Assessing the Rainfall Implications on Surface Coal Mining Operations: Thar Case Study

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Abstract

Rainfall directly impacts the open-pit surface mining operations in the Thar Coalfield, Pakistan. The overall lithology hosting the lignite type of coal seams in the study area includes Dune Sand, alluvium, and soft sedimentary rocks. Due to the presence of three primary aquifers, the strata overlying and underlying the coal seams are under substantial porewater pressure. Additionally, heavy rainfalls in the Thar area lead to the accumulation of water in mines and may cause pit flooding, making it impossible to continue mining activities until the water is pumped out. Pit flooding often results in equipment damage and production delays. The main focus of the study is to investigate the impacts of heavy rainfall on the mining activities at Thar Coalfield. Two major aspects of open pit mining are considered in this study, i.e., production, and dewatering systems. Due to heavy rainfall, a significant production deviation (V) was noticed in comparison to regular months. The quantity of water drained from the pit (Qa) and anticipated inflow quantity (Qt) values were compared for the rainy season and other times. It was observed that heavy rainfall increases the production deviation from the planned targets and also increases the pit dewatering cost. Moreover, this study suggests preventive measures to address potential losses arising from intense rainfall.

Keywords—Mine Dewatering, Open-pit Mining, Rainfall Impacts, Rainwater Inflow, Thar Coalfield

1 Introduction

With the advent of novel manufacturing and advancements in modern materials technologies, the mining of raw materials has become of primitive importance for the social and economic development of any nation. The modern mining industry is engaged in producing millions of tons of raw materials in a possible shortest time period to meet the market demands [1]. To achieve such a massive task, the scale of operations has been enhanced to an extremely larger level and to suit such large-scale operations, heavy investments are made [2]. All these efforts are carried out to achieve the planned production targets within the specified time to meet the market demands. Pakistan boasts vast mountain ranges that serve as reservoirs for collecting rainwater, alongside extensive flat plains spanning hundreds of acres that are effectively employed for irrigation purposes [3]. Even though, historical evidence reveals that the majority of the rainwater has often taken the shape of a flood, which not only affects the domestic life and business of people but also severely affects the mining companies as well. Recently, global climate change has significantly affected mining operations and thus it is of great concern among mining operators throughout the world [4]. In Pakistan, the current monsoon season brought heavy rains which extended over a prolonged period as compared to the past. Pakistan Meteorological Department (PMD) has stated that the monsoons of 2022 were excessively above average [5] and this situation may occur in the future as well. Figure 1 compares the actual precipitation in 2022 and the normally predicted [6].

During the monsoon season (June to mid-September 2022), about nine widespread rainy spells were experienced in Sindh Province. Climatologically, August is a wet month of the year but 243% above-average rainfall. During this month the number of rainy days was considerably higher than normal over the country, especially in Sindh and Baluchistan. On

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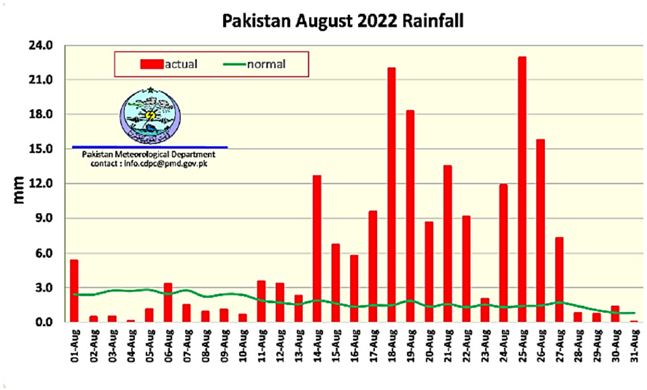

Fig. 1: Rainfall – largely above average over the country (source, PMD)

TABLE 1: Open pit mining system, impact areas directly affected due to rainfall

Area/System	Impact due to Rainwater
Digging System	Excavation and Loading Process
Slope Stability	Bench and Overall Slope
Transportation System	Haul Roads and Ramps
Dumping Process	Dump Structure degradation
Coal Handling System	Coal Production and Mud accumulation
Dewatering System	Addition of rainwater with Aquifer rechargeable water

average, Sindh and Eastern Baluchistan have encountered 15 and 9 rainy days, respectively, compared to the usual 2 rainy days in the month. Table 1 shows the impact areas of an open pit mining system, directly affected due to rainfall.

Compared to underground mines, surface mines such as open pits are more severely affected due to the heavy and continuous rains. This is because the open pit mines are exposed to the atmosphere as compared to underground mines [7]. To address this issue, a careful assessment of the existing open pit mining system in the area of focus is carried out in this study, and an effective solution approach is suggested to overcome the production losses in open pit coal mines at Thar. The location of the study area is presented in Figure 2 [8]. Since the mining activities started in 2020, the operation stopped due to heavy rainfall at Thar open pit coal mine as follows:

- Year 2020 – 13 working days
- Year 2021 – 24 working days
- Year 2022 – 67 working days

2 Effects of Rainwater in Mines

2.1 Impacts on the Stability of Mining Structures

Water remains an unfavorable factor for mining operations, causing serious issues related to the stability of mining structures and, safety of the operations and directly increasing the project cost incurred over the pumping of water to keep the local water table below the mining zone [9]. In surface mines, water has a great impact on the stability of open-pit slopes, especially in soft sedimentary rock formations such as Thar Coalfield [10]. Pathan et al. (2022) conducted a Slope stability analysis for an open pit coal mine at Thar Coalfield to investigate the effect of groundwater on the stability of slopes [1]. The study involved the development of computer models by using Slide-2D and Phase2 software and stability analysis against circular failure was performed incorporating the local groundwater conditions. Two types of analysis techniques were used i.e., a two-dimensional limit equilibrium technique and a finite element method-based shear strength reduction technique. It was suggested that the overall slope angle of 29 degrees will remain safe and stable under the current hydrogeological scenario. Figure 3 presents the generalized lithology of the study area indicating the presence of three aquifer zones [11].

Regional geology, geological structures, groundwater, rock mass strength, and deformability, in situ stress conditions, and seismicity are essential parameters involved in the assessment of rock slope failure mechanisms [12]. Rose and Hungr (2007) predicted the potential rock slope failure in open pit mines using the inverse-velocity method. The study suggested that as the excavation extent is increased during advanced phases of mining, the stress and strain levels within the rockmass also increase which eventually leads to deformation and consequently to failure of slope [13]. Furthermore, Fukuzono's inverse-velocity method significantly improves the ability to interpret slope monitoring data and estimate the possible timing of rock slope failure in open pit mines.

In surface mining, the material (whether ore or waste) is moved from the extraction point to its intended destination, which could be a processing plant or a waste disposal site. The condition of the transportation ramps is very important for the reduction of cycle time. Felipe and Rodrigo (2021) detected the drainage pitfalls in open pit mines and the damage to ramps by using UAV photogrammetry. Open pit mines generally have inappropriate water flow over ramps, these situation increases the cycle time and also the maintenance cost of the truck [14]. These impacts become more critical with high precipitation levels. The

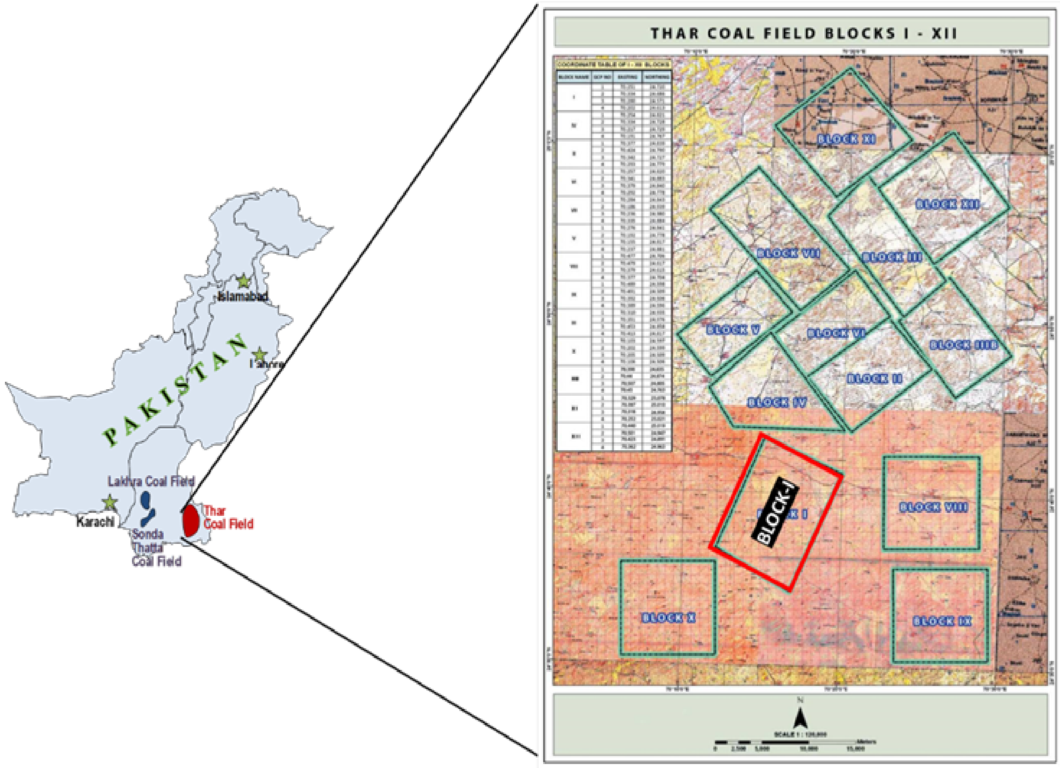

Fig. 2: Location of the study area

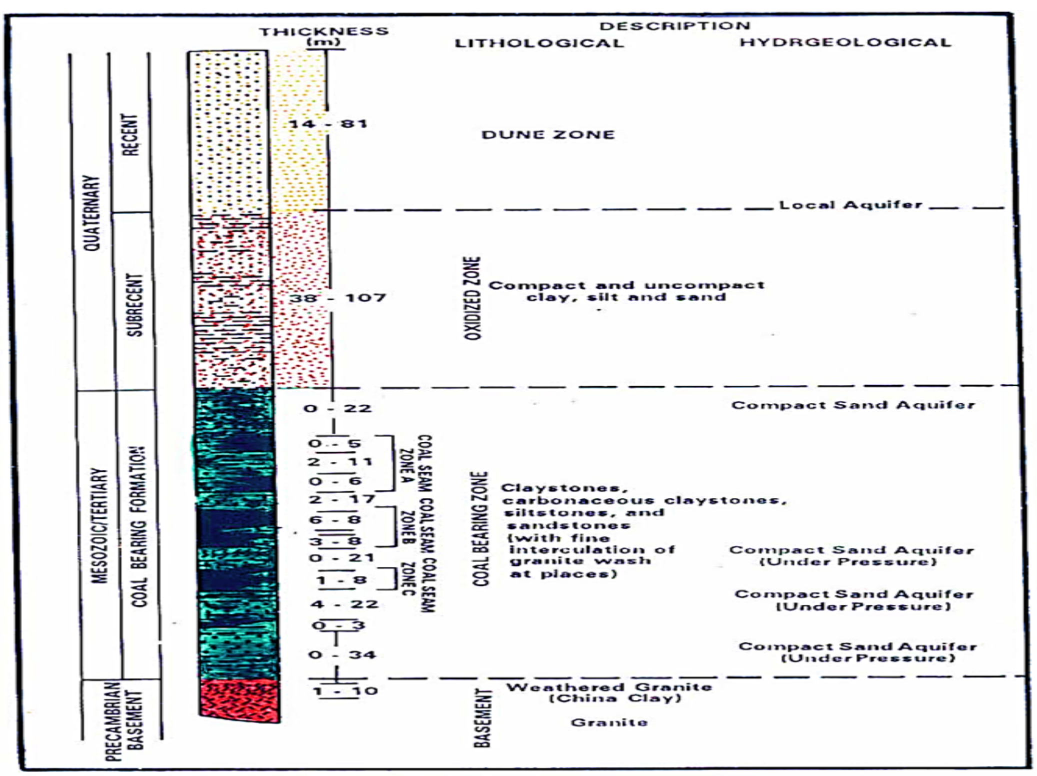

Fig. 3: Generalized lithological column representing the stratigraphic units also showing hydrogeological conditions in the Thar Desert (modified after JTB, 1994)

use of a high-resolution three-dimensional elevation model created based on the Unmanned Aerial Vehicle (UAV) photogrammetry technique to detect anomalies in a fast and precise way. The impacts (damage to the roads, operating benches, and drainage infrastructure) can be prevented if this method is implemented on a routine basis at the mine site.

As open pit mines get deeper, the volume of waste to be removed also increases and the number of accidents due to the waste dump slope failure also increases [15]. This eventually leads to excessive costs as well as environmental and safety liabilities for the coal mining companies. Gupta et al. (2021) conducted an open-pit slope stability analysis of waste dumps using a numerical modeling technique. The factors considered in assessing the dump slope stability were grain size, density, permeability, porosity and void ratio, friction angle, Young's modulus, Poisson's ratio, cohesion, pore-water pressure (moisture content, groundwater table, rainfall), and compaction level of dump material [16]. To overcome the instability of the dump slope, the Numerical modeling approach is used to assess the stability and design the dump slope structure. It considers the stress–strain relationship along with the strength of the material during the stability analysis process. It provides additional output parameters along with FoS for the stability analysis. Parameters derived from contour analysis, such as displacement, shear strain, plasticity, and velocity profile, offer a precise evaluation of the vulnerable areas within the slope structure.

2.2 Impacts on Mining Operations and Environment

During the rainfall season, the mines become more prone to the inrush of rainwater. Especially the open-pit or surface mines, the overburden removal or mineral extraction process is stopped during the rainfall period. Tlhatlhetji and Kolapo (2021) investigated the effect of rain on mining operations in an opencast mine at Wescoal's Khanyisa and assessed the production losses associated with rainfall. This study analyzed the coal exploitation operations between December month of 2019 and January 2020, including the daily and weekly rainfall, the pumping efficiency, machinery breakdown frequency, and performance of loading and haulage operations [17]. The use of land and climate affects the quality and quantity of both, the groundwater, and the surface water [18]. Chernos et al. (2022) conducted a study that provided the cumulative effects of the use of land and the climate change in the Oldman River Basin, Alberta Canada. A hydrological model was developed which estimates the future selenium loading, water use, and the changes in the climate. The model was used to measure the change in water use and selenium mass loading associated with two future mine development scenarios [19]. At the scale of the ORB, the anticipated consumptive water demand from mine development scenarios is rather minor, but it is seasonally significant and accounts for a sizeable amount of the winter streamflow in important tributaries, where many mines are likely to be situated.

Kumar and Sinha (2016) proposed a water harvesting technique at Chasnala Coal Mine, Dhanbad, India. This study indicated that the water harvesting technique is much more effective in providing water supplies in water-scarce arid regions [20]. The technique involved the usage of rainwater in limited amounts to meet the domestic water demands of local people. However, this technique is not a long-term solution because of the variation in the chance of occurrence of rainfall and precipitation levels.

Silwamba and Chileshe (2015) proposed various strategies that can be adopted in order to prevent the Nchanga Open Pit (NOP) from flooding situation during the rainy season [21]. This study also discussed different techniques related to the water control mechanism at the Nchanga open pit mine to ensure the safety and environmental feasibility of the mining at NOP. In deep opencast mines, the major purpose of the dewatering system is the seepage-water extraction from the phreatic formations overlying the mineable deposit, and the water accumulated within the mine pits during rainfall. However, at Neyveli mines, the danger of flooding from the mine floor also exists, due to excessive hydrostatic pressure of the underlying aquifer of confined nature [22]. A hydrogeological assessment was proposed assuming steady-state flow conditions for the confined aquifer underlying the mine through a network of dewatering wells. Singh et al. (2010) investigated the quantity and quality of groundwater, acquiring water samples from three primary aquifers present in Thar [23, 24]. It was concluded that the groundwater is chloride-type water with a TDS value of 1000-20,000 mg/L, and free from any metallic or toxic contaminations such as lead, arsenic, cyanide, or mercury.

3 Materials and Methods

Two major aspects of open pit mining are considered in this study, i.e., production, and dewatering systems. The main emphasis of mining operations is directed towards assessing the economic feasibility of the project. Therefore, production planning is crucial for efficient operation on a daily, monthly, and yearly basis. The data related to overburden removal and coal production operations was collected on a monthly basis, before and after the rainfall season. At first, the number of 'Zero Production' days was calculated and then compared with the planned production on a monthly basis. The production data variations were then analyzed using comparative analysis in MS Excel. Since dewatering of mine water is necessary to carry out safe and effective mining operations. Due to the presence of three aquifers within the mining zone, a continuous dewatering system is working to drain out the aquifer water from the mine. During the rainfall, excessive rainwater accumulates within the pit which is subsequently pumped out. The pit dewatering data was collected during the rainfall period for the years 2021-22. The following parameters of the existing dewatering system were investigated:

- Sump storage capacity to hold water.
- Daily average phreatic layer displacement in the sump.
- Daily dischargeable volume of water from Pit pumps (both during rainy days and on normal routine).

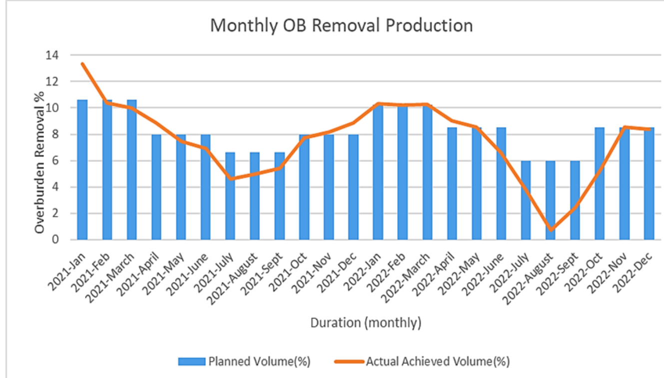

Fig. 4: Comparison between planned (VP) and actual achieved (VA) volumes of OB removed

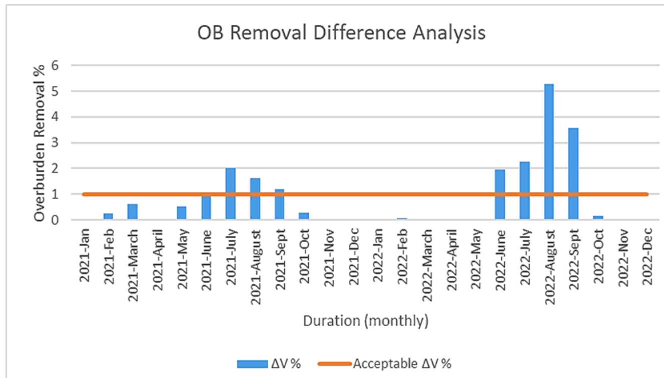

Fig. 5: Comparison between V and acceptable V

4 Analysis and Discussion

4.1 Impacts on Mine Production

Water is a major problem in surface mine workings because it is a physical hindrance to the extraction of minerals, it has economic significance in extracting minerals and may cause major pollution potential to the surface environment [25].

During the period of investigation for this study, the Thar open-pit coal mine was in the process of removing the overlying layers of soil and rock (overburden) to access and extract the coal deposits from the site. Two-year pro-duction data from January 2021 to December 2022 for OB removal was collected and analyzed as presented in Table 2.

$NV0$ = Number of Zero Production Days, VP = Planned Volume, VA = Actual Achieved Volume ΔV = Production Deviation (Difference between Planned and Actual Volume removed against acceptable difference of 1).

It was observed that, every year the monsoon months deviate from the planned volume targets. Due to rainfall, the mining operations are completely stopped and the number of zero production days (NV0) is calculated. As this number increases production is decreased and consequently, the actual achieved volumes (VA) are lesser than the planned volumes (VP). The production deviation parameter (V) is eventually increased than the allowable difference of 1. Figure 4 shows the planned volume of OB removal which is quarterly sub-planned from annual planning in % (bar represented), and the line graph shows the actual achieved OB volume removed. This clearly indicates a decrease in OB removal during June, July, August, and September of 2021 and 2022 respectively. Figure 5 presents a comparison between V and its acceptable value (i.e., 1), indicating a considerable increase during monsoon months due to a decline in production. Table 2 also shows that due to heavy rainfall, the planned production target was achieved by 97.1% in the year 2021. Whereas due to the increased intensity and consistency of precipitation in 2022, the planned target was achieved by 83.98%.

5 Impacts on Mine Dewatering System

Most of the surface water entering a surface mining accumulation originates as surface precipitation. Water from surface precipitation may directly enter the excavation as rainfall or indirectly enter the excavation

TABLE 2: Production data for OB removal from January 2021 to December 2022

Year-Month	NV0 (Days)	VP (%)	VA (%)	V (VP – VA)	Remarks
2021-Jan		10.6	13.33	-2.73	
2021-Feb		10.6	10.37	0.23	
2021-Mar		10.6	10	0.6	
2021-Apr		8	8.86	-0.86	
2021-May		8	7.48	0.52	
2021-Jun	5	8	6.93	**1.07**	Rainfall
2021-Jul	6	6.6	4.6	**2**	Rainfall
2021-Aug	3	6.6	4.98	**1.62**	Rainfall
2021-Sept		6.6	5.4	**1.2**	Mine maintenance work after rainfall
2021-Oct		8	7.73	0.27	
2021-Nov		8	8.16	-0.16	
2021-Dec		8	8.86	-0.86	**Planned 100%, Achieved 97.1%**
2022-Jan		10.25	10.3	-0.05	
2022-Feb		10.25	10.2	0.05	
2022-Mar		10.25	10.25	0	
2022-Apr		8.54	9	-0.46	
2022-May		8.54	8.54	0	
2022-Jun	7	8.54	6.6	**1.94**	Heavy rainfall
2022-Jul	13	6	3.74	**2.26**	Heavy rainfall
2022-Aug	27	6	0.71	**5.29**	Heavy rainfall
2022-Sept	9	6	2.44	**3.56**	Heavy rainfall
2022-Oct		8.54	5.25	**3.29**	Mine maintenance work after rainfall
2022-Nov		8.54	8.54	0	
2022-Dec		8.54	8.4	0.14	**Planned 100%, Achieved 83.98%**

as flood water during unprecedented rainfall. Rainwater entering the surface mining excavation has a direct bearing on the cost of pumping as water that has once entered the excavation has to be pumped out of the mine under high hydraulic heads. The study area has three primary aquifer formations. The first lies near the base of the Recent formation Dune Sand stratum, the second aquifer lies within the Subrecent formation above the coal zone, and the third aquifer exists at the base of the pit (i.e., below the bottom-most mineable coal seam). For the safe exploitation of coal, continuous mine dewatering is carried out using a system of intermediate sumps connecting to the main sump where the water is collected and then pumped out for disposal. The study area was investigated to analyze the dewatering operations and to compare the normal-routine dewatering and the dewatering during the rainfall scenarios. Three water stations within the pit are investigated, each having multiple intermediate sumps and a main sump to dewater the water accumulated within the pit. The volume of water discharged from the sump in a day is calculated as:

$$Q_a = v_h \times t_r \tag{1}$$

In Equation 1, Q_a = Daily discharged volume of water from Sump (m^3), vh = Real Time Flow (m^3 / hr), tr = Running time of the pump ($hr.$). Tables 3 and 4 present daily recharge and discharge volumes of water at normal and during rainfall respectively.

Forced repair after working (FRAW) hours is the time after which a pump is stopped to cool down and checked for repair (if required). Figure 6 shows a comparison between the normal routine and rainfall scenarios. In the case of submersible pumps, the FRAW hours are comparatively less during the rainy

TABLE 3: Dewatering scheme during normal routine (dry season); PWS = Pit Water Station, IS = Intermediate Sump, MS = Main Sump, SMP = Submersible Pump, MSP = Main-Stream Pump

Pit water Station	Sump Type	Sump Dimensions (m)	Sump capacity to hold water (m^3)	Pump Type	Normal-Routine				
					Real-Time Flow (m^3/h)	Running Time of the Day (hours)	Daily Discharged water volume from Sump-Qa (m^3)	Daily Average recharge in Sump (m^3)	Forced repairment after working hours
PWS-1	IS-1	10*10*6	550	SMP-1	170	6	1020	2400	275
				SMP-2	120	11	1320		280
	IS-2	10*8*6	440	SMP-3	170	4	680	1600	275
				SMP-4	80	11	880		280
	MS-1	15*12*10	1700	MSP-1	450	14	**6300**	2500	2200
PWS-2	IS-3	10*10*7	650	SMP-5	170	8	1360	2600	275
				SMP-6	80	15	1200		280
	MS-2	12*12*8	1080	MSP-2	450	7	**3150**	1000	2200
PWS-3	IS-4	12*10*8	900	SMP-7	120	6	720	3000	280
				SMP-8	80	14	1120		280
				SMP-9	80	14	1120		280
	MS-3	15*12*10	1700	MSP-3	450	11	**4950**	2000	2200
					TOTAL		**14400**	**15100**	

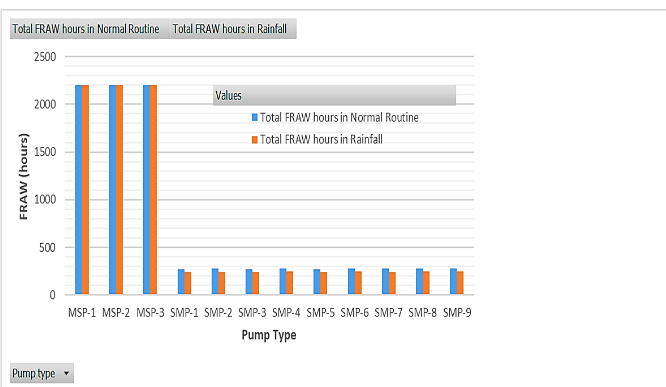

Fig. 6: Comparison between FRAW hours for dewatering pumps

season. This indicates a decrease in pump performance and an increase in pump repair costs. However, no significant effect on main-stream pumps is observed in both cases, because main-stream pumps are capable of delivering high heads. However, if the daily average recharge volume of water in the sump increases due to the intensity of precipitation, the main-stream pumps may also require frequent repair.

In order to compare the inflow regime of water, the dewatering data of the pit during the operational years 2021-22 was collected and analyzed (Table 5). The actual quantity of water drained from the pit (Qa) for each month is compared with the theoretical (inflow) quantity (Qt). It can be observed that during the rainfall months, excessive dewatering is required to pump out the rainwater along with the water drained during normal routine. Figure 7 indicates a significant rise in pit drainage due to rainfall.

6 Conclusions

Rainwater presents a range of problems in different mining conditions. Currently, there is no hard and fast rule to combat such water problems in open-pit mining operations. In extreme cases, open-pit flooding due to heavy rainfall and mining over a confined aquifer may result in a complete stoppage of the mining operations. The passive method of mine water control (allowing water to enter mining excavation before it is pumped out) is an inefficient method of dealing with surface mine water. This study was carried out to analyze the impacts of rainfall on the production and dewatering

TABLE 4: Dewatering scheme during rainfall season

Pit water Station	**Sump Type**	**Sump Dimensions (m)**	**Sump capacity to hold water (m^3)**	**Pump Type**	**Rainfall Season**				
					Real-Time Flow (m^3/h)	**Running Time of the Day (hours)**	**Daily Discharged water volume from Sump-Qa (m^3)**	**Daily Average recharge in sump (m^3)**	**Forced repairment after working hours**
PWS-1	IS-1	10*10*6	550	SMP-1	170	10	1700	3900	240
				SMP-2	120	18	2160		240
	IS-2	10*8*6	440	SMP-3	170	9	1530	3200	240
				SMP-4	80	20	1600		247
	MS-1	15*12*10	1700	MSP-1	450	22	**9900**	4000	2200
PWS-2	IS-3	10*10*7	650	SMP-5	170	23	3910	5900	240
				SMP-6	80	24	1920		247
	MS-2	12*12*8	1080	MSP-2	450	22	**9900**	5000	2200
PWS-3	IS-4	12*10*8	900	SMP-7	120	18	2160	6000	240
				SMP-8	80	24	1920		247
				SMP-9	80	24	1920		247
	MS-3	15*12*10	1700	MSP-3	450	22	**9900**	4800	2200
						TOTAL	**29700**	**32800**	

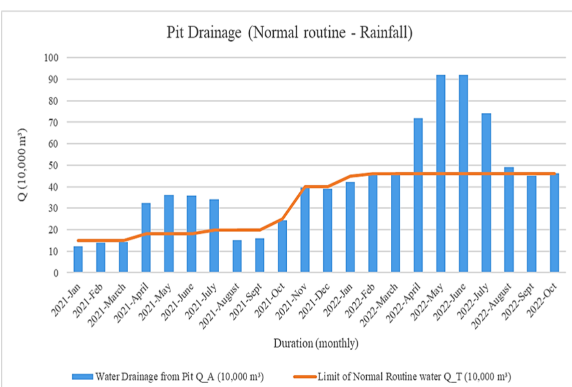

Fig. 7: Pit Dewatering comparison (Normal-Routine – Rainfall)

system of an open-pit coal mine on Thar Coalfield. A comparison has been established between normal-routine and rainfall scenarios, based on analysis of production and dewatering data collected for the years 2021 and 2022. The following conclusions have been made from the analysis:

1) The total number of 'zero production days' (N_{v0}) reported was 70 days during the years 2021-22, causing the production decline and consequently increasing the production deviation parameter (ΔV).
2) The planned production target was achieved by 97.1% in 2021. Whereas due to the increased intensity and consistency of precipitation in 2022, the planned target was achieved by 83.98%.
3) Maximum production deviation occurs during August, for the past two years. A maximum deviation of 1.62 and 5.29 is calculated for the years 2021 and 2022 respectively.
4) The total discharge volume of water per day from three pit water stations was determined. A total volume of 14,400 m3/day was pumped out during normal routine, whereas the dewatering volume during rainfall was calculated as 29,700 $m_3//day$.
5) The Forced Repairment After Working (FRAW) hours for submersible type pumps are comparatively less during the rainy season, indicating a decrease in pump performance and an increase in pump repair cost. However, no significant effect on the performance of main-stream pumps is observed in both cases.
6) The dewatering requirement is increased by 100% during the peak rainy months of July and August each year, eventually increasing the dewatering cost in the same proportion.

TABLE 5: Month-wise Pit Dewatering Summary during 2021-22

No	Year-Month	Qa (10,000 m^3)	Qt (10,000 m^3)	Remarks
1	2021-March	12.15	15	1st Aquifer Encountered
2	2021-April	14.1	15	
3	2021-May	14.3	15	
4	2021-June	32.5	18	Rainwater Included
5	2021-July	**36**	**18**	Rainwater Included
6	2021-August	**35.77**	**18**	Rainwater Included
7	2021-September	34.2	20	Rainwater Included
8	2021-October	15.1	20	
9	2021-November	16.1	20	
10	2021-December	24.33	25	2nd Aquifer Encountered
11	2022-Janaury	39.7	40	
12	2022-Fabraury	38.92	40	
13	2022-March	42.3	45	
14	2022-April	46	46	
15	2022-May	45.97	46	
16	2022-June	71.89	46	Rainwater Included
17	2022-July	**92.07**	**46**	Rainwater Included
18	2022-August	**92.07**	**46**	Rainwater Included
19	2022-September	74.25	46	Rainwater Included
20	2022-October	49.1	46	
21	2022-November	45.2	46	
22	2022-December	46.1	46	

7 Recommendations

In order to effectively deal with the rainwater entering in mind, the following preventive measures are suggested:

1) A temporary retaining wall may be built surrounding the pit periphery. The height and width of this may be sufficient enough to effectively prevent the catchment water from entering the pit area.
2) A rainstorm drainage pumping station must be stationed at a pit-bottom mining area, so that the upper part of the rainfall catchment may be discharged uniformly through the external drainage pipeline towards some surface disposal point.
3) A water-retaining dike is required to be constructed every 500 meters on each completed bench in the mining area. This forms a directed water flow channel (towards the collection point) to reduce the water accumulation and its entry towards the working levels of the pit. This may also protect the bench crest from water erosion, which may lead to bench sliding (bench slope failure).
4) Before the rainy season, management ensures a sufficient amount of materials to temporarily block the main entrance(s) and exit(s) of the pit as soon as the forecast is received. This prevents external ingress of surface run-off water into the mining area.
5) The dump site, where the excavated overburden is dumped, is mainly composed of sand and loose alluvium. Some of the rainwater will infiltrate quickly, due to the good permeability of the loose (excavated) material. However, a major portion of the rainwater may flow as surface run-off from the dump towards the mining area. A series of water collection ditches may be constructed over the dump surface to collect the rainwater and prevent its ingress towards the mining region. The collected water will progressively infiltrate and/or evaporate.
6) A water collection grid of size $100m^2$ (each portion), may be structured at the dumping site. The precipitation will be concentrated over this grid and subsequently drained through infiltration and evaporation. The dividing walls of the grid can be formed by trucks dumping the excavated sandy material from the mine as per grid design. Additionally, a main roadway having a width of 8 to 10 meters, and the connecting roads (if required) may also be left between the grid area, which is required for inspection and maintenance after the

rain.

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