

Seasonal Rainfall Effects on Mine Water Balance and Production Reliability: Evidence from an Open-Pit Gold Mine in Southwestern Nigeria

S.M Haruna and G.O Oniyide

Department of Mining Engineering, Federal University of Technology Akure, Ondo State

DOI: <https://doi.org/10.51244/IJRSI.2026.1308000240>

Received: 03 September 2026; Accepted: 08 September 2026; Published: 18 September 2026

ABSTRACT

Effective water management is essential for maintaining safe and efficient open-pit mining operations, particularly in tropical regions where seasonal rainfall can significantly influence mine water inflow and dewatering requirements. This study evaluates the impact of seasonal rainfall variability on dewatering performance and production efficiency in an operational open-pit gold mine in Southwestern Nigeria. The research utilised rainfall records, pit water inflow measurements, dewatering performance data, and monthly production reports collected from mine operational records and supplemented with meteorological data. The datasets were processed and analysed using descriptive statistics, Pearson correlation, regression modelling, independent sample t-tests, and analysis of variance to establish relationships between rainfall variability, water accumulation, dewatering response, and production performance. Results revealed a moderate positive and statistically significant relationship between rainfall and surface water inflow ($r = 0.577$, $p = 0.001$), indicating that increased rainfall directly contributes to pit water accumulation through surface runoff. Regression analysis showed that rainfall explained 33.3% of the variation in surface inflow, with each additional millimetre of rainfall increasing surface water inflow by approximately 12.98 m³. In contrast, groundwater inflow showed a weak and statistically insignificant relationship with rainfall ($R^2 = 0.007$, $p = 0.677$), suggesting that subsurface hydrogeological characteristics have greater influence on borehole inflow behaviour. The relationship between rainfall and production output was also statistically insignificant ($r = 0.132$, $p = 0.503$), demonstrating that effective dewatering systems and operational planning reduced the direct impact of rainfall on mine productivity. The study concludes that rainfall primarily affects open-pit mining operations through increased surface water inflow rather than direct production losses. The existing dewatering system was found adequate for managing seasonal water challenges; however, improved borehole utilisation, real-time water monitoring, energy-efficient pumping strategies, and enhanced runoff control are recommended to optimise future mine water management.

Keywords: Seasonal rainfall; Open-pit mining; Mine dewatering; Surface water inflow; Groundwater inflow; Production efficiency; Gold mining.

INTRODUCTION

Open-pit mining remains one of the most widely adopted methods for extracting near-surface mineral deposits because of its ability to achieve high production rates and efficient resource recovery. However, the success and continuity of open-pit operations depend strongly on effective management of mine water arising from surface runoff, seasonal rainfall, and groundwater inflow. As mine pits deepen below natural groundwater levels, water accumulation becomes a major operational challenge requiring effective dewatering strategies to maintain safe working conditions and production continuity (Serafini et al., 2015; Younger, 2004). Poorly managed water inflow can reduce equipment efficiency, restrict haulage activities, increase operational costs, and create safety risks associated with unstable pit walls and flooded working areas (Angel et al., 2015).

The influence of rainfall on open-pit mining operations is particularly significant in tropical regions where seasonal precipitation patterns produce substantial variations in surface runoff and water inflow. During wet

seasons, intense rainfall events can rapidly increase pit water levels, placing additional pressure on existing pumping systems. Studies have shown that excessive rainfall can disrupt mining activities by reducing heavy equipment mobility, damaging haul roads, increasing maintenance requirements, and causing unexpected production delays (Adebayo & Taiwo, 2011; Agyei & Tetteh, 2022). In addition, rainfall-induced infiltration can increase pore-water pressure within pit slopes, potentially reducing slope stability and increasing the likelihood of geotechnical failures (Silva et al., 2017). These challenges demonstrate that rainfall variability must be considered as an important factor in mine planning and operational water management. Mine dewatering systems are designed to control water accumulation through a combination of surface drainage, sump pumping, groundwater abstraction wells, and other water control measures. The effectiveness of these systems depends on several factors, including rainfall intensity, geological characteristics, pit geometry, aquifer conditions, and pumping capacity (Unsal & Yazicigil, 2015). Recent approaches have focused on integrating real-time monitoring systems, predictive modelling, and improved pump management to enhance mine water control. For example, Johnson (2023) demonstrated the value of combining in-pit sumps, dewatering wells, and continuous water-level monitoring in a gold mining operation in Guinea to manage groundwater inflow effectively. Similarly, Darlami et al. (2025) highlighted that modern dewatering technologies can improve operational reliability by increasing pumping efficiency and reducing energy consumption. However, the suitability of these approaches depends on site-specific hydrological and geological conditions.

The relationship between rainfall, mine water accumulation, and production efficiency has been investigated in several mining regions globally. Gao et al. (2017) emphasised that effective mine-water management requires balancing water availability, operational requirements, and climatic variability. Research from China demonstrated that extreme precipitation events can significantly affect mining productivity by increasing flooding risks and reducing operational efficiency (Liu & Song, 2019). Similarly, Liu et al. (2018) reported that rainfall intensity influences coal mine production performance through its effects on equipment operation, transportation activities, and working time losses. In Nigeria, Afeni et al. (2023) identified seasonal variations as important factors affecting quarry operations in Southwest Nigeria, while Adebayo and Taiwo (2011) reported that rainfall-related disruptions influence overburden stripping activities. These studies indicate that seasonal rainfall remains an important operational consideration across different mining environments.

Despite the growing understanding of mine water challenges globally, limited quantitative studies have examined the direct relationship between seasonal rainfall, dewatering performance, and production efficiency in active Nigerian gold mining operations. Existing Nigerian research has mainly concentrated on environmental impacts of mining, including groundwater contamination, abandoned mine pits, and water quality deterioration (Okogbue & Ukpai, 2013; Nnabo, 2015). Although these studies provide valuable information on environmental consequences, they do not adequately explain how operational mines manage rainfall-induced water challenges or how rainfall variability influences pumping requirements and production performance. Furthermore, there remains limited empirical evidence on the effectiveness and adequacy of existing dewatering systems under seasonal rainfall conditions in Southwestern Nigeria.

Research Gap

Although previous studies have examined rainfall impacts on mining operations and mine water management, significant knowledge gaps remain regarding active open-pit gold mines in Nigeria. International studies have demonstrated the importance of rainfall forecasting, water balance modelling, and efficient dewatering systems in reducing operational disruptions (Serafini et al., 2015; Gao et al., 2017; Sahoo et al., 2014). However, most available research originates from mining regions outside Nigeria, where climatic conditions, geological characteristics, and mining practices differ considerably.

Within Nigeria, previous studies have largely focused on environmental consequences associated with mining activities, particularly groundwater pollution, abandoned mine pits, and community health impacts (Okogbue & Ukpai, 2013; Nnabo, 2015). Limited attention has been given to the operational challenges faced by active mines, particularly the quantitative assessment of rainfall influence on pit water accumulation, dewatering response, and production performance. Consequently, mine operators lack sufficient site-specific evidence to determine how seasonal rainfall affects water management requirements and operational reliability.

Furthermore, while modern mine water management studies have investigated advanced pumping strategies, energy optimisation, and predictive monitoring systems (Cilliers et al., 2014; Darlami et al., 2025), there is limited documentation of how such approaches apply within Nigerian gold mining conditions. This study addresses this gap by integrating rainfall records, surface and groundwater inflow measurements, dewatering performance data, and production outputs to establish the relationship between seasonal rainfall variability and operational efficiency in an open-pit gold mine in Southwestern Nigeria.

MATERIALS AND METHODS

The study was conducted in an operational open-pit gold mine located in Atakumasa East Local Government Area of Osun State, Southwestern Nigeria. The mine lies within a tropical climatic zone characterised by distinct wet and dry seasons, with rainfall occurring mainly between April and October. The geological setting consists of Precambrian basement rocks containing fractured aquifer systems that contribute to groundwater inflow during periods of increased precipitation. Mining activities are carried out using conventional open-pit methods supported by haul trucks and shovel operations, while water control is achieved through a combination of deep borehole dewatering systems and surface sump-and-pump arrangements. Data used for the study consisted of rainfall records, pit water inflow measurements, dewatering performance records, pumping volumes, and monthly production reports collected from mine operational records and supplemented with rainfall data obtained from the Nigerian Meteorological Agency (NiMet). The datasets covered the operational period beginning from 2021 and were processed through data cleaning, standardisation, and aggregation into monthly and seasonal values to establish relationships between rainfall variability, water accumulation, dewatering response, and production performance. Descriptive statistics, time-series analysis, Pearson correlation, regression modelling, independent sample t-tests, and analysis of variance (ANOVA) were applied to evaluate seasonal trends and determine the statistical significance of relationships between rainfall, mine water behaviour, and production output. The adequacy of the dewatering system was assessed by comparing rainfall patterns with pumped water volumes and evaluating the response of surface and groundwater control systems during wet-season conditions. Data reliability was ensured through comparison of on-site measurements with external rainfall records, while confidentiality of operational information was maintained through adherence to mine data management procedures.

RESULTS AND DISCUSSION

Rainfall Patterns in the Study Area

Table 1: Monthly Rainfall Trend in the study area across four years

	2021		2022		2023		2024		Monthly Average
Months	Total (mm)	Rainfall	Total (mm)	Rainfall	Total (mm)	Rainfall	Total (mm)	Rainfall	OGIVE
Jan	NA		0		28.7		29.6		19.43333
Feb	NA		2		11		11.3		8.1
Mar	NA		122		62.7		64.6		83.1
Apr	NA		159		156		160.7		158.5667
May	78		188		241.1		248.3		188.85
Jun	183		237.5		295		303.9		254.85
Jul	138		219.8		215.2		221.6		198.65
Aug	140		162.5		208.5		214.7		181.425
Sep	161		228.5		NA		235.4		208.3
Oct	181		245		NA		252.4		226.1333

Nov	124	9	NA	9.3	47.43333
Dec	15	0	NA	0	5
NA- Not Available					

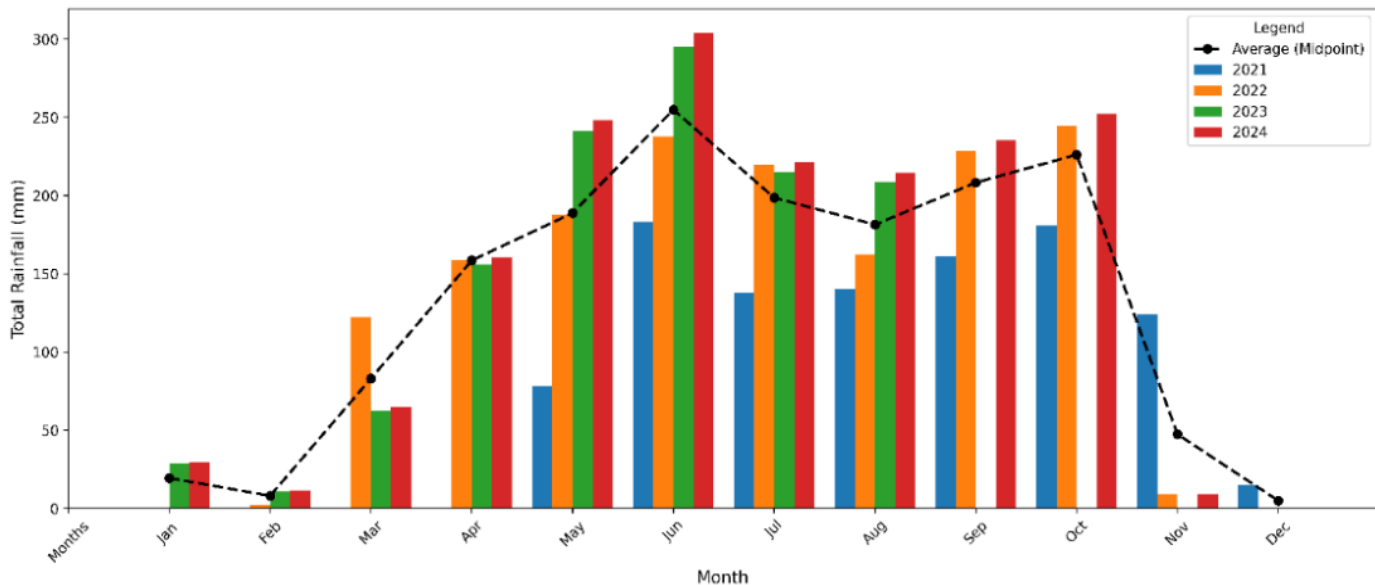


Figure 4. 1: Bar Chart of Monthly Rainfall Trend in the study area across three years

Rainfall records as shown in Figure 4.1 and Table 4.1 for the study area covering the period between 2021 and 2024 demonstrate a clear seasonal pattern, with rainfall concentrated mainly between April and October. June recorded the highest four-year monthly mean rainfall of 254.9 mm, followed by October (226.1 mm) and September (208.3 mm). The lowest monthly mean values occurred in December (5.0 mm), February (8.1 mm), and January (19.4 mm). Annual records also show variation in the timing of rainfall onset, with measurable rainfall beginning in May 2021, March 2022, March 2023, and January 2024, although the January 2024 value represented light rainfall. The highest monthly rainfall recorded during the study period was 303.9 mm in June 2024, followed by 295.0 mm in June 2023. These results confirm a pronounced wet-season and dry-season cycle in the study area.

Production Output in the Study Area

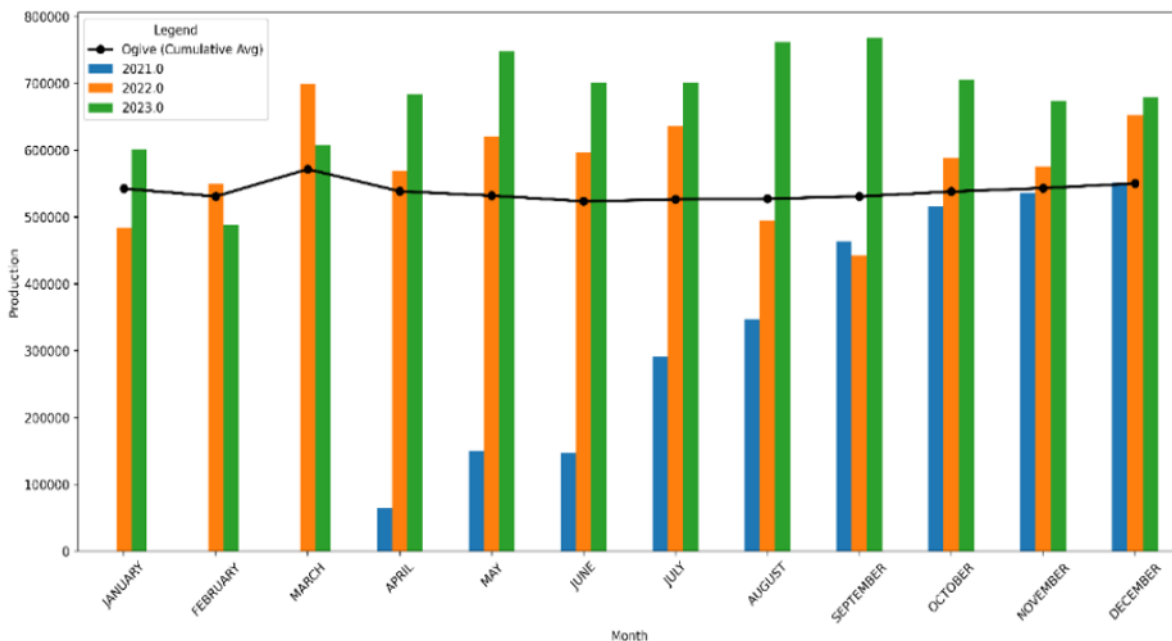


Figure 1: Bar Chart of Monthly Production Trend in the study area across three years

Mine production records for 2021–2023 show substantial monthly variation, with production patterns displaying a general relationship with the seasonal rainfall regime. Production commenced in April 2021, with monthly output increasing from 64,097 tonnes in April to 551,229.5 tonnes in December. Production declined during the peak rainfall period, particularly in June and July, when output was 147,081 tonnes and 290,701 tonnes, respectively. Production recovered during the second half of the year, exceeding 500,000 tonnes per month from October to December. In 2022, production ranged from 442,539 tonnes in September to 699,584 tonnes in March. The strongest performance occurred during the first quarter, followed by a decline between June and September, corresponding with the peak rainfall period. Production stabilised during the final quarter. In 2023, output increased from 488,739 tonnes in February to 767,439 tonnes in September. Production remained relatively strong during June and July, with outputs of 701,577 tonnes and 701,871 tonnes, respectively. Across the available records, the highest monthly average production occurred in September at 657,055 tonnes, followed by October at 603,515 tonnes. The reported lower average values were 519,217 tonnes for February and 632,325 tonnes for April.

Sunk Borehole Pumps (Dewatering) Data of the Study Area

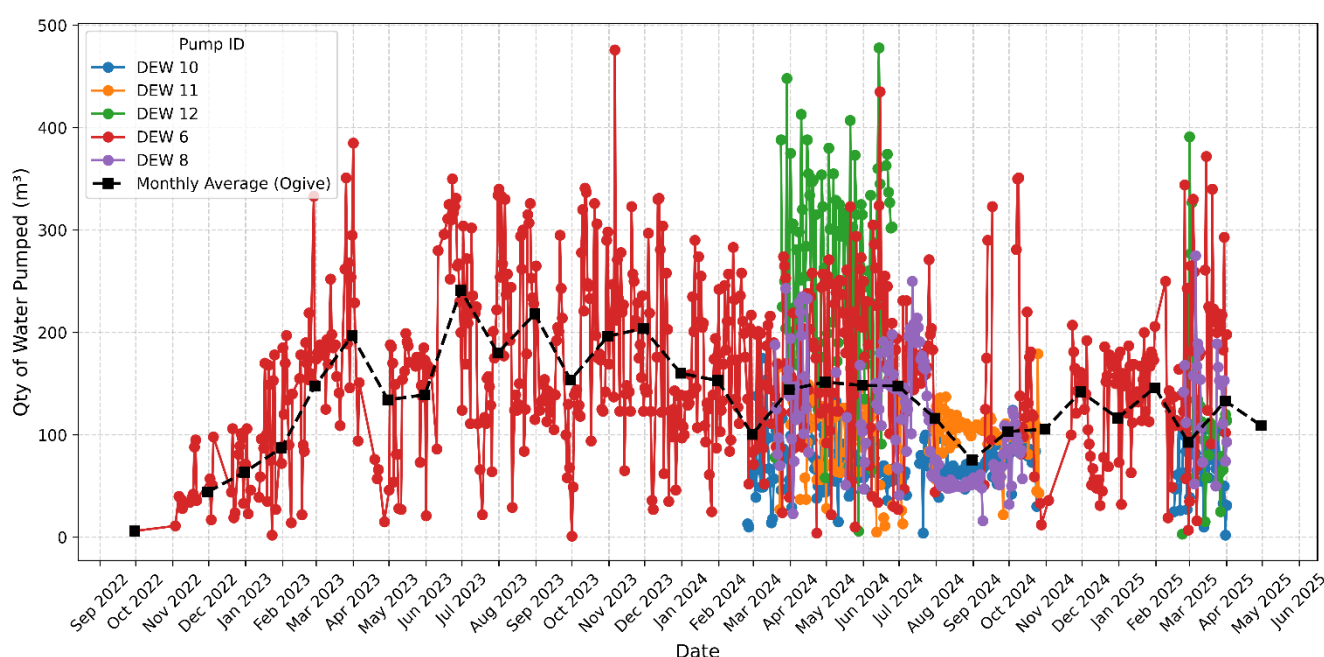


Figure 2: Time series Graph of groundwater pumped out of the mine

The sunk borehole dewatering data as shown in Figure 4.3, covering the period from September 2022 to April 2025, show considerable variation in the average monthly volume of water pumped from the pit. These fluctuations are likely driven by the seasonal rainfall patterns, as higher rainfall corresponds with greater water inflow into the pit, necessitating increased pumping.

In 2022, average monthly pumping volumes started low in September (6 m^3), with a substantial increase in November (44.1 m^3) and December (63.4 m^3), reflecting the onset of the rainy season. The average monthly volume of water pumped rose dramatically in the first half of 2023, with March recording the highest monthly average volume of 196.8 m^3 , followed by a consistent increase throughout the wet months (e.g., June with 241.1 m^3). This data suggests that the borehole dewatering system was operating under high pressure during the peak of the rainy season.

During the dry months, such as January and February of 2023, average monthly pumping volumes decreased slightly, with January recording 87.2 m^3 and February 147.7 m^3 . However, as the rainy season began again in May, the volume surged to 139.1 m^3 , peaking again in June and July (241.1 m^3 and 179.9 m^3 respectively).

In 2024, average borehole pumping volumes fluctuated around similar levels, with monthly averages peaking at 152.9 m^3 in January and dipping to a low of 75.5 m^3 in August, indicating reduced inflow during the latter

part of the dry season. However, as the rains returned, pumping volumes again saw a rise, with September 2024 recording 103.1 m³ and October 2024 rising to 105.4 m³.

In 2025, the volumes continued to demonstrate seasonal variability, with the highest volume of 145.97 m³ recorded in January 2025, reflecting the typical surge in pumping at the beginning of the rainy season. Over the course of the 2022-2025 period, the borehole system's pumping performance was heavily influenced by the rainfall cycle, as expected in open-pit mining operations in tropical climates.

Surface Dewatering Pumps Data of the Study Area

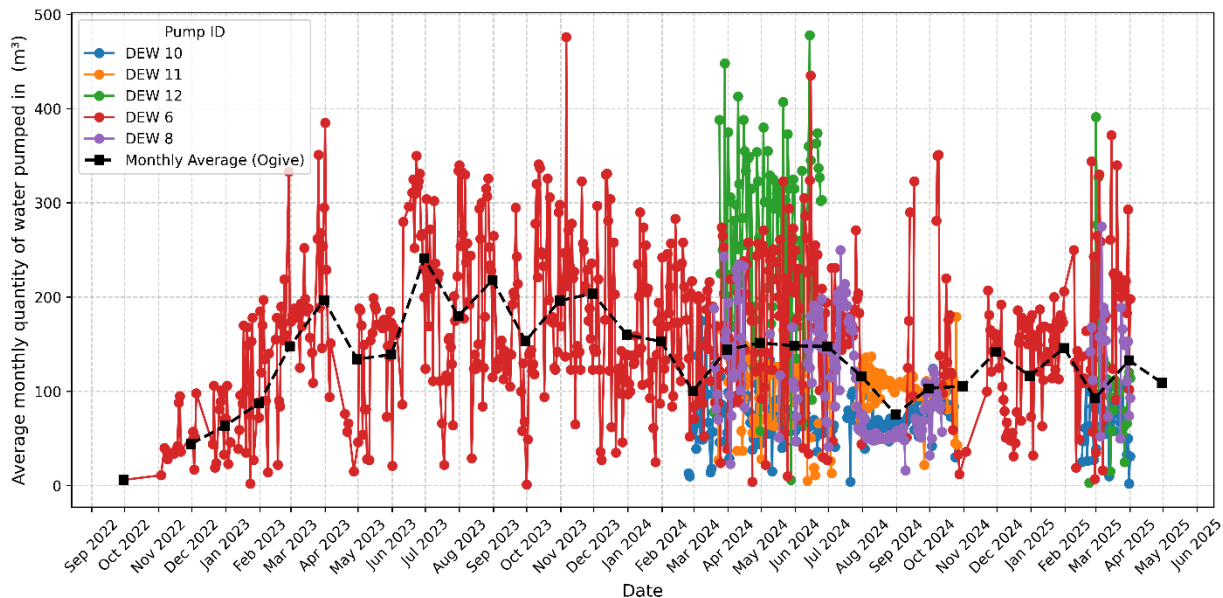


Figure 3: Time series Graph of Surface water pumped out of the mine

The surface dewatering pump data as shown in Figure 4.4, spanning from December 2021 to April 2025, indicate significant seasonal fluctuations in the volume of water pumped from the open pit. In December 2021, the surface pumps recorded a moderate pumping volume of 608.81 m³. This volume remained relatively low until February 2022 (880.6 m³) and March 2022 (1,316.2 m³), before experiencing a marked increase with the onset of the rainy season. In May and June 2022, surface pumping volumes surged to 1,299.4 m³ and 3,471.8 m³ respectively, reflecting the heightened inflow of water due to increased rainfall.

The peak pumping volume for 2022 occurred in September, with an exceptional 4,981.3 m³ pumped, coinciding with the heavy rainfall period. This trend continued through the following months, with October 2022 recording 4,203.4 m³ and December 2022 witnessing 2,216.1 m³ of water pumped.

In 2023, the surface dewatering system operated at similarly high levels. January 2023 began with 2,031.6 m³, while March (3,618.1 m³), April (5,099.7 m³), and June (7,005.1 m³) saw increased pumping to handle the larger volumes of water entering the pit. The highest monthly pumping volume for 2023 occurred in June at 7,005.1 m³, correlating with peak rainfall. Pumping volumes in the dry months (e.g., January 2024: 1,361.5 m³) were noticeably lower, although still substantial compared to earlier periods in 2022.

In 2024, surface pump volumes fluctuated with the seasonal rainfall. January and February 2024 were relatively dry, with pumping volumes of 1,361.5 m³ and 1,258.4 m³, respectively. The year peaked in October 2024 with a massive 13,065.8 m³, following significant rainfall that month. After October, the volume gradually decreased as the wet season ended, with the lowest pumping volume in April 2025 at 325 m³, reflecting the dry season.

Overall, the surface dewatering system's performance indicates a clear seasonal pattern, with the wet months of June to October consistently requiring higher pumping volumes, peaking at 13,065.8 m³ in October 2024.

The seasonal variability observed here highlights the mine's dependence on the efficiency of its dewatering infrastructure to manage increased water inflow during the wet season.

Relationship Between Rainfall and Pit Water Build-Up (Total Inflow)

Table 2: Pearson correlation analysis between monthly rainfall and surface water inflow

Correlations		Rainfall_m m	SurfaceInflow_w_m3	BoreholeInflow_m3	TotalInflow_m3
Rainfall_mm	Pearson Correlation	1	.577**	.082	.577**
	Sig. (2-tailed)		.001	.677	.001
	N	28	28	28	28
SurfaceInflow_m3	Pearson Correlation	.577**	1	.167	1.000**
	Sig. (2-tailed)	.001		.396	.000
	N	28	28	28	28
BoreholeInflow_m3	Pearson Correlation	.082	.167	1	.190
	Sig. (2-tailed)	.677	.396		.334
	N	28	28	28	28
TotalInflow_m3	Pearson Correlation	.577**	1.000**	.190	1
	Sig. (2-tailed)	.001	.000	.334	
	N	28	28	28	28

** . Correlation is significant at the 0.01 level (2-tailed).

The Pearson correlation analysis revealed a moderate positive relationship between monthly rainfall and surface water inflow ($r = 0.577$, $p = 0.001$), indicating that as rainfall increases, surface water inflow into the pit also increases (Table 4.2). The correlation coefficient of 0.577 suggests a moderately strong association between these variables. This is consistent with the expectation that higher rainfall would result in greater surface runoff, contributing to the accumulation of water in the pit.

For the borehole inflow, the correlation with rainfall was weak and non-significant ($r = 0.082$, $p = 0.677$). This suggests that groundwater inflow into the pit is not strongly influenced by the amount of seasonal rainfall, possibly due to other hydrogeological factors such as subsurface aquifer levels or geological characteristics that are not directly related to surface precipitation.

When examining the relationship between total inflow (the sum of surface and borehole inflows) and rainfall, the correlation was moderately strong ($r = 0.577$, $p = 0.001$), like the relationship with surface inflow. This indicates that rainfall does indeed have a substantial impact on the overall water accumulation in the pit, primarily through surface runoff.

Rainfall Vs Surface Water Inflow

Table 3: Regression Analysis between monthly rainfall and surface water inflow

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.577 ^a	.333	.307	2032.205731260
a. Predictors: (Constant), Rainfall_mm				

ANOVA ^a						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	53613596.597	1	53613596.597	12.982	.001 ^b
	Residual	107376363.488	26	4129860.134		

	Total	160989960.085	27			
a. Dependent Variable: SurfaceInflow_m3						
b. Predictors: (Constant), Rainfall_mm						

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	2048.882	635.765		3.223	.003
	Rainfall_mm	12.975	3.601	.577	3.603	.001
a. Dependent Variable: SurfaceInflow_m3						

Regression Analysis: Rainfall vs Surface Inflow

The regression analysis confirmed that rainfall is a statistically significant predictor of surface water inflow. The model yielded an R^2 value of 0.333, meaning that 33.3% of the variability in surface inflow can be explained by rainfall (Table 4.3). The regression equation indicates that for every millimetre of rainfall, the surface water inflow increases by approximately 12.98 m³ ($p = 0.001$), with a high level of statistical significance. The F-statistic (12.982) also suggests that the regression model fits the data well, with the relationship between rainfall and surface inflow being robust.

Rainfall Vs Ground Water Inflow

Table 4: Regression Analysis between monthly rainfall and Ground water inflow

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.082 ^a	.007	-.031	58.59862643636
a. Predictors: (Constant), Rainfall_mm				

ANOVA ^a						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	609.037	1	609.037	.177	.677 ^b
	Residual	89278.775	26	3433.799		
	Total	89887.811	27			
a. Dependent Variable: BoreholeInflow_m ³						
b. Predictors: (Constant), Rainfall mm						

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	125.396	18.332		6.840	.000
	Rainfall_mm	.044	.104	.082	.421	.677
a. Dependent Variable: BoreholeInflow_m3						

Regression Analysis: Rainfall vs Borehole Inflow

In contrast, the regression model for borehole inflow revealed a very weak relationship with rainfall, with an R^2 value of 0.007, indicating that rainfall explains only 0.7% of the variance in borehole inflow. The

coefficient for rainfall was 0.044 m³ per mm of rainfall, but this was not statistically significant ($p = 0.677$) (Table 4.4). The results suggest that borehole inflow is minimally influenced by seasonal rainfall and may be more closely linked to other factors such as subsurface water movement and aquifer recharge.

Effect of Rainfall on Mine Production Output

Table 5: Pearson correlation analysis between monthly rainfall and production output

Correlations			
		Rainfall_mm	Production
Rainfall_mm	Pearson Correlation	1	.132
	Sig. (2-tailed)		.503
	N	28	28
Production	Pearson Correlation	.132	1
	Sig. (2-tailed)	.503	
	N	28	28

The Pearson correlation analysis between monthly rainfall and production output revealed a very weak positive correlation ($r = 0.132$), with a non-significant p -value of 0.503 (Table 4.5). This suggests that there is little to no meaningful relationship between rainfall and production output in the study period. The correlation coefficient indicates that changes in rainfall are not strongly associated with fluctuations in mine production.

Table 6: Regression Analysis between monthly rainfall and Surface water inflow

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.132 ^a	.017	-.020	102326.34907
a. Predictors: (Constant), Rainfall_mm				

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4836455803.912	1	4836455803.912	.462	.503 ^b
	Residual	272237724540.767	26	10470681713.106		
	Total	277074180344.679	27			
a. Dependent Variable: Production						
b. Predictors: (Constant), Rainfall_mm						

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	577835.629	32012.281		18.050	.000
	Rainfall_mm	123.238	181.329	.132	.680	.503
a. Dependent Variable: Production						

Further regression analysis was conducted to evaluate whether rainfall is a significant predictor of production. The regression model returned an R^2 value of 0.017, indicating that only 1.7% of the variation in production

can be explained by rainfall. The model's F-statistic of 0.462 and p-value of 0.503 confirm that the relationship between rainfall and production is statistically insignificant. The regression coefficient for rainfall was 123.238 (per mm of rainfall), but this was not statistically significant ($p = 0.503$). The t-statistic of 0.680 further supports the conclusion that rainfall does not have a substantial impact on production output.

CONCLUSION AND RECOMMENDATIONS

This study assessed the influence of seasonal rainfall on dewatering performance and production efficiency in an open-pit gold mine in Southwestern Nigeria. The findings showed that rainfall has a significant positive relationship with surface water inflow ($r = 0.577$, $p = 0.001$), indicating that increased rainfall directly contributes to pit water accumulation through surface runoff, while groundwater inflow showed a weak and statistically insignificant relationship with rainfall ($R^2 = 0.007$, $p = 0.677$), suggesting stronger control by subsurface hydrogeological conditions.

Although production output showed seasonal variations during peak rainfall periods, statistical analysis revealed that rainfall was not a significant predictor of production performance ($r = 0.132$, $p = 0.503$), demonstrating that effective dewatering practices and operational planning helped reduce rainfall-related disruptions. The surface pumping system effectively managed peak wet-season inflows, but opportunities exist to improve system efficiency through better integration of borehole capacity, real-time water monitoring, energy-efficient pumping strategies, improved surface runoff control, and regular maintenance of dewatering infrastructure. Future studies should incorporate detailed hydrogeological modelling, economic evaluation of pumping operations, advanced predictive monitoring systems, and multi-site assessments to improve understanding of rainfall-driven water management challenges across Nigerian mining operations.

REFERENCES

1. Adebayo, B., & Taiwo, O. A. (2011). Effect of seasonal changes on overburden stripping in limestone quarry. *World Journal of Engineering*, 8(2), 191–194.
2. Afeni, T. B., Adebayo, B., & Ogundayo, A. A. (2023). Effect of seasonal variations on quarry operations in Southwest Nigeria. *International Journal of Mining and Mineral Engineering*, 14(1), 27–40. <https://doi.org/10.1504/IJMME.2023.10056431>
3. Agyei, E., & Tetteh, S. (2022). Impact of rainfall variability on mining operations and productivity.
4. Akinsanola, A. A., & Ogunjobi, K. O. (2014). Analysis of rainfall extremes in Nigeria using daily rainfall data. *Journal of Environment and Earth Science*, 4(24), 39–51.
5. Angel, M. L., Johnston, S., O'Steen, K., Brown, C., & Sando, T. (2015). Groundwater control issues in transportation engineering: A short review of dewatering methods and lessons learned. *Journal of Engineering Science and Technology Review*, 8(3), 8–13.
6. Cilliers, C., Van der Zee, L., & Kleingeld, M. (2014). Cost savings on mine dewatering pumps by reducing preparation-and comeback loads. *Proceedings of the International Conference on Industrial and Commercial Use of Energy*, 1–8.
7. Darlami, H. B., Jha, A. K., & Ghimire, K. (2025). A critical review of recent dewatering technologies: Performance and applications. *Asian Journal of Water, Environment and Pollution*, 22(5), 55–64.
8. Gao, L., Bryan, B. A., Liu, J., Li, W., Chen, Y., Liu, R., & Barrett, D. (2017). Managing too little and too much water: Robust mine-water management strategies under variable climate and mine conditions. *Journal of Cleaner Production*, 162, 1009–1020.
9. Johnson, A. (2023). Mine dewatering case study at a gold mine in Mandiana Region, Eastern Guinea. *Ground Water Division Annual Conference*, Johannesburg, South Africa.
10. Liu, Y., & Song, W. (2019). Influences of extreme precipitation on China's mining industry. *Sustainability*, 11(23), 6719.
11. Liu, Y., Zhang, J., & Wei, L. (2018). Impact of rainfall on coal mine production efficiency: A quantitative assessment. *Journal of Cleaner Production*, 189, 510–518.
12. Mallo, S. J. (2012). Challenges of mineral exploitation in Nigeria and its impact on economic growth. *Journal of Economics and Sustainable Development*, 3(5), 49–54.

13. Nnabo, P. N. (2015). Environmental and health impact of abandoned mine pits in Enyigba, Ebonyi State, Nigeria. *Journal of Environmental Science and Water Resources*, 4(2), 58–67.
14. Okogbue, C. O., & Ukpai, O. (2013). Impact of open cast mining on water quality in Enyigba, Ebonyi State, Nigeria. *Applied Water Science*, 3(1), 19–24.
15. Oluwadare, A. O., & Oluwadare, E. J. (2025). Understanding climate variability and rainfall distribution patterns in Osogbo, southwestern Nigeria. *Nigerian Journal of Physics*, 34(2), 177–185.
16. Sahoo, L. K., Bandyopadhyay, S., & Banerjee, R. (2014). Water and energy assessment for dewatering in opencast mines. *Journal of Cleaner Production*, 84, 736–745.
17. Serafini, P., Franks, D., & Boger, D. (2015). Hydrological challenges in open-pit mining: A review. *Resources Policy*, 46(1), 16–24.
18. Silva, A., Mendes, J., & Costa, M. (2017). Rainfall-induced slope instability in Brazilian open-pit iron mines. *Engineering Geology*, 222, 209–220.
19. Unsal, M., & Yazicigil, H. (2015). Mine dewatering and hydrological assessment approaches.
20. Younger, P. L. (2004). *Mine Water: Hydrology, Pollution, Remediation*. Kluwer Academic Publishers.