CONTROLLING MINE WATER IN GOLDEN GIRL QUARRY IN IKPESHI, EDO STATE, NIGERIA

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Abstract

The current study focus on the determination of the volume of mine water during dry and rainy season in Golden Girl Quarry, Ikpeshi, Edo State; the selection of appropriate pump control system for drainage operations for sustainable working environment in this quarry. The rationale for conducting this research is to control the challenges that come with mine water, in order to get profitable and commercial production. Hence, the appropriate controlling measures adopted. The preliminary study conducted reveals that the quarry has five pits. Hence, the required number of data is acquired. The water volume is confirmed highest in the rainy seasons than the dry seasons in this quarry. Some pumps were chosen from among some suggested water pump engines with their attributes of operations, and the source of their manufacturers. This pump selection was made for Golden Girl Quarry, considering individual mine pit locations.

Introduction

Mine water is the water that collects or accumulates at the surface of the mine that is later drained or pumped out of the open pit. It is the water produced throughout the life of mine projects (especially during excavation), including polluted surface run-off from facilities associated with the project, and the entire water or waste flowing out. It encompasses the total water impacted during mining operations, such as freshwater, process wastewater, contact water and mine drainage. Mine water includes seepage below impoundments, or waste rock. This surface or subterranean water enters the mine during mining operations and poses threats to its operation.

Mine water in mines poses difficulties and challenges for mining operations to be carried out; and it can be overcome by drainage or dewatering of the mine pits (Richard, 1978). Mine water control should be considered in mine planning, because it can cause a potential hazard during mining operations and can also, reduce production pace (Catarina, 2019). The presence of mine water disrupts mining operation by cutting down on the production capacity (Silwamba and Chileshe, 2015).

To match this, control measures were employed to check this menace, in order to achieve an effective and safe mining operation, leaving no damp situation. A combined approach of controlling mine water (mine dewatering, mine depressurization and pit-void water management) will help in achieving adequate mine water management (Ahumada, 2020).

The flow rate of mine water varies significantly from tens to thousands of cubic meters per hour. Different studies have shown that the content of mine water is lower during the dry season (Malhi *et al.,* 2002) and evaporation is lower in the wet season (Harris *et al.,* 2004). Rainy season is a significant factor in mining operations (Bonal *et al.,* 2000), as it invariably determines the amount of water from its run-off into the mine pit (Khatun *et al.,* 2016; Mannana *et al.,* 2015). A good instance of mine water impact occurred in some mines in Scandinavia and the United Kingdom (David *et al.*, 1997). In China, flooded mines were observed to get water from overlying and/or adjacent flooded mines, by vertical infiltration from overlying freshwater aquifers and/or from surface water sources (Hawkins and Dunn, 2007). Joseph and Eric (2019), in their research recorded water level fluctuation in a

series of adjacent closed mine as a result of mine flooding in the Fairmont Coalfield, one of the oldest coal mining districts in the Pittsburgh coal basin, West Virginia, USA. The closure of an Open-pit mine was observed in the equatorial region of Indonesia (Sangatta and Bengalon mining areas) which left a pit that eventually developed into a pit lake (Edy *et al.*, 2021). The mine water gotten during different mining operations must therefore be controlled in order to sustain a balanced in mining operation and production.

Control of mine water can be done by dewatering through in-pit pumping or pump-out to reduce the level of groundwater underneath the pit situated in the work zone. It involves the removal or drain away standing and turbid surface mine water produced within the pit, which actually had a run-off across the floor of the pit and its pathways for dewatering of suspended particles and sediments (Leech and McGann, 2008; Beale and Read, 2013). The selection of which control system to use depends on factors such as: hydro-geological conditions, length of time that pumping is required, volume of water to be removed, whether pumping equipment can be installed in the operational area, dewatering equipment and contractor experience (Kym, 1993). The three main types of pumps are: axial-flow pumps, that use axial force in low head designs and high flow applications (Dennis, 2017); the positive displacement pumps, built to move a constant and fixed quantity of fluid at uniform and regular rate (Juan and Alvaro, 2007); and the centrifugal Pumps which is a divisional unit of mobile aligned-symmetric and load-absorbing turbo- machine used to transport fluids by transformational energy from rotation (which comes from electric motor) into the energy of hydrodynamic flow of fluid.

The category for mine pumps is the centrifugal pumps which includes a water pump that uses petrol, electricity and diesel. The different factors that should be considered for the selection of pumps are the pump efficiency, flow rate and pressure.

There is rarely a pump that can transform all of its mechanical power into that of water power. Some of these mechanical powers incur losses and wastes during the process of pumping, caused mostly by friction. It is for this reason of wastes that the water horsepower entering the pump must be greater than the water horsepower exiting the pump. Therefore the efficiency of any pump (η) is a ratio of the water horsepower output ($H_{p\ out}$) divided by the water horsepower input ($H_{p\ in}$) of the pump, having range of Efficiency $= H_{pout} \div H_{pin;}$ 0 - 1 (Sinaga, 2010).

The flow rate of a pump determines the total volume it can discharge and the length of time to displace or remove the fluids. The pump differential pressure can be calculated using the size of the pipe (Scott, 2021) of the pump (its length and fittings), its static lifts, and the friction losses on the components of the pump (valves, filters, and so on) - (Stephan, 2006).

There are different ways of measuring mine water volume which includes the use of rain gauge, staff water level gauge and tape rule

Materials and Method
Location and Geology of the Study Area
The study area is located in Ikpeshi, a village in Akoko Edo in Auchi part of Edo Local Government Area. It is a major dolomite deposit mine with permit license on ML116, located on longitude (06° 01' 15") to (06° 11' 15") and latitude (07°10' 15") to (07°12' 00").
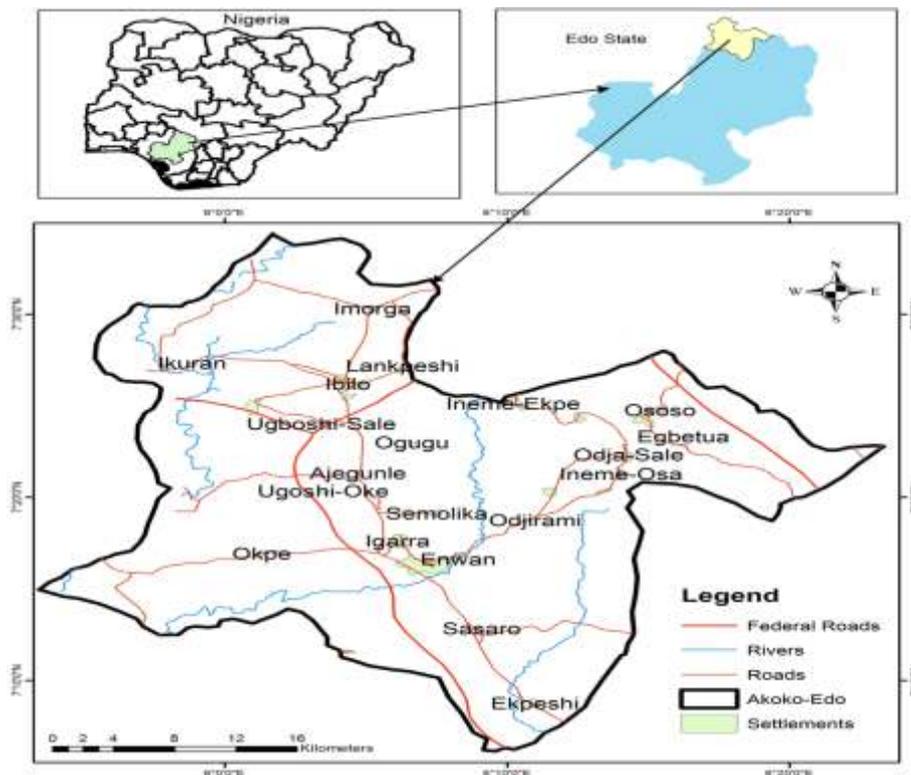
Figure 1: Physical Map of Study Area (Taiwo and Omotehinse, 2021).

The study area is dolomite rocks of Golden girl, located at Ikpeshi and its environs in Igarra which lies within latitudes 7°08'N to 7°10'N and longitudes 6°10'E to 6°15'E. This is part of Igarra schist belt, the south-western Basement complex of Nigeria. This is a part of the major lithology component that makes up the geology of Nigeria. The basement rocks are about four major groups which have been observed within this area. These are the migmatite-gneiss complex, the meta-sediments (schists, calc-silicate rock, quartzites, marble, meta-conglomerates) and the porphyritic older granite which are discordant, non-metamorphosed Syenite dyke (Odeyemi, 1976). Marble deposits are present in many areas. They are being mined by small-scale miners for industrial minerals and rocks. The calc-silicate rocks are similar to marble, medium to coarse-grained with porphyroblasts. In short, about 80% of Akoko Edo community is underlain by carbonaceous rocks. The topography relief is influenced by the underlying geology. The region is known for quarrying activities dominating the major occupations.

Materials
The materials that were used in this study are: Staff water level gauge, tape rule, rain gauge, and pumps.

Method
This project seeks to select appropriate controlling system; and determine the volume of mine water during dry and rainy season; to select the appropriate pump control for drainage operations.

Comparison of Volume of Mine Water during Seasons
The water volume of the mine pits was determined using the staff water level gauge (for water depth measurement), and the tape rule (for water area measurement). The depth and volume calculated from these apparatuses was compared to the volume of the rain gauge. The peak of a major rainfall date was considered, and the staff water level gauge was thence erected, and readings recorded. During the selected dry season date, depth measurements was taken from the staff water level gauge four time daily, 6am, 9am, 12 noon and 3pm, in order to obtain sufficient volume of water. The tape was used to measure the length and breadth of individual mine pits, which was thereafter used for calculating the area, and the eventual volume, after including the depth of pit.

The rain gauge was used to measure the rainfall volume – The rainfall measurement for the quarry under observation was conducted when there is rainfall, and

field records of the rain gauge volume taken when rainfall recedes. Five days in selected major rainy season months was utilized to get rainfall values. The same was done for selected dry season months.

Measurement for the depth of mine pits (for the five locations under observation) was conducted four time in the day of a major rainfall downpour at three (3) hours interval, 6am, 9am, 12 noon and 3pm also. The rain gauge used (locally fabricated and graduated plastic water bottle) was of the size of 2.5 inches (63.5 mm).

Appropriate Pump Selection for Drainage Operations
Some pumps were chosen from among some suggested water pump engines with their attributes of operations, and the source of their manufacturers:
(I) Diesel Engine Water Pump – 5HP, Neptune, DP30H, AMICO, LDP100C, B80-80- 125L;
(ii)Electric Engine Water Pump – Kirloskar, Pacer, 1.5 HP; and
(iii) Petrol Engine Water Pump – WB30X, WP-30, VGT WP30.

Further selections were done to narrow down to the best choice among these three (3) categories of available pumping machines. This selection was based on three criteria, which are flow rate, power motor speed and efficiency of the different pumps. At the end of further selection, the best fit pumps was adopted and recommended for the five (5) individual mine pit locations.

Results and Discussion
Results
Volume of Water Recorded During the Rainy and Dry Seasons

(A)Volume Measurement Using Staff Level Gauge
Table 1 shows the minimum and maximum volume of water measurements recorded, considering the month of July, 2021, with location 3 having the highest recorded values, with 0.480 meters on the 3rd, 10th and 23rd day of July with average volume of 0.455 m^3, 0.463 m^3 and 0.453 m^3 while the lowest recorded values is location 1, with 0.200 meters, with average volume of 0.235 m^3 and 0.240 m^3 on the 3rd and 10th. The overall average water depth was also calculated for all the individual locations.

Table 1: Depth Measurement of Pit Water Using the Staff Meter Rule for Individual Location   in July, 2021

Day	Time	Location/ Distance 1 (m)	Location/ Distance 2 (m)	Location/ Distance 3 (m)	Location/ Distance 4 (m)	Location/ Distance 5 (m)	Overall Average Water Depth (m)
3rd	6am	0.250	0.350	0.460	0.280	0.450	
	9am	0.240	0.350	0.480	0.330	0.440	
	12 noon	0.250	0.340	0.440	0.300	0.420	
	3pm	0.200	0.300	0.440	0.430	0.460	
Average Water Depth (m)		0.235	0.335	0.455	0.335	0.443	0.361
10th	6am	0.260	0.370	0.450	0.300	0.470	
	9am	0.260	0.370	0.450	0.320	0.450	
	12 noon	0.240	0.300	0.470	0.320	0.450	
	3pm	0.200	0.350	0.480	0.390	0.430	
Average Water Depth (m)		0.240	0.348	0.463	0.333	0.450	0.367
17th	6am	0.248	0.349	0.448	0.310	0.429	
	9am	0.238	0.339	0.436	0.301	0.415	
	12 noon	0.233	0.332	0.430	0.290	0.407	
	3pm	0.220	0.320	0.418	0.280	0.390	
Average Water Depth (m)		0.235	0.335	0.433	0.295	0.410	0.342
23rd	6am	0.230	0.350	0.430	0.300	0.460	
	9am	0.240	0.350	0.430	0.390	0.450	
	12 noon	0.230	0.300	0.470	0.340	0.450	
	3pm	0.200	0.300	0.480	0.340	0.400	
Average Water Depth (m)		0.225	0.325	0.453	0.343	0.440	0.357
28th	6am	0.240	0.360	0.450	0.340	0.440	
	9am	0.240	0.370	0.440	0.320	0.430	

Area Measurement of Pit Locations
Table 2 shows the recorded area measurement of water coverage in the five (5) locations with location 3 having the largest area of 504.000 m^2 and location 1 has the smallest area of 143.000 m^2. Figures 2 – 5 shows the minimum and maximum average volume of water coverage measurements recorded, considering five (5) days in selected months of July and December for year 2021 and 2022.

Table 2: Area Measureent of the Five (5) Pit Locations Using Tape Rule

Location	Area Covered By Water (Measured By Tape Rule) m^2	
1	11 x 13	143.000
2	16 x 18	288.000
3	21 x 24	504.000
4	12.5 x 17	212.500
5	17 x 20	340.0

(A)   Volume Measurement of the Five (5) Pit Locations Using Staff Level Gauge and Tape Rule

Figure 2 shows location 3 having the highest recorded values with 150.62 m^3 on the 3rd day of July, 2021 while location 1 has the lowest value of 33.61m^3
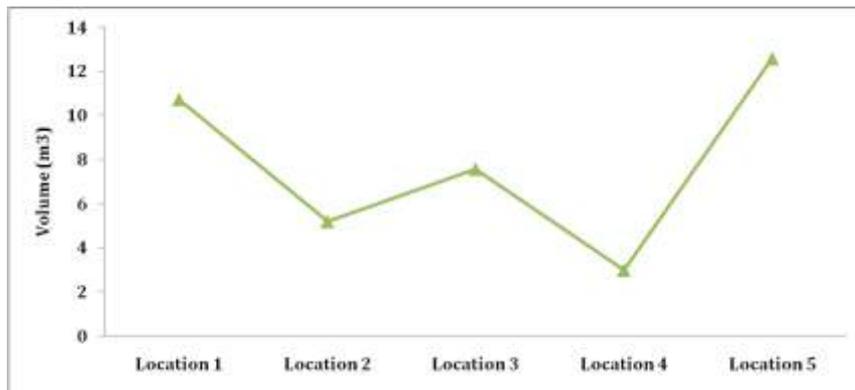

Figure 2: Average Mine Water Volume, Using Staff Level Gauge and Tape Rule considering 3rdJuly, 2021

Figure 3 shows location 5 producing the highest water volume of 47.26 m^3 for December 3rd, 2021, while location 1 produced the lowest water volumes of 6.55 m^3.
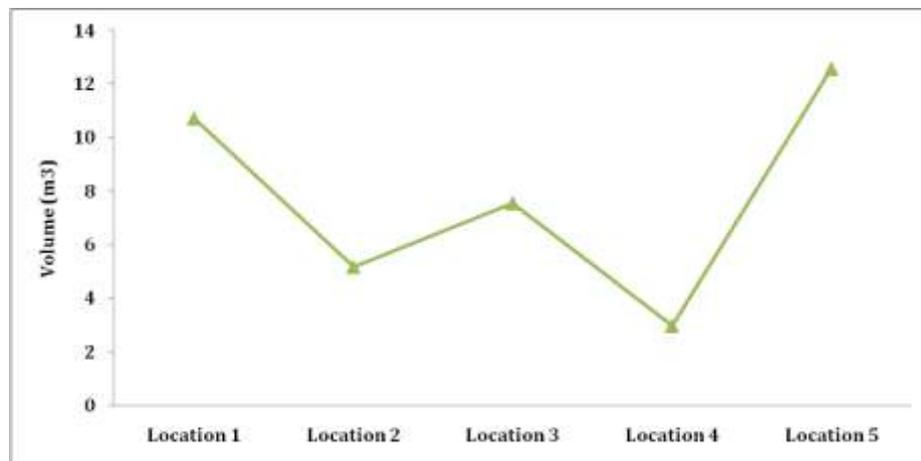

Figure 3: Average Mine Water Volume, Using Staff Level Gauge and Tape Rule considering 3rdDecember, 2021

Figure 4 shows location 3 producing the highest water volume of 504 m^3 for July 5th, 2022, while location 1 produced the lowest water volumes of 143 m^3.
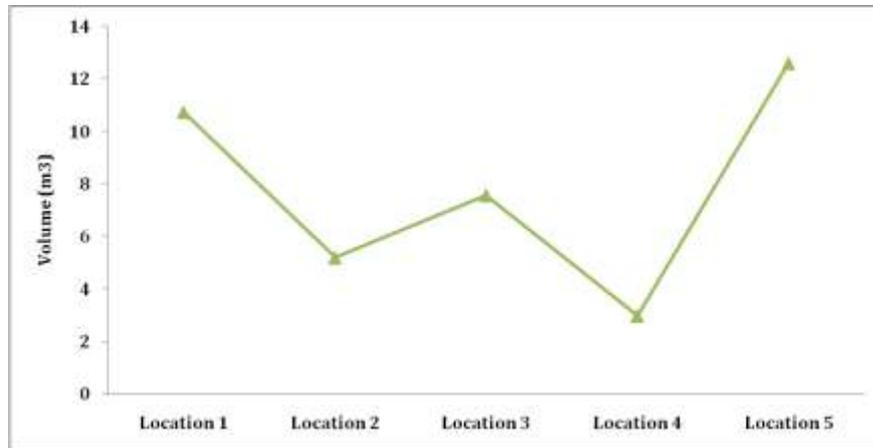

Figure 4: Average Mine Water Volume, Using Staff Level Gauge and Tape Rule considering
    5thJuly, 2022

Figure 5 shows location 5 producing the highest water volume of 12.58 m^3 for December 4th, 2022, while location 1 produced the lowest water volumes of 2.98 m^3

Figure 5: Average Mine Water Volume, Using Staff Level Gauge and Tape Rule considering
    4thDecember, 2022

(A) Volume Measurement Using Rain Gauge

Table 3 shows the recorded depth or amount of rainfall measurement of water volume coverage in the five (5) location with location 3 having the highest value of 183.456 m^3 and location 1 having the lowest value of 45.045 m^3 in July, 2021; location 3 has the highest value of 187.992 m^3 and location 1 has the lowest value of 45.331 m^3 in September, 2021; location 3 has the highest value of 37.800 m^3 and location 1 has the lowest value of 9.009 m^3 in November, 2021; location 3 has the highest value of 17.640 m^3 and location 1 has the lowest value of 3.003 m^3 in December, 2021.

Table 3: The Depth or Amounts of Rainfall Measurement, Using Rain Gauge, in 2021.

Location		Location 1	Location 2	Location 3	Location 4	Location 5
Area Covered By Water -Measured By Tape Rule (m^2)		143.000	288.000	504.000	212.500	340.000
Month / Day	Average Depth (m)	Average Volume of water (m^3) For Each Location				
July, 3rd	0.357	51.051	102.816	179.928	75.863	121.380
July, 10th	0.315	45.045	90.720	158.760	66.938	107.100
July, 17th	0.345	49.335	99.360	173.880	73.313	117.300
July, 23rd	0.33	47.190	95.040	166.320	70.125	112.200
July, 28th	0.364	52.052	104.832	183.456	77.350	123.760
Overall Average Depth (m)	0.3422					
September, 5th	0.317	45.331	91.296	159.768	67.363	107.780
September, 10th	0.33	47.190	95.040	166.320	70.125	112.200
September, 12th	0.32	45.760	92.160	161.280	68.000	108.800
September, 18th	0.325	46.475	93.600	163.800	69.063	110.500
September, 22nd	0.373	53.339	107.424	187.992	79.263	126.820
Overall Average Depth (m)	0.333					
November, 4th	0.063	9.009	18.144	31.752	13.388	21.420
November, 7th	0.065	9.295	18.720	32.760	13.813	22.100
November, 13th	0.06	8.580	17.280	30.240	12.750	20.400
November, 19th	0.069	9.867	19.872	34.776	14.663	23.460
November, 28th	0.075	10.725	21.600	37.800	15.938	25.500
Overall Average Depth (m)	0.0664					
December, 3rd	0.032	4.576	9.216	16.128	6.800	10.880
December, 8th	0.027	3.861	7.776	13.608	5.738	9.180
December, 12th	0.021	3.003	6.048	10.584	4.463	7.140
December, 19th	0.027	3.861	7.776	13.608	5.738	9.180
December, 23rd	0.035	5.005	10.080	17.640	7.438	11.900
Overall Average Depth (m)	0.0284					

(Year: 2021)

Table 4 show the recorded depth or amount of rainfall measurement of water volume coverage in the five (5) location with location 3 having the highest value of 183.960 m^3 and location 1 having the lowest value of 49.335 m^3 in July, 2022; location 3 has the highest value of 183.960 m^3 and location 1 has the lowest value of 43.615 m^3 in September, 2022; location 3 has the highest value of 35.784 m^3 and location 1 has the lowest value of 7.865 m^3 in November, 2022; location 3 has the highest value of 13.608 m^3 and location 1 has the lowest value of 3.575 m^3 in December, 2022.

Table 4: The Depth or Amounts of Rainfall Measurement, Using Rain Gauge, in 2022.

		Location		Location 1	Location 2	Location 3	Location 4	Location 5
		Area Covered By Water -Measured By Tape Rule (m^2)		143.000	288.000	504.000	212.500	340.000
Year		Month / Day	Average Depth (m)	Average Volume of water (m^3) For Each Location				
2022		July, 5th	0.361	51.623	103.968	181.944	76.713	122.740
		July, 16th	0.36	51.480	103.680	181.440	76.500	122.400
		July, 19th	0.345	49.335	99.360	173.880	73.313	117.300
		July, 25th	0.365	52.195	105.120	183.960	77.563	124.100
		July, 30th	0.348	49.764	100.224	175.392	73.950	118.320
		Overall Average Depth (m)	0.3558					
		September, 8th	0.334	47.762	96.192	168.336	70.975	113.560
		September, 16th	0.285	40.755	82.080	143.640	60.563	96.900
		September, 21st	0.305	43.615	87.840	153.720	64.813	103.700
		September, 25th	0.365	52.195	105.120	183.960	77.563	124.100
		September, 28th	0.35	50.050	100.800	176.400	74.375	119.000
		Overall Average Depth (m)	0.3278					
		November, 6th	0.071	10.153	20.448	35.784	15.088	24.140
		November, 17th	0.069	9.867	19.872	34.776	14.663	23.460
		November, 19th	0.055	7.865	15.840	27.720	11.688	18.700
		November, 26th	0.059	8.437	16.992	29.736	12.538	20.060
		November, 28th	0.059	8.437	16.992	29.736	12.538	20.060
		Overall Average Depth (m)	0.0626					
		December, 4th	0.027	3.861	7.776	13.608	5.738	9.180
		December, 10th	0.027	3.861	7.776	13.608	5.738	9.180
		December, 18th	0.026	3.718	7.488	13.104	5.525	8.840
		December, 22nd	0.026	3.718	7.488	13.104	5.525	8.840
		December, 29th	0.025	3.575	7.200	12.600	5.313	8.500
		Overall Average Depth (m)	0.0262					

Note: The duration of rainfall range is 24 hours (1 day) before retiring the rain gauge

Selection of Pump using Flow Rate, Power of Motor and Efficiency of a Pump

In Table 5, water flowrate was calculated for the individual mine pit locations, for location 1-5, using average water depth, area covered by water and calculated average volume of water; it also display graphics of each mine pit location. The calculated comfortable flowrate for location 1 is 33.61 m^3/ hour (or 0.560 m^3/min); for location 2, it is 96.48 m^3/ hour (or 1.608 m^3/min); for location 3, it is 218.23 m^3/ hour (or 3.637 m^3/min); for location 4, it is 62.69 m^3/ hour (or 1.045 m^3/min) and for location 5, it is 139.40 m^3/hour (or 2.323 m^3/min).

Table 5: Mine Pit Locations and Calculation of Water Flow Rate

Location	Average Water Depth (m)	Area Covered by Water (m^2)	Average Volume Covered by Water (m^3)	Q = V/t (m^3 / min)
1	235.0 (0.235)	143.000	33.610	33.61 (0.560)
2	335.0 (0.335)	288.000	96.480	96.48 (1.608)
3	433.0 (0.433)	504.000	218.230	218.23 (3.637)
4	295.0 (0.295)	212.500	62.690	62.69 (1.045)
5	410.0 (0.410)	340.000	139.400	139.40 (2.323)

where, V = Volume of Water (m^3); Q = Flowrate (m^3/ hour); t = time taken (Hours)

The formula used for the calculation of pump efficiency is:

$$\text{Pump Efficiency, } \eta = \frac{\text{Pump Output}}{\text{Pump Input}} = \frac{\text{Pump Head (m) } * \text{ Flow Rate (m3/hr)}}{367 * \text{Power of Motor (KW)}}$$

In Table 6, Selection of some water pumps (petrol, diesel and electric engine) extracted from literatures were determined using flowrate, power of motor and total pump head to calculate pump efficiency; and in Table 7, further selection of water engine pump were determined. Some pumps were chosen from among some suggested water pump engines with their attributes of operations, and the source of their manufacturers. This pump selection was made for Golden Girl Quarry, considering individual mine pit locations.

Table 6: Selection of Pumps based on Flow Rate, Power of Motor and efficiency

Type of pump	Flow rate, Q	Pump Speed (RPM)	Maximum Horse power, HP	Power of Motor, (KW)	Flow rate, Q (m^3/min)	Total Pump Head, z (m)	Flow rate, Q (m^3/hr)	Pump Efficiency, (%)
				Pump Input		**Pump Output**		
Online Materials (www.indiamart.com)					**Calculated**			
Petrol Engine water Pump								
WB30X	900 Ltr/Min	3600	2.0 - 5.0	4	0.9	26	*54*	*96*
WP-30		-	6.5	5	-	26	*30*	*42*
VGT WP30	30 L/Min	3000-3600	6.5	5	0.03	26	*1.8*	*2*
Diesel Engine water Pump								
5HP	48000 Lt./Hr.	-	5	3.7	0.8	-	*48*	-
Neptune	133.33 L/min	-	1.67	1.3	0.13	30	*7.8*	*49*
DP30H	<50 Ltr/Min	3600	-	-	0.05	75	*3*	-
AMICO	-	3600	4.5	3.4	-	-	-	-
LDP100C	1083 L/min	-	8.6	6.4	1.083	25	*65*	*69*
B80-80-125L	45 m^3/h	2900	4.4	3.3	0.75	16	*45*	*60*
Electric Engine water Pump								
Kirloskar	133 m^3/Hr	-		0.75 – 15	2.217	76	*133*	*28 -184*

Note: 1L / min = 0.001 m^3 / min and 1 HP = 0.746 kW.

Further selections was done for these best available pumping machines into three (3) categories in Table 7 as previously enumerated in Table 6. This selection was based on three criteria, which are flow rate, power motor speed and efficiency of the different pumps. At the end of further selection, the best fit pumps are as follows:

Petrol Engine Water Pump - WB30X (54 m^3/hr flow rate, 4 kilowatt and 96 % efficiency); Diesel Engine Water Pump - LDP100C (65 m^3/hr flow rate, 6.4 kilowatt and 69 % efficiency); and Electric Engine

Water Pump – (133 m^3/hr flow rate, 0.75 -15 kilowatt and 26 – 184 % efficiency).

Finally, selection of the pumps was then decided for the five (5) mine pits location considering individual mine pit location.

Location 1: WB30X (Petrol Engine Water Pump);
Location 2: Kirloskar (Electric Engine Water Pump);
Location 3: Kirloskar (Electric Engine Water Pump);
Location 4: LDP100C (Diesel Engine Water Pump);
Location 5: Kirloskar (Electric Engine Water Pump).

Table 7: Further Selection of Water Engine Pump

Best Choice of Pump	Maximum Horse power, HP	Pump Speed (RPM)	Total Pump Head, z (m)	Flow rate, Q (m^3/hr)	Power of Motor, (KW)	Pump Efficiency, (%)
	Online Materials (Source: www.indiamart.com)			**Calculated**		
Petrol Engine water Pump						
WB30X	2.0 to 5.0	3600	26	*54*	4	*96*
Diesel Engine water Pump						
LDP100C	8.6	-	25	*65*	6.4	*69*
B80-80-125L	4.4	2900	16	*45*	3.3	*60*
Electric Engine water Pump						
Kirloskar	1.0 to 20	-	76	*133*	0.75 - 15	26 *-184*

Conclusion

This field research work focuses on Golden Girl, which is a surface mine or quarry in Ikpeshi, Nigeria. This quarry like any other produces continuous water influx from the underground seepages, surface run-off and atmospheric precipitation which volume constitutes unimaginable risks and untold hazards on mining operations, since its impacts is felt on production. The Golden Girl stands to tackle such menace and challenges which daily confronts their mining activities by controlling it in order to avert or prevent eventual abandonment. From graph representations, the rain gauges gave more reliable measurements and higher volume values than the staff level gauges. Also, water volume is highest in the rainy seasons than the dry seasons. Location 3 and 5 are always high on flooding , while location 1 and 2 are is relatively low pumps selected for the five (5) mine pits locations are: WB30X

Petrol Engine Water Pump for location 1; Kirloskar Electric Engine Water Pump for location 2, 3 and 5; and LDP100C Diesel Engine Water Pump. This project considers the situations that surround the control or checking of mine water from the pit mines, as well as proffer pump system as a way out. Five different mine pits were selected and the appropriate pump set for dewatering such pits was considered.

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