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Optimized Drainage System Design for Andesite Mining at PT. Rolas Nusantara Tambang, Kejayan, East Java

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Abstract

This study presents a systematic approach to designing a filtration system aimed at efficiently managing rainwater and surface runoff outside mining areas. Utilizing a quantitative method, the data collection predominantly involves secondary sources. The data is processed through a series of steps: rainfall projection, delineation of rainwater catchment areas, calculation of rainfall intensity and inflow rate, and determination of open channel and settling pond dimensions. The designed open channels have a trapezoidal shape with specific dimensions including a base width of 0.51 m, a side length of 0.62 m, a slope angle of 60°, and a channel depth of 0.54 m. These channels span a total length of 2.216 m. The accompanying settling ponds are rectangular with dimensions encompassing a length of 31 m, a width of 11 m, a depth of 6 m, and an area of 341 m². These ponds have a volume capacity of 2,046 m³, achieving an impressive 90.89% efficiency. Notably, maintenance of the settling pond involves periodic dredging using the Kobelco SK200 Excavator at intervals of roughly 16 years (5,817 days). Given that this maintenance duration surpasses the expected mine lifespan, no further interventions are required for the pond during the mine's operational period.

1. Introduction

PT. Rolas Nusantara Tambang stands as a distinguished company in the andesite mining industry, representing a significant segment of the regional mining community. It predominantly relies on an open-pit mining strategy, leveraging the comprehensive quarry method [1]. This specific methodology, while efficient, tends to result in expansive leveled terrains. These areas, due to their structure, inherently possess the capacity to act as reservoirs, collecting both surface runoff and groundwater [2].

During the rainy seasons, this characteristic becomes especially pronounced. The mining area witnesses a considerable influx of water, emphasizing the dire need for a robust drainage system. Such a system is pivotal not just for mitigating water-logging challenges, but to ensure that production cycles are continuous, efficient, and devoid of interruptions due to water accumulation [3].

For any mining venture, especially one employing the quarry method, appropriate infrastructural management is essential. The objective is to preempt potential challenges, thereby ensuring that the mining operations are conducted in line with planned schedules and objectives [4]. It's noteworthy that PT. Rolas Nusantara Tambang, at present, does not have a dedicated drainage framework in place. Given the operational challenges posed by water accumulation, designing and implementing an effective drainage infrastructure becomes a strategic imperative to bolster the company's mining efficiency and overall output

2. Methodology

The methodology underpinning this study is rooted in a quantitative framework, aligning with principles commonly associated with applied research [5]. By employing such an approach, the research effectively addresses and quantifies variables of interest, such as rainfall intensity, runoff water discharge, as well as the dimensions of both open channels and deposition ponds [6].

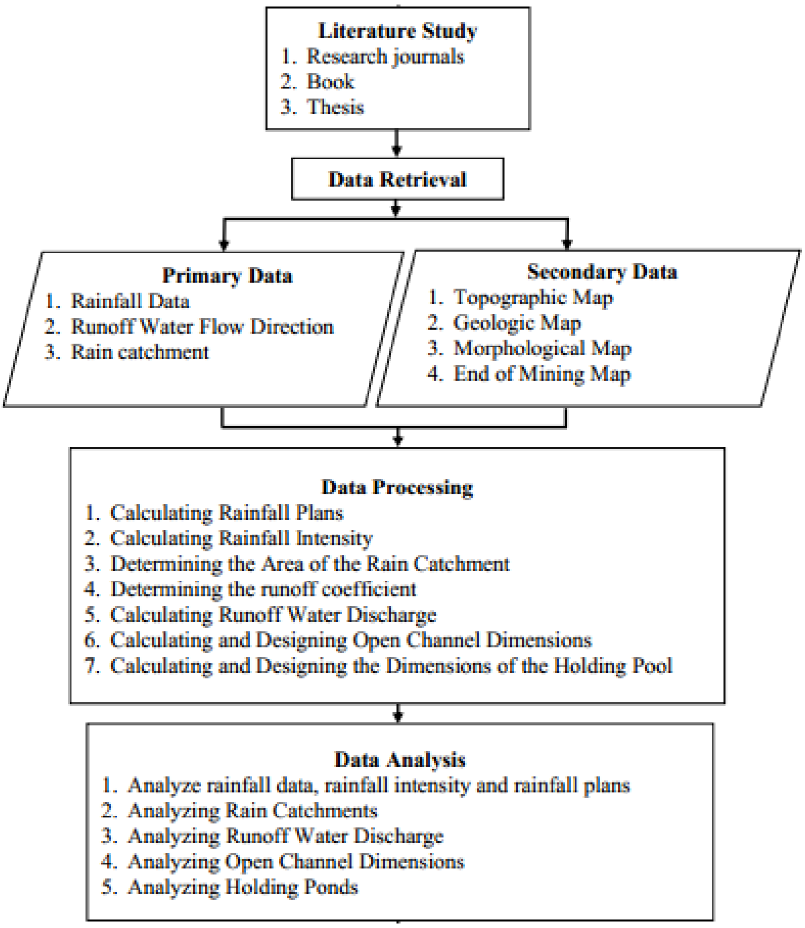

Figure 1. Research Diagram

2.1. Data Collection Techniques

To ensure the authenticity and relevance of the data, a direct field observation method was employed. On-site inspections were meticulously conducted, allowing for an in-depth exploration of the research site's numerous facets. During these visits, paramount information was gathered concerning the overall condition of the mining area, the mining techniques currently in operation, the intricate topography of the region, and its distinctive morphological attributes [7]. Additionally, interactions with local experts and workers were conducted to gain supplementary data and deeper contextual understanding.

2.2. Data Processing Approach

Once all the necessary data had been compiled, the next phase involved rigorous mathematical processing. This stage is imperative as it synthesizes both primary and secondary datasets to generate meaningful outputs [8]. This comprehensive processing encapsulated a range of tasks, including determining projected rainfall patterns, calculating rainfall intensity, identifying catchment areas, estimating runoff water volumes, and meticulously deriving the dimensions of the deposition pond. The union of both raw observational data with established literature and datasets ensures accuracy in the findings.

2.3. Data Analysis Techniques

Having processed the data, the subsequent step was its detailed analysis. This segment was dedicated to critically examining the outcomes from the data processing phase, drawing meaningful interpretations and insights. Key components scrutinized during this phase encompassed the runoff water's discharge rate, discharge attributes of mine water, volume evaluations of open channels, and the comprehensive volume assessment of settling ponds. [9] Through such a detailed analysis, a robust understanding of the research objectives was achieved, enabling the formulation of actionable recommendations. A comprehensive visualization detailing the sequential flow and interrelation of the various steps in the research methodology can be found in Figure 1.

Table 1. Maximum Rainfall

Moon	Maximum Rainfall (Xi)	Average (X)
January	819,4	81,94
February	638,2	63,82
March	639,6	63,96
April	452,5	45,25
May	294,6	29,46
June	219,9	21,99
July	179,9	17,99
August	121,2	12,12
September	281,2	28,12
October	379,6	37,96
November	459,9	45,99
December	561,4	56,14

3. Results and Discussion

3.1. Rainfall Data Insights

The foundational data for rainfall was sourced both from proprietary company records and the Central Statistics Agency (BPS). This dataset serves as an instrumental benchmark for deriving metrics like rainfall intensity and runoff water discharge. Spanning a decade, from 2010 to 2019, this data chronicles the peak annual rainfall, facilitating a nuanced understanding of year-to-year climatic variability. A detailed representation of these maximum annual rainfall values across the ten-year window is encapsulated in Table 1 [10].

3.2. Projections of Rainfall Patterns

To forecast and strategize, it's pivotal to extrapolate future rainfall trends based on historical data. The Gumbel distribution method provides a robust framework for this analytical endeavor [11]. Delving into the Gumbel distribution analysis, the projected monthly rainfall value is discerned to be 512.966 mm, as illustrated comprehensively in Table 2.

3.3. Nuances of Rainfall Intensity

Rainfall intensity doesn't just hinge on the volume of rain, but also its temporal distribution. While several methodologies can estimate this, the study employed the Mononobe equation given the dataset's attributes [12]. Post-analysis, the derived rainfall intensity stands at 5.847 mm/hour, which translates to approximately 0.000001624 m/second, marking a key metric for various hydrological applications.

Table 2. Rainfall Plan

Average Rainfall	Standard Deviation	Standard Deviation Correction	Variate Reduction	Average Variate Correction	Rainfall Plan
(X)	(Sd)	(Sn)	(Yt)	(Yn)	(XT)
81,94	245,820	1,001	2,250	0,495	512,966
63,82	191,460	1,001	2,250	0,495	399,530
63,96	191,880	1,001	2,250	0,495	400,406
45,25	135,750	1,001	2,250	0,495	283,277
29,46	88,380	1,001	2,250	0,495	184,427
21,99	65,970	1,001	2,250	0,495	137,663
17,99	53,970	1,001	2,250	0,495	112,622
12,12	36,360	1,001	2,250	0,495	75,874
28,12	84,360	1,001	2,250	0,495	176,039
37,96	113,880	1,001	2,250	0,495	237,639
45,99	137,970	1,001	2,250	0,495	287,909
56,14	168,420	1,001	2,250	0,495	351,451

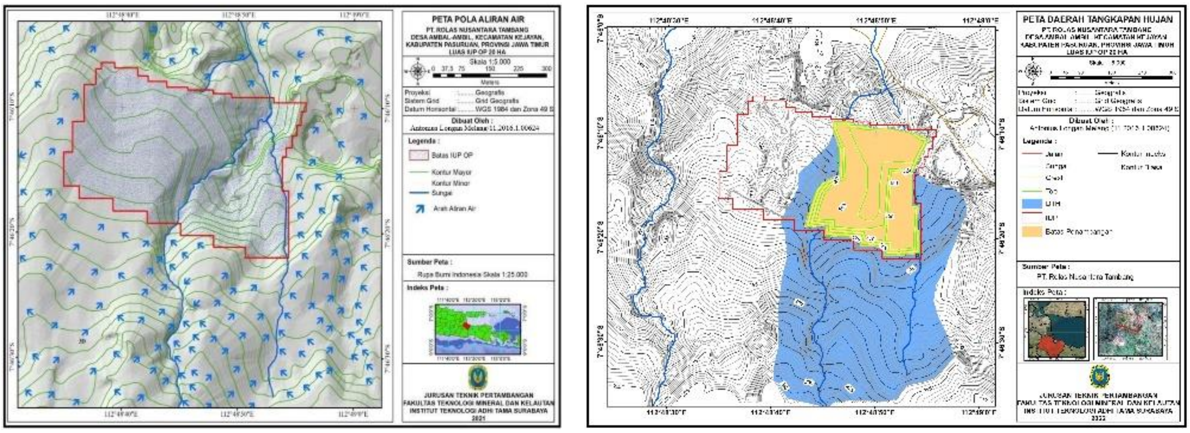

Figure 2. Runoff Water Flow Direction Map (left), Rain Infiltration Map (right)

3.4. Deciphering the Runoff Coefficient

The runoff coefficient, symbolized as 'C', remains a pivotal hydrological variable, mirroring the proportion of rainfall volume that eventually transforms into the runoff. It's a metric heavily influenced by the terrain's topography, slope, and vegetative cover [13]. Ground-level observations and assessments in the study region revealed a runoff coefficient of 0.6. This value resonates with the area's profile, characterized predominantly by forested terrain with an incline surpassing 15%, precisely at 22%.

3.5. Determining the Rainwater Catchment Area

The delineation of the rainwater catchment area is driven by the variations in elevation, which dictate the flow direction of the runoff water streaming into the mining vicinity [14]. At the specified study location, this catchment area spans an expanse of 22,034 Ha, equivalent to 220,340 m^2. A visual representation of the rainwater catchment area is depicted in Figure 2.

3.6. Analyzing Water Discharge Patterns

- Direct Rainwater Discharge

Direct rainwater discharge pertains to the volume of water channeled directly into the mining pit. It's primarily influenced by the magnitude of the mine opening (A) and the prevalent rainfall intensity (I) [15]. Given an opening area of 12.1 Ha or 121,000 m^2 and a rainfall intensity of 5.847 mm/hour (or 0.000001624 m/second), the resultant rainwater discharge rate is gauged at 0.2 m^3/second.

- Runoff Water Discharge

This refers to the volume of rainwater from the delineated catchment area that eventually finds its way into the mining domain (pit) [16]. The computation of this discharge value takes into account a runoff coefficient (C) of 0.6, a catchment expanse (DTH) of 22,034 Ha (or 220,340 m^2), and the aforementioned rainfall intensity. The deduced runoff water discharge stands at 0.2 m^3/second.

- Cumulative Water Discharge

By amalgamating the direct rainwater and runoff water discharges, we ascertain the total influx of water into the mining zone. In this context, with both the former components measuring at 0.2 m^3/second, the cumulative water discharge is pegged at 0.4 m^3/second.

3.7. Configuring the Open Channel

The design and dimensions of the open channel are meticulously tailored to accommodate the anticipated runoff water discharge. This conduit envisioned to channel the runoff water towards settling ponds, adopts a trapezoidal configuration — an optimal choice considering its efficiency in managing high discharges and its ease of construction and upkeep [17]. A visual blueprint of the open channel's architecture is illustrated in Figure 2, while its detailed dimensional specifications are tabulated in Table 3.

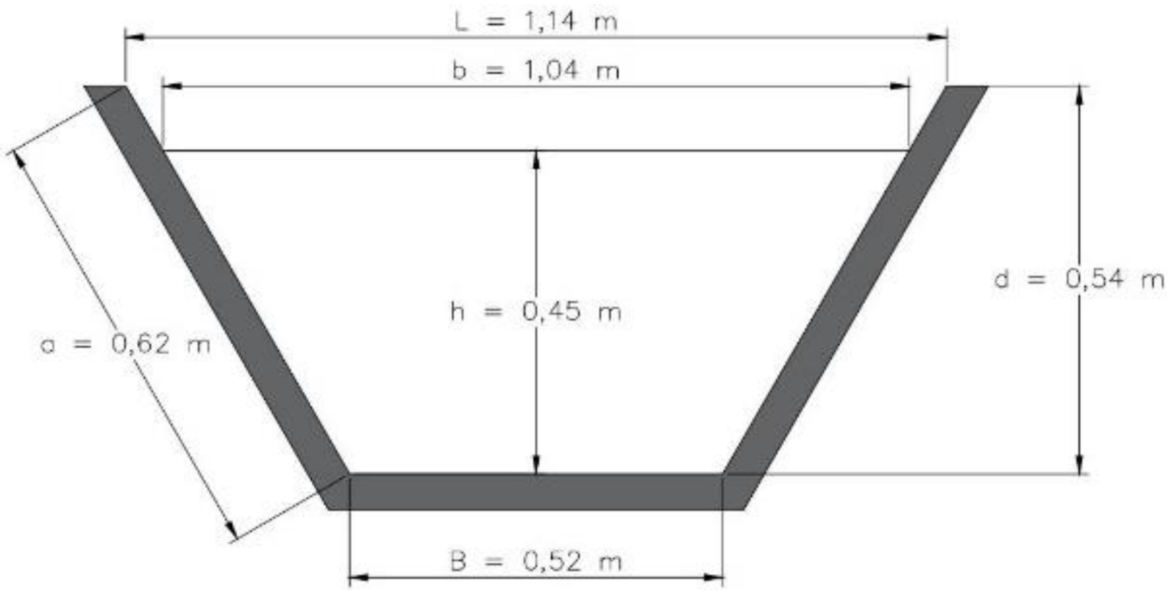

Figure 3. Open Channel Dimensions

3.8. Designing the Settling Pond

In any mining operation, effective water management is paramount, and this is where the settling pond plays a crucial role. The design dimensions of the settling pond are carefully determined by the collective volume of water it is intended to handle. To ensure that the pond operates at its peak efficiency, a combination of engineering principles, hydrological data, and environmental considerations is meticulously integrated during its design phase [18].

- Strategizing the Dimensions of the Settling Pond

The primary objective of the settling pond is to serve as a temporary reservoir. Here, the water is held long enough to allow solid particles, which could be byproducts of the mining process, to settle at the bottom. This sedimentation process ensures that the water released from the mining site is relatively clear and free from large particulate matter. The settling pond at this particular mining site is designed to accommodate a peak water discharge of 1,850 m^3. This volume determination isn't arbitrary but is rooted in careful analysis and calculations.

Another pivotal factor influencing the pond's design is the excavation machinery employed by the company. The Kobelco SK200 Excavator, with its specific operational requirements, predicates a square-shaped pond. Unlike multi-compartment designs seen in other mining operations, this pond is singular in its compartmental structure, a design choice visually illustrated in Figure 4. For a granular understanding of the pond's spatial configurations and engineering specifics, readers are directed to Figure 3. Additionally, Table 4 provides a detailed breakdown of the pond's dimensions, ensuring a comprehensive grasp of its structural blueprint.

Table 3. Open Channel Dimensions

No	Information	Units
1	The slope of the channel wall (°)	60°
2	High Guard(W)	0,09 m
3	Water depth (h)	0,45 m
4	Channel height (d)	0,54 m
5	Top width of wet surface (b)	1,04 m
6	Top width of open channel (L)	1,14 m
7	Channel base width (B)	0,52 m
8	Channel side length (a)	0,62 m

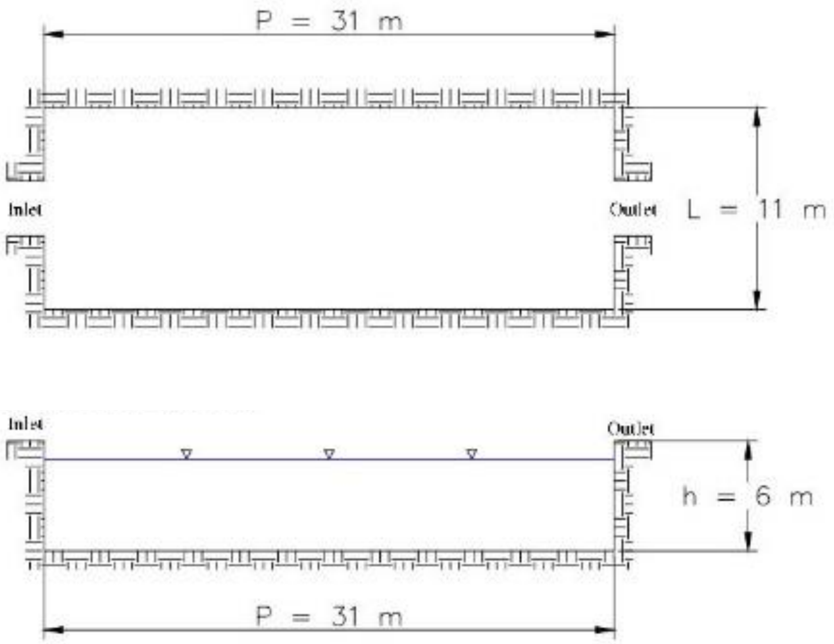

Figure 4. Settling Pond Dimensions, top view (top), side view (bottom)

- Precipitation Percentage

A vital metric in the assessment of a settling pond's performance is the precipitation percentage. This quantitative measure sheds light on the pond's effectiveness in allowing contained particles within the water to precipitate, ensuring clearer water discharge [18]. The precipitation percentage derives its value from various factors including the total water discharge that enters the settling pond, which in this study was calculated to be 0.4 m^3/second, and parameters such as the pond's dimensions (length, width, depth) and the inherent settling velocity of particles in the water.

From the gathered data, it was deduced that the time required for particles to settle, denoted as (tv), amounts to 43 minutes. In contrast, the water takes approximately 428 minutes to exit the pond, termed as (th). The efficiency of the pond's deposition process hinges on this comparison; a particle deposition time (tv) that is shorter than the water's exit time (th) suggests an optimal functioning of the settling process. In this case, the settling pond exhibited a promising precipitation percentage of 90.89%, pointing to a well-designed structure.

- Settling Pond Maintenance

Effective upkeep of the settling pond is pivotal for its longevity and functionality. One of the primary maintenance practices involves the dredging of settled solid particles from the pond's base. This ensures that the pond remains clean and there's no alteration in its original dimensions. The equipment chosen for this task is consistent with the excavation tool used for the pond's creation - the Kobelco SK200 Excavator. From the computations, a noteworthy insight was gleaned: dredging would be essential every 5,871 days, translating to approximately once every 16 years. However, given that this span surpasses the operational lifespan of the mine within the company's purview, periodic maintenance of the pond is deemed unnecessary in this specific context [19].

Table 4. Settling Pond Dimensions

Information	Size
Pool Depth (h)	6 m
Pool Length (P)	31 m
Pool Width (L)	11 m
Pool Area	341 m^2
Pool Capacity (Volume)	2.46 ^{3}

Based on the results of calculation, data processing, and analysis, the following conclusions are obtained; Rainfall at PT Rolas Nusantara Tambang based on rainfall data from 2010 – 2019 has the highest rainfall in January 2013 of 819,4 mm and a maximum rainfall intensity of 5,85 mm/hour. The total water discharge entering the mine area is 0,4 m 3/sec and the maximum water discharge is 1.850 m^3. The dimensions of open channels and settling ponds are as follows:

a. Open Channel made the trapezoidal shape with the following dimensions:

Channel Wall Slope (α)	: 60^0.
High Guard (W)	: 0,09 m.
Water Depth (h)	: 0,45 m.
Channel Height (d)	: 0,54 m.
Top width of wet surfaces (b)	: 1,04 m.
Open Channel Top Width (L)	: 1,14 m.
Channel Base Width (B)	: 0,51 m.
Channel Side Length (a)	: 0,62 m.

b. The settling pond is made rectangular in shape with the following dimensions:

Pool Depth (h)	: 6 m.
Pool Width (L)	: 11 m.
Pool Length (P)	: 31 m.
Pool Area	: 341 m^2.
Maximum Water Discharge (Q_{max})	: 1.850 m^3.
Pool Volume	: 2.046 m^3.
Volume of Dissolved Solids	: 1,1 $x10^{-3}$ m^3/sec.
Precipitated solids	: 90,89%.

4. Conclusion

In assessing the hydrological characteristics at PT Rolas Nusantara Tambang, several conclusions have been drawn based on a detailed calculation, data processing, and subsequent analysis. The data from 2010 to 2019 showed that the region experienced its highest rainfall in January 2013, recording a substantial 819.4 mm, leading to a peak rainfall intensity of 5.85 mm/hour. This equates to a total water inflow into the mine area of 0.4 m^3/sec, with the highest water discharge recorded at 1,850 m^3.

From a structural perspective, the open channels designed are trapezoidal in shape, with specific dimensions such as a channel wall slope of 600, guard height of 0.09 m, water depth of 0.45 m, and a channel base width of 0.51 m, among other specifications. On the other hand, the designed settling ponds adopt a rectangular format. These ponds have a depth of 6 m, width of 11 m, and length of 31 m, providing an area of 341 m^2. The maximum water discharge for these ponds is gauged at 1,850 m^3, with the overall volume being 2,046 m^3. Another noteworthy figure is the volume of dissolved solids, which stands at 1.1 $x10^{-3}$ m^3/sec, with the precipitation rate of solids being a commendable 90.89%.

In light of these findings, future researchers might consider diversifying their distribution methods, possibly looking beyond just the Gumbel distribution. A crucial recommendation for enhancing accuracy would be ensuring the completeness of the rainfall data, which could be facilitated by installing a dedicated rain timer at the research site. Lastly, for the sustainability and functional efficacy of the drainage infrastructure, regular maintenance of both the open channels and settling ponds is strongly recommended. This ensures their consistent performance and longevity in effectively managing water and sediment flow.

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