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Analysis of the Effects of Rainfall on Production Performance of a Surface Mine in Ghana

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Abstract
Monthly production rates of most surface mines fluctuate with season and the Nzema Gold Mine is no exception. Located in the western region of Ghana, which is considered the wettest part of the country, the monthly production rates of the mine fluctuate with rainfall. Data covering three years were obtained from the mine and subjected to some statistical analyses including regression analysis and t-test. Using regression analysis, the production data were regressed on the rainfall records to establish a coefficient of determination (R^2) and also to observe the general trend between the two variables. The obtained coefficient of determination was further scrutinized with a t-test to prove the existence of a linear correlation between rainfall and production. The results obtained show that there is no linear correlation between rainfall and production in the Nzema Gold Mine. Nevertheless, the presence of rainfall in the mine has an impact on production values, preventing the mine from meeting its desired production targets. From the results, rainfall comes third place on the hierarchy of general delays with a percentage contribution of 13% and causes an average loss of about 4,145 Bank Cubic Metre (BCM) worth of material annually. The presence of rainfall also introduces some benefits as well as deprivations to the mine, causing an average of about $243,000 worth of fuel to be saved concerning the water dust suppression activities, and an average of about $273,000 worth of fuel to be lost on dewatering pumps.

Keywords: Surface Mine, Rainfall, Productivity, Ghana, Regression Analysis

1.0 INTRODUCTION

The main aim of every mine is to make a profit at the least possible cost with a reasonable emphasis on safety. However, in the history of most surface mines, the monthly production fluctuates with the season, with several factors suspected to be responsible for this phenomenon. Mining might be chiefly about what comes out of the earth's crust, but when it comes to safety and effective production, some of the greatest threats come from the atmosphere

Climate can be defined as the composite or generally prevailing weather conditions of a region, such as temperature, air pressure, humidity, precipitation (rainfall), sunshine, cloudiness, and winds, throughout the year.

The weather or general climatic conditions present some hazards that affect production and safety; lightning poses a risk to personnel involved in heavy equipment operation as well as explosives handling and construction activities, heavy rains can close down mines and bog down access roads, winds disrupting blasting, high temperatures affecting staff and machinery and others. The most predominant amongst these factors is rainfall since it affects almost every activity in surface mining operations.

Rain is a major component of the water cycle and is responsible for depositing most of the fresh water on the earth, providing conditions for many types of ecosystems. It plays a role in the hydrological cycle in which moisture from the oceans evaporates, condenses into droplets, precipitates fall from the sky, and eventually returns to the ocean via rivers and streams to repeat the cycle [2].

Rainfall or precipitation is measured using a rain gauge. When classified according to the rate of precipitation, rain can be divided into the following [2]:

a. Very light rain – when the precipitation rate is < 0.25 mm/hr;
b. Light rain – when the precipitation rate is between 0.25 mm/hr – 1.0 mm/hr;
c. Moderate rain – when the precipitation rate is between 1.0 mm/hr – 4.0 mm/hr;

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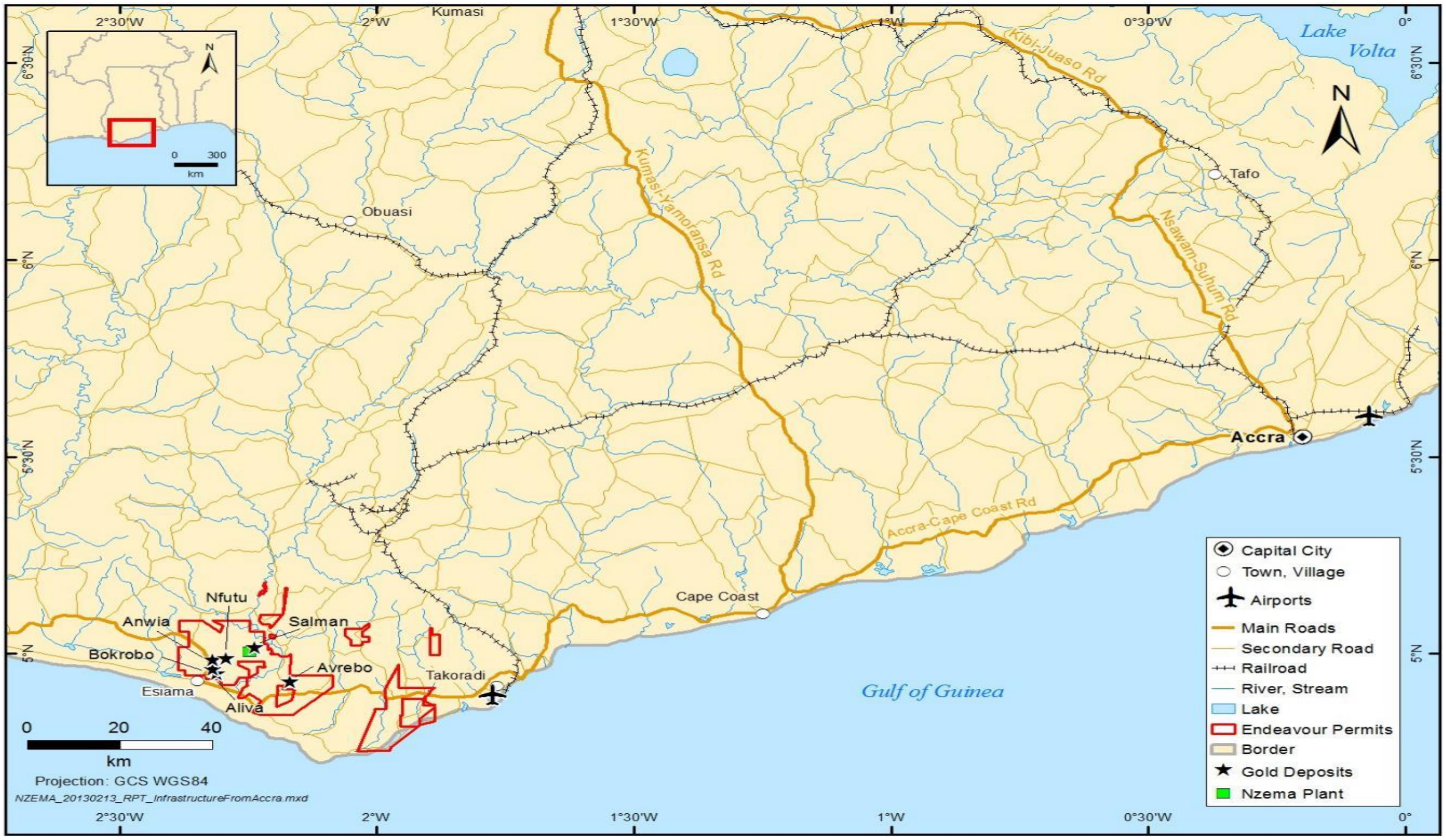

Figure 1: The location of the mine. [1]

d. Heavy rain – when the precipitation rate is between 4.0 mm/hr – 16.0 mm/hr;
e. Very heavy rain – when the precipitation rate is between 16.0 mm/hr – 50.0 mm/hr; and
f. Extreme rain – when the precipitation rate is > 50.0 mm/hr.

Most underground water can be attributed to rainfall since surface runoffs usually seep into the earth. The presence of geological or structural features such as faults, pores, and fissures facilitates the process. Thus, rainfall can be viewed as a direct natural recharge to the underground water table, increasing its level. The sources of inflow to a surface mine can be classified as follows [2]:

a. Inflow from atmospheric precipitation and percolation through the backfill which forms its water table;
b. Inflow from mineral beds and underground aquifers;
c. Inflow through geological/structural features;
d. Inflow via pit floor heave and/or piping; and
e. Transmission via disused/abandoned mine workings.

Precipitation acts as a direct natural recharge to sub-surface aquifers. Surface runoffs due to rainfall can drain or percolate through the superficial deposits to feed an underground aquifer. Usually, the presence of fault zones facilitates the process, as the unconsolidated nature of the backfill provides an excellent conduit for the passage of water into the pit.

Aquifers generally serve to store and transmit groundwater, and when such beds are disturbed or intercepted by mining operations, the inflow may be induced to the excavation. A concealed outcrop of mineral bed adjoining heavy water-bearing strata may similarly allow a direct yielding of water into the excavation [2]. Geological features associated with the environment of a mine can serve as a conduit or pathway through which water can enter an excavation. Examples of such features include faults, joints, cleavage, and bedding planes as well as dykes. In the event of a geological feature bringing a heavy water-bearing rock sequence into proximity to the mining horizon, flooding may occur. The flooding of the pit floor as a result of an artesian aquifer underlying a structurally weak confining bed of excavation is termed "heave". Floor heaves result from the imbalance of forces that occur when the overburden and the mineral bed are removed in the process of mining. If the confining bed is incompetent, fracturing may occur and large quantities of pressurized water may be released into the mine posing a hazard. Inflow will be rapid if the transmissivity and the hydrostatic head of the aquifer are high [2]. Surface mine operations near-surface deposits that have been previously worked on can provide highly permeable water reservoirs, which when intercepted by mine workings may provide a high potential inrush situation [2]. Rainfall is generally the most predominant climatic condition that affects productivity concerning surface mining operations. This can be attributed to its constant interference with almost all the stages of production which include drilling, blasting and loading, and hauling. The objective of the paper is to determine the correlation between production and rainfall and investigate the hierarchy of general delays as well as the percentage contribution of rainfall to the delays. The Nzema Gold Mine (ADAMUS) employing an open-pit mining surface system, is on the southwestern part of Ghana approximately 280km west of the country's capital, Accra, and the southern end of the Ashanti gold belt, approximately 70km from Takoradi (Fig. 1).

2.0 METHODS AND MATERIALS

The methods used include;

Production, rainfall, and other relevant data for this work were obtained from African Mining Services (Nzema Mine) and complemented with data from Ghana Meteorological Agency designated rainfall data collection centre in the area. The recorded rainfall heights and rain delays were given in millimeters and hours respectively, as the production records were given in bank cubic meter (BCM). All data were initially taken daily before they were composited into monthly equivalents covering a period of three (3) years i.e.; from January 2015 to December 2017 to determine the possibility of a trend.

Statistical analysis using correlation analysis and T-test. The estimated population correlation coefficient, (ρ) was tested at a 5% level of significance to investigate the existence of any correlation between rainfall and production employing t-test as follows:

H_0 is the null hypothesis: r = 0 (means there is no correlation among the variables)

H_1 is the alternate hypothesis: r≠ 0 (means there is a correlation among the variables)

Level of significance, α = 5%

The significance level of the t-test is given by equation

$$t = r\sqrt{n-2}/\sqrt{(1-r^2)} \qquad (1)$$

where r is the coefficient of correlation

n is the number of paired samples

t is the t value

Critical Region: $t_{c\,0.025} < -(2.0336)$ and $t_{c\,0.025} > (2.0336)$

The plot of the estimated regression equation and all the graphs were done using Microsoft Excel

The Coefficient of Determination (R^2) value was used to determine the relationship between rainfall and mine production.

3.0 RESULTS AND DISCUSSION

The production, rainfall height, and rainfall delays including their averages recorded from the mine were plotted on graphs to show their monthly trends. Fig. 2 shows the monthly rainfall trend experienced within the mine. From Fig. 1, it can be observed that:

i. The average rainfall curve shows the two rainfall seasons experienced within the mine and its environs;
ii. The major rainy season starts from March and ends in August with its peak in June;
iii. The minor rainy season is usually between September and November with its peak in October;
iv. The minimum rainfall height recorded was in February whiles the highest was in June. The months that recorded low rainfall heights were January and February while those with high rainfall heights were June and October. The highest recorded monthly rainfall height was in June 2015 with a value of 858 mm with the lowest in February 2016 with a value of 13.5 mm.

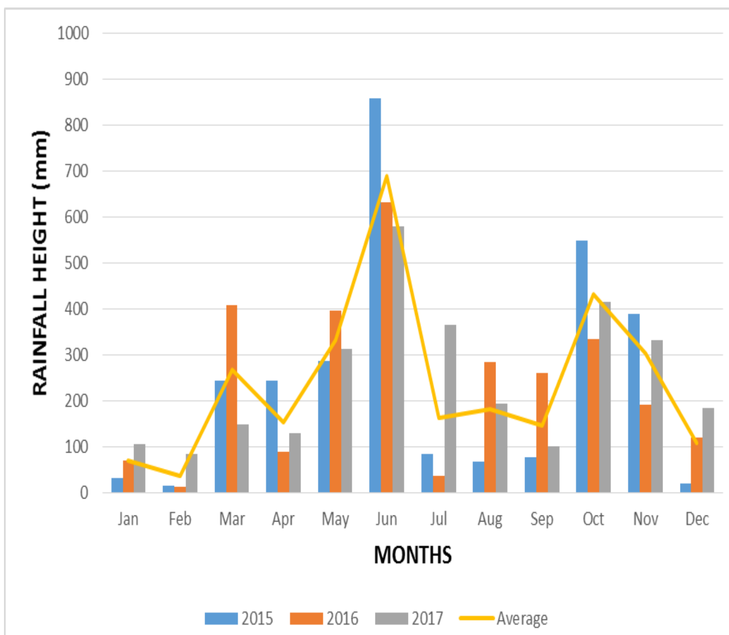

Figure 2: Monthly Rainfall Trend of Nzema Gold Mine Site

Fig. 3 shows a chart of the monthly production trend of the mine.

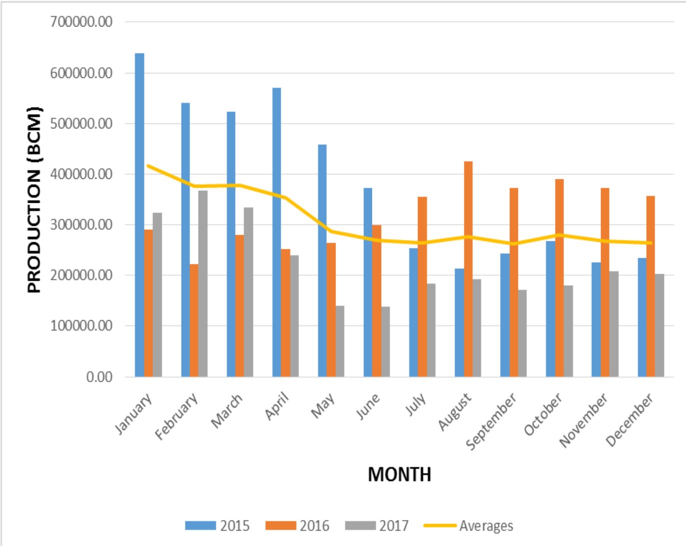

Figure 3: Monthly Production Trend of the Period

From Fig. 3, it can be observed that;

a. The monthly production distribution curve exhibits similar trends as the rainfall figures.

b. The average production curve shows high production obtained for months with minimum rainfall heights and vice versa.

c. From the average production curve, high production values were recorded in January, February, March and April with their peak in January.

d. Low production values were recorded in June which constitute the major rainy season; and

e. The highest production value was recorded in January 2015 with a value of 638,843 BCM and the lowest in June 2017 with a value of 139,111.0 BCM.

The production values were then regressed on the rainfall values to investigate the existence of any correlation. From the scatter diagram shown in Fig. 4, it can be observed that;

i. Almost all rainfall values recorded fell between 0 and 400 mm;

ii. Most of the production values recorded fell between 200,000 and 400,000 BCM; and

iii. The trend line gives a linear correlation of determination of 0.0226 with a negative gradient of 93.67. It can also be observed from the trend line that an increase in rainfall values results in a decrease in production values and vice versa.

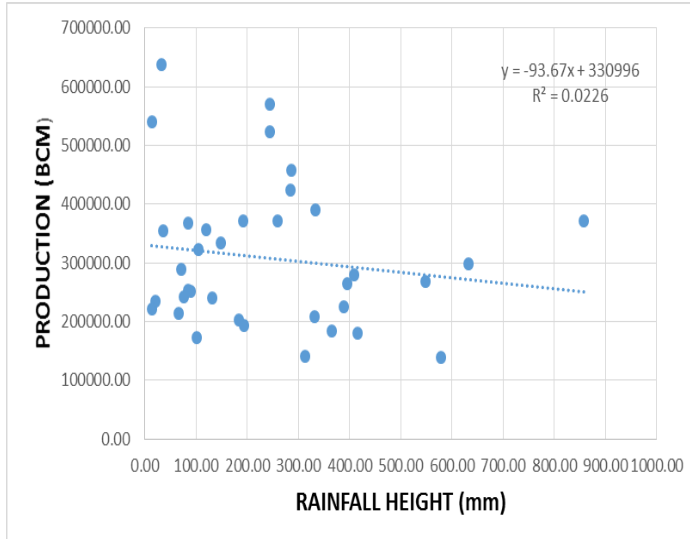

Figure 4: Production with Rainfall Height

Given that r^2 is -0.0226, and n is 36 and substituting in Equation 1

$$t = -0.15\sqrt{(\sqrt{((36-2)})\,)/\sqrt{(1-(-0.0226)}}$$

$$t = -0.8847$$

Since the calculated t value (-0.8847) does not lie within the critical region but rather the acceptance region, the null hypothesis is accepted signifying the absence of linear correlation between rainfall and production.

Table 1 cumulative Yearly Statistics for three years. (2015-2017)

Table 1 Cumulative Yearly Statistics

Year	Total Rainfall (mm)	Total Rain Delay (hrs)	Total Client Target (BCM)	Total Actual Production (BCM)
2015	2,859.90	485.20	4,444,242	4,543,625
2016	2,833.00	293.88	4,045,200	3,878,148
2017	2,950.30	270.88	2,712,954	2,684,456
Average	**2,881.11**	**349.80**	**3,734,132**	**3,702,077**

From Table 1;

Average production loss = total client target – total actual production

Average production loss = 3,734,132 – 3,702,077 = 32,055 BCM

Average production loss per year = 32,055 BCM

The average production loss however is a result of general delays or factors which affect production.

Table 2 shows the general delay parameters in the mine.

Table 2: General Delay Parameters

Delay Parameters	Average Delays (hrs)	Percentage (%) Influence
Under truck	531.84	19.66
PSI/ Transit to pit	425.48	15.73
Rain delay	349.80	12.93
Tramming	285.09	10.54
Battering	233.75	8.64
GSA	214.33	7.92
Clean up	165.53	6.12
End of shift change	124.55	4.60
Operational delays	88.80	3.28
Safety meetings	79.50	2.94
Coffee break	60.05	2.22
Hourly hire	56.95	2.11
Fueling/ Greasing	32.00	1.18
Geos delay	18.82	0.70
Survey delays	15.80	0.58
Blast delays	13.23	0.49
Delays after chop	8.53	0.32
Sleipner transport	1.22	0.04

From Table 2, it can be observed that the highest delay parameter encountered by the mine is the under truck delay with an average annual delay of 531.84 hrs contributing 19.66 % of the general delay. The second highest delay parameter faced by the mine is the pre-shift inspection (PSI) or transit to pit delay contributing 15.73 % to the general delays with an annual average of 425.48 hrs corroborating with [3] on the effect of internal operational factors on production variation. The third highest delay parameter is rainfall with an annual average of 349.80 signifying 12.93 % of general delay parameters encountered by the mine.

Thus, the effect of rainfall on production is quantified as follows;
Percentage influence of rainfall = 12.93 %
Average production loss = 32,055 BCM
Production loss due to rainfall = 12.93% × 32,055 BCM
Production loss due to rainfall = 4,144.712 BCM
Therefore, on average, the mine loses 4,144.712 BCM worth of material to rainfall coinciding with [4] on the effect of weather conditions on production volume.

Fig.5 shows a bar chart of rainfall and the corresponding delays caused.

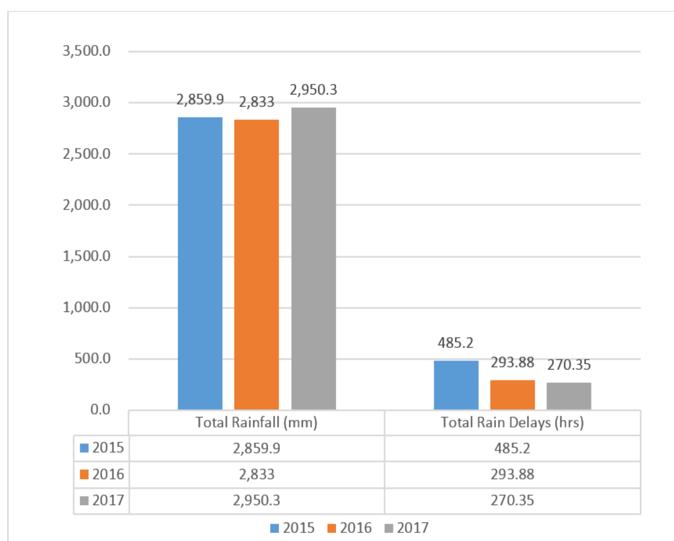

Figure 5: Bar Chart of Rainfall and Rain Delays

From Fig 5, it can be observed that the total rainfall recorded for the respective years was almost similar, with the highest of 2,950.3 mm recorded in 2017. The highest rain delay was recorded in 2015 with a total of 485.2 hrs whiles the least was in 2017 with a total of 270.35 hrs. An upward trend is observed concerning rainfall height whereas a downward trend is observed for rain delays concerning the three years. An increase in rainfall does not necessarily influence its delay. This may be attributed to the advancement of mining methods and technologies, for example sheeting. Fig. 6 shows the average monthly fuel consumption of the water cart.

The cumulative average consumption for dust suppression activities was 69,366 litres.

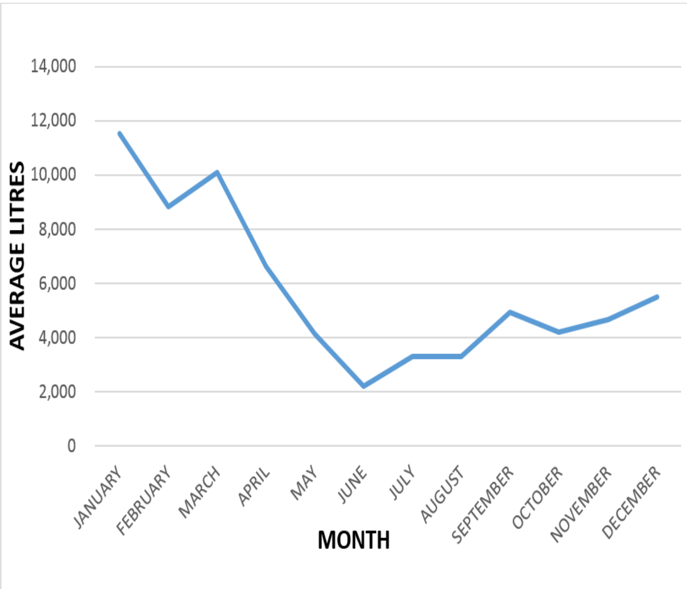

Figure 6: Line Graph of Average Monthly Water Cart Fuel Consumption

From Fig 6, it can be observed that the fuel usage trend line shows an inverse relationship to the rainfall trend line. The highest fuel consumption of 11,521 litres was recorded in January which usually has the least recorded rainfall. The lowest fuel usage of 2,207 litres was recorded in June, where rainfall is mostly at its peak.

To quantify the amount of fuel saved as a result of rainfall;

Actual Fuel Consumption Per Annum = 69,366

The average number of working days per year = 278

Average fuel burning rate (per hour) = 43.21 ltr

Estimated average fuel usage per year = 278 × 24 × 43.21
= 288,297.12 ltr

Total average fuel usage per year = 69,366.0 ltr

Rainfall contribution = 288,297.12 – 69,366
= 218,931.12 ltr

Average Cost of fuel per litre = $ 1.11

Average amount saved per year = 1.11 × 218,931.12
= $ 243,013.50

Therefore, averagely, $243,000 worth of fuel is saved each year in dust suppression as a result of increased rainfall. Concerning deprivations, Table 3 shows the average fuel consumption of the dewatering pumps in the mine.

Table 3: Average Fuel Usage of Pump

Month	Pump Fuel Usage (ltr)
January	15,121
February	18,935
March	15,830
April	21,492
May	11,169
June	27,834
July	27,684
August	12,118
September	8,652
October	30,362
November	34,163
December	22,266
Total	**245,626**

The results have revealed that rainfall does not count as the leading factor concerning the reduction of production rates. However, it has been proven to have an impact on production and therefore necessary to be considered in planning to corroborate with similar results obtained by [4-7]. The study of the reliability of the equipment parts and their dependence on environmental factors data in product support logistics by [8] suggests that forecasting of product support and spare parts requirements together with operating environmental factors is one of the most effective means to improve availability and utilisation for enhanced productivity.

The following recommendations when adhered to will improve the production rates of the mine:

a. Improvement of drainage mechanisms and dewatering activities to ensure that the pits are in optimal conditions at all times to reduce pumping costs.
b. Effective sheeting of pit floors and haulage roads to increase traction and aid in drainage.

4.0 CONCLUSIONS

Linear regression analysis of the rainfall and production values shows a negative gradient with equation $Y = -93.67X + 330996$ and a coefficient of determination of 0.0226 where Y is the value of the dependent variable (production), 93.67 is the slope, X is the independent variable (rainfall) and 330,996 is the Y-intercept. An increase in rainfall values results in a decrease in production values.

However, from the t-test, no correlation was found to exist between production and rainfall values at a 5% level of significance. The absence of correlation depicts the absence of a linear prediction model for the two variables and proves that production is not dependent on rainfall. This is further buttressed by the fact that rainfall is not the highest delay parameter that affects production but rather the third in rank, with a percentage influence of about 13%.

An average of 4,145 BCM worth of material is lost or left unmined annually as a result of rainfall interruptions. Also, an average amount of $243,000 was saved in dust suppression with water bowsers whilst is $273, 00 lost in dewatering pumps. Rainfall is generally an undesirable parameter encountered in open-pit mining, primarily because of its uncontrollable nature.

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