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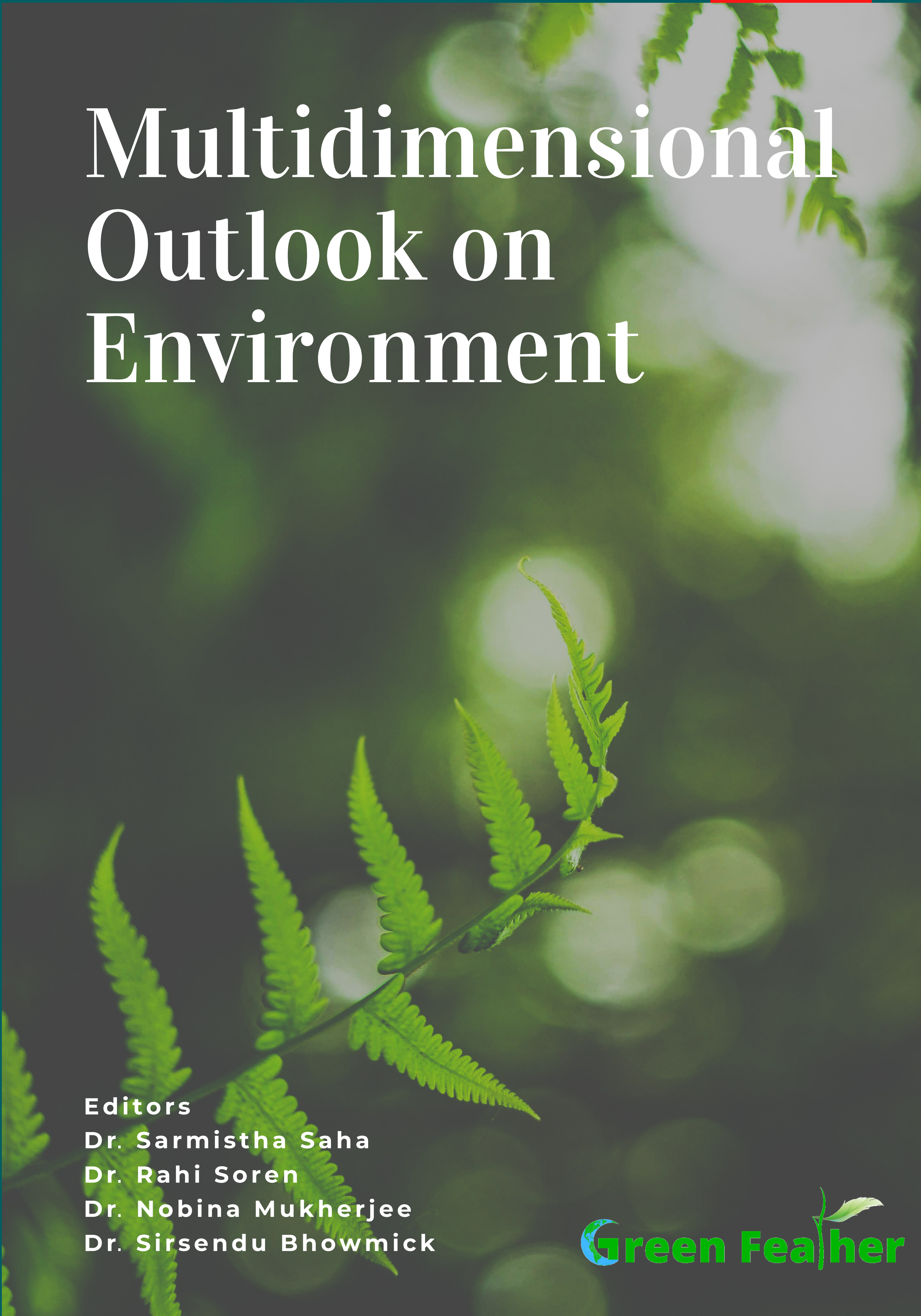

# Multidimensional Outlook on Environment


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# Environmental Impact Assessment through Integrated Approaches in a Coal Mining Area: A Case Study of Jharia coalfield, India

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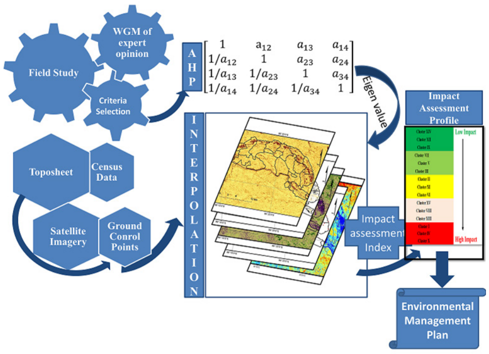
## GRAFICAL ABSTRACT

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## ABSTRACT

The impact of opencast mining on the environment and public health is critical in the present scenario. Therefore, impact assessment is of utmost importance to safeguard these elements in the mining area's vicinity. However, the Environmental Impact Assessment (EIA) of a coal-mining project is challenging because the coalfield covers a vast area of land. However, many organizations take environmental clearance (EC) from the regulatory authorities for a section of the coalfield, resulting in duplicity in baseline data, erroneous results, and ineffective management plan. Granting EC for individual mines also hinders the total extraction of coal and queue up many reports that delays the starting of projects. To evade these issues, the present work develops an environmental model for impact assessment using an integrated approach of Geographical Information System (GIS) and Analytical Hierarchy Process (AHP). Satellite imagery was used to develop an impact assessment score through the thematic maps of the impacted parameters. Further, AHP was used for the calculation of eigen values based on the weighted geometric mean value of the relative score of the parameters assured by the experts. Finally, the impact assessment model designed through eigen value and scores was used to creates an impact assessment profile of the mining area. This study demonstrates the usefulness of interdisciplinary approaches for assessing a large mining area under time and manpower constrain.

## 1. Introduction

The global demand of coal for energy production in the industrial and domestic sectors has grown up manifold in the present era (1). Therefore, coal mining is one of the major projects taken by various private and government organizations to export coal to different countries. The mining is carried out by two techniques, i.e., opencast and underground mining (2). Preference of opencast mining is due to its large production capacity, less capital investment, assured production, and better safety (3). Underground mining is undertaken where opencast mining is not conceivable due to the presence of unfavourable surface features. Even though the preference for opencast over underground mining is due to economic advantages, but it has an inevitable impact on the environment and public health (4, 5).

Land, water, vegetation, and public health are considered as major parameters that are mainly affected by opencast activities. The mining procedure starts with stripping of complete vegetation that alters the land's physical, chemical, and biological characteristics. It also creates uneven topography such as dumping of overburden, open voids, steep pit slopes prone to erosion, etc. Even after completion of mining, these land structures are difficult to reclaim back to their indigenous quality. It also contaminates the aquatic environment along with flora and fauna of the surroundings (6, 7, 8, 9, 10). Although it has upgraded the socio-economic status, but simultaneously it has deteriorated the physical and mental health of the public settled in the vicinity. Respiratory problems, water-borne diseases, even some catastrophic diseases like cancer occur because of mining activities (11, 12, 13). Therefore, it is required to assess the impact of mining activity on the environment and public.

Remote Sensing (RS) and Geographical Information System (GIS) has proved as an efficient technique to evaluate a large mining area (14, 15, 16, 17, 18). Impact assessment through RS & GIS can be more intensified by assimilating an improved qualitative method of Analytical Hierarchy Process (AHP) (19, 20, 21). Several researchers use AHP proposed by Thomas L. Saaty (22) as a decision-supporting mathematical tool to solve complex multi-criteria problems (23, 24, 25).

In this study Jharia Coalfield (JCF), a well-known storage house of India's prime coking coal, was selected as the study area. This coalfield is endowed with thick seams at shallow depths amenable to opencast mining (26). A decade ago, coal was extracted unexpectedly for economic benefit without considering the impact on the environment. After nationalization, it was divided into many geographical mining clusters in a proper scientific way and owned by public and private sector mining companies. However, mining for decades has caused an inevitable change in the environment and public health. Therefore, assessment of impact due to mining activities and proper planning is required to safeguard the environment and public health.

In light to this, various studies has been carried out to assess the impact of mining on environment in JCF (27, 28, 29). However, very limited study is carried out to assess the impact on individual clusters of JCF. Even, the comparisions of the clusters with respect to the environmental degradation is yet not reported. Therefore, the present study aims to model an impact assessment profile in JCF using the integrated technique of RS-GIS and AHP. This will help the planners to implement a better management plan.

## 2. Material and Methods

*2.1 Description of Study Area*

Jharia Coalfield (JCF), located in eastern India, geographically bounded by latitude 23°39' - 23°50' N and longitude 86°05' - 86°30' E, was selected as the study area. The total reserve of coking coal in this coalfield extends up to 450 $Km^2$. It was formed in the Gondwana period of the Permian age. Barakar formation of the Upper Permian age formed a sickle-shaped outline in the northern part and the Raniganj formation of Lower Permian age in the southern part holds the major coal bearing formation (30, 31). The major production of the coal and the mining activities are found in the Barakar formation. The coalfield is subjected to intensive opencast mining activities because of the easy availability of coal at shallow depths in thick seams. This coalfield was divided into 15 geographical clusters (I-XV) according to the flow of river and its tributaries, geology, coal seam orientation, and quality of coal in the study area (Fig.1) as: Barora: Cluster: I, Block-II : Cluster-II, Govindpur : Cluster-III, Katra: Clusteter IV, Sijua: Cluster-V; Kusunda: Cluster-VI, Pootkee Balihari: Cluster-VII, Bastacola: Cluster-VIII, Lodna: Cluster-IX, Eastern Jharia: Cluster: X, W.Jharia- Moonidih Cluster-XI, W. Jharia –Mohuda: Cluster-XII, TISCO_ Sijua: Cluster XIII, TISCO Block: Cluster-XIV, IISCO Block: Cluster-XV.

*2.2 Data*

Resourcesat-2 LISS IV (MX70) and IRS P5 Cartosat- 1 Digital elevation model (Carto DEM) satellite imagery were acquired as primary data. Topographic map of sheet no 73 I/1, I/2, I/5, I/6 (1:50,000 scale) published in 1973-74 by Survey of India (S.O.I.), mining plans procured from mining office and census data of 2011 published by Government of India were used as secondary data (32). The accuracy of results were validated through field survey.

*2.3 Data Analysis*

Data analysis by integrated

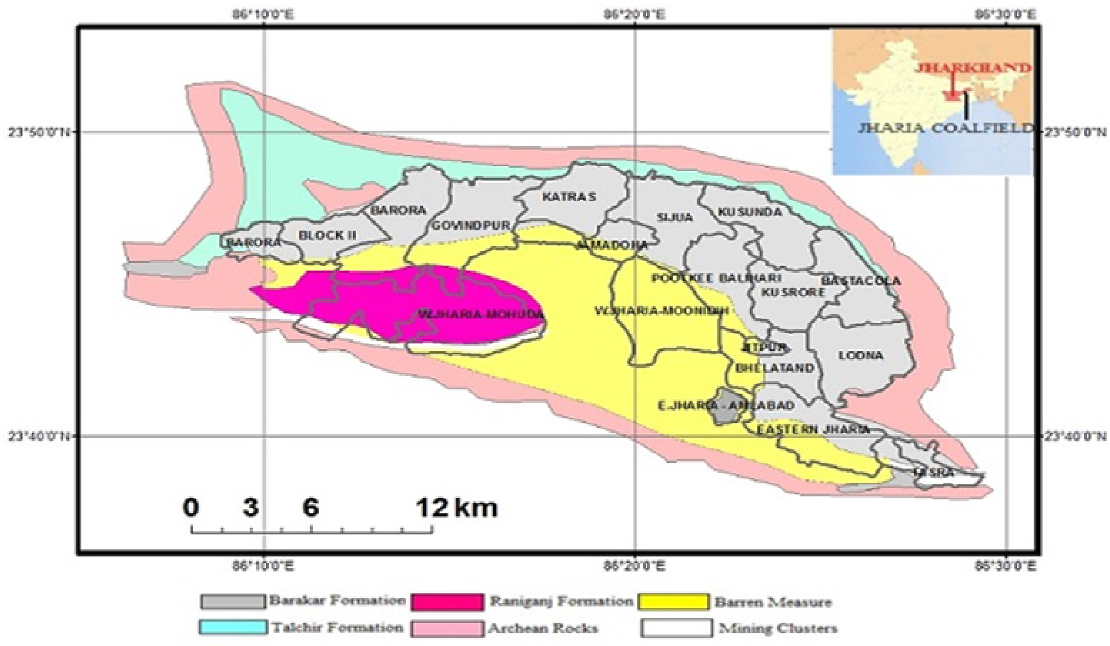


Fig.1:Location and geological map showing all mining clusters of the study area

approaches of GIS and AHP for impact assessment was divided into four main phases: (1) generation of thematic layers, (2) determination of impact assessment score based on thematic layer, (3) modeling of impact assessment index integrating AHP with the impact assessment score and (4) development of impact assessment profile.

### *2.4 Thematic Layer Generation*

This study deals with the land, water, vegetation, and population impacted due to opencast mining activities. Thematic map of slope and opencast mining area represents land, while vegetation cover and water spread represent vegetation and water resource, respectively. The impact on public health was assessed through the settlement map. The acquired data and imagery were processed using ArcGIS10 and Erdas Imagine 10 software.

The slope is expressed as the change in elevation over a certain distance. The values generated through the advanced GIS tool were represented in degree.

Opencast mining areas appear dark in the near-infrared (NIR) as well as in the visible band in the LISS IV image. Further, verification was done in the panchromatic image, where coal seams appear as black linear-curvilinear topographies, along with the general strike of the rocks in the vicinity. In false-color composite band 4, band 3, band 2 (FCC 432), the opencast mining areas appear black. However, coal dumps in the area also appear as black patches. With the comparison of all the criteria, the thematic map of the opencast mining area was prepared. Similarly, the overburden (OB) dump is small and associated with the coal mining areas, which appear as whitish-grey in FCC 432, and moderately bright in the visible band.

Qualitative analysis for vegetation cover of the entire area was carried out by the Normalized Difference Vegetation Index (NDVI) which uses near infra-red (NIR) and red bands to distinguish the differences between vegetation and non-vegetation cover as given in Eq.1 (33):

$$NDVI = ( NIR - Red ) / ( NIR + Red) \ldots \quad (1)$$

The ratio of NDVI varies from −1 to +1, where, values closer to +1 represents green vegetation and values closer to -1 are maily due to the rocks and bare soil (14, 34, 35). On a panchromatic image, the vegetated areas appear as bright tone. The NDVI image was further color enhanced for better visualization.

The water spread area was calculated using normalized difference water index (NDWI), which is very much similar to NDVI. The equation is reversed, and the green band is used instead of the red to enhance the water cover as expressed in Eq.2 (33):

$$NDWI= (Green-NIR)/(Green +NIR)\ldots.. \quad (2)$$

The equation developed for calculating NDWI have a positive value for water bodies while zero or negative values for non-water features (16, 36).

The thematic layer of the settlement was developed using the census data of 2011 published by the Government of India. In the base map of JCF, villages and urban clusters obtained from field surveys were delineated using the GIS tool.

### *2.5 Impact Assessment Score and Impact Assessment Model*

Impact Assessment Score (IAS) of 1 to 15 was assigned to the clusters based on the thematic maps (20). The area where the slope is less indicates that the impact of mining activities on land was limited. Therefore, the score for cluster was assigned proportional to the respective slope value of the region. Scoring of clusters for water and vegetation was based on the positive value of NDWI and NDVI (16, 36, 37). The mining cluster that has high vegetation and water cover implies that the impact of mining on these resources are high. The vegetations will be removed for excavation of the minerals. The cluster having high population density has high impact due to mining activities. Therefore, the ranking of the cluster for this parameter is directly proportional.

Further, AHP was used for impact assessment model. The first step includes the pairwise comparision and relative scoring of the parameters. The questionnaire survey of experts such as environmental engineers, scientists, researchers, health and safety experts working in mine was done to assign a relative comparision score of the parameters in a scale of 1- 10. The format of the questionnaire survey is provided in the Annexure 1. The parameters were scored as 1 if it is being considered as least impacted and 10 if it is most impacted due to the mining activies. Further, the mean of the scores were calculated through weighted geometric mean (WGM), Eq.3, where weitage was assigned as per the experience of the experts who have taken part in the questionnaire survey. These geometric mean is used for calculation of pairwise matrix and consequently the eigen values (38, 39, 40, 41).

$$WGM = \left(\sum_{i=1}^{n} x_i w_i\right)^{1/\sum_{i=1}^{n} wi} \quad \text{................(3)}$$

Where, $x_i$ is the relative score assigned by the experts for i=1,2,......n parameters and $w_i$ is the corresponding weight of the experts.

Further, a consistency check was done to ensure the consistency of original scores given by the experts, which are to be used for obtaining the final result. Consistency analysis proposed by Thomas Saaty (22) includes consistency index (CI) and consistency ratio (CR) as Eq.4 & Eq.5

$$CI=(\lambda_{max} - n)/(n-1) \quad \text{..............................(4)}$$

$$CR=CI/RI \quad \text{.......................................(5)}$$

Where $\lambda_{max}$ is the largest eigen value of all parameters that have been considered, n represents the number of parameters and RI is a random index formulated by Thomas Saaty (22) (23, 42).

Final equation is modeled from the eigen values derived from the normalized pairwise comparison matrix which in turn was generated from pairwise matrix. Eq.6 shows the equation for finding impact assessment due to opencast mining activities based on the parameter studied by the integrated approach of GIS and AHP .

$$IAI=(IAS_{Slope} \times EV_{Land})+(IAS_{Opencast\ mining\ area} \times EV_{Land}) + (IAS_{Vegetation} \times EV_{Vegetation}) + (IAS_{Population} \times EV_{Population}) + (IAS_{Water} \times EV_{Water}) \quad \text{.....................................................(6)}$$

Where IAI represents Impact Assessment Index, $IAS_{Slope}$, $IAS_{Opencast\ mining\ area}$, $IAS_{Vegetation}$, $IAS_{Population}$, $IAS_{Water}$ are Impact assessment score of slope, opencast mining area, vegetation, population and water resapectively. $EV_{Land}$, $EV_{Vegetation}$, $EV_{Population}$, $EV_{Water}$ signifies eigen value of land, vegetation, population and water resapectively.

## 3. Result and Discussion

Thematic maps of the slope, opencast mining area, vegetation, settlement, and water were processed to find the impact of opencast mining activities in the vicinity. These maps illustrate the features present in the study area. The northern portion of the study area shows significantly high

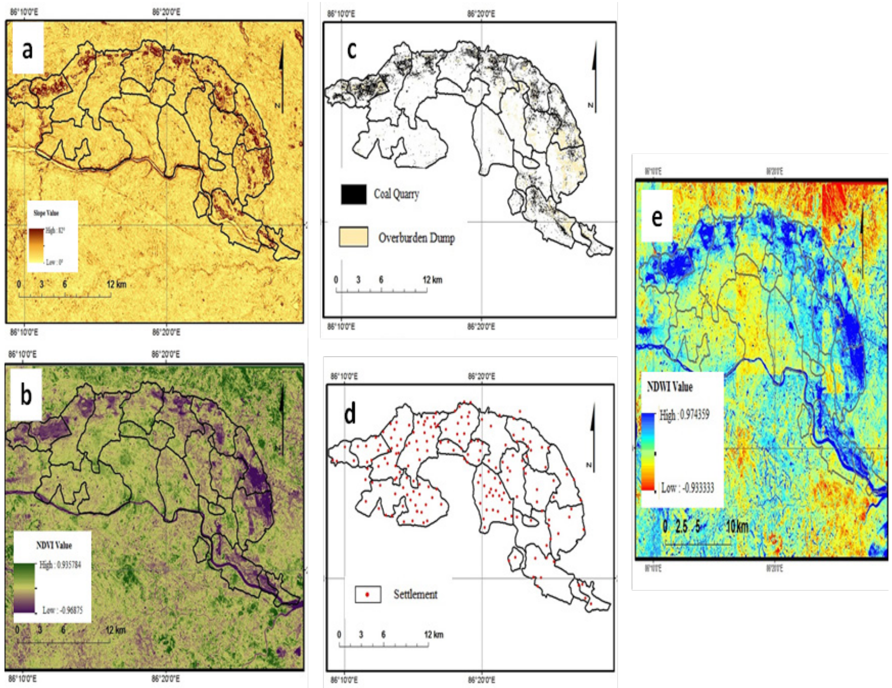


Fig.2: Thematic maps of the study area representing (a) slope (b) vegetation cover (c) opencast mining areas (d) settlement map (e) water cover

slope and opencast regions with respect to other parts (Fig.2a,c). Inversely this region lacks vegetation cover (Fig.2b). The area is highly populated with a total of 158 villages or urban clusters well spread across the area (Fig.2d). Jharia coalfield is blessed with excellent water resource (Fig.2e) with Damodar river demarcating the southern boundary of the coalfield and its tributaries flowing in different clusters. Many ponds and mine water sumps also contribute to the water resource of the area.

**Table 1:Impact Assessment Scores (IAS) of the clusters derived from the thematic maps**

| Clus-ters | Slope | OC Area | Vegeta-tion | Popu-lation | Water |
|---|---|---|---|---|---|
| I | 15 | 14 | 15 | 7 | 1 |
| II | 3 | 15 | 2 | 5 | 9 |
| III | 6 | 8 | 9 | 6 | 4 |
| IV | 9 | 9 | 13 | 14 | 14 |
| V | 4 | 11 | 4 | 10 | 3 |
| VI | 13 | 5 | 14 | 9 | 11 |
| XII | 5 | 2 | 11 | 2 | 6 |
| XI | 8 | 4 | 8 | 3 | 13 |
| VI | 10 | 10 | 10 | 4 | 10 |
| VII | 7 | 3 | 5 | 8 | 8 |
| VIII | 11 | 13 | 6 | 12 | 7 |
| IX | 1 | 7 | 1 | 13 | 5 |
| X | 14 | 12 | 12 | 11 | 12 |
| XIV | 2 | 6 | 3 | 1 | 2 |
| XV | 12 | 1 | 7 | 15 | 15 |

The scores derived from the thematic maps are tabulated in Table 1. Further, the weighed geometric mean were obtained through the relative scoring of the parameters by the experts (Table 2) through questioner survey to derive the eigen values/ weighatage. Here in the study the weightage of the experts to obtain the WGM were 0.06, 0.05, 0.04 and 0.01. These weighatage were established based on the experience and knowledge of the experts in this area.

**Table 2:Weighted geometric mean (WGM) based on scoring by experts**

| Parameter | W.G.M. |
|---|---|
| Land | 7.24 |
| Water | 5.95 |
| Population | 6.01 |
| Vegetation | 5.87 |

**Table 3:Pairwise Matrix for individual features**

| | Land | Population | Water | Vegetation |
|---|---|---|---|---|
| Land | 1 | 1.205 | 1.217 | 1.233 |
| Population | 0.830 | 1 | 1.010 | 1.024 |
| Water | 0.822 | 0.990 | 1 | 1.014 |
| Vegetation | 0.811 | 0.977 | 0.987 | 1 |
| | 3.463 | 4.171 | 4.213 | 4.271 |

**Table 4:Normalized Matrix for individual features**

| | Land | Population | Water | Vegetation | |
|---|---|---|---|---|---|
| Land | 0.289 | 0.289 | 0.289 | 0.289 | 1.155 |
| Population | 0.240 | 0.240 | 0.240 | 0.240 | 0.959 |
| Water | 0.237 | 0.237 | 0.237 | 0.237 | 0.949 |
| Vegetation | 0.234 | 0.234 | 0.234 | 0.234 | 0.937 |
| | 1 | 1 | 1 | 1 | 4 |

These mean values of the parameters were utilized in the pairwise matrix (Table 3) to attain the normalized pairwise matrix (Table 4). The normalization of the matrix is done on the basis of sum based normalization as proposed by Saaty (22) (43, 44). Eigen values (Table 5) were calculated using the normalized pairwise matrix. The consistency analysis of the eigen values were done for n=4 and where RI was 0.90. The value of CR obtained was $1.8 \times 10^{-3}$, which is far less than 0.1. It confirms the statistical acceptance of the modelled equation.

The final ranking was obtained by weighted aggregation of all the criteria through the Impact Assessment formulae derived in the present study.

**Table 5:Eigen Value obtained from normalized pairwise matrix.**

| Parameter | Eigen Value |
|---|---|
| Land | 0.289 |
| Population | 0.240 |
| Water | 0.237 |
| Vegetation | 0.234 |

The result has been field validated and it was found that cluster X, I and IV have high impact of opencast mining activities as illustrated in impact assessment profile (Fig.3). Cluster X have highly inclined seams and in order to maintain coal production, stripping of coal layer is high. Therefore, degrading the land structure with respective to other clusters is more. The cluster is also enriched with good vegetation; rivulet and high population, making the place most sensitive to mining activities. Cluster I and IV have high population density along with a number of opencast mines in the vicinity, demarcating the clusters as high impact zone. Cluster XIV, XII, VII follows mostly underground

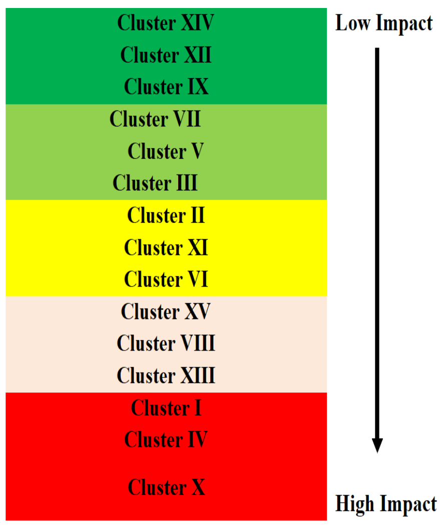


Fig.3: Impact Assessment Profile of the study area

mining methods as the coal seams are oriented in deeper horizon.

The presence of less habitat in these clusters also clubs to the reason for the lesser impact. Field validation reveals that the mining has already devastated cluster IX many decades ago and will not affect much further. The area is bereft of vegetation and water bodies and has less settlement of population due to the presence of mining companies. Therefore, IX cluster apparently seems to have less impact due to mining. V, III, II, XI, VI, XV, VIII, XIII clusters have an intermediate effect of mining activities on its environment because of the varying impact on land, population, vegetation and water.

## 4. Conclusions

In this study, environmental impact assessment due to opencast mining was investigated. The results clearly indicate the importance of using RS and GIS for evaluating a large area like Jharia Coalfield. The integration of AHP with GIS assists in determining the impact of mining in the nrarby areas. The impact assessment model aids in framing the impact assessment profile of the study area, which in turn helps to identify the highly impacted clusters. This profile in the future will guide in recommending a proper environmental management plan to combat the impact of opencast mining activities.

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## Declaration of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Annexure 1:Format for the questioner survey from the experts in the field of mining

**`QUESTIONARIE FORM FOR THE EXPERTS**

The purpose of this survey was to obtain the opinion or view from the experts regarding the environmental parameters that are impacted due to opencast mining activity.

| | |
|---|---|
| **Name** | |
| **Designation** | |
| **Address** | |

Scoring should be done on the scale of 1-10.

**1 - being least impacted due to mining activity.

**10 - being most impacted due to mining activity.

| Sl No. | Parameters | Score |
|---|---|---|
| 1 | Land | |
| 2 | Water | |
| 3 | Population | |
| 4 | Vegetation | |

Thank you for your cooperation and feedback.