Using Sorghum Stalk as a Partial Replacement of Lime in the Stabilization of Red Clay Soil for Road Sub-Grade Construction

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Research Article

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Abstract

This research aimed at testing the viability of using Sorghum Stalk Ash (SSA) as a partial replacement of lime in the stabilization of red clay soils for road subgrade construction. Red clay soils have been identified as highly expansive soils, which are affected by both climatic conditions and loading patterns. The consideration of both traffic loading patterns and climatic effects on these soils has been taken into account. A penetration test of 2.5mm has been used on both pure red soils and stabilized soils at 10% and 15% partial replacement of lime with SSA and showed an improvement in the CBR of stabilized red clay soils up to 11.6%. Again, the PI of stabilized soils at 15% partial replacement of lime reduced up to 11.2%. The results obtained on both CBR and PI of these red clay soils are within the recommended values for the effective subgrade required for laying both permanent and flexible pavements. As a result, a recommendation of making use of SSA to lower the quantities of lime and its costs used in the stabilization of highly expansive soils have been tested through this research. However, further research on a more percentage partial replacement of lime to improve the PI of these soils to below 10% while keeping the CBR levels within the road construction regulations is welcomed. Therefore, the use of sorghum stalk plant parts in this study complies with international, national, and institutional guidelines regarding the properties of an effective pozzolana material.

Chapter 1: Introduction

A. Background Information

Soil is one of the most abundant naturally occurring construction materials. However, before it can be used in any construction practice, an understanding of its properties should be made to help avoid construction errors, which would be costly in both efforts and materials. The suitability of soil for a particular construction use should be determined based on its engineering characteristics. In most cases, weak and highly susceptible soils need different improvement practices to meet the Geotechnical properties required for a specific project.

Soil improvement can be achieved by properties modifications or stabilization, or through both practices. Soil modification involves adding modifiers in form of lime, cement, etc. to a weak soil to change its index properties, while soil stabilization involves the treatment of soils to enable their strengths and durability to gain an improved dimension; such that they become effectively suitable for construction beyond their original classification.

Different research types concerning soil stabilization with additives like cement, lime, bitumen, and polymers have already been extensively carried out. However, in recent years, a recommendation on the use of various waste products in civil engineering construction practices has gained considerable attention, taking care of principal material shortages and the high cost of conventional construction materials. Again, an increased cost of waste disposal and various environmental constraints have posed a big question on the re-use of these waste products. As a result, waste products with construction engineering material properties have been proposed for use in engineering works.

Sorghum Stalk Ash (SSA) is one of the waste products that has been mentioned with the potential to be used for the stabilization of soils for road construction. When burnt, the resulting Sorghum Stalk Ash (SSA) contains a high percentage of siliceous compounds, making it an excellent material for road construction.

B. Problem Statement

The increased vast lands covered by red soils susceptible to collapse have created a need for their stabilization. Over the years, lime has been one of the main materials used for soil stabilization to improve the engineering properties of soils. However, the cost of lime has rapidly increased over time, making road sub-grade realization expensive. As a result, there is a need to introduce other materials such as SSA to partially replace the quantity of lime needed to stabilize red clay soils for road sub-grade construction.

C. Problem Justification

The cost of the Marua-Nyeri road exceeded the planned 200 km budget. The stabilization process on the vast portions of Red Cotton soils with lime has contributed to this high cost, asking questions on what viable material to adopt to cut these costs.

Investigating the viability of SSA as a partial replacement of lime in the stabilization of red clay soils would help reduce these road sub-grade construction costs. Sorghum stalks are cheap and sometimes in big heaps at farms. However, the cost perspective goes behold investigate whether the quality of the road subgrade is not affected due to the reduction of the lime quantity in the stabilization process. Therefore, both quality and economy would be of aim in recommending SSA as a viable material for partial replacement of lime in red clay soil stabilization processes.

D. Objectives

i. General Objective

To investigate the viability of using sorghum stalk ash (SSA) as a partial replacement of lime in the stabilization of red clay soil for road subgrade construction.

ii. Specific Objectives

- To determine the effects of SSA on the California Bearing Ratio (CBR) of the red clay soil;
- To determine the effects of SSA on the Plasticity of red clay soils;
- To determine the effect of SSA on the plastic limit of the red clay soils;
- To determine the effects of SSA on the liquid limit of the red clay soil.

Chapter 2: Literature Review

A. Introduction

Sub-grade soils are a very essential component of road pavement and as such, inadequate sub-grade performance is the cause of most premature pavement failures. The quality and stability of a subgrade is a major factor responsible for adequate performance and service of the road during its lifespan. The physical properties of the subgrade soils determine the total thickness requirement of the pavement structure which bit supports and the life of the structure in good working condition. Generally, sub-grade performance depends on three basic characteristics:

a. **Strength**: The subgrade must be able to support the loads transmitted from the pavement structure. This load-bearing capacity is often affected by the degree of compaction, moisture content, and soil type. A sub-grade having a CBR of 10 or greater is considered essential and can support heavy loads and repetitious loading without excessive deformation (Spangler, 1982).
b. **Moisture Content**: Moisture tends to affect a number of subgrade properties, including load-bearing capacity, shrinkage, and swelling. Moisture content can be influenced by a number of factors like drainage, groundwater table elevation, infiltration, or pavement porosity. Generally, excessively wet subgrades will deform under load, according to Adlinge & Gupta, (2013) on pavement deterioration and its causes.
c. **Shrinkage and/or swelling**: Some soils shrink or swell, depending upon their moisture content. Soils with excessive fine aggregates may also be susceptible to frost heave in northern winter climates. Shrinkage, swelling, and frost heave tens to deform and crack any pavement type constructed over them. For both a temporary access road and a permanent road built over a soft subgrade, large deformations of the subgrade will lead to deterioration of the paved or the unpaved surface.

Clay subgrades, in particular, may provide inadequate support, especially when saturated. Soils with significant plasticity may also shrink and swell substantially with changes in moisture content conditions. As a result, a shift or heave on the pavement may be experienced, leading to a significant change in the density and strength of the subgrade. Therefore, stabilizing these weak soils with different materials like geopolymers (Phetchuay et al., 2014), lime (Ogundipe, 2013), and cement-related materials (Ardah, Chen, & Abu-Farsakh, 2017); has been proposed.

B. Stabilization of Road Pavements

Stabilization of road construction materials arises from the lack of good quality to a desire to reduce material usage by reducing the thickness of the pavement layers. The fragile economy of the developing nations also would be protected by achieving a cost-saving activity. Therefore, achieving a durable problem-free pavement that will last for its intended design life at a most economic life guides modern engineers.

The cost savings associated with stabilization can take many forms such as reduced construction costs, reduced maintenance costs throughout the life of the pavement, or even an extension of the normal pavement life. Again, the location of effective materials for road construction has become increasingly difficult because conventional high-quality materials are being depleted daily. Furthermore, the excavation of weak soils and the creation of their deposits adds more costs to the construction process. Therefore, identifying alternative materials for construction or ways of reducing construction practices would boost the economy and maintain the lifespan of different established engineering structures like road pavements.

Spangler (1970) discussed that it is essential for highway engineers to develop a subgrade with a CBR value of at least 10 for roads, streets, and parking areas. As a result, if a subgrade has a CBR value of less than 10, the sub-base material will deflect under traffic loadings in the same way as the subgrade; causing pavement ineffectiveness and deterioration with time. As a result, soil stabilization of different forms has been recommended to achieve this stated CBR value.

Not all materials can be successfully stabilized. For instance, when cement is used as a stabilizer, then sandy soils would be more likely to yield satisfactory stabilization results than clay or other soft soils. Therefore, testing on both the material to be stabilized and the stabilizing material is paramount. As a result, this research recommended sorghum stalk ashes (SSA) that have not been applied before and exhibit similar lime properties for the soil stabilization process.

C. The Role of Stable Subgrade

A well-stabilized soil plays an integral part in the road pavement by providing adequate support, and good drainage of rainwater percolating through the road pavement. The stable soil has a substantial impact on the base and the subsurface drainage requirements and on long-term pavement ride quality, overall performance, and stability. Therefore, the stabilization process of the subgrade layer aims at evading the vulnerability to failure aspects of these soils under the vehicle traffic loading due to the non-uniform distribution of the load from overlying layers and the presence of high moisture content. Ironically, the subgrade layer gets less emphasis compared to other layers, in spite of many pavement failures occurring due to inadequate bearing capacity within this layer.

D. Stabilization Processes on Red Clay Soils

Red clay soils have been classified as a form of highly expansive soils. These soils have been identified as highly susceptible to failures under loads. They are characterized by their high swelling aspects due to wetting, shrinkage due to drying, and a decrease in strength and bearing capacity; leading to cracking. However, with extensive areas in the world covered by these types of soils, engineering construction practices have been greatly affected. The stabilization processes have been recommended, as the activity carried out in the realization of the Marua-Nyeri road in Kenya.

Stabilization types are different and depend on the form of stability to be achieved as well as the costs incurred in each chosen practice. Again, the process may involve mechanical (force application) and chemical injections. These soil stabilization processes are classified as mechanical stabilization, cement stabilization, lime stabilization, and pozzolanas stabilization.

Mechanical soil stabilization is achieved without the application of any chemical practices. A different material is added to existing weak soil to improve the grading or decrease the plasticity of the original material. The blending of two or more materials could be carried out at the construction site, central plant, or a borrow area and then spread and compacted to required densities through conventional methods like the application of heavy construction equipment. Only physical modifications of the stabilized soils will be achieved but no wear would be experienced since no chemicals would be applied, the process is time-consuming, expensive, and difficult to achieve due to desired physical modification targeted.

Chemical soil stabilization processes involve the application of secondary manufactured materials into weak soils. This covers both cement, lime, and pozzolana stabilization processes. The presence of moisture in the weak soil plays a role in activating the stabilizing factors in these chemical components. For instance, the addition of cement to the soils, in the presence of moisture, produces hydrated calcium aluminate and silicate gels, which then crystalize and bind the soil particles together. Cement stabilization has been greatly applied on sandy soils or soils with less clay soil particles or properties.

Lime stabilization involves the addition of lime to the soil to trigger an exchange of cations that eventually results in the decrease of the plasticity of the soil. Lime is produced from chalk or limestone by heating and combining with water. Lime is of different types like Calcium Oxide (CaO) (quick lime), Calcium Carbonate lime ($CaCO_3$), and Slaked or hydrated Calcium Hydroxide lime ($Ca(OH)_2$). Lime stabilization has been found effective on materials that contain clay for a positive reaction to take place. Again, quick and slaked limes have been used as stabilizers in road construction processes.

In the absence of cement and lime, an application of pozzolanas has been adopted. Pozzolanas have been identified to contain siliceous or aluminous materials, which in the presence of water (moisture) and calcium hydroxide will form a cemented product of great and improved strength. Different pozzolana materials like silica fumes, fly-ashes, banana skin ashes, and sorghum stalk ashes have been applied in places of cement and lime for the stabilization of different types of soils. These pozzolanas can be used independently or in combination with lime if the material does not contain adequate silica or aluminum components. The resulting compounds of either calcium silicate or aluminate hydrates act as stabilizers in improving the soil's plasticity.

E. Research Gap

The use of fly ash, plastics, and rice husks as partial engineering materials has been studied and published. For instance, Alhassan (2008) studied the possibility of using rice husks in the stabilization of natural soils. The presence of silicates in rice husks recorded an increase in the soil's CBR and unconfined compression values. The moisture content in the soils was used to activate the pozzolana properties in the rice husks.

Stabilization of weak soils to improve their load-bearing capacity has been carried out continuously. Clay soils, black cotton, and highly expansive soils, which are susceptible to heaves, swelling, shrinkage, and subsidence have been targeted. As a result, different materials have been applied to better the strength, stiffness, and durability of pavements realized on these soils. There exists a substantial history based on the use of admixtures as soil stabilizers. Sorghum stalk ashes (SSA), identified in this research, have been the basis of improvised lime for the soil stabilization process, which has not been identified by past research. The presence of silicates in these ashes would target in using the high moisture content in red clay soils to activate its pozzolana properties, which would lead to a decreased maximum dry density of the soils and improve its CBR. As a result, an identification of the partial replacement of lime in the stabilization process was the aim.

Chapter 3: Methodology

Introduction

Sorghum Stalk Ashes (SSA) have been identified as a pozzolana material. However, activating the prepared component of its properties would be required to ensure an effective test of its stabilization effectiveness on red clay soils would be required. The research process took this path in identifying the viability of using SSA as a partial replacement of Lime in the stabilization of red clay soils.

A. Preparation of SSA

Sorghum stalks were obtained from Tigania West in Meru County in Eastern Kenya (can also be obtained from any other region). The stalks were burnt in a furnace at around 550^0C for around two hours. The obtained SSA was crushed into very fine particles.

B. Soil Sample

Red clay soil samples used in this research identification were obtained from Nyambene Hills near Maua town. A similar soil was identified vastly along the Marua-Nyeri road that caused a hike in the budget for the construction of the 200km road.

C. Tests and Objectives’ Satisfaction

The research followed to determine:

i. The effect of SSA on CBR of red clay soil;
ii. The effect of SSA on the Plasticity Index of red clay soil.

In order to achieve these objectives, the following tests were carried out from the preparation of SSA to the application to the target soil types and the change of properties identified.

i. Sieve analysis;
ii. Atterberg limits for pure and SSA + Lime stabilized red clay soils;
iii. Standard Proctor Compaction test for pure red clay soils;
iv. CBR tests for pure and SSA + Lime stabilized red clay soils.

For the clarity of the results, a pure red clay soil sample was used as a control experiment. The improved soils consisted of various levels/percentages of SSA that led to obtaining the optimum effect on CBR and PI of red clay soil.

The tests identified here were carried out as discussed by Polidori (2007), Rehman, Khalid, Farooq, & Mujtaba H. (2017); amongst other researchers.

Chapter 4: Results, Analysis, And Discussions

Introduction

Improving the mechanical properties of red soils carried from achieving improved physical properties. The sieve analysis on pure and SSA-added red clay soil was used as a process of improving the physical properties of this soil.

Pure red clay soils were tested and their respective results were found as shown in the table below:

TYPE OF EXPERIMENT	VALUE
Maximum dry density (MDD)	1275kg/m3
California bearing ratio (CBR) at 100% MDD after four day's soak	7.75%
Optimum moisture content (OMC)	36.4%
Plasticity index (PI)	32.8
Linear shrinkage	15.4%
Swell 4 day's soak	0.655%
Greatest particle size	Not greater than 10mm
Organic matter content	0.48%
Grading modulus	1.58
Coefficient of uniformity	7
Coefficient of gradation	1.29

Summary of laboratory test results for neat red clay soil

Each test produced the discussed results.

A. CBR Test Results

- At 2.5 mm penetration, pure red clay exhibited a CBR of 7.75%. The value was lower than the prescribed (at least 10%) for an effective subgrade material for use in pavement construction. However, it improved to 9.1% at 5% partial replacement.
- At 10% partial replacement of Lime with SSA in the stabilization process and at 2.5 penetration, a CBR of 10.3% was recorded.
- At 15% of partial replacement of Lime with SSA, a CBR value of 11.6% was recorded and adapted for the conclusion of this research.

B. PI Test Results

- At similar moisture content, 32.8% of 250g pure red clay soil attained its plastic characteristics, which gradually improved to 23.6% at just 5% partial replacement.
- At 10% partial replacement of lime with SSA added to red clay soils and maintaining similar moisture content, 13.9% of 250g improved soil attained its plastic characteristics.
- At 15% partial replacement of lime with SSA to the improved soils and maintaining similar moisture content, 11.2% of 250g improved red clay soil attained its plastic properties.

Discussion

The partial replacement of lime with SSA up to 15% partial replacement showed an improved CBR and PI value record. While the recommended PI of below 10% was not achieved in this process for an effective subgrade material, CBR has been taken to play an important soil in the design of traffic loads imposed on pavement layers. As a result, SSA – as a pozzolana material, when used up to 15% levels with lime, would effectively play a lime-pozzolana stabilization role on subgrade pavement layers.

Chapter 5: Conclusion & Recommendations

CONCLUSION

SSA is a pozzolana material that contains high deposits of silicates when well furnished. Its realization does not depend on the growth place or pattern of the sorghum. The SSA applied in this research does not restrict the place of acquisition.

The silicate in the SSA has been found to combine with an 85% of the usual slaked lime used in the lime stabilization process to form calcium hydroxide silicate, which greatly contributes to the improvement of the plasticity index of red clay soils. While lime itself has been used for this stabilization process, the costs incurred have been hefty due to its cost. The acquisition of sorghum stalks and the preparation of SSA is cheap and the 15% partial replacement of lime, without affecting the chemical stabilization properties, would play in favor of engineering construction realizations. Therefore, the pozzolana properties in SSA, when activated effectively, would serve with lime in the stabilization of red clay soils in vast regions of the world today.

RECOMMENDATION

Different materials contain various levels of silicates and aluminum that would play the pozzolana roles in natural soil stabilization processes. Again, different parts of plants contain varied levels of these pozzolana components. As a result, this research recommends:

- Testing of the viability of using Egg-Shell Powder (ESP) as a full and partial replacement of cement or lime in the stabilization of highly expansive soils.
- Resting on the viability of using Sorghum Root Ashes (SRA) as a full and partial replacement of lime or cement in the stabilization of weak soils.
- Identifying the various ways of overcoming expansion and contraction due to weather effects on plant-based pozzolana materials (Ramadan, Ghanem, Khatib, & Elkordi (2022)

Declaration

I, the author is this article, declare no competing interest.

NB: All data generated or analyzed during this study are included in this published article [and its supplementary information files are attached as a link in the Appendix].

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Appendix

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Figures

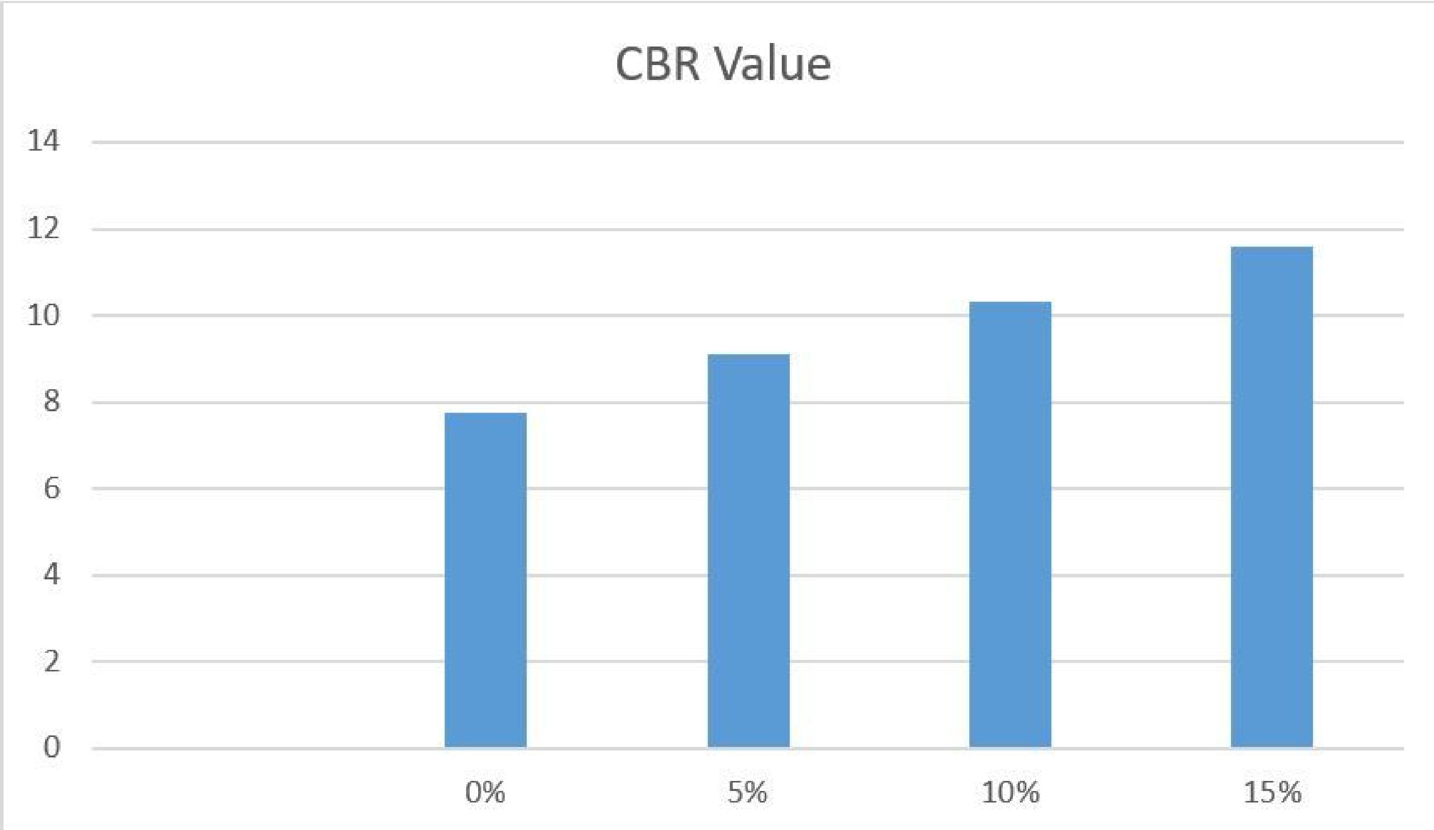

Figure 1

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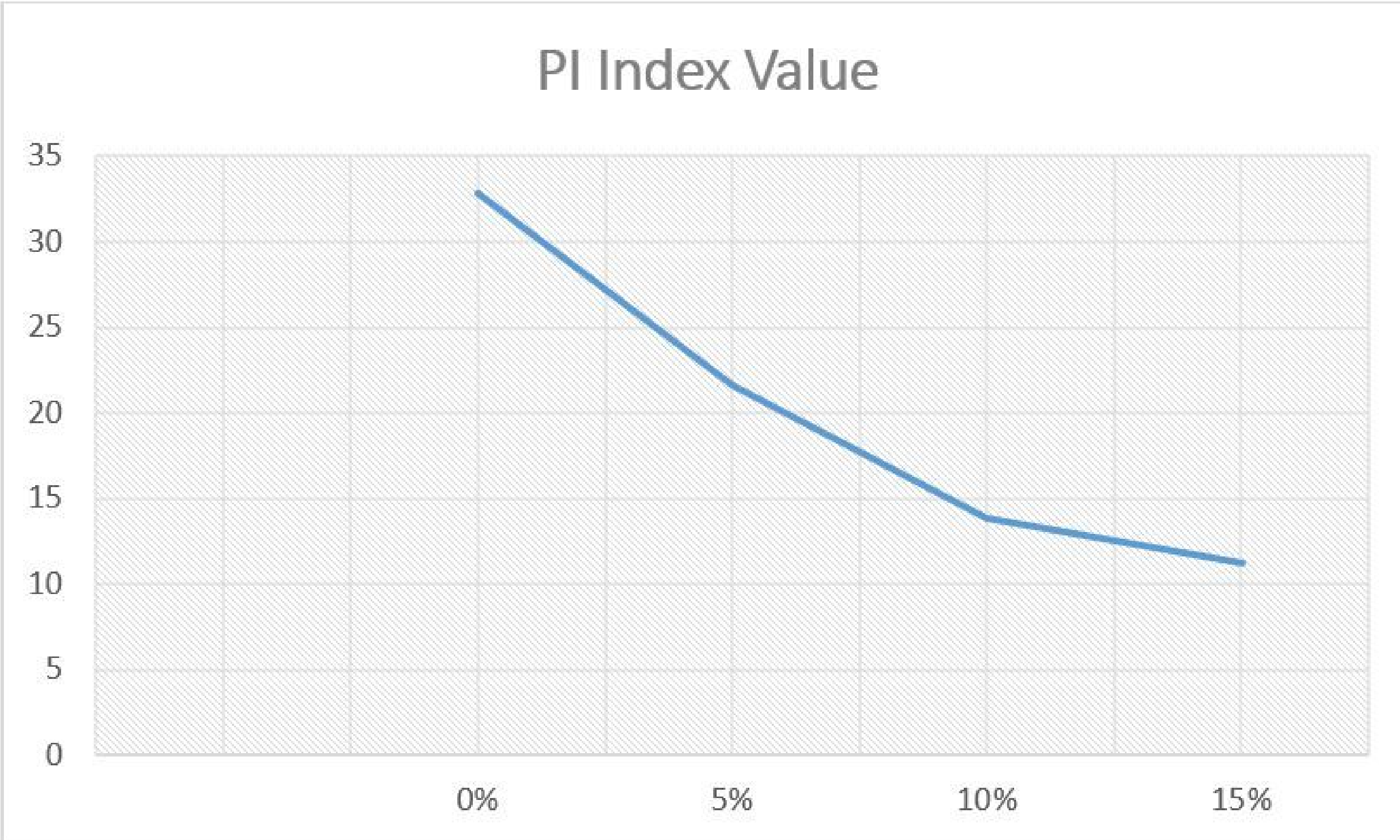

Figure 2

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