ANALYSIS OF GROUNDWATER TABLE FLUCTUATION IMPACT ON THE SLOPE STABILITY DESIGN OF DISPOSAL XYZ AT PT. BUKIT ASAM TBK. WITH MORGENSTERN-PRICE METHOD

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ABSTRACT : *Disposal areas are critical components in open-pit mining as designated locations for overburden placement; therefore, ensuring slope stability is essential. This study evaluates the impact of groundwater table (GWT) fluctuations on the safety factor (SF) of slopes at Disposal XYZ of PT Bukit Asam Tbk. The research utilizes primary data obtained from groundwater level measurements in monitoring wells and secondary data including slope geometry and geomechanical properties of the material. Analyses were conducted using GeoStudio (Seep/W and Slope/W) with the Morgenstern–Price method. The results indicate that increasing GWT elevations significantly reduce the SF. For the F–F' cross-section, the SF ranges from 0.970 under saturated conditions to 1.647 at a GWT depth of 18.87 m, while for the D–D' cross-section, the SF ranges from 1.018 (saturated) to 1.787 at a depth of 2.10 m. These findings demonstrate that a shallower GWT leads to reduced slope stability. Technical recommendations include the development of surface and subsurface drainage systems, real-time GWT monitoring, and revegetation to maintain stable conditions.*

Keywords: Groundwater table, Slope Stability, Safety Factors, Disposal, Morgenstern-price

1 Introduction

PT Bukit Asam Tbk. is a state-owned enterprise engaged in coal mining, located in Muara Enim Regency, South Sumatra Province, with a Mining Business Permit (IUP) area of 66,414 hectares. Open-pit mining activities generate overburden material that must be placed in designated areas known as disposals. The design of disposal areas must consider geotechnical aspects to ensure operational safety and prevent disruptions to mining activities [1].

A disposal serves as a storage area for waste material in open-pit mining. Therefore, its construction must be integrated into the overall mine planning process [2]. An effective disposal design must follow established geometric and geotechnical parameters to ensure that it accommodates production requirements while remaining safe for field implementation [3].

In early 2025, a landslide incident occurred in the Disposal XYZ area following several consecutive days of heavy rainfall. This event disrupted mining operations. External factors, particularly fluctuations in the groundwater table, can trigger increases in pore-water pressure and reduce soil shear strength, ultimately affecting the slope safety factor [4].

Previous studies have demonstrated that groundwater table fluctuations significantly influence the stability of coal mine slopes [5]. As water infiltrates through soil pores and fractures, saturation gradually increases, leading to a reduction in shear strength—one of the key factors contributing to slope failure.

National regulations also govern minimum slope safety factor requirements in mining operations, as outlined in the Ministerial Decree of Energy and Mineral Resources No. 1827 K/30/MEM/2018 [6].

Based on these considerations, this study is conducted under the hypothesis that an increase in the groundwater table will significantly reduce the safety factor (SF) of the disposal slope, thereby increasing the potential for instability when the groundwater level is close to the surface or in a saturated condition. Therefore, I conducted this research with the title: “Analysis Of Groundwater Table Fluctuation Impact On The Slope Stability Design Of Disposal At Pt. Bukit Asam Tbk. With Morgenstern-Price Method“.

2 Research Methodology

The research was carried out at PT Bukit Asam Tbk., located in the Tanjung Enim area, Muara Enim Regency, South Sumatra. The site is specifically situated between coordinates 3°42'46"S – 3°44'38"S and 103°45'38"E – 103°48'47"E.

This study began with the collection of references as a literature review to obtain supporting data relevant to the research topic. The study utilized two types of supporting data: primary data obtained directly from field observations and measurements, and secondary data obtained from PT Bukit Asam Tbk. The research methodology was conducted by integrating literature review with direct field observations at the study location. The stages of the research are as follows:

2.1 Literature Study

The initial stage involved an in-depth review of relevant literature related to the subject of the research, including books, scientific journals, and other credible sources.

2.2 Field Observation

Field observation was conducted through direct on-site inspection of mining activities related to the research problem.

2.3 Data Collection

Several types of data were required to support this research, consisting of two categories :

2.3.1 Primary Data

Primary data refers to information obtained directly from the field through systematic observations at the research site. In this study, the primary data consisted of groundwater table measurements collected using a probe attached to a water level meter, which was inserted into monitoring wells. A total of two monitoring wells were used in the Disposal “XYZ” area of PT Bukit Asam Tbk.

2.3.2 Secondary Data

Secondary data refers to supporting information obtained from PT Bukit Asam Tbk. The secondary data required in this study include :

(1) Topographic map of Disposal "XYZ" at PT Bukit Asam Tbk
(2) Cross-section data of Disposal "XYZ" at PT Bukit Asam Tbk.
(3) Material properties data for the disposal area at PT Bukit Asam Tbk.

2.4 Data Processing

Data processing was conducted by integrating theoretical concepts with the field data obtained during observations. The stages of data processing are as follows:

2.4.1 Slope Geometry Processing

(1) Topographic maps and cross-section data of the disposal area were processed to obtain the slope geometry for analysis
(2) The geometric parameters included slope height, slope angle, and dump configuration based on the company's design.

2.4.2 Geotechnical Data Processing

(1) Material property data (cohesion, internal friction angle, dry unit weight, saturated unit weight, and permeability) were used as input for the GeoStudio software (Seep/W and Slope/W)
(2) The Limit Equilibrium Method (Morgenstern–Price) was applied, with shear strength parameters based on the Mohr–Coulomb failure criterion.

2.4.3 Groundwater Table (GWT) Analysis

(1) Groundwater data from monitoring wells in Disposal XYZ were used to determine the groundwater table elevation.
(2) The data were modeled in Seep/W to obtain pore-water pressure distribution under steady-state seepage conditions.

2.4.4 Slope Stability Analysis with GWT Variations

(1) Slope modeling was performed using Slope/W software with the Morgenstern–Price method
(2) Each groundwater table scenario (from dry to fully saturated conditions) was simulated to determine the Safety Factor (SF). The SF values were then compared with the safety criteria specified in KEPMEN ESDM No. 1827 K/30/MEM/2018,

2.4.5 Comparative Analysis

(1) The results of safety factor calculations under various groundwater table conditions were presented in graphical form, showing the relationship between GWT elevation and SF.
(2) This analysis aimed to determine the direct effect of groundwater fluctuations on the stability of the disposal slope

2.4.6 Interpretation and Technical Recommendations

(1) Based on the analysis results, interpretations were made regarding slope stability conditions at Disposal XYZ
(2) Technical recommendations were proposed, including surface and subsurface drainage systems, groundwater monitoring using automatic water level recorders, and revegetation.

2.5 Results and Dicussion

The results focus on determining whether the slope conditions meet the stability criteria set by KEPMEN ESDM No. 1827 K/30/MEM/2018. The discussion highlights technical recommendations for mitigating groundwater fluctuations caused by rainfall to maintain slope stability in the disposal area.

2.6 Conclusions and Suggestions

The conclusions and recommendations were derived from the observations and analyses conducted. These findings can serve as a reference for further studies related to slope stability and landslide potential in disposal areas affected by groundwater table fluctuations.

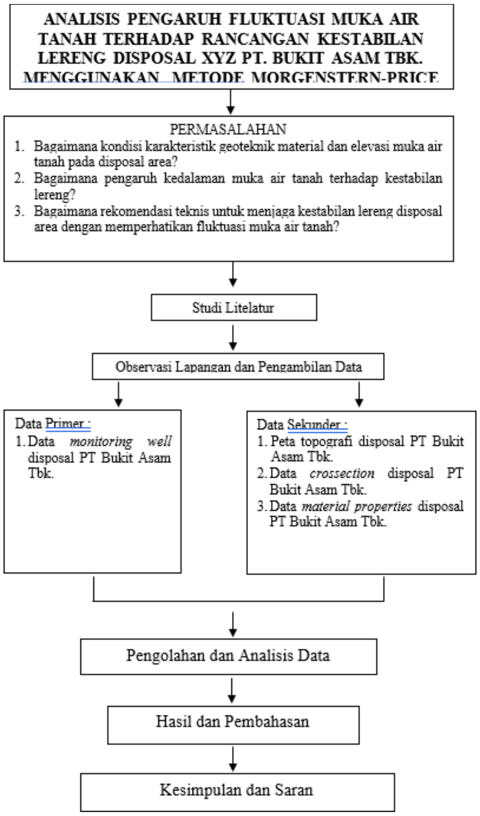


Figure 1. Research Flowchart

3 Results and Discussion

3.1 Geotechnical Conditions and Groundwater Table of the Disposal Area

3.1.1 Geotechnical Conditions

The physical properties of the soil or rock mass that are relevant in analyzing slope stability include unit weight (γ). The greater the unit weight of the material, the higher the driving force acting on the slope, which can increase the potential for failure due to the material's own weight, thereby reducing overall slope stability.

The mechanical properties consist of the internal friction angle (ϕ) and cohesion (c). Higher values of internal friction angle and cohesion indicate a greater ability of the material to resist external stresses. The mechanical and physical parameters of the slope materials were obtained through laboratory testing of soil physical and mechanical properties. The following table presents the material properties of the disposal slope.

Table 1. Material Properties of the XYZ Disposal Slope

Lapisan	Material	*Unit Weight* (γw) (kN/m³)	Kohesi (C) (KPa)	Sudut Geser Dalam (ϕ)
Timbunan Disposal Baru	*Clay*	17,15	20,25	13,91
Timbunan Disposal Lama		16,78	23,19	10,43
Material Lunak *Undrained*		18,03	18,00	-
Material Insitu		21,08	107,53	24,35

3.1.2 Groundwater Table Elevation

Groundwater table monitoring was conducted using a water level meter installed in monitoring wells. These monitoring wells are former geotechnical drilling holes where groundwater elevation measurements were taken by slowly lowering the probe of the water level meter into the borehole (Figure 2)

Figure 2. Monitoring Wells in the XYZ Disposal Area (a). Monitoring well photograph, (b). Water level meter photograph

Groundwater conditions were monitored using these monitoring wells, as shown in Table 2 below.

Tabel 2. Groundwater Table Levels in Monitoring Wells

Periode Pengukuran	*Monotoring Well*		Z (elevasi sumur)		Elevasi Muka Air Tanah (MAT)	
	SPR 01	SPR 08	SPR 01	SPR 08	SPR 01	SPR 08
03/03/2025	18,87	2,10	115,00	117,00	96,13	114,90
10/03/2025	16,80	1,88	115,00	117,00	98,20	115,12
17/03//2025	15,79	1,90	115,00	117,00	99,21	115,10
24/03/2025	15,00	1,70	115,00	117,00	100,00	115,30
31/03/2025	13,50	1,10	115,00	117,00	101,50	115,90
07/04/2025	12,70	0,70	115,00	117,00	102,30	116,30

The Following values were obtained from geotechnical laboratory tests related to parameters such as volumetric water content (θ) and Hydraulic conductivity (K) :

Tabel 3. Seep/W Parameters for the Disposal Slope

Lapisan	Material	*Water Content (%)*	*Hydraulic Conductivity* (m/sec)
Timbunan Disposal Baru		50,17	1,95 E-07
Timbunan Disposal Lama	*Clay*	50,97	3,11 E-08
Material Lunak *Undrained*		50,00	1,00 E-09
Material Insitu		31,34	5,25 E-08

3.2 Influence of Groundwater Table Depth on Slope Stability

Changes in groundwater table depth can affect pore-water pressure within the soil mass, which in turn influences shear strength and the potential for slope failure.

3.2.1 Disposal Conditions and Geotechnical Cross-Sections

Laboratory testing parameters were obtained based on the Mohr–Coulomb failure criterion, including unit weight (γ), cohesion (c), and internal friction angle (ϕ) used as inputs for Slope/W. Meanwhile, the inputs for Seep/W were developed using the Saturated/Unsaturated model, incorporating parameters such as volumetric water content (%) and hydraulic conductivity (m/sec).

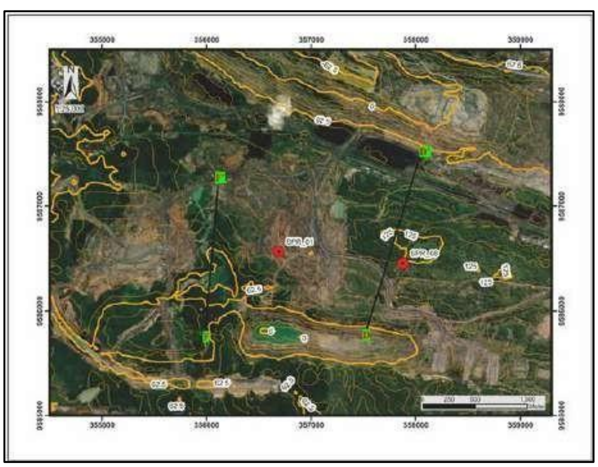
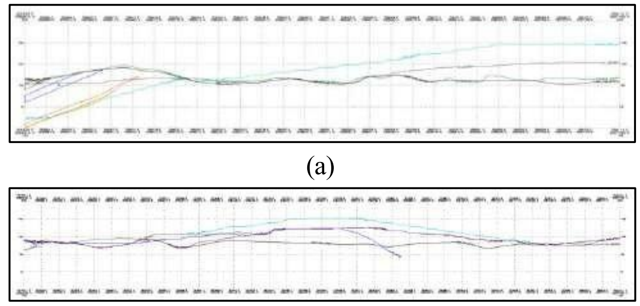


Figure 3. Google Earth Imagery of the Cross-Section Line and Monitoring Well Locations

The slope geometry was constructed based on the RKAP (Annual Work Plan and Budget), resulting in cross-sections F–F' and D–D'. The blue line represents the RKAP slope geometry, while the green line shows the topographic profile. The model also includes seam B and seam C1 (Figure 4).



(a)

(b)

Gambar 4. *Cross section* yang digunakan (a). *Cross Section* F-F' (b). *Cross Section* D-D'

The F–F' cross-section (Figure 5) has a slope height of 86.9 m, extending from an elevation of +59 m to +145.9 m above sea level, with an overall slope angle of 8.42°. Meanwhile, the D–D' cross-section (Figure 6) has a slope height of 75.7 m, from an elevation of +77.3 m to +153 m above sea level, with an overall slope angle of 8.85°.

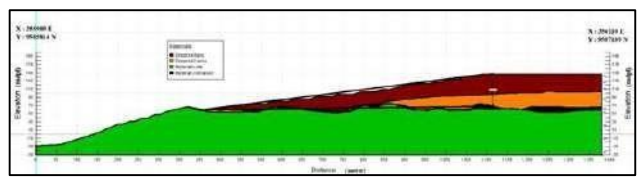


Figure 5. Slope Modeling Results for Cross-Section F-F' and Assigned Materials

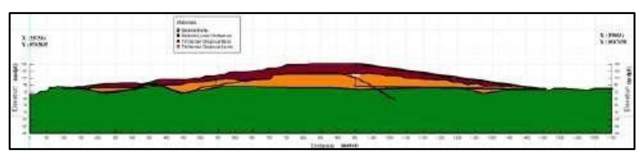


Figure 6. Slope Modeling Results for Cross-Section D-dD' and Assigned Materials

3.2.2 Analysis of Groundwater Table Influence on Slope Stability

Clay, which constitutes the majority of the disposal slope material, is categorized as an aquiclude, meaning it allows very limited water flow. During rainfall, water infiltrates into the soil pores, increasing the water content and pore-water pressure. This results in additional load on the slope, and if not properly drained if not properly managed, it may lead to slope failure.

Therefore, this study analyzes the influence of groundwater table elevation on the safety factor of the slope based on the RKAP design. The analysis results are as follows :

(1) Safety Factor Analysis of Cross-Section F–F' with Saturated Groundwater Table (SF 0,970.< 1,3 (KEPMENESDM, 2018))

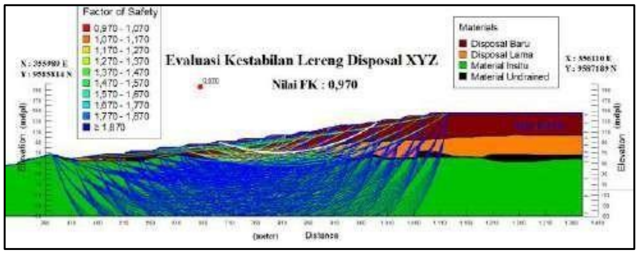


Figure 7. Slope Stability Analysis of Disposal F–F' with Saturated GWT

(2) Safety Factor Analysis of Cross-Section F–F' with GWT at 18.87 m (SF 1.647)

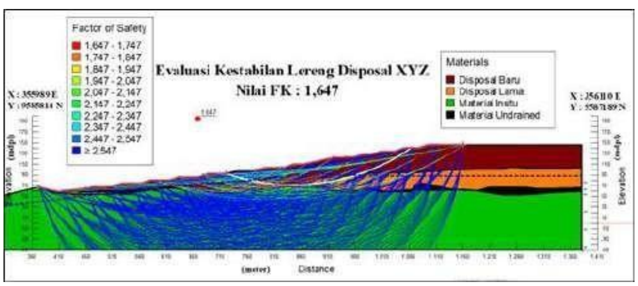


Figure 8. Slope Stability Analysis of Disposal F–F' with GWT at 18.87 m

(3) Safety Factor Analysis of Cross-Section F–F' with GWT at 16.80 m (SF 1.576)

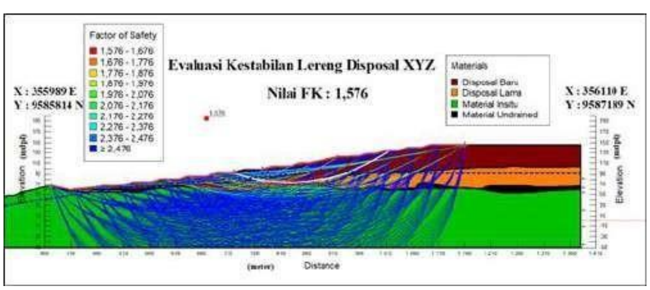


Figure 9. Slope Stability Analysis of Disposal F–F' with GWT at 16.80 m

(4) Safety Factor Analysis of Cross-Section F–F' with GWT at 15.79 m (SF 1.546)

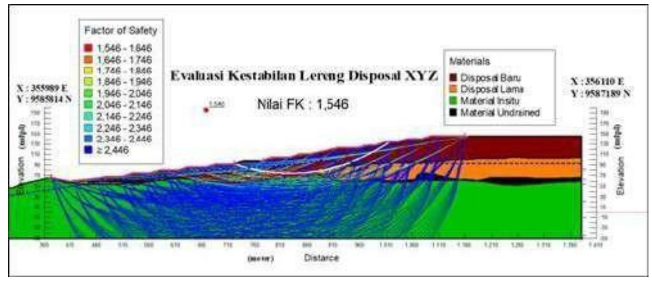


Figure 10. Slope Stability Analysis of Disposal F–F' with GWT at 15.79 m

(5) Safety Factor Analysis of Cross-Section F–F' with GWT at 15.00 m (SF 1.522)

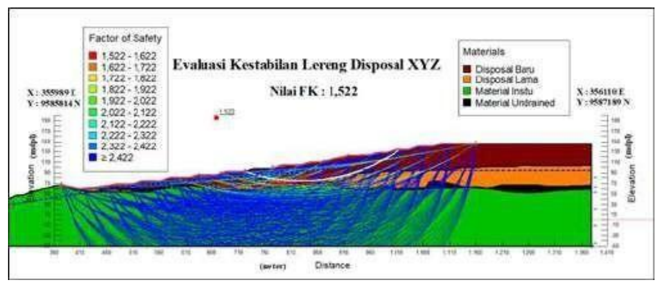


Figure 11. Slope Stability Analysis of Disposal F–F' with GWT at 15.00 m

(6) Safety Factor Analysis of Cross-Section F–F' with GWT at 13.50 m (SF 1.474)

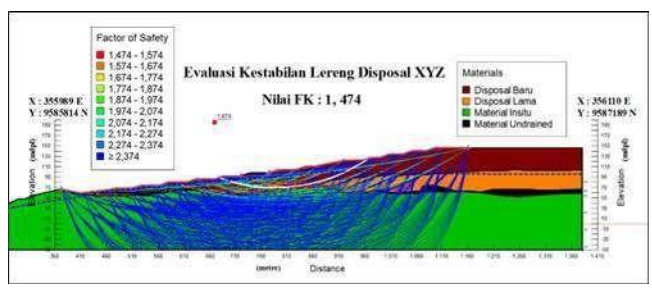


Figure 12. Slope Stability Analysis of Disposal F–F' with GWT at 13.50 m

(7) Safety Factor Analysis of Cross-Section F–F’ with GWT at 12.70 m (SF 1.449)

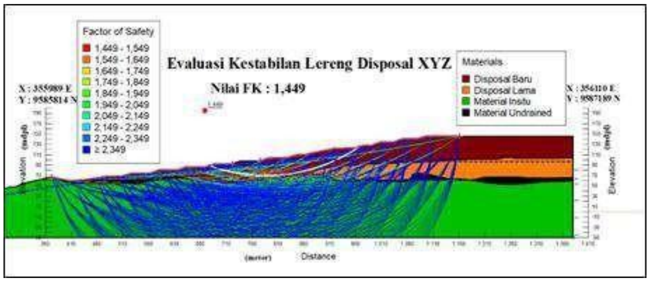


Figure 13. Slope Stability Analysis of Disposal F–F’ with GWT at 12.70 m

(8) Safety Factor Analysis of Cross-Section D–D’ with Saturated Groundwater Table (SF 1.018)

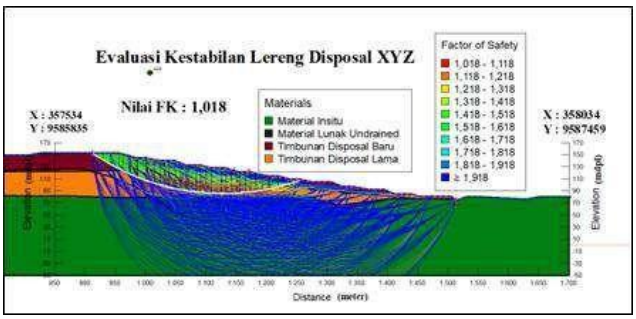


Figure 14. Slope Stability Analysis of Disposal D–D’ with Saturated GWT

(9) Safety Factor Analysis of Cross-Section D–D’ with GWT at 2.10 m (SF 1.787)

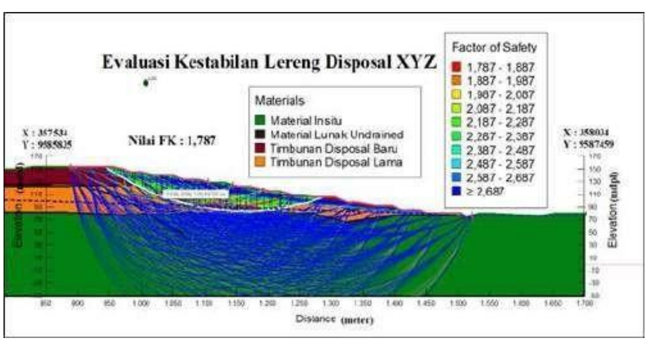


Figure 15. Slope Stability Analysis of Disposal D_D’ with GWT at 2.10 m

(10) Safety Factor Analysis of Cross-Section D–D’ with GWT at 1.88 m (SF 1.786)

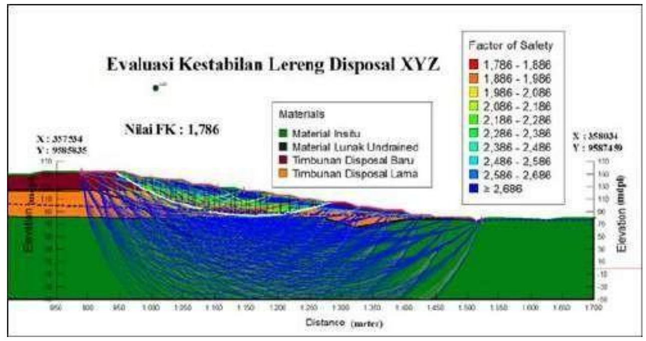


Figure 16. Slope Stability Analysis of Disposal D-D’ with GWT at 1.88 m

(11) **S**afety Factor Analysis of Cross-Section D–D’ with GWT at 1.90 m (SF 1.786)

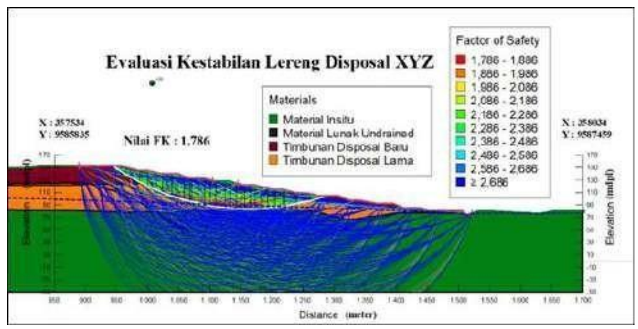


Figure 17. Slope Stability analysis of Disposal D-D’ with GWT at 1.90 m

(12) Safety Factor Analysis of Cross-Section D–D’ with GWT at 1.70 m (SF 1.785)

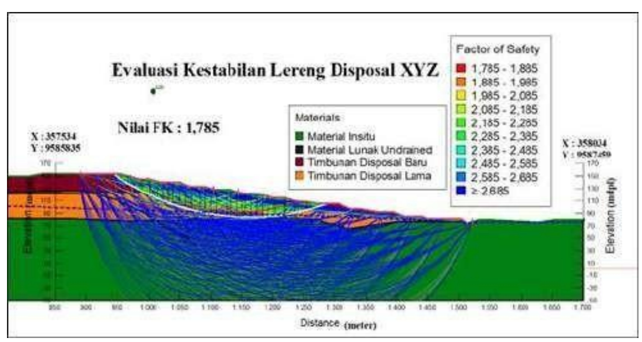


Figure 18. Slope Stability Analysis of Disposal D-D’ with GWT at 1.70 m

(13) Safety Factor Analysis of Cross-Section D-D with GWT at 1.10 m (SF 1.782)

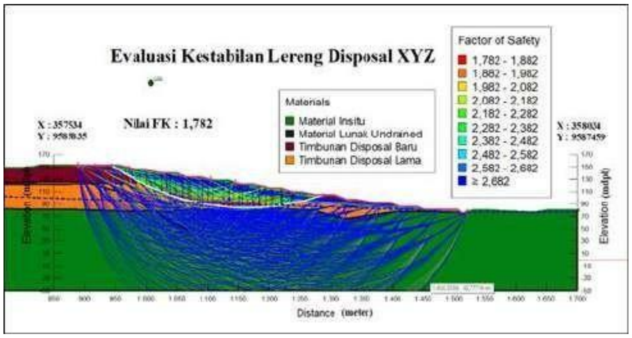


Figure 19. Slope Stability Analysis of Disposal D-D' with GWT at 1.10 m

(14) Safety Factor Analysis of Cross-Section D-D' with GWT at 0.70 m (SF 1.780)

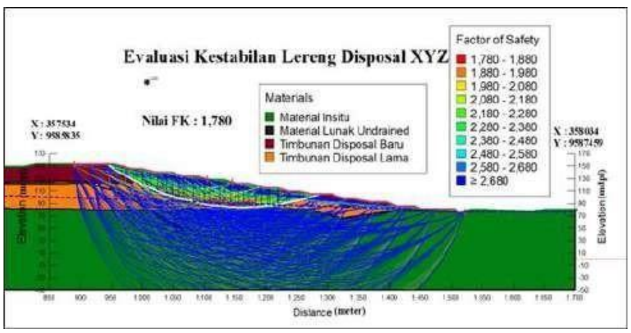


Figure 20. Slope Stability Analysis of Disposal D-D' with GWT at 0.70 m

The results of the saturated groundwater table analysis and its fluctuations indicate a significant influence on slope stability. The closer the groundwater table is to the slope surface, the lower the stability becomes, as shown in Table 4, Figure 21, and Figure 22

Table 4. Influence of of Groundwater Table on Slope Stability

MAT F-F' (m)	FK F-F'	MAT D-D' (m)	FK D-D'
Jenuh	0,970	Jenuh	1,018
12,70	1,449	0,70	1,780
13,50	1,474	1,10	1,782
15,00	1,522	1,70	1,785
15,79	1,546	1,88	1,786
16,80	1,576	1,90	1,786
18,87	1,647	2,10	1,787

Figure 21. Graph of Groundwater Table Influence on Slope Stability for Cross-Section F–F'

Figure 22. Graph of Groundwater Table Influence on slope Stability for Cross-Section D-D'

3.3 Technical Recommendations for Improving Disposal Slope Stability Considering Groundwater Fluctuations

Understanding groundwater table dynamics, especially during the rainy season, is essential for geotechnical risk mitigation and designing an effective drainage system in the disposal area. The technical recommendations provided in this study are as follows:

3.3.1 Groundwater Table Monitoring

(1) Determine monitoring points (crest, mid-slope, and toe).
(2) Install monitoring wells using perforated PVC pipes with gravel filters.
(3) Install automatic water level recordes for real-time monitoring.
(4) Verify instrument accuracy through manual measurements.
(5) Comapre groundwater level data with rainfall records.
(6) Purpose: to identify groundwater fluctuations, locate high-risk areas, and establish an early warning system

3.3.2 Surface Drainage

(1) Construct diversion channels above the disposal area.
(2) Apply benching with small drains leading to the main drainage channel.

(3) Provide sedimentation ponds and conduct routine
(4) Purpose: to reduce infiltration, landslide risk, erosion and sedminet contamination.

3.3.3 Subsuracfe Drainage

(1) Determine drain locations based on seepage analys.
(2) Install horizontal drains from the benches into the disposal body.
(3) Install toe drains at the base of the disposal and connect them to the main drainage channel.
(4) Conduct regular maintenance.
(5) Purpose: to reduce pore-water pressure, lower the groundwater table, increase the safety factor (SF), and minimize ponding and erosion.

3.3.4 Additional Reinforcement (Revegetation)

(1) Prepare the land, spread topsoil, select suitable vegetation, and perform planting and maintenance.
(2) Purpose: to reduce infiltration, strengthen the surface, improve stability, reduce dust, and support ecosystem restoration.

4 Conclusions and Recommendations

(1) The material characteristics of Disposal XYZ consist mainly of clay, with varying geotechnical properties between new dumps, old dumps, and in-situ materials. In-situ material has the highest strength (ϕ = 24.35°; c = 107.53 kPa), whereas dumped materials are weaker. The groundwater table fluctuates, influenced by rainfall, with depths ranging from 0.70 to 18.87 m below the surface.
(2) The analysis shows that the shallower the groundwater table, the lower the slope safety factor (SF). In the F–F' cross-section, saturated conditions yield an SF of 0.970 (unstable), whereas when the GWT lowers to 12.7–18.87 m, the SF increases to 1.449–1.647 (stable). In the D–D' cross-section, saturated conditions produce an SF of 1.018 (unstable), but when the GWT lowers to 0.7–2.1 m, the SF increases to 1.780–1.787 (stable)
(3) To maintain slope stability, water control is required through surface drainage, subsurface drainage, groundwater monitoring integrated with rainfall data, and revegetation. These measures ensure that the safety factor remains ≥1.3, in accordance with KEPMEN ESDM standards.kriteria KEPMEN ESDM.
(4) he researcher recommends regular groundwater level monitoring, especially during the rainy season or periods of high rainfall, and suggests adding vibration variables from heavy equipment and blasting activities to obtain a more detailed assessment of landslide potential.

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