24’N, 33°29’E

This roadside (fill slope) erosion is one of the essential hazards facing Gezira State roads during intense rainfall. Many of the highways in Sudan constructed without a proper slope prevention, drainage system, highway bridges, and culvert protection. The category of Gezira State is rainy zone area [9].

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This slope is human-made (filled), and it can affect the rainfall intensity erosion [10]. Advantages of native vegetation for this slope erosion addressed in this study. This paper explores the suitable different native plants that can use for environmental bioengineering protection to stabilize the slope erosion in Gezira State (Sudan). Traffic accidents cause loss of human lives with eroding roadways, and the ecological impact creates more problems due to slope erosion. As known, rehabilitation and slope erosion control are very costly, which caused a natural disaster? Therefore, finding the suitable solution for preventing soil erosion is essential. The bioengineering method of slope restoration and erosion control is cost-effective and considered as a sustainable solution that can apply in developing a country like Sudan [11]. From the problem mentioned above, biological and bioengineering slope erosion control is the
suitable method. Building additional roads are one of the leading elements of accelerating economic growth. Therefore, to maintain the highway in excellent condition and continue to fuel economic growth, continuous improvements must be made in respect to soil erosion. During construction new roads the slope occurs, and there is a need to prevent the steep slope and stabilize it. Hence, the biotechnical protection of slopes refers to the stabilization of slopes using native plants [12]. It will be more cost-effective and more beautiful than mechanical structure methods for slope stabilization.

2.5. The Study Objectives
The primary target of this study is to select a suitable and best native plant species to plant on the surface of roadside embankment soil (filled slope), by providing using indigenous vegetation identification, categorization, and salient study features. The careful study of local plants around the project site for use as bioengineering methods for soil erosion will also implement.

2.6. Identification and type of the slope
In classifying soil, there have been many different techniques applied along with laboratory experiments. Particles Size Distribution (Grain Size) as shown in Table 4, Atterberg Limits Test, Water Content, and Field Soil Density as shown in fig. 7, [13]. Most of the experiments prepared in the Gezira university faculty of Engineering and Technology (Soil Laboratory).

2 Methodology
Carried out the procedure on this research addressed below. Followed the relevant works of literature cited in the study context and field survey (included site survey, native vegetation), and conducting soil.

3.1. Literature review
Reviewing works of literature and stating new and modern theories about reducing the risk of slope erosion caused by an intensity of rainfall are adopted as a new methodology cited in the study context and used to carry out this study. Literature review used live vegetation materials for ramp stabilize and corrosion manages as novel methodology [3].

3.2. Erosion and Infiltration
Understanding of how does vegetation occur? Ways of vegetation work as soil stabilized by applying mechanics of the root system inside soil; provide cover for the
ground which improves microclimate condition of the soil, therefore, protecting stratum counteract raindrops (rain splash) by adding the nitrogen from roots [14].

3.4. Vegetation Identification

Plant species determination and native vegetation, which exists on the surface topsoil of slope [16], should be identified by an expert on botany because some plant species are difficult to be recognized so it can be collected and take samples to check at a later date. Study the most natural native vegetation which already has grown around the site slope area should also consider.

3.5. Properties of the Plants

The salient selected plant properties are germination rate, height, lifetime, density, propagation, leaf shape, the ability of soil surface covering climate conditions, etc. The study also mentioned plant properties to select the proper type of native vegetation for cultivating in slope surface as a bioengineering method.

3.6. Vegetation Role in Controlling Soil Erosion

Mechanical or geotechnical techniques have the immediate effect of controlling soil erosion and operate the maximum efficiency of protection erosion [17], but construction and maintenance costs are high. Bioengineering method which used live vegetation is cheaper but has a smaller immediate effect. However, once plants established, they provide a self-perpetuating and increasing effective permanent solution of soil erosion control [18].

Infiltration and soil erosion created by rainfall factor makes soil on the slope more cumbersome because of the immediate exposition of soil superficies to raindrops. Surface runoff proportionally increases, and then the pressure of pore water increases by infiltration. Then the soil will be washed down to the land, causing what is called soil erosion. This type of intense rainfall erosion makes the roadside slope dangerous. Also, the outside soil of the ramp corrodes because of storms. In all cases, slope failure will occur. Protecting roadside embankment should be defended, and a cost-effective and sustainable method is bioengineering.

3.7. Protection of Slope Surface Erosion

The causes mentioned above of roadside slope erosion can be used to protect it by preventing infiltration which occurred due to rainfall; it can be accomplished by applying plaster of Shotcrete, using riprap, or building masonry blocks. But there is no aesthetic value and bioengineering will add a more beautiful landscape view and is cost-effective. Slope stability and vegetation interrelated by the ability of live plants growing on the topsoil. These plants will promote and provide slope stabilization [15]. The relationship of the rainfall intensity regime, soil, the present species of installation, the slope type and steepness is very complex. Combining the correct methods in selecting suitable native vegetation will aid in environmental bioengineering and preventing slope erosion.

3.8. Vegetation

As reported in recently up-to-date research data, plants showed how it is essential in the process of controlling soil
erosion and preventing failure of slopes. As for protecting erosion of soil surface against rainfall, wind, and the light of the sun, etc. Vegetation plays the primary role and that through the cover; it can use the root system which goes deep providing topsoil up to some depth. The significant ways of vegetation influencing stabilization slope:

1. Stop sediment blowing in the wind.
2. Water removal.
3. The vegetation mass and roots mechanical reinforce the soil by root system mechanism.

Plants are controlling the sediments and biodiversity maintenance. The energy of kinematic of raindrops is the leading cause of soil particle disturbance as shown in fig. 9 &10. Kinematic energy dissipated by the vegetation. And this the main advantage of soil erosion. Also, it grows rapidly and efficiently and does not need much maintenance.

3.9. Vegetation Survey

Through some visits of the road site vegetation types, properties, root system, plant locations can identify. The diverse vegetation types based on the slope height of the road. Must take some pictures of native vegetation in the relevant slope, data about each plant species such as name, root type, their climate condition, and the ability to cover the surface. All of this information can collect by interviewing the residents near the slope project area. Understanding Soil type is critical to the function of the slope stability: such as its age, the compaction, and how other essential features impact makes the central understanding of how vegetation will stabilize the slope in the future. Then data of native vegetation must be discussed with a specialist in botany science. Based on the local vegetation found at the site, the plants which have the highest density of their root
system will select to use in the ecological bioengineering protection method. The primary species of the investigation and surveying the site are Cynodon Dactylon and Vetiver as the best example [19], and some local plants shown in fig. 9.

### 3.10. Soil Classification

The soil of the roadside slope classified by conducting several experiments, the native vegetation is identified through some site visits and discussing with experts in botany. In the laboratory of Wad Medani Technological College WMTC as shown in fig. 12, wash sieve analysis for the grain size test done. As fig. 11 illustrated particle size distribution curves based on soil samples at each location. These are drawn using Excel software. Table 10 shows the USCS particle size distribution. Firstly, according to USCS method [13], from examples taken of the soil content, the quantities of gravel, sand, silt, and clay were estimated. Atterberg limits (liquid & plastic) tested of each sample of the soil determined in the laboratories of Wad Medani Technological College department of Civil Engineering. The field density test was completed at that the roadside site. In the lab, the hydrometer test shows the results in Table 9. Based on the experimental work results, the soil classified using AASHTO and US Department of Agriculture, USDA [20]; Table 2 shows the symbols used to identify the roadside slope soil. Secondly, the vegetation was selected based on the salient plant’s properties, and it did after surveying the native vegetation at the site of the slope to determine proper plant and species for use in the bioengineering method. Then would help in controlling the slope erosion with the description of vegetation and the vital information.

After calculating the results of soil, the experiments found percentages as follows:

74% of the total samples are soft soil, fine aggregates are 8.5%, and Course aggregates are 40%. Results of Plastic Limit and Liquid Limits as PI: 17%, PL: 32%, and LI: 50%. Following international codes and standards as unified Soil Classification, the soil of the roadside can classify as MH and OH.
Debate of Outcomes

5.1. Categorization of the Soil

According to soil elements predominant as aggregates, fine aggregate, and fine (silt & clay), it must call. From the results of the experiments, the grain size found as shown in Table 7. Moisture Content: WC = 22.1%. Using the method of Sand Cone for conducting field density, which found = 1.510 and dried out bulk = 0.939. Following international standards to classify using the results of experiments which done before, the finer percentage was > 50% and applying on LL and PL chart; the soil is MH based on the theory of [13].

5.2. Geotechnical Experiments

In this part, fundamental features of soil analysis will be detailed, describing the conducting soil experiments as water content as shown in Table 7. Field density, hydrometer test, sieve analysis and Atterberg limits (L.L & P.L) and provide all tables and diagrams related to this part. Table 1 shows Soil separated grain- size, and ceiling, Table 3 and Table 5.

Soil particle size distribution determined according to grain size (Sieve Analysis). And passing size the amount for every element as Course aggregates, fine aggregates, and finer shown in Table 6, this also, based on two international standards (USCS & USDA) [13 & 14] shown in Table 2 & 3.

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>USCS</th>
<th>USDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Gravel</td>
<td>18%</td>
<td>26%</td>
</tr>
<tr>
<td>Sand</td>
<td>39%</td>
<td>32%</td>
</tr>
</tbody>
</table>
Many Geotechnical organizations tried to put a limit size of gravel, sand, silt, and clay based on which soil grain size included. In Table 3 size limit recommended by American Highway and Transportation Officials (AASHTO) and USCS and Corps of Engineers, Department of Army and Bureau of Reclamation as in Table 3.

**Table 3 International standards for the soil - separate Size Limits according to USCS.**

<table>
<thead>
<tr>
<th>Classification System</th>
<th>Grain-Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USCS</td>
<td>Gravel: 75 mm to 4.75 mm</td>
</tr>
<tr>
<td></td>
<td>Sand: 4.75 mm to 0.075 mm</td>
</tr>
<tr>
<td></td>
<td>Silt &amp; Clay (fine): &lt; 0.002</td>
</tr>
</tbody>
</table>

Assessed soil engineering properties like sieve analysis and other soil indexes (plasticity, shear strength, compressibility, and Atterberg Limits) by proper laboratory tests [22], as in Table 4 showing the results of the sieve analysis test for the roadside embankment slope.

**Table 4 Results of the conducting Sieve Analysis test.**

<table>
<thead>
<tr>
<th>Sieve no.</th>
<th>Sieve Opening (mm)</th>
<th>Mass: sieve (g)</th>
<th>Mass: sieve + retained soil (g)</th>
<th>Retained soil %</th>
<th>Cum. retained soil %</th>
<th>Passing %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3&quot;</td>
<td>75.0</td>
<td>1057.0</td>
<td>1057.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>1.5&quot;</td>
<td>37.5</td>
<td>1084.0</td>
<td>1084.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>1&quot;</td>
<td>25.0</td>
<td>1187.0</td>
<td>1187.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>19.0</td>
<td>716.0</td>
<td>716.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>½&quot;</td>
<td>12.5</td>
<td>584.0</td>
<td>584.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>3/16&quot;</td>
<td>9.5</td>
<td>508.0</td>
<td>508.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>4.75</td>
<td>570.0</td>
<td>577.0</td>
<td>1.0</td>
<td>1.3</td>
<td>98.3</td>
</tr>
<tr>
<td>No. 8</td>
<td>2.36</td>
<td>390.0</td>
<td>399.0</td>
<td>9.0</td>
<td>1.1</td>
<td>97.1</td>
</tr>
<tr>
<td>No. 16</td>
<td>1.18</td>
<td>313.0</td>
<td>325.0</td>
<td>12.0</td>
<td>1.5</td>
<td>94.4</td>
</tr>
<tr>
<td>No 30</td>
<td>0.6</td>
<td>287.0</td>
<td>303.0</td>
<td>16.0</td>
<td>2.0</td>
<td>76.4</td>
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<tr>
<td>No 100</td>
<td>0.15</td>
<td>261.0</td>
<td>281.0</td>
<td>22.0</td>
<td>2.5</td>
<td>87.4</td>
</tr>
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<td>No 200</td>
<td>0.075</td>
<td>424.0</td>
<td>425.0</td>
<td>1.0</td>
<td>0.1</td>
<td>87.3</td>
</tr>
</tbody>
</table>

In the soil moisture condition, liquid and plastic limits and shrinkage limit conducted to determine the situation of the liquid boundary of the site soil is shown in fig. 13. The test depends on the following chart of liquid plastic limit is given in Figure 8.

**Figure 13 Soil moisture conditions & Plasticity condition for determining soil type**

Water content is a critical factor in soil classification. Usually, expressed in percentage [13 - 22], as in Table 5. Laboratory
tests give a precise method for determining water content as in Table 5 stated the water content percentage results of soil for the roadside slope soil.

### Table 5 Moisture content result

<table>
<thead>
<tr>
<th>Number</th>
<th>Empty Cont.</th>
<th>Cont. + Wet Dirt</th>
<th>Cont. + Dried up Dirt</th>
<th>Moisture</th>
<th>W2 – W3</th>
<th>Test Weight (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W1</td>
<td>W2</td>
<td>W3</td>
<td>W2 – W3</td>
<td>0.012</td>
<td>0.134</td>
</tr>
</tbody>
</table>

**Equation:**

\[
W = \frac{W_2 - W_3}{W_1}
\]

To determine the finer allocation by conducting wet analysis by using the hydro analysis as illustrated in Table 6, the test experiment for the fine course soil from the road site, the test is conducted to provide the small particles of soil as a grain-size distribution. Table 6 illustrates the wet analytical test results for the finer-grain size of the roadside embankment soil.

### Table 6 Wet analysis test results in readings of fine soil

| Elapsed Time (min) | Actual Hydro meter readings | Corrected Hydro meter readings | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Fine Combine (%) | Fine (%)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>1.0325</td>
<td>1.0306</td>
<td>7.7</td>
<td>0.129</td>
<td>0.0506</td>
<td>97.85</td>
<td>83.37</td>
</tr>
<tr>
<td>0.5</td>
<td>1.0325</td>
<td>1.0306</td>
<td>7.7</td>
<td>0.129</td>
<td>0.0506</td>
<td>97.85</td>
<td>83.98</td>
</tr>
<tr>
<td>1</td>
<td>1.0310</td>
<td>1.0301</td>
<td>8.10</td>
<td>0.129</td>
<td>0.0260</td>
<td>93.05</td>
<td>81.19</td>
</tr>
<tr>
<td>2</td>
<td>1.0310</td>
<td>1.0291</td>
<td>8.10</td>
<td>0.129</td>
<td>0.0164</td>
<td>93.05</td>
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<td>1.0291</td>
<td>8.10</td>
<td>0.129</td>
<td>0.0116</td>
<td>93.05</td>
<td>81.19</td>
</tr>
<tr>
<td>10</td>
<td>1.0305</td>
<td>1.0291</td>
<td>8.23</td>
<td>0.129</td>
<td>0.0083</td>
<td>91.45</td>
<td>7.79</td>
</tr>
<tr>
<td>20</td>
<td>1.0300</td>
<td>1.0291</td>
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<td>0.129</td>
<td>0.0068</td>
<td>89.85</td>
<td>78.80</td>
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<tr>
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<td>1.0290</td>
<td>1.0281</td>
<td>8.63</td>
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<td>0.0069</td>
<td>86.66</td>
<td>75.61</td>
</tr>
<tr>
<td>60</td>
<td>1.0275</td>
<td>1.0271</td>
<td>9.03</td>
<td>0.129</td>
<td>0.0050</td>
<td>81.22</td>
<td>70.86</td>
</tr>
<tr>
<td>1440</td>
<td>1.0270</td>
<td>1.0254</td>
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<td>0.0010</td>
<td>80.26</td>
<td>70.03</td>
</tr>
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<td>1.0070</td>
<td>1.0251</td>
<td>14.45</td>
<td>0.129</td>
<td>0.0022</td>
<td>13.75</td>
<td>12.00</td>
</tr>
<tr>
<td>1440</td>
<td>1.0060</td>
<td>1.0043</td>
<td>14.71</td>
<td>0.129</td>
<td>0.0013</td>
<td>10.55</td>
<td>9.21</td>
</tr>
</tbody>
</table>

### 5.3. Chemical Experiments

For the soil of the roadside slope, chemical components (Nutrient data) were collected to determine the soil fertility situation. It can help to identify what grasses or species can use in the future for bioengineering method of slope erosion protection. The chemical tests are done at the University of Gezira. In accord to select the proper plants, there was a productive discussion with some experts in botany from the University of Gezira. Table 13 shows the chemical test and soil nutrients, fertility of important soil factor to improving the plants and spices growth. A chimerical element for the site the Organic Matter is 4.5%, Nitrogen is 0.35%, Potassium is 3 ppm, and Calcium is 0.55%, Ph of 7.5.

### 5.3. Identification Plants and selection types

After surveying the site at the roadside, in
the slope surface were found some common native plants common to the site area. The density of the vegetation noticed was Cynodon Dactylon. Its roots have significant importance in increasing soil reinforcement by adding additional shear strength, and shallow soil stability enhancing. Other plants originated close to the site, vegetation which has poor root mass will be absent. The vegetation which was a most prosperous root density was Cynodon Dactylon and Vetiver [18] & [23], this can produce fast-grow species.

Other observed native vegetation was a boundary, which will be easy to analyze. Plants and shrubs originate in the sloping site area were:

(1). Mesquite, which has some benefits in contributing environmental stability through dunes, windbreakers, hedging, shelterbelts round villages, and in additional contributing soil conservation [24 - 25].

(2). Cassia Angustifolia, which grew in the zone of low-intensity rainfall [26].

(3). Striga Harmonica as in [26], in Sudan, known in some other African countries, it is classified as a harmful plant [27], as shown in Figure 14.

Based on data on the vegetation density, grass and shrubs were selected for bioengineering method on the roadside slope erosion control as Cynodon Dactylon is grass and can cover the soil surface; it has a deep creeping root system. Cassia Angustifolia is plant also has deep creeping roots and can cover the soil surface, and Striga Hermontica is small bushes, has fibrous Root and can cover the soil surface too. And Vetiver or Indian grass has massive deeply fibrous Root and achieve good soil surface cover.

Hence, the native plants identified according to the soil classification, which was conducted based on studies by the USCS. Soil types found were MH or OH from the result laboratory tests. Slope angle ranged from 26 degrees to 47 degrees, and in some parts of the longitudinal section of the roadside, the slope reached 60 degrees. Depending on meteorological data about general climate, rainfall intensity, temperatures, and humidity, also on experimental soil works which had done, the site investigation and survey studies about native vegetation and local plants. All data mentioned above, the study recommended using the chosen vegetation mentioned before to be the plants used in environmental bioengineering roadside ramp control. These were the best choices to
control the erosion due to intense rainfall, fig. 15 A: proves the slope which covered with local plants has less soil erosion, B: shows a future restored of the roadside using bioengineering method.

![Image](image-url)

Figure 15 A: Some parts of the road that have natural vegetation show less erosion due to the rainfall intensity. B: Proposed application of the vegetation on the road slope.

3 Conclusion and Recommendations

According to the results discussed, the paper concludes the following:

1- Design the drainage system along the national road to control the surface water, maintain the eroded parts of the street.

2- In spite of no diversity plants, this research proves that some local vegetation growing on the sloping site can be used in the environmental bioengineering protection against the erosion due to the intense rainfall in autumn, causing erosion.

3- The study, based on experimental works, site investigation, meteorological data, the chemical elements of the soil, soil tests and indexes, shows that some native vegetation such as Cynodon Dactylon, Vetiver, and Cassia Angustifolia can use in slope protection and stabilization. These plant root systems work as reinforcement the soil. As it is a new method to help increase the slope stability and prevent soil erosion.

4- Protection of sedimentation soil can achieve by using vegetation. Also, many benefits of using bioengineering method beside it can improve the landscape, improve rainfall intensity corrosion (meteorological situations), and restore soil conservation.

5- Applying ecological and bioengineering method can decrease the
victim’s numbers of traffic accidents occur during autumn.

The study recommends extension research papers on the same topic of this article to achieve a new understanding of the benefits of eco-protection for soil and slope stabilization in Sudan.

6- Make expanding research papers for the results above and open the ecological protection studies for other researchers for adopting the environmental slope protection in Sudan Highway construction.

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Authors Contribution

AL contributed in prepared and write the manuscript, collect the field data, write and review the final draft of this study. XW shared the review of the study, financial support. DY supported the technical sequence and proofreading this study. XZ organize the final draft of the paper.

Competing interests

The authors declare that the funding provided did not lead to any conflicts of interest regarding the publication of this manuscript.

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