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IMPACTS OF STONE MINING AND CRUSHING ON STREAM CHARACTERS AND VEGETATION HEALTH OF DWARKA RIVER BASIN OF JHARKHAND AND WEST BENGAL, EASTERN INDIA

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Abstract

Dwarka River basin (3882.71 km^2) of Eastern India in the Chotonagpur Plateau and Gangetic Plain is highly affected by stone mining and crushing generated dust. In the middle catchment of this basin, there are 239 stone mines and 982 stone crushing units. These produce approximately 258120 tons of dust every year and this dust enters into the river and coats the leaves of plants. On the one hand, this is aggrading in the stream bed, increasing sediment load, decreasing water quality, specifically increasing total dissolved solid, pH, water colour, and it also degrades the vegetation quality. Vegetation quality is also degraded as indicated by decreasing of NDVI values (maximum NDVI in 1990 was 0.70 and in 2016 it was 0.48). Considering all these issues, the present paper intends to identify dust vulnerable zones based on six major driving parameters and the impact of the dust on river morphology, water quality and vegetation quality in different vulnerable zones. Weighted linear combination method (in Arc Gis environment) is used for compositing the selected parameters and deriving vulnerable zones. Weight to the each parameter is assigned based on analytic hierarchy process, a semi quantitative method. According to the results, 579.64 km^2 (14.93%) of the catchment area is very highly vulnerable: Here 581 rivers have a length of 713 km and these riversare prone to high dust deposition, increased sediment load and water quality deterioration.

Keywords: Dwarka river basin, stone mining, stone crushing, river bed aggradations, sediment load, water quality, vegetation health

INTRODUCTION

Stone crushing industry is an important industrial sector engaged in producing crushed stone of various sizes depending upon the requirement which acts as raw material for various construction activities such as construction of roads, highways, bridges, buildings, and canals etc. It is counted that there are over 12,000 stone crusher units in India (Patil, 2001). In India, the stone crushing industry sector is estimated to have an annual turnover of >US$ 1 billion and 500,000 principally unskilled or semi skilled rural people engaged in this sector (CPCB, 2009). These stone crushers though socio-economically an important sector, give rise to substantial quantity of fine fugitive dust emissions which create health hazards to the workers as well as surrounding population by causing respiratory diseases.

The dust is generated primarily due to size reduction and handling of the stones at various stages. The major sources of dust generation are the size reductions in the primary, secondary and tertiary crushers. In different stages the amount of dust production varies. The Central Pollution Control Board (CPCB, 2009) reported the proportion of dust contribution at different stages of crushing (see Table 1). The fine-grained dust production depends on the type of the crusher and the parent rock. Primary crushers produce 1- 10% of fines, secondary crushers produce 5 – 25% fines, and tertiary crusher produce 5 – 30% fines. Similarly limestone contains 20–25% of fines; sandstone contains 35–40% fines, whilst igneous and metamorphic rocks contain 10–30% fines (Mitchell 2009). Blatt and Tracy (1997) analyzed the composition of stone dust emitting from a stone crusher unit. They documented that the chemical composition was SiO_2-72.04%; Al_2O_3-14.42%; K_2O-4.12%; Na_2O- 3.69%; CaO-1.82%; FeO_3-1.22%; MgO-0.71%; TiO_2-0.30%; P_2O_5-0.12% and MnO_2-0.05%. This proportion varies according to composition of the rock from which crushing is done. Average dust contamination level in the atmosphere is 0.10 mg/m^3 in USA (Moran et al., 1994; Tucker et al., 1995, IARC,1997; US EPA, 1996). The actual area of the source of the dust generation is quite small (about 0.5- 1 m^2) at each source, but as the dust rises it spreads and typically the area in which it spreads is more than 10 to 15 times larger (CPCB, 2009) than the area of actual emission at about 3 to 8 m height. Mining must be planned so that after the mining process the dumped land can be reclaimed by vegetation and agriculture.

The problems of waste rock dumps become devastating to the landscape around mining areas (Goretti, 1998; Sarma, 2005). The dust adversely affects visibility, reduces growth of vegetation, agricultural crops and hampers aesthetics of the area as well as river system (CPCB, 2009). Sharma and Kumar (2016) pointed out that dust deposition on agricultural field reduces productivity of rice and carbohydrate content within the rice grain. Such dust is one of the most visible, invasive, and potentially irritating impacts associated with quarrying, and its visibility often raises concerns that are not directly proportional to its impact on human health and the environment (Howard and Cameron, 1998). It has noteworthy impact on landscape and biological communities of the Earth (Down, 1997; Bell et al., 2001) and leads to ecosystem disturbance. Natural plant communities get disturbed and the habitats become impoverished due to mining, presenting a very rigorous condition for plant growth (Shivacoumar et al., 2006; Mishra and Kumari, 2008). The unscientific mining of minerals poses a serious threat to the environment, resulting in the reduction of forest cover, erosion of soil in a great scale, pollution of air, water and land and reduction in biodiversity (Pandey and Pandey, 2010; Prasad et al., 2010; Saha and Padhy, 2011; UNESCO, 1998). Most of the plants experience physiological alterations before morphological injury symptoms become visible on their leaves (Liu and Ding, 2008). Rai et al. (2010) reveals that the foliar surface was an excellent receptor of atmospheric pollutants leading to a number of structural and functional changes. Increasing dust concentration in atmosphere will raise the temperature state of the environment and hamper the ambient ecological condition (Ziaul and Pal, 2016). Site conditions that affect the impact of dust generated during extraction of aggregate and dimension stone include rock properties, moisture, ambient air quality, air currents and prevailing winds, the size of the operation, proximity to population centres, and other nearby sources of dust (Bell et al., 1977). Drainage direction and volume both channelized or unchannelized form is also an important vector for spreading these effects in its surrounding. Degree of drainage slope controls the dispersal rate of sediment and dust from the place of origin and pools and riffle condition, variability of discharge regulate persistence of materials within the channel or swiping off the same (Sipos et al., 2014; Nagy and Kiss, 2016). Dust concentrations, deposition rates, and potential impacts tend to decrease rapidly away from the source (Howard and Cameron, 1998).

Table 1 Particulate emission factors for stone-processing operations. Source: Pollution Data Division of Environment Canada (2008)

Sources	Emission factors kg/10000kg production		
	Total Particulate Matter(TPM)	PM_{10}	$PM_{2.5}$
Drilling	0.000 800	0.000 040	0.000 002
Primary crushing	0.005 800	0.000 290	0.000 017
Secondary crushing	0.001 208	0.000 290	0.000 017
Tertiary crushing	0.001 208	0.000 290	0.000 017
Screening	0.004 286	0.000 420	0.000 124
Conveying and handling	0.007 327	0.000 720	0.000 213

Most of the previous studies mainly concentrated on impact of mining and crushing dust on vegetation and human health (Pyatt and Haywood, 1989; John and Iqbal, 1992; Grewal et al., 2001; Prajapati and Tripathi, 2008; Rai et al., 2010; Saha and Padhy, 2011; Sharma and Kumar, 2016). But the present study intends to find out the impact of stone mines and stone crushing units on surrounding rivers specifically in terms of stone dust deposition within stream bed and water quality of the river. This study also aimed to find out the vulnerable zones to stone dust considering the fact that the region nearer to the stone mines and crushing units are more vulnerable to dust. Although the dimension of contamination is multi furious like effect on human health, agricultural production, water quality, stream morphology etc. but concentration mainly is given on to the stream morphology, water quality and vegetation health in the dust affected areas. Figure 1(A-D) shows the logic behind setting such objective.

Fig. 1 Field evidences highlights the problems of stone dust (A) crushing of stone and admixing dust in the atmosphere (B) draining of heaped up dust to the river (C) deposition of dust in the channel bed and banks (D) thick dust layer to the tree leaves

STUDY AREA

The Dwarka River is a tributary of Mayurakshi River. Originating at Kushpahari of Santhal Parganas in Jharkhand it has been flowing through eastern Chotonagpur plateau fringe area of Jharkhand and West Bengal, ultimately it joins the Dwarka Babla river near Hizole wetland (88°4'12.93"E; 24°4'42.27"N) in Murshidabad flood plain of West Bengal (Fig. 2). This basin area is covering an area of 3882.71 km^2 with along its 156.54 km. long main channel and some major tributaries like Brhamni, Bamni, Gambhira, Borkunda, Ghagar etc. It comprises a small portion of Chotonagpur plateau fringe (Santhal Pargana Upland) at its upper course (40% of the total basin area) and Rarh plain (Birbhum Rarh); Moribund deltaic West Bengal (Murshidabad Plain) in the lower course. It lies to the north of river Mayurakshi and to the south of river Bansloi. Two major faults lines namely Rajmahal fault line (RFL) and Gaibandha fault line (GFL) and one normal faults line are existing within the south west to northwest part of the basin. There are two seismic points situated one at upper (Sismicity Hypocentral Depth 25-70 km) and another is at the lower catchment (Sismicity Hypocentral depth more or less 25 km) of the Dwarka river basin (Fig. 3).

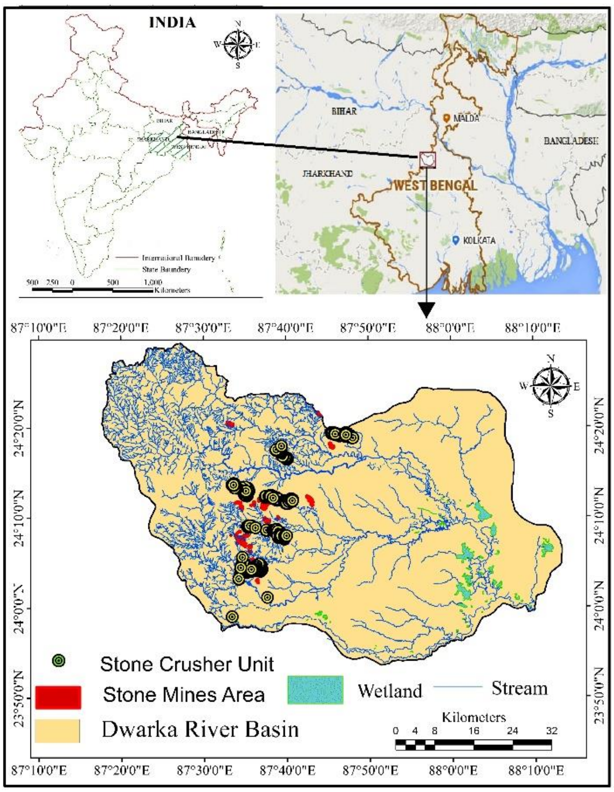

Fig. 2 Location of the studied Dwarka River basin showing the drainage, stone mines and crushing sites

Geologically the upper part of the basin dates back to the deposition of Dharwanian sedimentary followed by Hercinian orogeny from Cambrian to Silurian period. The extreme eastern part of the upper basin is characterized by unclassified granitic gneiss with enclaves of metamorphic geomaterials. The middle catchment is mostly characterized by the deposition of Lateritic soil and hard clays impregnated with Caliche nodules. The platform of this region was set through the tectonic activities associated with tertiary epoch. The lower catchment is mostly characterized by recent alluvial deposition of alternative layers of sand, silt and clay attributed by alleviation river diversion, flooding and consequent shaping by twin action of Bramhani (main tributary of Dwarka) and Dwarka River. The upper basin area of undulating well drained tract of Chotonagpur fringe have fragile coarse lateritic soil containing siliceous matter, karoline, magnesium and iron oxide and sandy gravelly soil or gravelly soil with proximate rich pegmatite rock (Let, 2012). Elevation of the basin ranges from 14m to 497m, out of total basin area, 58.88% area lies below 76m asl Maximum slope of this river basin is 5.76° in the isolated hillocks of upper and upper middle catchments of the basin. Almost flat surface is found in the Murshidabad plan region where drainage deranging is observed. Total 2552 river units were identified with 3297.49 km length with seven orders hierarchy (Strahler, 1964). Distribution of stream frequency in different orders and their respective lengths is shown in Table 2. Average stream frequency and density are respectively 0.710 nos./km^2 and 7.15 km./km^2

Administratively, the study region includes Pakur and Dumka Districts of Jharkhand and Birbhum and Murshidabad Districts of West Bengal. There are 16 CD Blocks (Kandi, Khargram, Berhampore, Nabagram of Murshidabad and Nalhati, Rampurhat, Mahammadbazar, Muyureshwar of Birbhum), 3 urban centres (Rampurhat, Nalhati, Kandi) within the study area. Among these Pakur, Mhammadbazar region is rich with stone mining and crushing of stone. At present 239 numbers of stone mining units covering an area of 7.62 km^2 are found at the middle catchment of the basin with 982 number of stone crusher units (Fig. 2). Most of the stone mining and stone crushing units are found at 40-110 m (asl) elevation in the plateau fringe area.

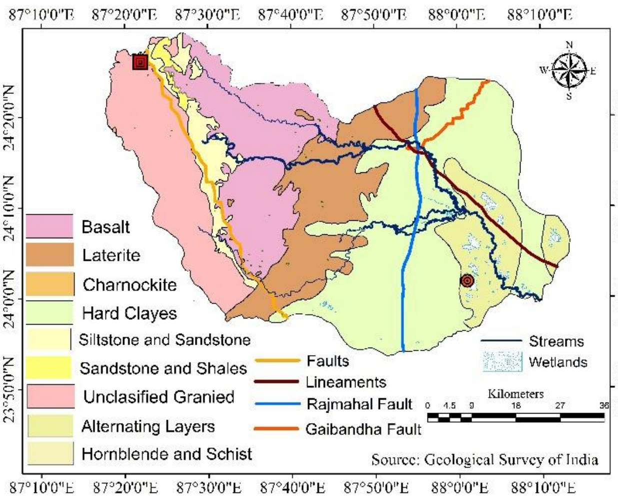

Fig.3 Geological map of the studied catchment

These soils are quite acidic, deficient in organic matter, poorly aggregated and possess low water holding capa-

Table 2 Order-wise number & length of the streams and some other morphometric aspect. Method followed for calculating morphometric properties: stream order after Strahler (1964), bifurcation ratio after Schumm (1956), mean bifurcation ratio after Strahler (1957), stream frequency after Horton (1932) and drainage texture after Horton (1945)

Stream Order	Number of Stream	Total Length (km)	Bifurcation Ratio	Mean Bifurcation Ratio	Stream Frequency (Df/km^2)	Drainage Texture
First	2058	1521.65		3.998	0.710	7.15
Second	349	638.18	5.896			
Third	115	468.55	3.034			
Fourth	22	207.56	5.227			
Fifth	4	111.59	5.500			
Sixth	3	272.83	1.333			
Seventh	1	77.12	3			
Total	2552	3297.49				

city. Transported secondary laterites and lateritic alluvium soils are found at the middle part of the basin (Chakraborty, 1970). These lateriatic regolith is carried out by the main river and tributary system (Jha, 1997; Jha and Kapat, 2003; Jha and Kapat, 2009). These lateritic mater Fine silty alluvium soil is found at the lower catchment of the basin. The average rainfall is 1500-1600mm Out of which 80% occurs during monsoon season (June to October). Volume of runoff is also maximum in this time. Bank full rivers found in this time. But upstream parts and streams of the upper catchment do not continue as bank full state even during peak monsoon time. Rest periods of a year shows almost dry rivers in the upper catchment of a basin. Wind direction highly varies seasonally. Out of 365 days in a year 123 to 162 days wind comes from southern and south western directions, 53 to 71 days wind comes from north eastern direction, 31-52 days wind comes from eastern and south eastern direction.

MATERIALS AND METHODS

Method for Evaluating Vulnerability

At first, six parameters have been taken into account as stated below for finding out stone dust vulnerability zones namely (1) stone crusher site (Scd); (2) stone mines site (Smd); (3) land use/land cover (Luc) (4) vegetation health (Ndvi); (5) surface slope (Sa); (6) surface runoff (Sro) Stone mining and crusher units have been identified from Google Earth satellite imageries and GPS survey where necessary. These are also identified from toposheets of Survey of India (SOI, 1972). These two layers are prime because the adjacent areas will be highly affected with stone dust (Down and Stocks, 1997; Howard and Cameron, 1998; Bell et al., 2001; CPCB, 2009) and its effects will decrease away from these sites (Bell et al., 1977). Vegetation health was identified from Landsat 8 (OLI) satellite imageries (path/row 139/43; spatial resolution 30m.; date of acquisition 12th january 2016) using NDVI technique of Rouse et al. (1973) (see Equation 1). NDVI of all three phases is calculated for the month of januray. NDVI value indicating vegetation usually varies from 0-1. 1 indicates good quality canopy density. Vegetation presence with greater density resists free spreading of dust from source points (Howard and Cameron, 1998; CPCB, 2009). Land use types surrounding the stone mine and crushing centres is a prime factor of stone dust vulnerability. Presence of human habitat, agricultural land and quality water bodies will up heave the degree of vulnerability (UNESCO, 1998; CPCB, 2009). Size of the stone mine area and size of crusher unit can exert multiplier effects on environment. It is true that if size of these units increase, volume of dust production soars up. Average surface slope is another important factor for draining subsided dusts through overland or channel flow. It is calculated from data received from Suttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) of United States Geological Survey (USGS) following the method of Wentworth (1930). United States Department of Agriculture (USDA, 1986) developed Natural Resources Conservation Service (NRCS) method for estimating runoff and developed equation for it (Eq. 2), where, Q is actual surface runoff in mm, P is rainfall in mm., Ia is 0.4S/0.3S/0.2S/0.1S (season and climatic region specific) initial abstraction (mm) or losses of water before runoff begins by soil and vegetation (such as infiltration, orrainfallinterception by vegetation),0.3S is usually used for wet, 0.1S is used for dry seasons based on the pattern of ppt. and evaporation ratio.S is the potential maximum retention. S can be calculated using Equation 3. For further details of this methods one can consult USDA (1986).

$$NDVI = \frac{\left(IR\,band - R\,band\right)}{\left(IR\,band + R\,band\right)} \qquad \text{(Eq.1)}$$

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{(Eq. 2)}$$

$$S = \frac{25400}{CN} - 254 \qquad \text{(Eq. 3)}$$

Scaling of the data layers

Scaling of data layers within their sub layers according to the magnitude of the sub classes and their influences toward the objective have been done using spatial analyst extension of Arc GIS environment, according to a 10 point scale. Natural break method is assigned for reclass of the individual layers. One example can be illustrated regarding distribution of scale to the parameter. Suppose stone crusher site is one of the parameters for measuring vulnerability of stone dust. This particular parameter is subdivided into 10 sub classes (distance classed) based on the proximity of crusher site. Ten rank is given to the sub class very adjacent to the crusher units and descends toward outside distance considering the fact that area nearer to crushing site will be affected intensively. If any parameter controls such stone dust vulnerability in reverse direction (higher magnitude of sub class value indicates less influence to the vulnerability), 10 rank should be provided to the low sub class value (Khatun and Pal, 2016). Such ranking helps all the data layers to be unidirectional. The influencing direction and scale consideration of the parameters has been shown in the table below (Table 5).

Assignment of Weight to the Parameters

The selected parameters applied in this study have not equal control on stone dust vulnerability. Here, a specific weight is distributed to all parameters following the Analytic Hierarchy Process (AHP) (Saaty, 1980), a semi quantitative method for weight assignment (Palaka and Jai Sankar, 2015). The AHP is a method to derive ratio scales from paired comparisons. The input can be obtained from subjective opinion such as satisfaction, feelings and preference. AHP allows some small inconsistency in judgment because humans are not always consistent (Saaty, 1980). The ratio scales are derived from the principal

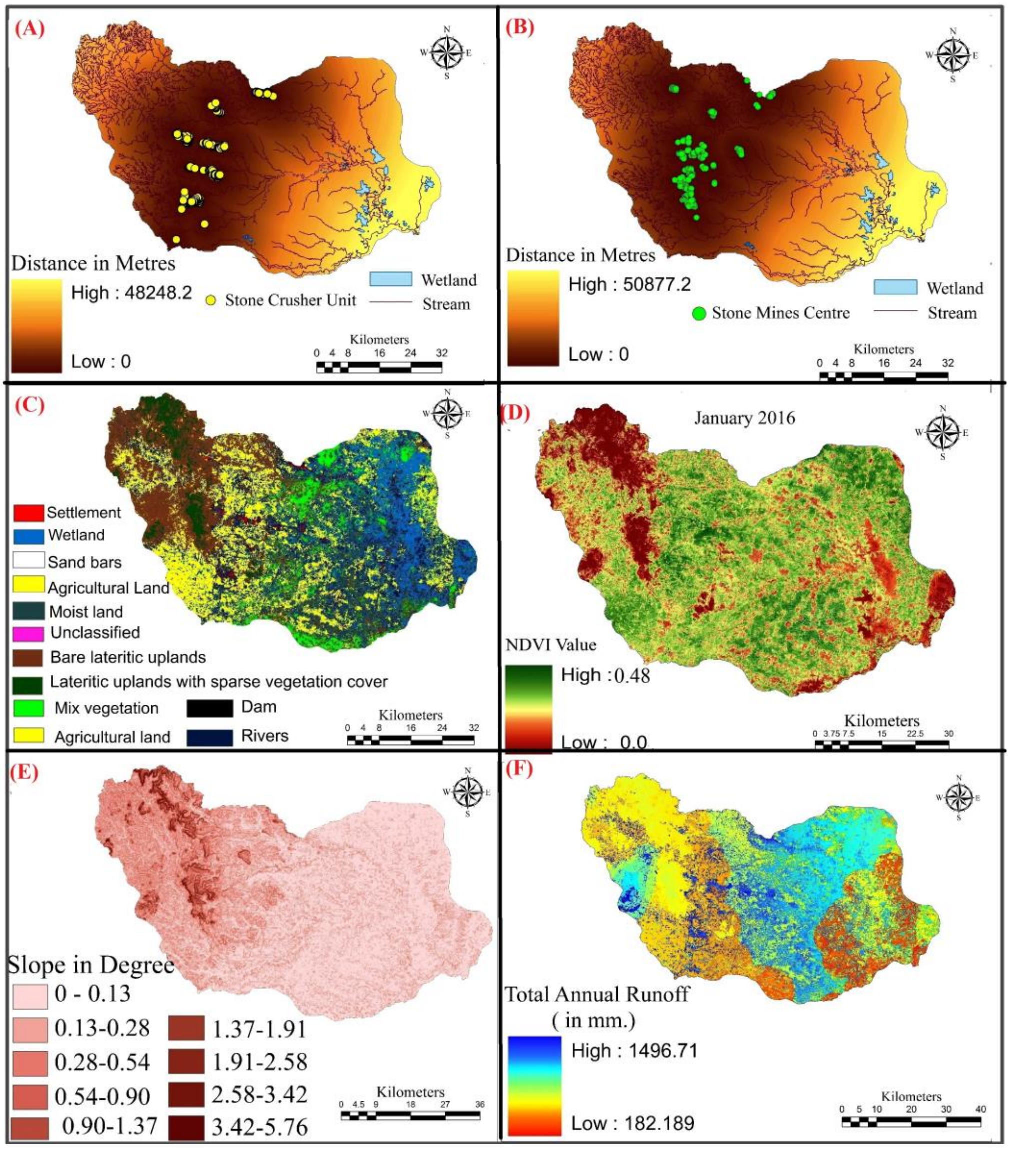

Fig.4 Selected parameters as spatial data layers used for evaluating vulnerability to stone dust (A) Distance map from stone crusher (B) Distance map from stone mines (C) Land use/land cover (LULC) (D) NDVI map (E) Surface slope (F) Surface runoff

Eigen vectors and the consistency index is derived from the principal Eigen value. The relative importance values are determined with Saaty's 1–9 scale (Table 3), where a score of 1 represents equal importance between the two themes, and a score of 9 indicates the extreme importance of one theme compared to the other one (Saaty, 1980**).** A matrix has been done for comparing the classes in order to achieve the priority. A pair wise comparison matrix is derived using Saaty's nine-point importance scale based on thematic layers used for zoning up the soil erosion susceptibility. Because six parameters were applied in the study, the matrix has 6 X 6 cells (Table 4). The diagonal elements of the matrix are always 1 and therefore it only needed to fill up the upper triangular matrix. Based on the judgment value by comparing one thematic layer with other upper triangle matrix is filled. To fill the lower triangular matrix, only reciprocal values of the upper diagonal are calculated. If aij is the element of row i column j of the matrix, then the lower diagonal is filled using this formula: aij = 1/ aji. After the completion of the comparison matrix as weights for the selected parameters have received with 4 % check consistency level.. Here maximum weight is found at stone crushing site (0.408) data layer followed by stone mine site (0.234) (Table 5).

Compositing of Parameters

After assigning weight to the parameters, scaling of the parameters, Weighted Linear Combination (WLC) method of Eastman (2006) was used for compositing all the selected parameters and deriving vulnerability map using spatial analyst tool in ArcGIS environment. This function can be presented using the following formula.

$$WLC= \sum_{j=1}^{n} a_{ij} w_j \quad \text{(Eq. 4)}$$

Where, a_{ij}= i^{th} rank of j^{th} attribute; w_j= weightage of j^{th} attribute.

Table 3 Saaty's 1-9 scale of relative importance (Saaty, 1980)

Scale	1	2	3	4	5	6	7	8	9
Importance	Equal	Weak	Moderate	Moderate	Strong	Strong Plus	Very Strong	Very, Very Strong	Extreme

Table 4 Pair wise comparison matrix for the applied parameters

	Stone Crusher Site	Stone Mines Site	Land Use Land Cover (LULC)	Vegetation Health	Surface Slope	Surface Runoff
Stone Crusher Site	1	2	3	4	5	6
Stone Mines Site	1/2	1	2	3	4	5
Land Use Land Cover (LULC)	1/3	1/2	1	2	3	4
Vegetation Health	1/4	1/3	1/2	1	2	3
Surface Slope	1/5	1/4	1/3	1/2	1	2
Surface Runoff	1/6	1/5	1/4	1/3	1/2	1

Table 5 Modes of ranking of the intra sub class of parameters and distribution of priority based weightage

Parameters	Sub-class	Rank (Highest rank: 10)	Weight of parameters
Stone Crusher Site (Distance from crusher sites)	natural breaks	1-10	0.408
Stone Mines Site (Distance from stone mines centre)	natural breaks	1-10	0.234
Land Use/Land Cover (LULC)	Healthy Vegetation	1	0.144
	Unhealthy Vegetation	2	
	Mix Vegetation	3	
	Lateritic upland	4	
	Moist land	5	
	Water body	6	
	Settlement area	7	
	Bare Land	8	
	Agricultural Field	9	
	Open Field	10	
Vegetation Health	natural breaks	1-10	0.095
Surface Slope	natural breaks	1-10	0.067
Surface Runoff	natural breaks	1-10	0.051

This weighted linear combination has been done using raster calculator tool in Arc GIS environment. Asproth et al. (1999), Jiang and Eastman (2000); Mendes and Motizuki (2001); Araujo and Macedo (2002); Rinner and Malczewski (2002); Malczewski et al. (2003); Makropoulos and Butler (2005) are some of the successful users of WLC mainly for land use suitability.

Based on compositing of the raster layers vulnerability model is generated. Equation 3 represents the WLC equation of the selected six parameters**.** Sdv_{wlc}= Stone dust vulnerability on the basis of weighted linear combination:

Sdv_{wlc}= (Scd*0.408)+ (Smd*0.234) + (Luc*0.144)+ (Ndvi*0.095)+ (Sa*0.067) + (Sro*0.051) – (Eq. 4).

Methods for Measuring Stream Bed Aggradations

From four different vulnerable zones, 81 sample tributaries have been taken into account and the sample distribution in different areal extent of vulnerable zones have been done following the rule of stratified random sampling. In all cases, the entire length of stream is not lying within a single zone. From each stream segment in respective zone, at least 5 cross sections have been carried out using dumpy level for understanding the channel bed aggradations. Most of the rivers in this region is composed with bed rock and stone duct loosely deposited over the bed. Therefore, while doing cross section, cross section over the bed rock and over the deposited dust surface have taken. Gap between two cross section is majorly stone dust in most of the stream segments. Along downstream course from the stone mining and crushing centres, mixing of stone dust and other sediments from other sources has become so complex and difficult to segregate only the volume of stone dust. Zone wise average aggradations have been calculated for understanding the spatial variation.

Methods for Measuring Water Quality

Stratified random sampling is carried out as done earlier from different vulnerable zones. Altogether 81 samples we have collected within 1st to 15th July, 2016. Total dissolved soild (TDS), pH, water colour have measured from laboratory testing of the sample. ATested results have been compared with BIS (10500) Standards of Inland Surface Water (1991) both for measuring drinkability and irrigability.

Methods for Detecting Vegetation Quality Change

According to Nayar (1985), leaf area is the main component of tree canopies and the leaf area index gives quantitative data of the depth of canopies. Forest canopies constitute the bulk of photo synthetically active foliage and biomass in forest ecosystems (Lowman and Wittman, 1996). Therefore, any fluctuation in chlorophyll, carbohydrate or protein content of foliar tissues of dominant tree species of a forest can be treated as disturbances in overall growth of forest biomass. For detecting vegetation quality change, normalized difference vegetation index (NDVI) of Rouse et al. (1973) is used for 1990, 2011 and 2016 from the Landsat satellite imageries of the respective periods. Three images representing different seasons (pre monsoon, post monsoon and winter) are taken into account for showing the average range of NDVI value. Separately, season specific NDVI images are calculated for each season of the respective years and then average is carried out for showing yearly state. For 1990, Landsat TM (resolution: 30m.; Date of acquisition-05th january 1990) and for 2011 and 2016 Landsat OLI (spatial resolution: 30m.; Date of acquisition respectively 11th january 2011and12 th January 2016images have been taken. Usually NDVI value 0-1 indicates vegetation; value nearer to 1 depicts high quality vegetation or good canopy density.

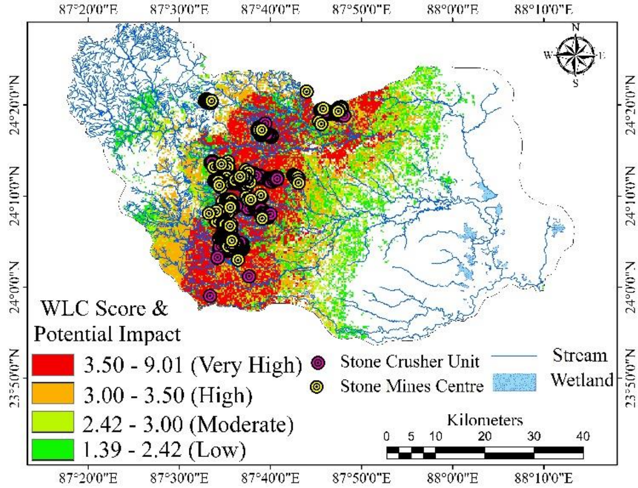

Fig. 5 Vulnerable zones and affected streams

RESULTS AND DISCUSSION

Based on weighted linear combination of the concerned parameters, vulnerability model has been prepared. WLC value ranges from 1.39-9.01 for entire basin. But it is assumed that effects of stone dust do not extend after a certain distance from the emitting units. Therefore, instead of considering entire range of WLC value, only higher range of WLC value is considered (>5) and classified this range into four categories. It is found that out of total basin area altogether 579.64 km^2. (14.93%) belongs to very high vulnerable categories and the high vulnerable category covers 09.06 of the catchment area. The first zone is highly affected by stone dust. Streams of this region receive huge volume of dust both in form of aerosols and dust with drainage. Number and length of the rivers under different vulnerable zones have been counted and measured thereafter. From this approach it is found that 581 river channels are situated in the very highly stone dust vulnerable zones carrying 713km length, 331river channel segments are found in the highly vulnerable zone with the length of 496km; 198river channels (323km) are situated on the moderately vulnerable zone and 113 stream channels covering a length 228 km is found in the low vulnerable zone.

Table 6 Potential impact classes of stone dust and their respective area, stream association

Potential Impact	Pixel Count	Area (km^2)	Area (%)	No. of Streams	Stream Length (km)
3.50-9.01	8240	579.64	14.93	581	713
3.00-3.50	4998	351.77	09.06	331	496
2.42-3.00	4732	332.74	08.57	198	323
1.39-2.42	5854	411.95	10.61	113	228

Impacts of Stone Dusts on Channel Bed Aggradations and Sediment Load

This field measurement in the one hand helps a lot to understand the impacts of stone dust and on the other hand it also introspects that how far the vulnerability model is valid. It is assumed that if rate of channel bed aggradations is very high and water quality is transformed substantially validity of the model inferred. For successful completion of this work during field study 81 tributaries have been selected on the basis of stratified random sampling

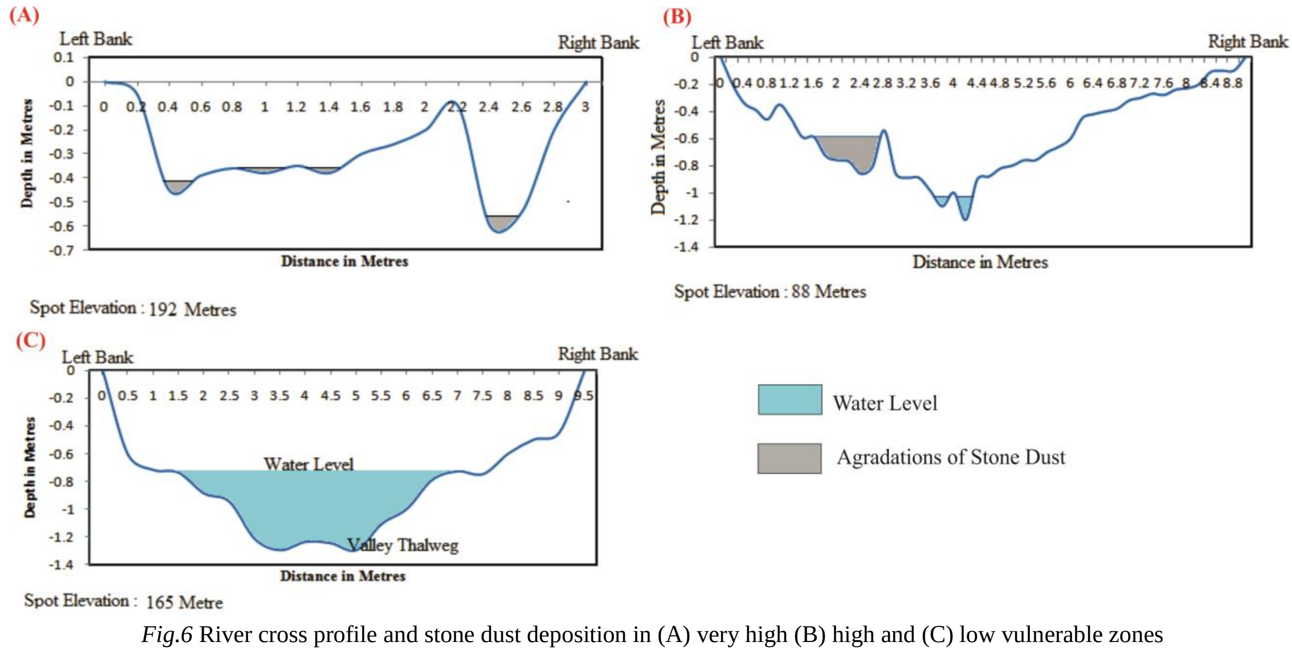

Fig.6 River cross profile and stone dust deposition in (A) very high (B) high and (C) low vulnerable zones

from different vulnerability classes. Twenty tributaries have been selected from very high vulnerable zone, 25 from highly, 20 from moderately and 16 from lowly vulnerable stone dust affected zones. From each stream at least 5 cross sections have been drawn to know the average situation of stream bed aggradations due to dust. In the very high vulnerable zone, depth of dust deposition ranges from 0.09 to 0.20 metre and average depth of dust deposition 0.125m Range of depth of dust deposition on river bed in the highly vulnerable zone is 0.09 to 0.19 metre with an average of 0.096m. Average depth of dust deposition on rivers within moderately and low vulnerable zones is 0.083 and 0.061 metres respectively (Table 8). It is to be mentioned that channel segments away from crushing unit truly show only dust. But it is clear that dust decreased away from the emitting units.

Impacts on Stream Load Characters

Most of the streams are over loaded with huge amount of dust especially those are located at very proximate region of mining and stone crushing centres. Due to such conditions, thick dust is deposited over the channel bed. During monsoon time carrying capacity of the streams increases, thus they carry the loose materials. Suspended load increases due to stone dust during early monsoon (June and July) because deposited dusts over surface drains to the river during initial period of over land flow and admixture with tributaries. Suspended and bed load varies directly downstream from stone mine and crushing units. Average suspended load is 15762g/m^{3}during monsoon time in the very high vulnerable zone, followed by 12456 g/m^3 in the highly vulnerable zone. In the low vulnerable zone, it is recorded that average load volume is 6782g/m^3. which is low enough and in this area maximum proportion of it is contributed by eroded soil not by the dust. This information also supports the vulnerability models. Studies also recorded that this volume of load decreases downstream with varying rate depending on the dust product ability of the mining and crushing centres, discharge volume of the rivers where these are in fluxed, slope of the region, nature of wind. Here it should be mentioned that effect of this dusts exerts down slope. So the vulnerability zones indicated by the model do not exhibits uniform results even within a single vulnerability zone. In the upslope part around a mining or crushing centre is less affected because stream flow does not carry such dust in this situation. Airborne dust mainly affects the upslope regions. Most of the cases load is almost 3-7 times lesser than down slope regions.

Impact on Water Quality

PH value as an indicator of water quality specifically neutrality of water reveals that in the very high vulnerable zone pH value of river water is above 9. Huge influx of stone dust is principally responsible for such transformed water quality, in the highly vulnerable zone, pH value is 8-8.5 (Table7). But in low vulnerable zones, pH value of the river water is 8.2 and it is near to normal. From this analysis it can be stated that both channel bed aggradations and water quality status is beyond normal situation in the very high and high vulnerable zones and therefore, this model can be treated as valid.

Total dissolved solid (TDS) is another water quality parameter altered after contamination by dusts. In the highly vulnerable zones, TDS value with an average of 2487mg/l. This value is high very adjacent stream segment to stone mine and crusher centres. This high value is beyond the permissible limit of both drinking (500mg/l) and irrigation (2250mg/l) as per BIS (10500) Standards of Inland Surface Water (1991). In the less vulnerable zone, this TDS value (1256mg/l) crossed permissible limit for drinkability but it is irrigable.

Water colour appeared as grey of black drain water according to degree of vulnerability. Even the animals do not drink this water because of huge suspended particulate matters in water. Repetitive supply of water to the agricultural field can heap up huge volume of dust to the field and can alter the basis texture and composition of the soil. Aquatic environment specifically fishing is strongly affected in these segments. Although these stream segments were not highly worth for fish availability and fishing, but during monsoon season, fishing was practiced. But due to alteration of such physico-chemical parameters, such ambient environment has become altered.

Impacts on Vegetation Quality

The middle catchment of the Dwarka river basin is highly affected due to the stone crushing and mining dust. Vegetation coverage has been decreased rapidly due to the construction of a new mine and crushing sites.

The effect of dust pollution on plants is observed in this study as it has reduced the quality of vegetation in study area. The average NDVI value of 1990 was 0.470, whilst in 2011 it dropped to 0.54 and finally it is reduced to 0.48 in 2016 (Fig. 7A, 7B and 7C). This decline of NDVI since 1990 to 2016 focuses on degradation of forest quality. Most of the forest in this area is dominated by *Shorea robusta* and *Madhuca indica*, two broad leaf vegetation species and these are highly sensitive to stone dust.

Table 7 Sample tributaries and their characteristics in different vulnerable zones

Vulnerable class	Selected tributaries	Range of depth of dust deposition on river bed(m)	Average depth (m)	pH	Avg. TDS (mg/1)
Very high	10	0.08-0.22	0.128	9	2487
High	6	0.09-0.16	0.092	8-8.5	2321
Moderately	5	0.03-0.08	0.074	8.2	(1543
Less Vulnerable	7	0.001-0.08	0.058	8.2	1256

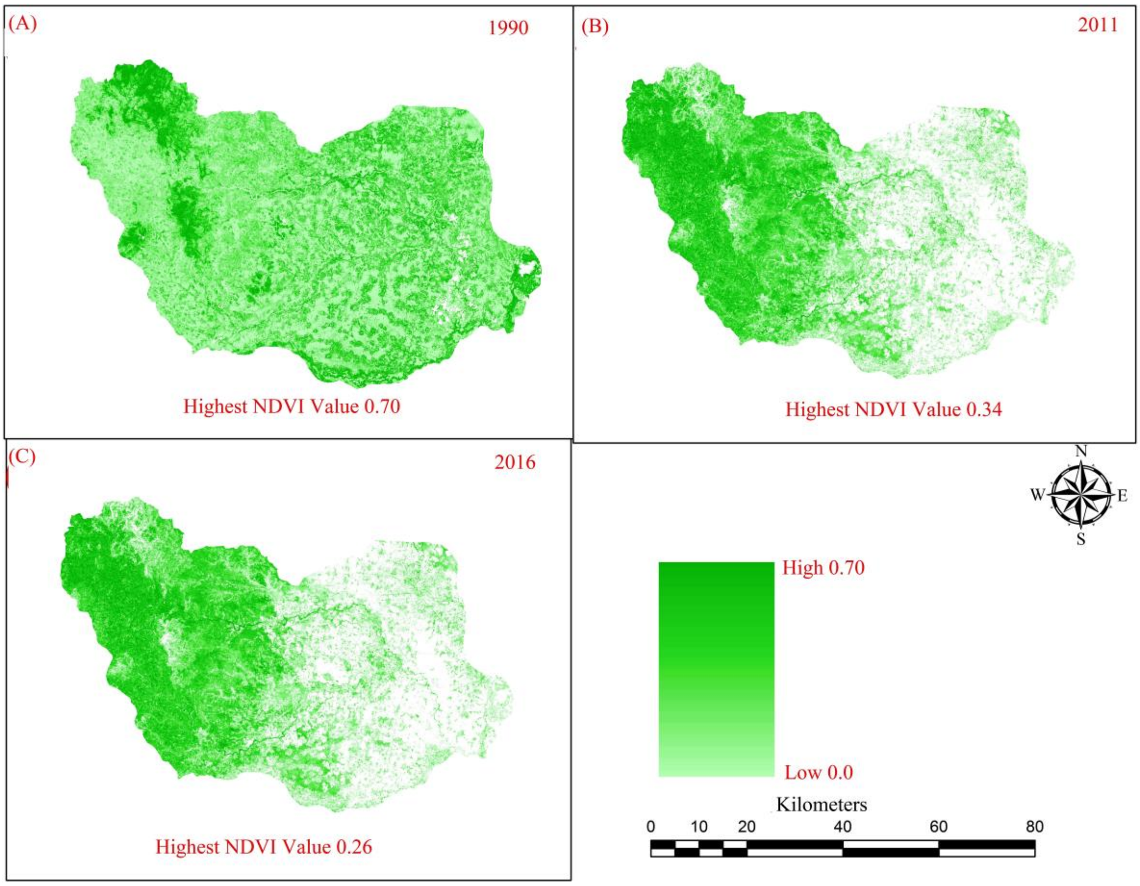

Fig.7 Vegetation Health (using NDVI) (A)1990 (B) 2011 (C) 2016

Saha and Padhy (2011) documented that high rate of dust deposition in the leaves decelerates rate of photosynthesis and food availability within the plant body and it causes weakening of vegetation health. During non monsoon time effects of dust becomes more prominent because of thick dust coating over leaves. In this time due to lack of rainfall, this thick dust coat becomes thicker. Apart from dust effects, continuous emission of hot smoke from crushing unit in the vegetation contiguous area causes partial plant celldamage. Apart from qualitative damage of vegetation, due to installation of stone mines and crushing unit within forest area it is also rapidly expunged.

CONCLUSIONS

From the above analysis, it is found that out of the total above mentioned basin area, a 14.93% area is very highly potential for dust vulnerability. Within this zone, 581 numbers of streams having a length of 713 km are found to be highly affected. Channel bed aggradations, increasing sediment load within water, degradation of water quality beyond permissible limits are some evident effects of dust emissions and spreading. Continuous deposition of such stone dust over vegetation causes qualitative degradation of vegetation as indicated by declining of NDVI values between 1990, 2011 and 2016. Due to mining activities, removal of prestigious forest has been rapidly degrading. Certainly, this fact is not solely responsible for deteriorating forest quality. Coarse grain lateritite soil (Chokraborty, 1970), and mass scale soil erosion (6-8t/ha/y) are another controlling factors for tree felling and degradation of vegetation (Jha and Kapat, 2009; Pal, 2016). The formation of dust layer on plant body damage plant tissue which reduces rate of photosynthesis. Dust particles emitted from stone crushing activity reduces the pigmentation in plant leaves (Saha and Padhy, 2011). Dust fall on open land reduces its fertility of soil (CPCB, 2009). Deposition of dust particles exerts stresses on plant which reduces productivity of plants.

Along with deterioration of forest environment, degradation of aquatic habitat is also vital issue. Fishes and other species will be in stress state if high level dust contamination happens and turbidity level raises. Fish prefers to avoid hypoxic waters and favours more highly oxygenated waters (Breitburg, 2000). But such hypo-oxygenated condition happened in the extra admixing of dusts. Rombough (1988) explained different species of fishes have different ability to tolerate low oxygen concentrations, depending on the natural change of dissolve oxygen concentration that fishes encounter in their preferred habitat. Catfishes tolerate wide range of oxygen variation but can't survive if oxygen comes 59% below ambient limit (Randolph and Clemenens, 1976). Opinion taken from local fishermen who were once engaged with fishing activities emphatically opined that river character has been changed and fish is become almost rare in this altered condition. Influx of dusts automatically enhances turbidity level in water. Turbidity impinges on both the density and metabolism of the plant populations present in stream channels (Wallen, 1951; Aldridge et al., 1987). A study by Clavel and Bouchard (1980) showed that the absorption of light energy by water is proportional to the concentration of suspended sediment. High level of turbidity in river segments adjacent to the stone mine and crushing centres influences first tropic level in same manner. Cordone and Kelley (1961) and Decker et al. (1999) etc. found out the impact of channel morphology, sand mining, dredging on water quality specifically, turbidity, TDS, temperature etc. and all these again exert negative impact on aquatic habitat. Pal et al. (2016) also reported the huge reduction of fish availability in Chandrabhaga river basin after inflowing huge particulate matter from plant. For energizing growing urban sector through supplying building materials, this sector is getting plenty of attentions to the concerned authorities and loss of forest issues is quite sacrificed. Such situation is also explored in different parts of the country with variable intensities. Pal et al. (2016) identified the effect of fly ash on Chandrabhaga river of Chotonagpur plateau fringe area. They identified that this river is highly affected by thick (>0.5m) dust deposition and as result simplification of unique topographic features and ecological deterioration. Dinda (2014) worked on Rupnarayan river and reported that due to aggradations of channel bed through fly ash fish influx is deduced significantly. Saha and Padhy (2011) highlighted how fly ash affected the growth of vegetation and vegetation quality of the Rarh tract of Eastern India. They clearly stated that due to such effect green pigment contents in forest leaves have reduced significantly. This similar condition is found in the present study area also. In long term environmental agenda, such trend is not good at all. In this paper, attention is paid for a few issues only as mentioned above but apart from all these, human health hazards is also another major emerging problem in this area. The labourers working in this sector are highly exposed to respiratory diseases. During field investigation, opinion of the labourers has been taken into account regarding their health hazard. Dust generated from mining and crushing unit should be used for filling of abandoned mines, fertilizer preparation, road and rail way constructions. But for a successful project, it should be kept in mind that sectoral coordination in this regard is highly necessary.

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