Water Management for Industrial use in arid region of Nagaur District in Rajasthan, India

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Abstract: Water scarcity in arid and semi-arid regions of Rajasthan is the extreme constraint for economic growth and sustainable development of the state. With the availability of variety of minerals in the state, the scope for industrial development is quite huge, although the water scarcity has restricted to the activity largely to mining. Even such activities are allowed with the restoration plan for water regime and ensured corporate social responsibility to enhance water availability to community. Further for the western districts, Rajasthan State Action Plan on Climate Change (RSAPCC) reports slight decrease in mean annual rainfall, although the extreme rainfall is expected to increase in frequency and intensity. Hence, the impact assessment of new water demanding project on the existing water resources is a critical factor for sustainability the project as well as its surrounding populations. A cement plant has been awarded in Nagaur district of Rajasthan with limestone mining lease for two areas in Marwar-Mundwa belt. Due to non availability of groundwater, the total water demand in the area is primarily satisfied by rainwater collected through ponds. With the development of new plant and mining activity, the catchment response for water availability needs to be evaluated and quantified to justify the clearance of the project. In this paper, the water management approach adopted in carrying out the hydrological impact assessment of the activities in plant and mining lease areas on the nearby ponds is presented. The water demands and water availability for pre and post project scenarios in the study area have been estimated. The district specific adaptation strategy recommended by RSAPCC have been proposed to water flow and enhance storage in the ponds while carrying out the impact assessment of the cement plant project. The ponds and settlements are identified from satellite data. The satellite images are further used for mapping of water spread area of various ponds during pre and post-monsoon seasons since 2006. The DEM of the study area has been generated from Cartosat-1 data. The drainage networks and the micro-watersheds of individual ponds have been extracted from this DEM in the GIS environment. As the rainfall in the area is very scarce, the entire micro-watersheds do not contribute to the pond, rather, it is trapped locally through farm bunds for cultivation, wherever the soil type permits. A part of the micro-watershed which is either government owned or barren land is mostly contributing rainwater to the pond. Sometimes, if condition permits the rainwater is trapped from similar land from the nearby micro-watersheds though engineering measures. The runoff estimation is made using SCS-CN and runoff coefficient method. The projected annual domestic demand of water within this zone is estimated as 1.73 MCM while for the cement plant it is 0.54 MCM. The study computes the average annual and seasonal rainfall as 382 mm and 334 mm, respectively. The annual water availability for all the ponds are computed as 474 MCM and 856 MCM for 90% and 60% dependable annual rainfall, while the cumulative capacity of all ponds in the study reach is 1.08 MCM only. Hence, the additional storage is needed to meet the water demand of the area. Moreover, the catchment treatment plans have been suggested which would further enhance the surface water yield. The drought analysis shows that the average frequency of occurrence of severe drought is once in 7-years, when 90% dependable rainfall is estimated as 165 mm. In the study, impact assessment of the proposed mining plan on existing water bodies and creation of additional storage due to mining activities have been estimated.

Keywords: Water availability, Arid zone, Pond, dependable rainfall, runoff estimation.

1. Introduction

Water scarcity in arid and semi-arid regions of Rajasthan are the extreme constraint for economic growth and sustainable development of the state. The share of state for land area, population and livestock are 10%, 5%, and is 20%, respectively while the surface and ground water resources is under 2%, compared to national average (SWP, 2019). With the high population growth, the water demand for domestic and agricultural use have been given utmost priority while any industrial use are always associated with multiple obligations. With the availability of variety of minerals in the state, the scope for industrial development are huge, although the water scarcity has restricted to the activity largely to mining. Even such activities are allowed with the restoration plan for water regime and ensured corporate social responsibility to enhance water availability to community (RMP, 2015). The western district of Nagaur is draught prone area and have been assessed 48.5% draught years in 100 year span during 1901-2002 (Rathore, 2004). The climate change report states slight decrease in mean annual rainfall, although the extreme rainfall is expected to increase in frequency and intensity. The scanty and irregular rainfall conditions have resulted in poor recharge to groundwater as compared to its extraction. In Western Rajasthan due to increased overdraft of groundwater from all the potential regions recharge to the aquifer during normal rainfall periods is inadequate, especially because of the sporadic rainfall distribution patterns and the terrain characteristics, with a major portion of the precipitation being lost as runoff or through evaporation (Rathore, 2005). The stage of groundwater development has exceeded 100% in Nagaur, district (CAZRI, 2009) where it is utilized mainly for agricultural activity. Rajasthan State Action Plan on climate change suggests alternative economical activity through integrated industrial development in the identified districts (including Nagaur) in addition to augmenting surface water storage through restoration of existing ponds and construction of additional ponds. It also suggests development of sites for ground water recharge through rain water harvesting, artificial recharging, afforestation etc. (TERI 2010).

Nagaur district of Rajasthan is well known place for several minerals including Makarana marble and cement grade limestone. Its Marwar-Mundwa limestone belt, spread in the length of 8 km and width of 0.5-2 km, is a major reserve and most suitable for industrial use. (MOEF, 2004). In the district, a cement plant has been awarded two limestone mining lease areas with the conditional industrial water use limited to rain water tapped from the leased area only without affecting the water availability of the surrounding areas. This paper report the approach adopted in carrying out the hydrological impact assessment of activities in plant and mining lease areas on the nearby ponds. The water demand and water availability for pre and post project scenario in the study area has been estimated. The remedial measures as per recommendations of Rajasthan State Action Plan on Climate Change to augment the water flow and storage in the ponds have also been suggested. The major objectives of study are: (i) analysis for surface water availability in the area and identification of nearby ponds, their existing capacity and watershed, (ii) Estimation of water demand; present and future use, (iii) impact analysis of proposed mining plan on ponds, their watershed and water availability and, (iv) suggesting measures to improve water availability and storage in the area.

2. Study Area

The study area, comprising of proposed plant site and the mining area, is located in Nagaur Tehsil of Nagaur district in Rajashthan. The plant site is located between 73°48'17"E to 73°49'23"E longitude and 27°5'26"N to 27°3'55"N latitude while two mining lease areas designated as ML-I & ML-II spread over the geographical extent of 73°49'42"E to 73°53'11"E longitude and 27°3'3"N to 27°8'40"N latitude with an aerial extent of 699.939 ha and 635 ha, respectively. The plant area terrain is almost flat, with elevation varies from RL 320.2 to 332 m. The limestone deposit of mining area has fairly flat to gently undulating topography, varying from RL 319.5 to 351.5 m. The regional slope of the area is predominantly towards west. Though the topography is adequate, the deficiency of rainfall has resulted into poor drainage development in the area. Construction of bunds around the agriculture field are very common practice adopted by farmers and most of the rainwater is completely trapped within the levelled farm area wherever the soil type permits farming. The minor streamlets appear only on government lands, ponds agor (water contributing area) or barren lands. The area experiences arid to semi-arid type of climate i.e. dry climate with a hot summer during March to June. The mean annual rainfall (1971-2008) of the district is 411.2 mm whereas normal rainfall is 363.1 mm (1901-1970) only. The rainy days are limited to maximum 15 in a year. The probability of occurrence of mean annual rainfall is 38%. More than 90% of the total annual rainfall is received during the south – west monsoon season. The humidity is highest in August with mean daily relative humidity is 80%. The annual maximum potential evapotranspiration in the district is quite high and it is highest (255.1 mm) in the month of May and lowest (76.5 mm) in the month of December. Based on agriculture criteria, it indicates that the district is prone to mild and normal type of droughts.

3. Methods

Various analysis carried out in the study includes; land use classification, analysis of surface water availability in ponds, terrain analysis for delineation of micro watershed, water availability study and estimation of water demand.

Land use classification-The multi-spectral classification of satellite images based on supervised classification technique have been used. The IRS Resourcesat-2, MX4 scenes for two seasons have been used for identification of water bodies (ponds) and their watersheds. Five major classes namely; water body, agriculture field, fallow land (agriculture land not cultivated), settlements and open barren land have been extracted. The agriculture fields are identified with its association with the bund formation.

Development of DEM-IRS satellite Cartosat-1 image of date 10 June 2011 with spatial resolution of 2.5 m has been primarily used for generation of Digital Elevation Model (DEM) through photogrammetric analysis using Leica Photogrammetry Suite (LPS) 9.1. In addition to RPCs obtained with Carto image data, additional ground control points (GCPs) are used for photogrammetric processing of stereo-images to improve the accuracy of DEM. Altogether, 47 number of the GCPs have been established using DGPS survey.

Estimation of Pond Capacity- The water spread area of the various ponds is extracted from temporal satellite images and using the derived DEM the contours of water spread are computed for the maximum and minimum spread for each of the pond. The depth of the pond are estimated through field data. The capacity between the consecutive contour levels are calculated using the prismoidal formula and the overall pond capacity between the lowest and highest estimated water levels are computed.

Micro Watershed Delineation for the Pond-The micro watershed for all the ponds in the nearby area have been delineated from terrain analysis of DEM developed using Cartosat-1 data. Arc Hydro Tool 9 has been used for micro watershed delineation in Arc GIS. The process includes filling of DEM to remove any local sink and then used to derive the flow direction and flow accumulation grids which are further used for defining and segmenting the streams and the catchment grid. The drainage points are defined at/ near the pond locations and the drainage network and catchment boundary is masked for individual ponds. The drainage point is selected on the stream grid near to the point of interest and therefore in some case the point on drainage line near to the pond is selected. The terrain analysis is carried out using digital surface model (DSM) where elevation of top surface of the features (like buildings, tree etc) are represented. The ponds have already delineated from satellite image and assigned with their local names. The micro-watershed of a pond is demarcated using this drainage pattern. Though there are various ponds within 10 km of the plant area, the micro watershed as delineated from DEM shows that watershed area of the ponds are very limited. The DEM coverage for plant and mining area within its 10 km radius is 72964 ha while the total watershed area for all the identified ponds is 5141 ha (7% of total area) only. It implies that the rainfall occurring on 7% of the area would naturally be collecting in various ponds as per topographical land slope. Further, the actual watershed depends, in addition to topographical constrains, on the land right and land use. The private lands though topographically forming part of the micro-watershed are not allowed to discharge the rainwater downstream to the pond and is used locally in the field for irrigation if soil and other condition permits for cultivation. Hence, it is evident that all area, though topographically drainage exists, are not part of the watershed of a pond. Further, for some of the ponds, if condition permits, the nearby waste land (mostly government owned) in the adjoining micro-watershed are included in the watershed of a pond by adopting man made engineering measures. Such practices are very common in the area as observed from high resolution satellite data wherein the small manmade channels/ bunds are observed which divert the water from nearby waste land though in different watershed. The water contributing area of these pond can be easily identified from satellite images due to its distinct appearance. The water contributing area is mostly open land with sparse vegetations at few locations and therefore the spectral characteristic of bare soil is predominant. Further, the absence of any human activity can be easily perceived as no linear features (farm bunds/ track etc.) appear in the area. In some of the water contributing area man made channels / bunds to divert the upstream flow in the pond can be visualised. This area can be easily identified from multispectral as well as panchromatic satellite data.

Estimation of Water Demand- The major water demand in Nagaur district is to meet the requirement for drinking purpose (in rural and urban area), livestock, farming, agriculture, institutional, fire fighting and industrial use. The district level water demand estimate is obtained from the Public Health Engineering Department of Government of Rajasthan. For the study area, the water requirement for drinking and cattle farming in the nearby village is estimated based on the population and per capita water requirement. The village/ block wise population and future growth including industrialization impact is considered as per 2011 Census to estimate the future population. The existing norm for rural water supply is 40 litres of drinking water per capita per day (LPCD), for cattle in rural area under Desert Development Programme (DDP) additional 30 LPCD and similar norms of CPHEEO, 1999 of 100 LPCD for urban population with population between 20,000 to 1,00,000 have been used to compute the water demand in the area.

Rainfall Analysis- The rainfall data for Nagaur are collected for the period from 1957 to 2012. The various steps of rainfall analysis includes estimation of annual and seasonal departure, estimating the probability distribution of annual rainfall and then carrying out rainfall runoff analysis.

Annual and Seasonal Rainfall Departure: The annual and seasonal rainfall at Nagaur for the period 1957 to 2012 has been analyzed. The mean annual rainfall at a given raingauge station was obtained as the arithmetic average of annual rainfall values over the period of record. The annual rainfall departures were computed as the deviation of the rainfall from mean divided by mean rainfall for the station. The year having annual departure value more than or equal to –25% is considered as a drought year. The sum of rainfall from June to September month has been taken as the seasonal rainfall and the seasonal rainfall departures were also estimated.

Probability Distribution of Annual Rainfall - Probability distribution of annual rainfall is important to predict the relative frequency of occurrence of a given amount of annual rainfall with reasonable accuracy. For calculating probability distribution of annual rainfall, the annual rainfall values of each station were arranged in descending order and were ranked according to order of occurrence and their probability distribution were calculated using Weibull's plotting position formula. The plots of annual probability distribution were prepared between the probability of exceedance and the corresponding rainfall value. Rainfall at 60%, 75% and 80% dependability level were obtained from graph.

Estimation of runoff- The runoff generation over a given area primarily depends on the regional climatic condition and the catchment characteristics. The runoff coefficient (C) represents the fraction of rainfall getting converted in to surface runoff at a given outlet. Various studies have been conducted by Central Arid Zone Research Institute (CAZRI) and others to estimate the runoff percentage in different parts of Rajasthan. Then runoff coefficient for study area has been adopted as 0.2, 0.3 and 0.4 from CAZRI report (Goyal and Issac, 2009) Accordingly, the runoff estimates have been made for annual and seasonal rainfall at 60%, 75% and 80% dependability level. The runoff has been estimated as the product of rainfall at given dependability level, runoff coefficient and the catchment area.

4. Analysis & Results

Plant and its Surroundings - The villages within 500 m, 5 km and 10 km are grouped together in Zone 1. Zone 2 and Zone 3 as shown in Figure-1.

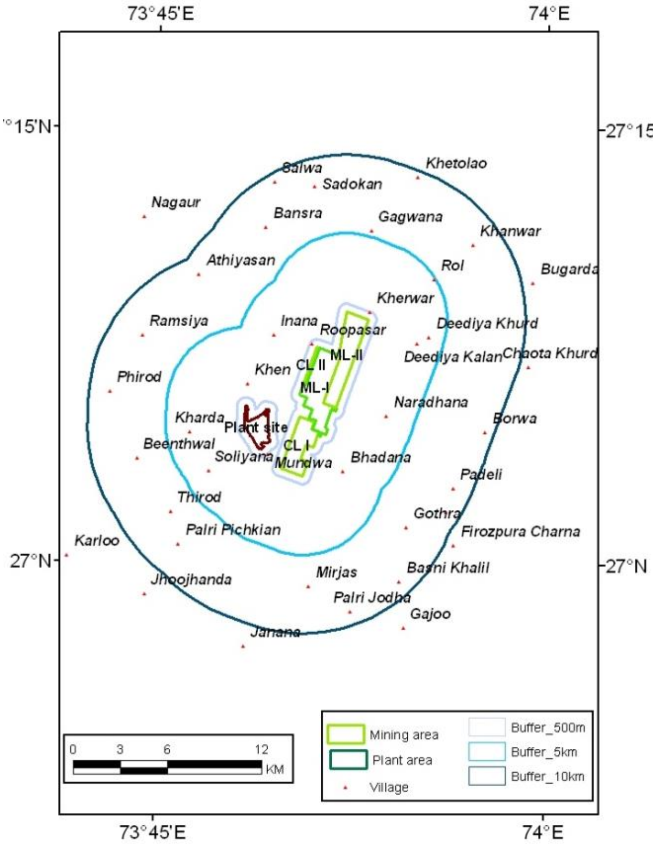

Figure 1: Ponds and villages around cement plant property in 3 zones of 500 m, 5 km & 10 km

Land Use Classification - The extent of land use/cover class for two seasons, pre and post monsoon is shown in Table-1.

Table 1: Land use/ cover class in pre and post monsoon season in 3 zones

SN	Land use/ cover class	Area in ha					
		Pre monsoon (May-Jun 2013)			Post monsoon (Oct-Nov 2012)		
		500 m	5 km	10 km	500 m	5 km	10 km
1	Water body	1	9	22	2	35	97
2	Vegetation	84	655	2413	505	5049	18847
3	Barren (Open barren)	1729	5897	20433	1678	5811	18945
4	Settlement	723	1956	7208	689	1927	7158
5	Fallow land (open agriculture land)	1596	16732	55109	1258	12426	40137

The ponds around the plant and mining lease area in a three buffer zones of Zone I, II & III, are mapped using the fine resolution satellite data. For identifying the ponds the satellite data of post monsoon seasons have been used. A total of 50 ponds have been identified in the buffer area of 10 km around the plant/ mining site from satellite data of 2010 when annual rainfall was 605 mm against the average annual rainfall of 382 mm. The DEM derived drainage network and micro-watershed of individual ponds are superimposed over the satellite data to visualise the actual water contributing area of a pond. The proposed mining plan of the cement plant is transformed and superimposed over the drainage network and water contributing area of the various ponds. to evaluate the impact of mining and plant activity over the water availability. It is observed that the watershed of ponds namely; Chaukari, Harchand, Nausia, Nava nadi and Khakhandi nadi intercept the mining lease area, the water contributing area of ponds Chaukari nadi and Nava nadi is affected by the mining activities. The GIS analysis shows that the water contributing area of ponds are slightly impacted and sufficient land is available nearby from where the loss of water in the contributing area may be compensated (Figure 2). The land free from mining activity from where water may be diverted to these ponds are identified and quantified. Further, runoff reduction in these affected ponds due to plant and mining have been estimated. The analysis shows that there is ample potential for runoff diversions to ponds to compensate and augment water in the ponds. The proposed runoff diversions have viable potential to enhance additional water collection in the affected ponds.

Creation of additional water storage due to mining activities - The spread area of mining pit in two lease areas are is 115.18 ha and 187.70 ha respectively. The mining activities in these pits would provide additional storage for surface runoff in the area in due course. The capacity of pits available for storage of surface runoff during various years of mining are computed from the mining schedule plan.

Estimation of Water Demand - The total yearly domestic water demand for the area is estimated as 1727864 m^3 (1.73 MCM) considering the accelerated growth with industrial development in the area with 25% growth rate against the reported decadal population growth rate of 16.5% in rural areas of Nagaur district. Further, the water requirement for plant and their domestic use is 1100 and 400 m^3 per day estimates the yearly demand for the project as 0.54 MCM.

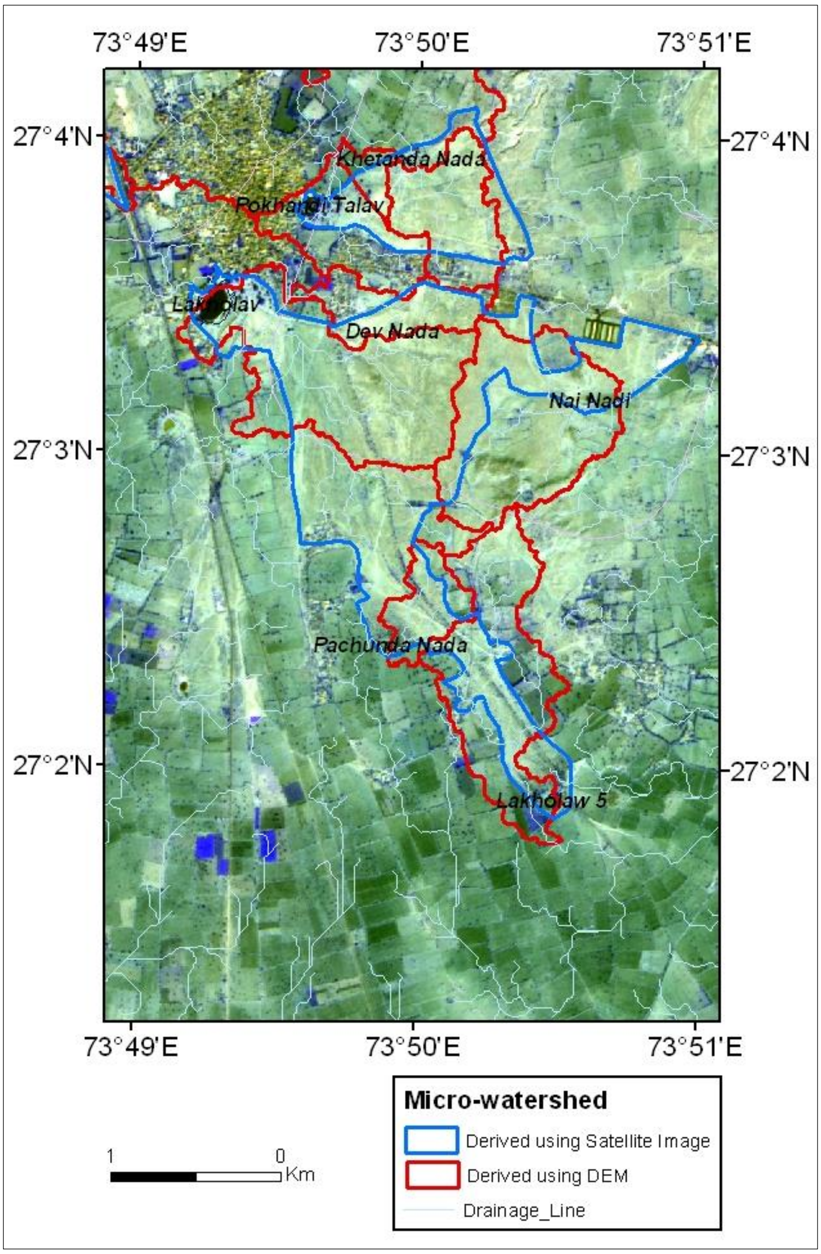

Figure 2 : Water contributing area of ponds

Rainfall analysis- The plots of annual and seasonal rainfall departure in Nagaur station are prepared that shows that there have been 8 years with annual rainfall deficiency beyond 50% during the period of past 56 years (1957-2012). But, there have been a total of 21 drought years in which the annual rainfall deficit was more that 25%. This indicates that the region has average frequency of drought once in every three years approximately. However, the average frequency of occurrence of severe drought is once in 7-years. Further, it also shows that there have been a total of 13-years in which the annual rainfall has been equal to or more than 125% of normal value. The average return period of a wet year is nearly one in four years.

Probability Distribution of Annual Rainfall: The plots of annual probability distribution were prepared between the probability of exceedance and the corresponding rainfall value. Rainfall at 60%, 75% and 80% dependability level were obtained from graph. The plots of annual and seasonal probability distribution are presented in Figure 3Figure 3 and Figure 4, respectively.

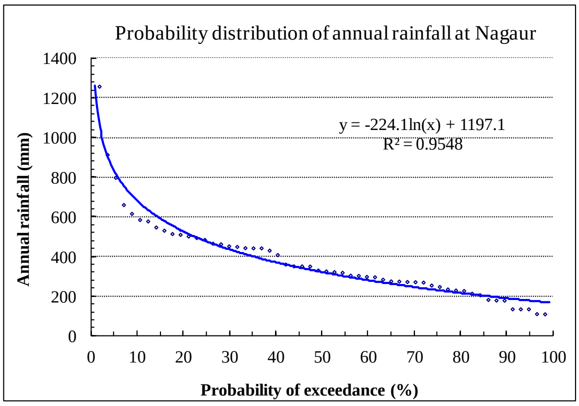

Figure 3: Probability distribution of annual rainfall for Nagaur, Rajasthan.

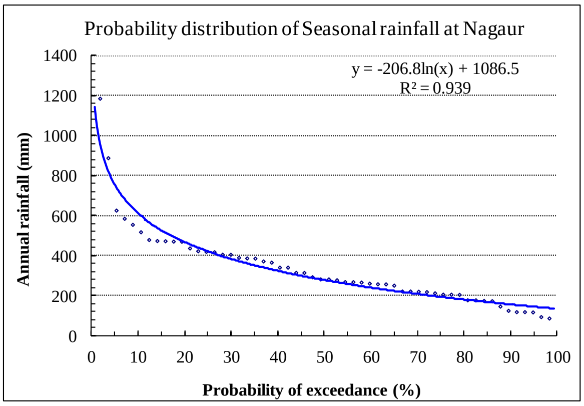

Figure 4: Probability distribution of seasonal rainfall for Nagaur, Rajasthan.

Estimation of runoff- The runoff estimates have been made for annual and seasonal rainfall at 60%, 75% and 80% dependability level using the different runoff coefficients of 0.3, 0.35 and 0.40. Thus the runoff has been estimated as the product of rainfall at given dependability level, runoff coefficient and the catchment area. The annual runoff estimate for one pond namely Harchand Talav is shown in Table 2. It shows that for 80% dependable rainfall, the catchment treatment to improve 'C' from 0.3 to 0.4 would enhance the runoff from 156744.5 to 182868.6 m^3 i.e. increase of 17%, while the present pond capacity is only 172822 m^3.

Table 2: Estimates of annual runoff (m^3) from the water contributing area of Harchand talav.

SN	Dependability Level	Annual Rainfall, (mm)	Estimated Annual Runoff in (m^3)		
			C = 0.3	C = 0.35	C = 0.4
1	60% dependable annual rainfall	298	204314.3	238366.7	272419.1
2	75% dependable annual rainfall	250	171158.9	199685.4	228211.9
3	80% dependable annual rainfall	229	156744.5	182868.6	208992.7
4	90% dependable annual rainfall	165	113279.5	132159.4	151039.4

5. Conclusions

The major land use / cover in the area include water body, vegetation, barren land, settlement and fallow land. The water spread area in pre and post monsoon season are 22 and 97 ha respectively within 10 km of cement plant property. There are 49 ponds identified in the study area within 10 km of plant The total of capacity of all ponds within study area is 1.08 MCM. The projected annual domestic demand of water within this zone is 1.73 MCM while for the ACL plant it is 0.54 MCM. The DEM generated from Cartosat-1 data are used to define the micro watersheds of the ponds. The micro watersheds of the ponds are intercepted by the plant/ mining lease area. The runoff/ water contributing areas of the ponds are also delineated from the satellite images. The total runoff/ water contributing areas for various ponds within plant site is 2403 ha. The runoff/ water contributing area falling within plant boundary does not completely affect the inflow to the pond, as the mining activity is confined to a limited extent within the mining lease area. Altogether due to mining activity, the affected runoff/ water contributing areas of the ponds in two mining lease area are 1.62 ha and 16.86 ha respectively. Whereas in ML-I and ML-II respectively, 20.69 ha and 60.36 ha additional land is available in the nearby area from where the rainwater water is proposed to be diverted to the respective ponds to compensate the impact of mining activities. The proposed mining activity will create additional storage of 85.4 MCM which may be used for rainwater harvesting and augmentation of ground water recharge. The annual water availability from the water contributing areas of all the ponds are 474 MCM and 856 MCM for 90% and 60% dependable annual rainfall. The runoff coefficient of the water contributing area can be improved to enhance the surface water yield to 632 MCM and 1141 MCM respectively. The study infers that the project is viable and sustainable and all the proposed activities leading to augmentation of surface water storage and ground water recharge are in line with recommendations of RSAPCC.

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