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Full Length Research Paper

Hydrological characterization of Mahd Ad Dahab Gold Mine, Saudi Arabia

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The present study focuses on the gold mining in Mahd Ad Dahab region of Saudi Arabia. The study aims at the integrated use of existing meteorological information with the drainage basin morphometry of the mine catchment for determining the preferential flow path for the mine contaminants. The study reveals that the actual mining area lies at the headwaters of two watersheds: Watershed A and Watershed B. The streams in Watershed A drain in a North East - South West direction, whereas the streams of watershed B trend in a South East – North West direction. The peak runoff estimates show that in case of a heavy rainfall event, more surface discharge will be generated in Watershed A mainly due to its large surface area thus, leading to potential contamination in the south of the mining area. The runoff estimates for a maximum rainfall event of 104 mm/day is equal to 21.527 m^3/s for Watershed A and 8.310 m^3/s for Watershed B. Studies related to the investigation of the water pollution from mining activities should be concentrated towards the south of the mine.

Key Words: Mahd Ad Dahab Gold Mine, meteorology, drainage basin morphometry, runoff.

INTRODUCTION

Mining forms the backbone of industrial development by providing the raw materials needed for building varied types of commodity; however the environmental consequences associated with mining can be grave if it is not carried out in a systematic manner. The impact of mining industry is principally contamination (often from Acid Mine Drainage (AMD) and related processes) and impacts on quantity. AMD is very common in mining areas (Durkin and Herrmann, 1994). It occurs when sulphide minerals in rocks are oxidized, usually as a result of exposure to moisture or oxygen. These results in formation of sulphates and acidity, which have many, fold environmental consequences.

The present study is focused on the Mahd Ad Dahab gold mining area, which lies in the Al Madinah Al Munawarah province of Saudi Arabia where it is believed that the mining started as early as 3000 BC with a major revival in the activities in the late 20th century, (http://www.ashgill.com.au/pdfs/MahdAdDahabMine.pdf).

Most of the gold mining carried out in Saudi Arabia lies at the sites of this ancient mining. At present Mahd Ad Dahab is mining gold at an annual rate of around 2.8 tons (Maaden, 2000).

The main purpose of this paper is to assess elements of surface hydrology, which plays an important role in determining the zones to be monitored for assessing the impact of groundwater pollution from mining activities in the region. Meteorological factors and detailed investigation of drainage morphometry plays a significant role in understanding the preferential flow path of the contaminants from the mine thus focusing on the groundwater protection in these zones.

METHODOLOGY

The methodology involved in the present study included the integrated use of the meteorological information and the drainage basin characteristics for the hydrological characterization of the Mahd Ad Dahab mine.

The meteorological data for the Medina province was obtained from the Presidency of Meteorology and Environment, Saudi Arabia, (PME, 2011). The rainfall data were provided by the Ministry of Water and Electricity, (MoWE, 2011).

Drainage basin morphometry plays a significant role in

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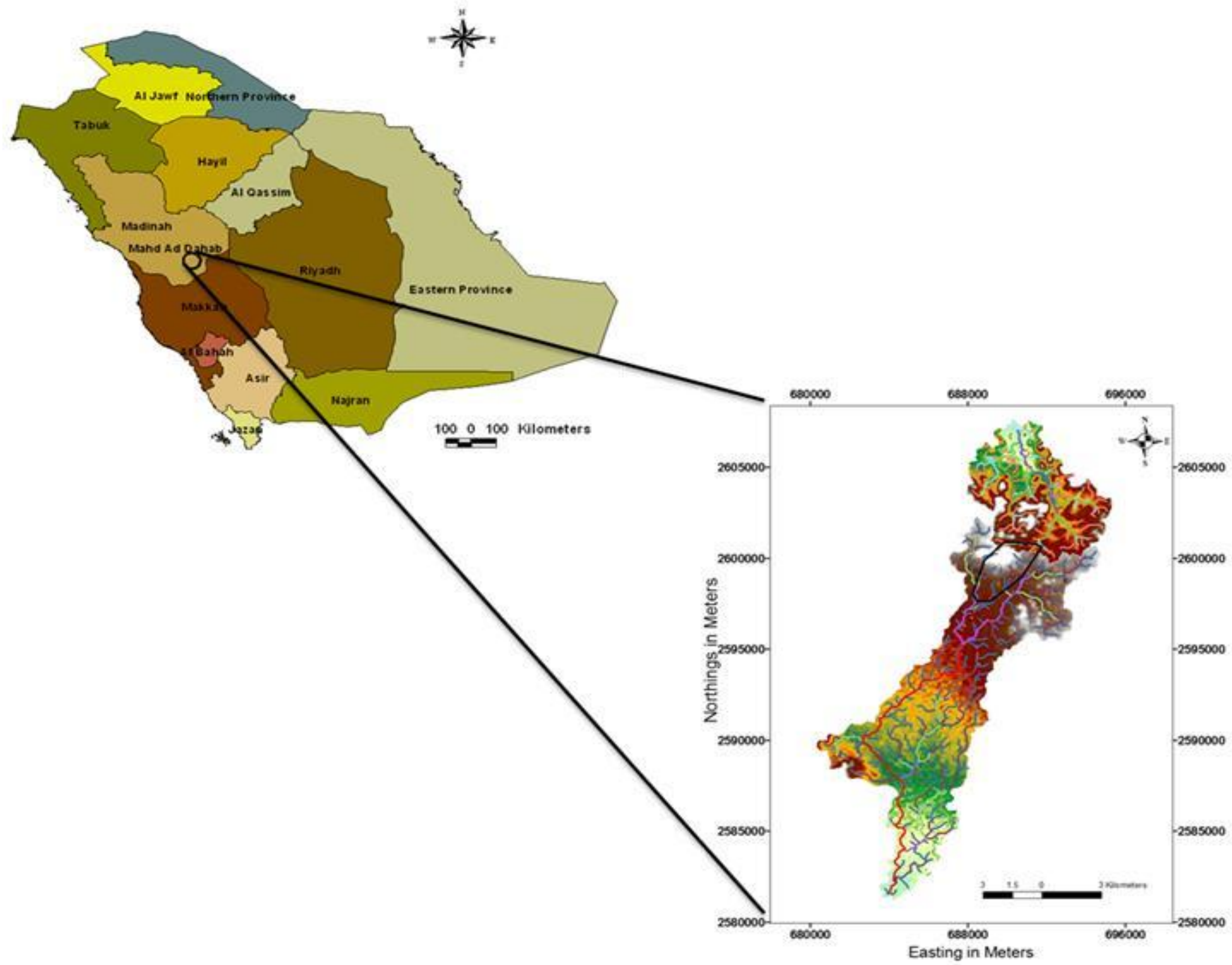

Figure 1. Location of the study area.

determining the groundwater potential of an area (Sreedevi et al., 2005), determining the zones of artificial recharge (Zaidi, 2011) and delineating the areas prone to flooding (Hussein and Zaidi, 2012). In the present study, the morphometric analysis was carried out determine the potential zones for groundwater pollution in a mining area and in conjunction with the meteorological data it helped in the hydrological characterization of the mining area.

The morphometric analysis of the Mahd Ad Dahab mine area was carried out on the basis of the available digital elevation model (DEM) data from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The ASTER DEM has a 30 by 30 m spatial resolution. Using Watershed analysis tools in arc view, the morphometric analysis of the study area was carried out.. The drainage channels were classified into different orders using Strahler's 1964 classification. Other basin parameters such as basin area, basin perimeter, basin length and stream length were obtained, which were further used to obtain the different ratios such as drainage density, drainage texture, bifurcation ratio, stream length ratio, stream frequency, form factor, elongation ratio and circulatory ratio.

Incorporating the information obtained from the meteorological data and drainage basin morphometry, the peak runoff estimate for the area was calculated using the Rational Method (US Soil Conservation Service, 1964).

Description of the study area

The Mahd Ad Dahab mine is a restricted area at a distance of about 170 km South-east of Medina, in Western Saudi Arabia, (Figure 1).

It lies between latitudes 23.275°N to 23.575°N and longitudes 40.625°E to 40.925°E. The study area is underlain by a complex of Precambrian pyroclastic volcanic and clastic rocks overlying a large body of dioritic to granodioritic composition, (Goldsmith and Kouther, 1971). The rock units are rhyolitic tuff, rhyolite and andesite, basalt, marble, rhyolite wake siltstone, basalt conglomerate cherty tuffite and jasper. These rocks are intruded by diabase microdiorite, gabbro and porphyritic rhyolite. It includes Au, Ag, Cu, Zn mineralization in quartz veins, Cu, Pb, Zn, Au, Ag sulfides as massive bodies and stock works, as well as some Fe, Ni sulfide lenses in cherty tuffite.

Mahd Ad Dahab gold mine occurs in an isolated mountain called Jabal Al- Mahd that rises some 800 m above the surrounding wadis and 1238 m above sea level.

For the purpose of the study a detailed investigation of the DEM was carried out and the drainage basin of the Mahd Ad Dahab mine

Table 1. Morphometric parameters of the watersheds of Mahd Ad Dahab.

Basin	Watershed A	Watershed B
Area (km2)	89.35	34.49
Total Stream Length (km)	211.90	74.42
Drainage Density(km/km^2)	2.37	2.16
Total number of Streams	336.00	136.00
Stream frequency	3.76	3.94
Drainage Texture	8.92	8.51
Bifurcation Ratio	4.09	4.73
Length (km)	21.30	8.30
Basin Perimeter (km)	75.53	31.30
Ht Max (mts)	1174.00	1142.00
Ht Min (mts)	925.00	947.00
Basin Relief (mts)	249.00	195.00
Form Factor	0.20	0.50
Elongation ratio	0.50	0.80
Circulatory Ratio	0.20	0.44
Slope(%)	2.49	5.18
Relief Ratio(m/km)	1.98	2.55

was demarcated. From the drainage basin analysis it was found that the mine falls at the head waters of two watersheds named as Watershed A and Watershed B (Figure 6).

Watershed A occupies and area of 89.35 km^2 and drains in a North East - South West direction. Watershed B occupies and area of 34.49 km^2 and drains in a South East – North West direction. The details of the morphometric parameters of the two watersheds have been given in Table 1.

Meteorology of Mahd Ad Dahab

Air temperature

The maximum air temperatures are reached during summer (June, July, August and September) and minimum temperatures are attained during winter (December, January and February). The mean maximum monthly air temperature reaches up to 43°C in summers and the mean minimum monthly air temperature goes down to 11°C in winters, (Figure 2). The mean annual air temperature is 28°C for the area.

Relative humidity

Since Mahd Ad Dahab is located far away from the Red Sea coast, the relative humidity is very low. The average values for relative humidity range from 12% in June to 39% in January and December, (Figure 3). Annual average relative humidity is 24% and corresponds to a dry arid type of climate.

Rainfall

In the Mahd Ad Dahab area the amount of rainfall is irregular through the years and through the months. The average annual rainfall for the region is less than 60 mm. Monthly rainfall distributions is uneven with little or no rainfall in the months of June, July and September. The maximum rainfall occurs in the month of January, March, April and November. Average monthly rainfall for the period 1966 to 2010 is given in Figure 4. The daily maximum recorded rainfall in the region was 104 mm on the 22nd of April 2003, (MoWE, 2011).

Wind

Mean monthly wind speed is almost constant throughout the year with values ranging from 5.35 km/h in October to 7.03 km/h in March, (Figure 5). The average annual wind speed is about 6.30 km/h.

Drainage Basin Morphometry of Mahd Ad Dahab Watersheds

Based on the results of the hydrological processing, the DEM of the study area was divided into two watersheds; Watershed A and Watershed B, (Figure 6). Watershed A occupies an area of 89.35 km^2 and drains in a North East - South West direction. Watershed B occupies an area of 34.49 km^2 and drains in a South East - North West direction, (Figure 6).

The various morphometric parameters for the two basins were calculated, (Table 1) and have been discussed in the following sections.

Drainage density

Drainage Density is the ratio of the total stream length in a given basin to the total area of the basin, (Horton, 1932, 1945). The drainage density of Watershed A is 2.37 km/km^2 and 2.16 km/km^2 for Watershed B.

Bifurcation ratio

Bifurcation ratio is the number of streams of any given order to the number of streams in the next higher order, (Horton, 1932). Bifurcation Ratio for Watershed A is 4.09 where as it is 4.73 for Watershed B. A high bifurcation ratio indicates more chances of flooding as water from different channels tend to accumulate in a single channel rather than spreading out.

Stream order

Strahler's, 1964 system was taken for the stream ordering. The number of streams gradually decreases as the stream order increases. Watershed A is a 5th order basin whereas Watershed B is a 4th order basin.

Stream length

The total stream length for the Watershed A is about 211.90 km whereas the total stream length for Watershed B is about 74.42 km. The length of stream is maximum in case of first order in both the basins.

Stream frequency

Stream frequency is the ratio of the total number of stream segments of all the orders in the basin to the total area of the basin, (Horton, 1945). The stream frequency for the Watershed A is 3.76 and 3.94 /km^2 for Watershed B. The stream frequency is dependent on the rainfall and the temperature of the region.

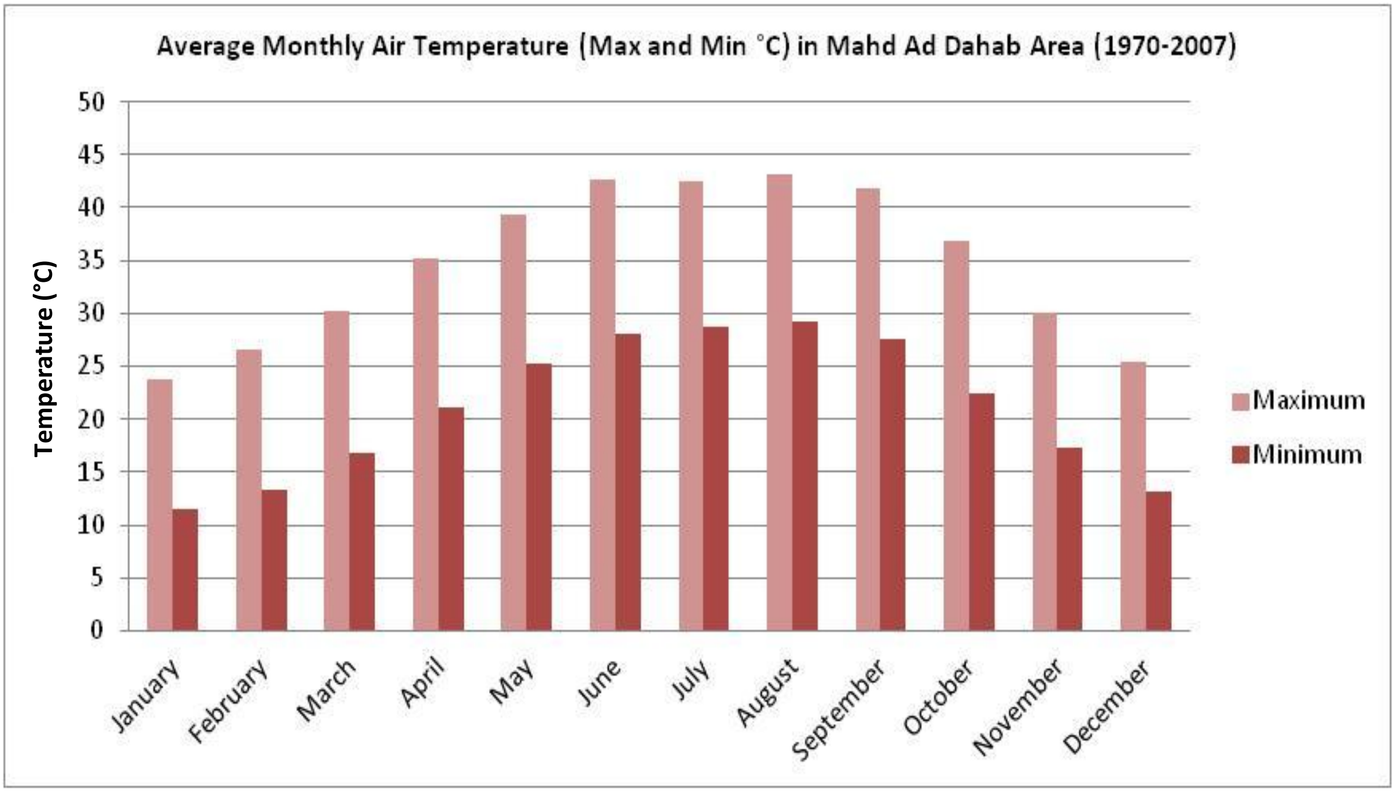

Figure 2. Average monthly air temperature.

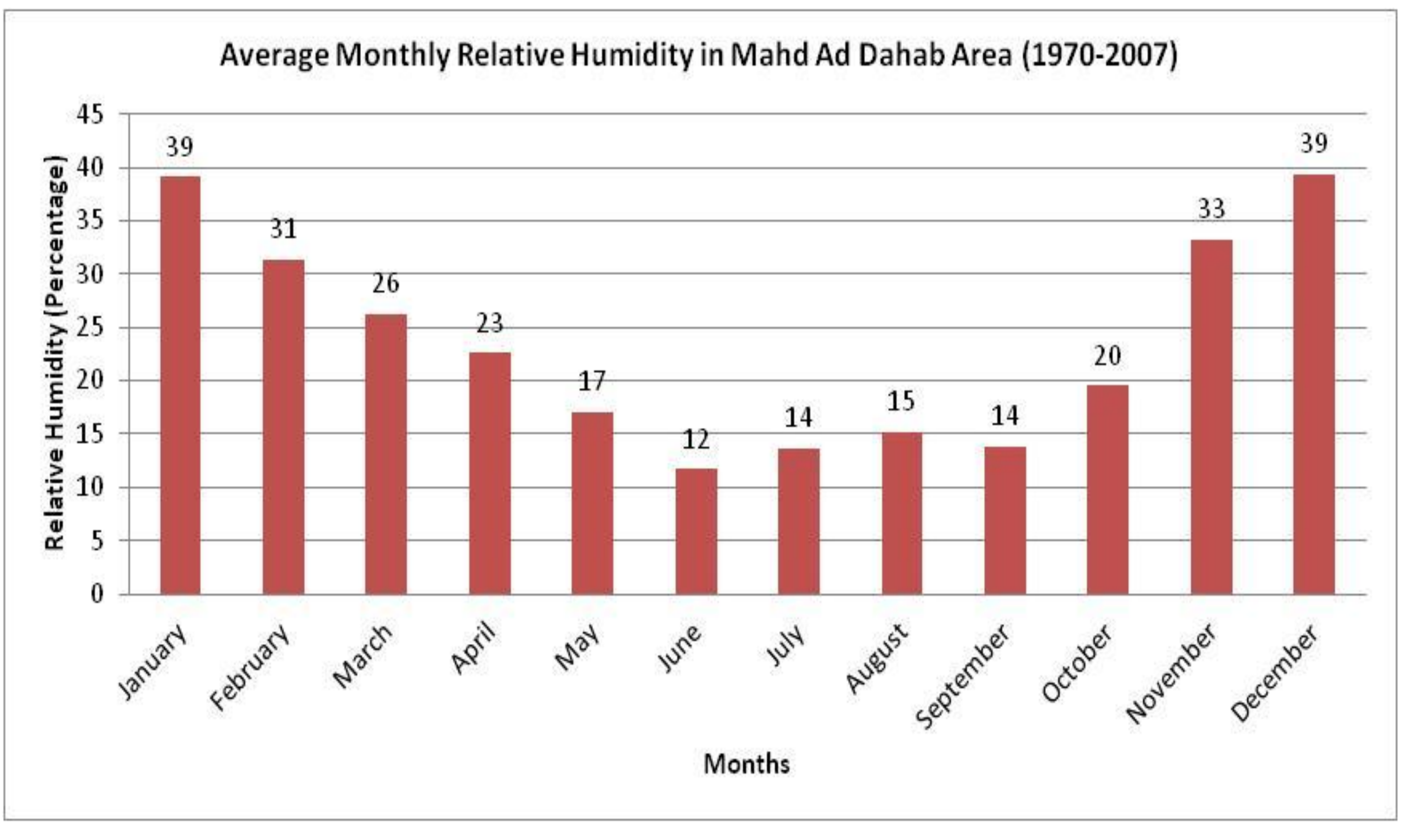

Figure 3. Average monthly humidity.

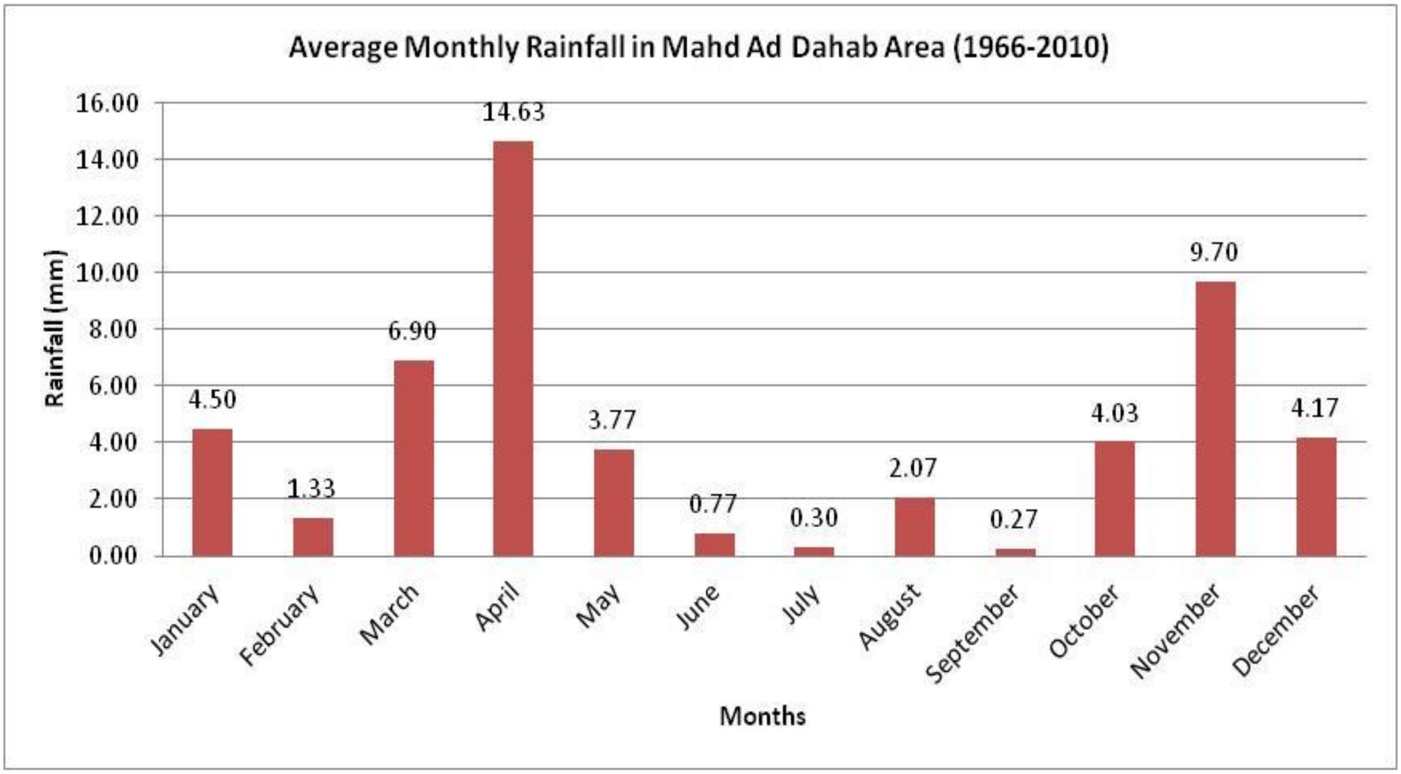

Figure 4. Average monthly rainfall.

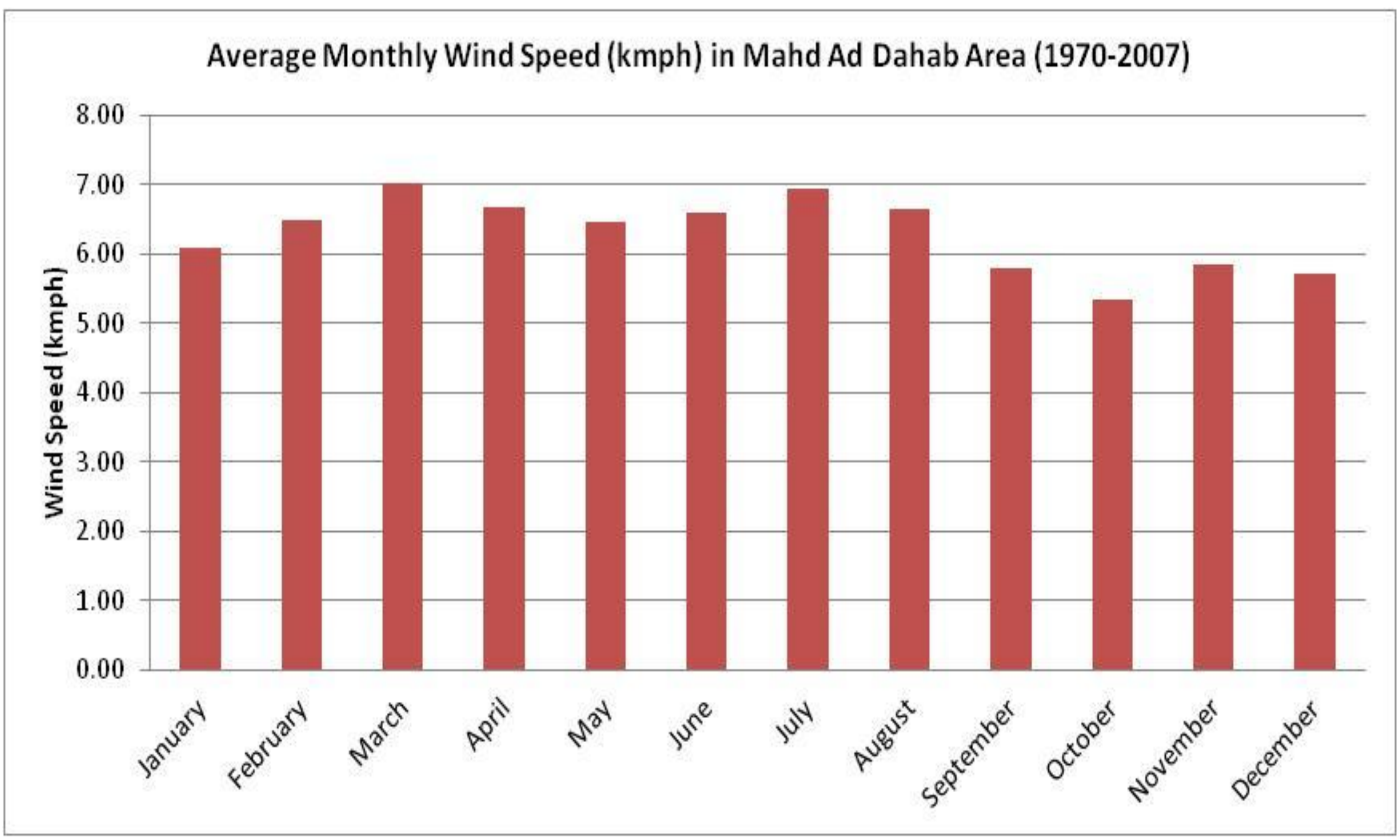

Figure 5. Average monthly wind speed.

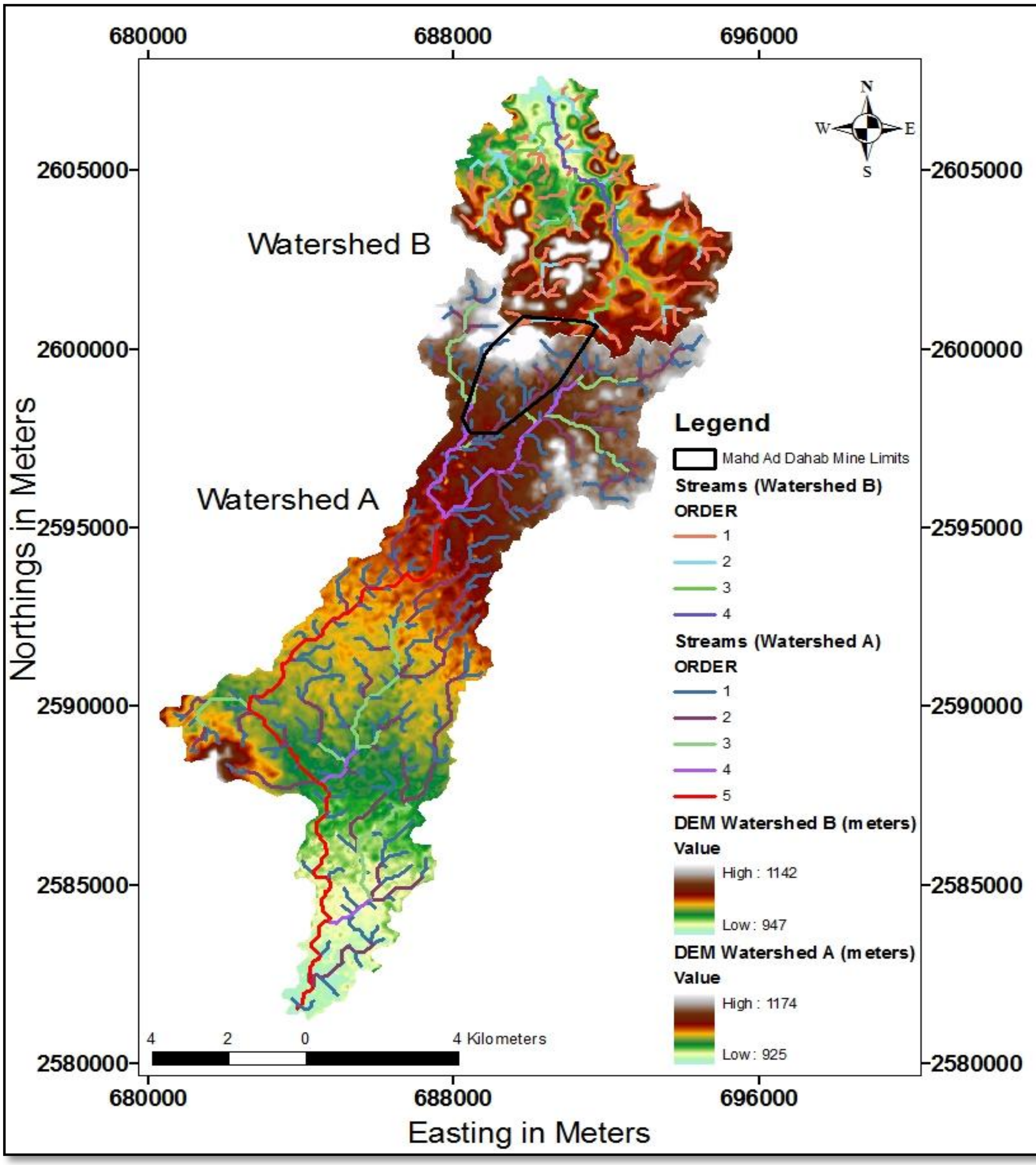

Figure 6. Extent of the watersheds of Mahd Ad Dahab Mine which forms the study area.

Basin length

Basin length is the longest length of the basin from the head waters to the point of confluence, (Gregory and Walling, 1973). Watershed A has a length of 21.30 km and Watershed B has a length of 8.30 km.

Form factor

Form factor is the ratio of the basin area to the square of the basin length. The form factor varies inversely to the basin length. Circular basins have a form factor close to 1. The form factor for Watershed A is 0.20 and 0.50 for Watershed B indicating the presence of elongated basins, which is quite evident from the Figure 6.

Elongation ratio

It is the ratio of the diameter of a circle having the same area as the basin to the basin length. The elongation ratio for the Watershed A is 0.50 whereas it is 0.80 for the Watershed B.

Circulatory ratio

It is the ratio of the basin area to the area of the circle having the same perimeter as the basin. The circulatory ratio for Watershed A

Table 2. Peak discharge rates for the two watersheds.

Maximum daily rainfall (mm/day)	Rainfall intensity (mm/h)	Peak runoff rate (m^3/s) Watershed A	Peak runoff rate (m^3/s) Watershed B
29.5	1.229	6.106	2.357
18.6	0.775	3.850	1.486
41.0	1.708	8.487	3.276
104.0	4.333	21.527	8.310
33.0	1.375	6.831	2.637
16.2	0.675	3.353	1.294
12.4	0.517	2.567	0.991
51.0	2.125	10.557	4.075
13.6	0.567	2.815	1.087
32.0	1.333	6.624	2.557
38.0	1.583	7.866	3.036
35.0	1.458	7.245	2.797

is 0.20 and the circulatory ratio for Watershed B is 0.44. This factor is influenced by the lithological characteristics of the basin.

Slope

The Watershed A shows a relief ratio (1.98 m/km) and has an average slope percentage of 2.49 as compared to Watershed B which has a relief ratio of 2.55 m/km and an average slope percentage of 5.18. The results clearly suggest that Watershed B has a more rugged terrain as compared to Watershed A.

Surface runoff

Surface runoff in the site was calculated by the Rational Method (US Soil Conservation Service, 1964; Chow et al., 1988; McCuen, 1998; Willson, 1990; McCuen, 1998). The rational method is used primarily for computing peak flows for small urban and rural watersheds.

This rational formula is characterized by consideration of the entire drainage area as a single unit, estimation of flow at the most downstream point only and the assumption that rainfall is uniformly distributed over the drainage area. The rational formula is as follows:

$$Qp = 0.278\, C*I*A$$

where: Qp = Peak runoff rate (m^3/s); C = Runoff coefficient (dimension less); I = Rainfall intensity (mm/h); A = Drainage area (km^2)

The rational formula follows the assumption that:

The predicted peak discharge has the same probability of occurrence as the used rainfall intensity (I), the runoff coefficient (C) is constant during the rain storm and the recession time is equal to the time of rise, (Hussein et.al., 2009).

Peak runoff rates have been calculated by the rational formula using the maximum total daily rainfall records for the period 1966 to 2010. The runoff coefficient, (C) was taken to be equal to 0.2 corresponding to unimproved areas. The total daily rainfall was converted into rainfall intensity (I) in mm/h. The results of calculation based on the maximum daily rainfall recorded for each month is shown on Table 2. Figure 7 shows the peak discharge rates for Watersheds A and B based on the maximum daily rainfall received for each month.

DISCUSSION

Based on the meteorological information it is revealed that the maximum rainfall occurs in the month of January, March, and April with little or no rainfall in the months of June, July and September. The average annual rainfall for the area as evident from the monthly rainfall records from 1966 to 2010 is approximately 53 mm/year. The annual relative humidity for the area remains low throughout and is about 24%. The average annual temperature for the region is 28°C. Overall the area corresponds to a dry desert type of climate (Wayne, 1995).

The DEM analysis reveals that the Mahd Ad Dahab mine lies at the headwater of two watersheds; Watershed A and Watershed B. Watershed A occupies an area of 89.35 km^2 and drains in a North East - South West direction. Watershed B has an area of 34.49 km^2 and drains in a South East - North West direction, (Figure 6). Drainage factors like drainage density, bifurcation ratio, drainage texture and stream frequency are close to each other for the two watersheds, (Table 1). The relief ratio however, suggests that Watershed B has more rugged topography as compared to Watershed A. This is also evident from the slope percentage of the two watersheds. Watershed A has a slope percentage of 2.49 whereas watershed B has a slope percentage of 5.18, (Table 1). The form factor for watershed A is 0.20 and is reflected in the elongated shape of this watershed. Watershed B has a form factor of 0.50 and is more circular as seen in figure 6.

Peak runoff rates for the two watersheds were calculated using the rational method. The maximum daily rainfall for each month was obtained from the PME

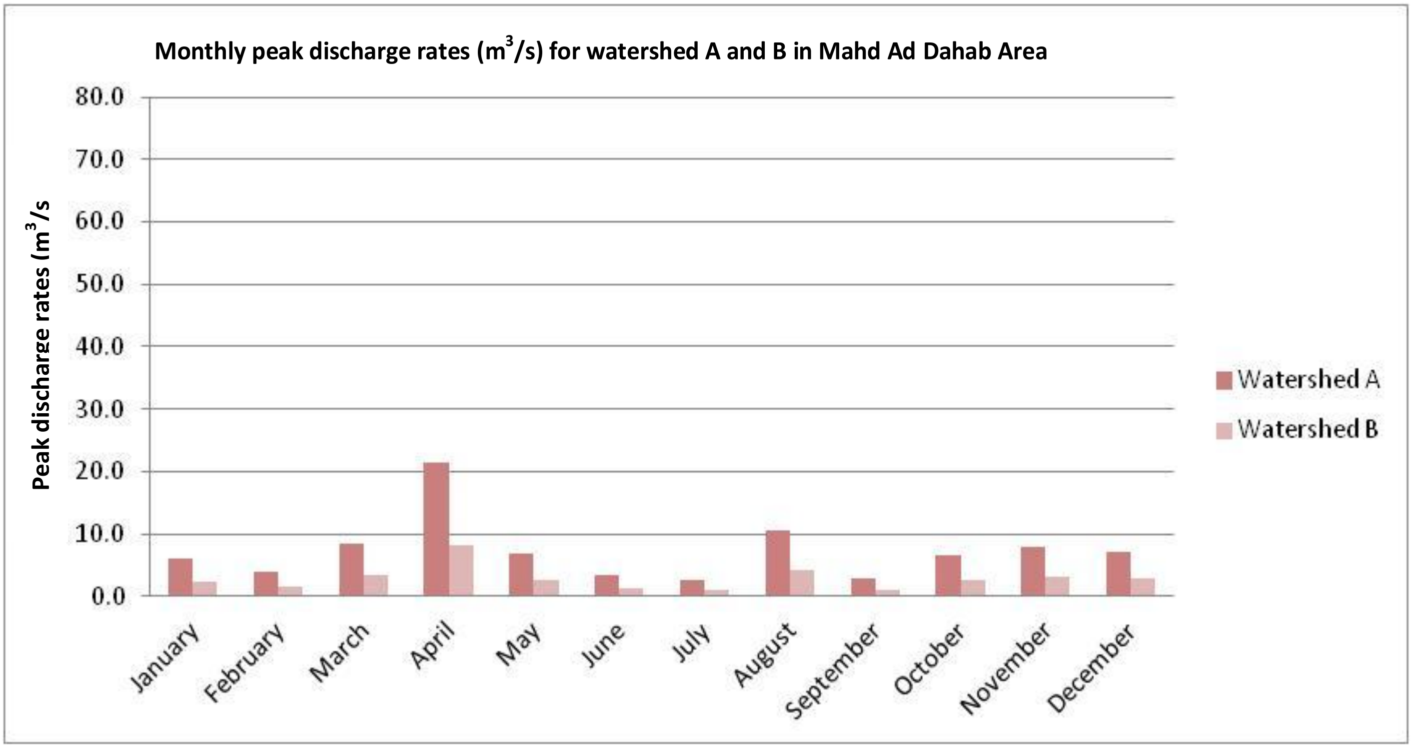

Figure 7. Monthly peak discharge.

rainfall data for the period 1966 to 2010.

The maximum discharge (m^3/sec) was obtained for the month of April, which corresponds to a rainfall of 104 mm on the 22nd of April, 2003. The peak discharge calculation shows that for the given rainfall intensity the volume of surface runoff generated is more in watershed A mainly due to its bigger drainage area, (Table 2 and Figure 7). The preferential flow path for the mine contaminants will be in the flow direction of the drainage of watershed B. Studies related to the impact of mining on the hydrological regime in the Mahd Ad Dahab gold mine should be concentrated to the south of the mine limits.

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