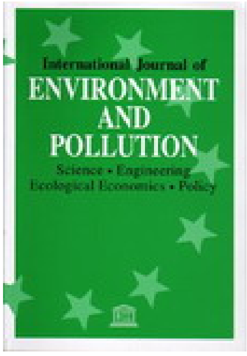

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Environmental sustainability (ES): a case study of Noamundi area in Jharkhand, India

Surajit Panda, Manish Kumar Jain, Krishnendu Banerjee, A.T. Jeyaseelan

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Environmental sustainability (ES): a case study of Noamundi area in Jharkhand, India

Surajit Panda*, Manish Kumar Jain and Krishnendu Banerjee

Department of Environmental Science and Engineering,
Indian Institute of Technology (ISM), Dhanbad,
Dhanbad – 826004, Jharkhand, India
Email: surajit.rsgis@gmail.com
Email: manishjkm@gmail.com
Email: rsgis.pintu@gmail.com
*Corresponding author

A.T. Jeyaseelan

Board of Studies for Water Resources,
Institute of Science & Technology,
JNTUH, Kukatpally,
Hyderabad – 500085, India
Email: jeyaseelant@yahoo.com

Abstract: Environmental issues such as mine-water drainage, land resources and socio-environment are threats to whole biosphere. An overview of environmental sustainability (ES) processes was analysed using weight-overlay with sub-surface/ground water quality (SWQ and GWQ), slope, land use/land cover (LULC), land surface temperature (LST), human comfort index (HCI) and crowdedness data. SWQ was between 06.43 to 92.94, LST was 27.8–40°C, and HCI was (79–103: uncomfortable) in study area. Degraded GWQ was observed near Bahada, Kothghar while better GWQ was seen near Noamundi, Mahudi, Meralgara village. Mines and rocky surfaces displayed very low sustainability with high LST, steep-slope, low organic-carbon and moisture content. Agricultural and forest cover areas indicate high to very-high sustainability due to low LST, more organic-carbon and moisture. This study investigates human-survival efficiency in respect of ES which may be considered as measurement tool for representing, analysing, and managing bio-geophysical environment.

Keywords: WQI; water quality indexes; HCI; human comfort index; LST; land surface temperature; crowdedness; environmental sustainability; LULC; land use/land cover.

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Biographical notes: Surajit Panda received his PhD from Department of Environmental Science and Engineering, Indian Institute of Technology (ISM), Dhanbad. He is currently working at Ministry of Environment, Forest and

Climate Change, IRO-Ranchi, Ranchi, Jharkhand. His research interests include application of remote sensing & GIS in mineral exploration, environmental sustainability, hydrology & natural resource management, etc. He had authored many research papers/book chapters related to his research interest. He also reviewed many research paper/manuscript for reputed/referred journals like Elsevier, Springer, etc.

Manish Kumar Jain is currently working as an Associate Professor, Centre of Mining Environment Department of Environmental Science and Engineering, Indian Institute of Technology (ISM), Dhanbad, India. He received his PhD from Indian Institute of Technology, Kharagpur. His research interests include fly ash as a mine void filling material, air, water, soil, noise and social pollution, their control measures and equipment, EMP, EIA and legislation. He had authored many research papers/books related to his research interest. He also guided many of research scholars of PhD and MTech.

Krishnendu Banerjee received his PhD from Indian Institute of Technology (ISM), Dhanbad (Department of Environmental Science and Engineering). He is currently working at Ministry of Environment, Forest and Climate Change, IRO-Dehradun. His research interests include application of remote sensing & GIS in mineral exploration, environmental impact assessment, hydrology & natural resource management, etc. He had authored many research papers/book chapters related to his research interest. He also reviewed many research paper/manuscript for reputed/referred journals like Elsevier, Springer, Taylor & Francis.

A.T. Jeyaseelan is currently working as Member, Board of Studies for Water Resources, Jawaharlal Nehru Technological University, Hyderabad. He was a former Consultant and scientist 'SG' of NRSC/ISRO, General Manager (Regional Center) and Director (JSAC). He received his PhD from Jawaharlal Nehru Technological University, Hyderabad. His research interests include application of agricultural drought monitoring, irrigation studies, international geosphere biosphere and water resources, etc. He had authored many research papers/books related to his research interest. He also guided many of research scholars of PhD and MTech.

1 Introduction

Environment is an undeniable critical and natural beauty of the world, plays an indisputable role in the every living life (Ahmed et al., 2019). Environmental Impact (EI) is practised in over 100 countries worldwide in past decades (Donnelly et al., 1998) which shows development activities are more responsible for negative environmental impacts (Tambekar et al., 2012). Successful exploration and development rewards can be huge if mineral deposits are discovered, evaluated and developed as a mine (Eggert, 2010). The forest cutting, blasting, digging etc., are associated with the mining, which are not eco-friendly. As well as air, water, noise, surface slope, LU/LC, socio economy and environments are affected by the mining activity. Singh and Shukla (2008) mentioned that the developmental activity and the conservation of mineral resources indicate the growth of a country. The conservation and developmental activity are incompatible and unplanned development is anti-social and harmful to the environment (Srivastava et al., 2013).

To protect and evaluate the EI, the concept of Environmental Impact Assessment (EIA) is originated at US National Environmental Policy Act (NEPA) in 1969 (Hollick, 1986). EIA and 'ES' had also been vindicate by Canada, France, Australia, Japan, New Zealand, Germany, Ireland, Sweden, Thailand etc countries. India enacted an umbrella like Environmental Protection Act (1986) to prevent, protect and improvement of the environment. The important facts of Environmental (Protection) Act (1986) mention about (1) Protection and improvement of the environment quality and (2) Controlling, Preventing and abating the pollution of environment.

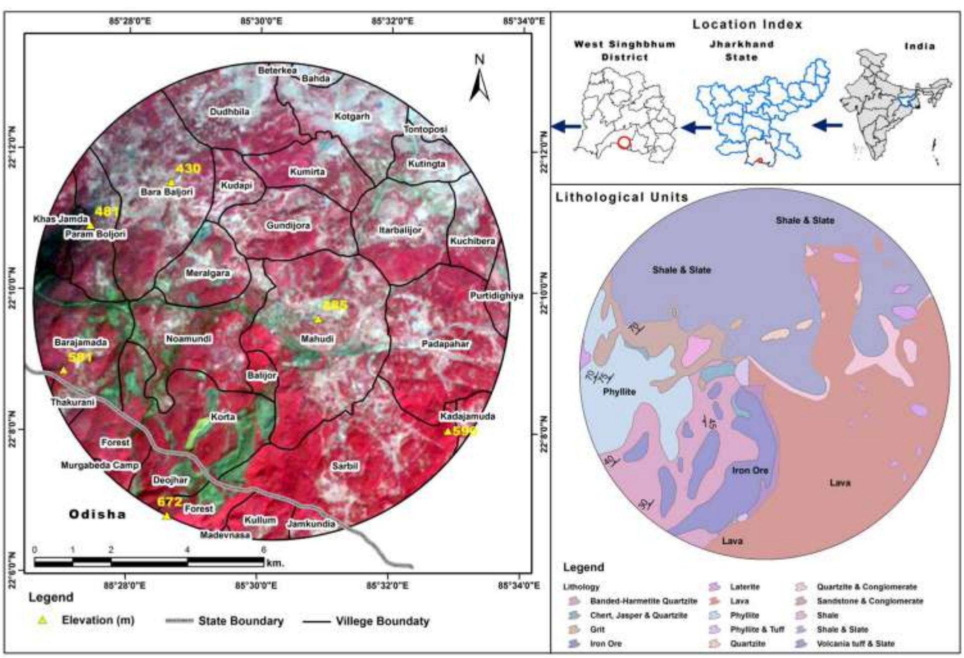
However, there are a number of examples of mutual reliance on relationships between environment and development (Jorgenson, 2016). There are some environment quality standards for impact assessment. The environmental standards are the values, which define by regulation, indicating the maximum permissible level of pollutants concentration mainly for water or air pollution levels also known as ambient standard (Ott et al., 2008). But the environmental standards values vary from country to country. For example, Indian standard, World Health Organization (WHO) standard etc, are the environmental standards. Sustainability covers two fundamental Issues; preserve the environmental degradation and natural resources with development activity. In 1992, the concept of sustainable development was discussed globally during Earth Summit at Rio de Janeiro. The summit work with the new thought to balance between the use and preservation of natural resources (Nkechinyere, 2010). Therefore, the sustainable development is the main key containing the present situation. The pattern of LU/LC change, mining and development activity also affect (direct/indirect) on surface and ground water quality, LST, green space, ecology, etc. (Kilic et al., 2004; Konig et al., 2013; Schirpke et al., 2017; Tampubolon et al., 2017; Nath et al., 2018; Sobrino et al., 2004). The primary source of drinking water is ground water which must be ensured as best quality for Human uses (Lloyd and Helmer, 1991; Kebede et al., 2018; Fenta et al., 2020). In this context, Heiß et al. (2020) developed DRASTIC model along with a new Water Quality Index based to assess groundwater vulnerability and water quality, in terms of drinking and irrigation purposes. Parker et al. (2010) considered the microbiological parameters to assess the surface and ground water quality of north-east Uganda using 346 different water samples, WHO standard and Ugandan national standard.

The occurrences of mineral resources are covered by forest. To explore these minerals, deforestation takes place which may encounter existing biodiversity, environment, ecology, green space, society etc (Rai, 2010). The main aim of this paper is, therefore, to assess the status of 'ES' with the help of basic environmental parameter. There are very few studies that deal with Noamundi area in the context of the environment. Sinha and Banerjee (1997) used the dust from the airborne haul road in Noamundi to estimate the health hazard as a physical character of the environment. Monty and Patel (2013) presented the soil condition along with forest and iron mines of Noamundi area. The ground water quality study conducted by Pandit et al. (2014) to estimate the quality of drinking water of Noamundi has revealed that most of the samples exceeding the acceptable limit that is 0.3 to 1 mg/l due to heavy Iron ore mining activities. They have suggested the proper treatment of ground water in this area before use. Tata mining companies have carried out various socio-environmental responsibilities such as education, sports, environment, drinking water missions, agriculture in Noamundi and surrounding areas (Tata Steel, 2015, 2016; Pandey, 2018). Air, water and noise quality alone are insufficient to assess the intensity of environmental sustainability and human comforts in the small-scale mining area of Noamundi. LST, human comforts, crowdedness, weather, and land use pattern are also very important to assess ES and Human Survival Efficiency (HSE).

1.1 General description of the study area

The projected study area is located at West Singhbhum district, known as a mining town in Jharkhand state, India (Figure 1). Physiographically, area is found at the Chotanagpur plateau of eastern India as well as adjacent parts of Odisha state. It extends over a wide range of 22°06′30″N to 22°13′05″N latitude and 85°26′45″E to 85°33′45″E longitude with an area of 12,230 ha. The entire area is rugged by ridge and valley fields. The area is located on a hilltop about 430 m to 765 m above the Mean Sea level (MSL) with average elevation of 480 m. The nearest Karo River, which is located about 10 km. of the Noamundi town. Maximum amount of rainfall passes over the surface through runoff as the foremost part of the area enveloped by undulating and rolling hill and eventually discharge into the Karo and Brahmni River through innumerable water cut channels like Kanda nala, Betlata nala, Barnallor and Katrogara nala.

Figure 1 Location map of the study area (see online version for colours)



The temperature in the area of Gua-Noamundi areas during the period of October to December 2013 ranged from 9.1°C to 26.5°C with average 318 mm. of the rainfall. The relative humidity of the area varied between 50% to 90.4% and wind speed ranged from 0 to 10.2 kmph with direction from West and South-West (Sosopi Iron Ore mines, 2013; Ghatkuri Iron Ore mines, 2015). The barometric pressure ranged from

702.6–744.2 mmHg and most of the times sky was clear. The rainy season, which begins in June and lasts until September, ranges from 8.50–297.44 mm. per month. This region generally receives a considerable amount of rainfall which is between 8.50–297.44 mm. per month (Ghatkuri Iron Ore mines, 2015).

According to the lithological information of the Geological Survey of India (GSI), there are different types of rocks (shale, tuff, phyllite, quartzite, jasper, sandstone, conglomerate, etc.) in the surrounding area (Figure 1: Lithological units). Most of the areas are envelopes with slate and shale (Sahoo and Das, 2015). The region is located as the Singhbhum Horseshoe Belt (SHB) of Singhbhum fold belt. Geologically the area is also known as Singhbhum Granite Craton (SGC) or Archean granite-greenstone terrain (Acharya, 1984; Sengupta et al., 1997; Mukhopadhyay, 2001; Roy and Bhattacharya, 2012). South Shinghbhum rock succession is lying unconformably over the older metamorphics rock namely as iron ore series (IOS) (Saha, 1994). The iron ore mines of Noamundi belong to this Iron Ore Group (IOG).

2 Methodology and environmental parameters

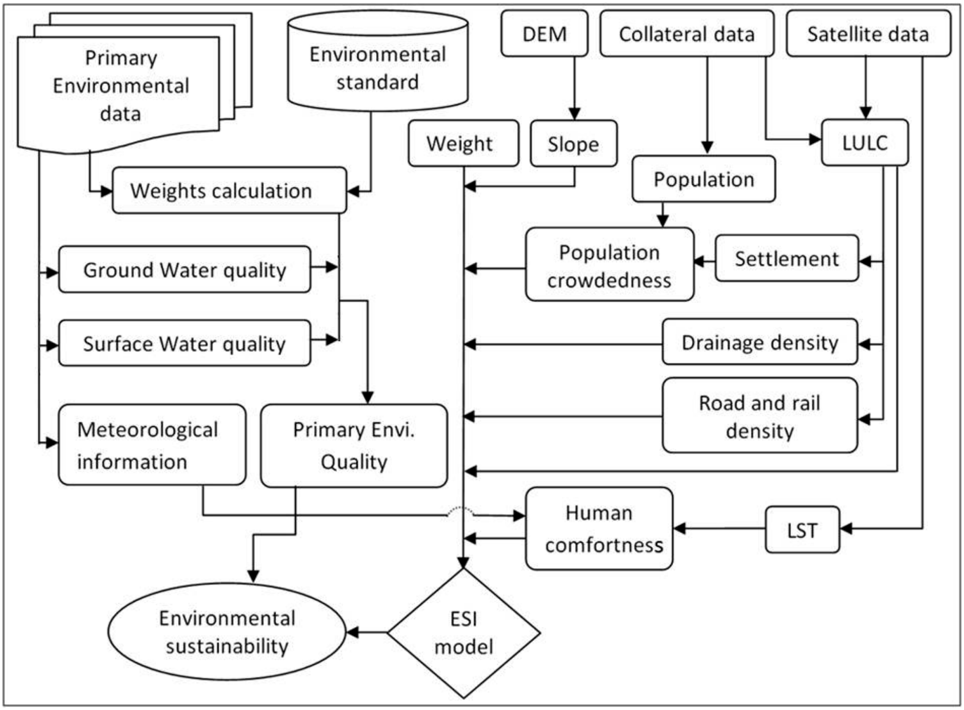
Environmental sustainability assessment and mapping of their status are basically divided into two sections. Metrological, surface and sub-surface water quality or GWQ are considered as a primary environmental parameter and all other parameters are considered as a secondary environmental parameter. Flanagan (1988) and Buijs and Toader (2007) primarily used water quality as an environmental classification. To assess the present situation of Noamundi Iron ore mine areas, several techniques like survey and data collection; water quality indexes (WQI) are adopted. Lastly, remote sensing methods and GIS base modelling techniques, as beneficial and powerful tools for assessing EIA or environmental sustainability assessment (ESA) and mapping, are reviewed and evaluated. A brief sketch of used datasets and workflow (Figure 2) are follows.

First, all information and data are converted into a GIS environment using the ArcGIS desktop or ArcMap software package. All the quality indices of water (ground and surface) were calculated based on weight (wi) and environmental standards values, individually. Those indices were categorised based on their quality status (usefulness) and assigned as a result of primary environmental quality.

In the present study, Resourcesat-2 (LISS-IV, 5.8 m) and Landsat-8 (OLI: 30 m and TIRS: 100 m) data were used for LU/LC mapping and LST estimation, respectively. Additionally, digital elevation model (DEM) has been used for ortho-rectification and slope generation. The ortho-rectification of Resourcesat-2 data was performed using DEM and ortho-rectified Cartosat-1 (2.5 m) data. Ortho-rectification is necessary for point to point geometrically correction of satellite data to retrieve the actual area or length. Additionally, the topographical slope has been generated from Cartosat-1 stereo DEM (10 m) data and it reclassified into six classes. The ortho-corrected data has been used for LU/LC generation by visual Interpretation technique. The drainage, rail, road, settlement, etc database has been generated with LU/LC.

The rail-road density and drainage density has been generated and reclassified to five classes (very low, low, moderate, high and very high) using ArcGIS desktop. Additionally, crowdedness has been generated by using population density and area of the settlement cluster. The Landsat 8 thermal Infrared (TIR) band has been used to retrieve the LST. Further, this LST and metrological information has been used to calculate the human comforts.

Figure 2 Flow diagram presenting the overall methodology for ESA



Furthermore, all these geospatial datasets have been weighted based on the importance of the environment. Finally, the simple weight overlay techniques were adopted to delineate the environment sustainability zone as an environmental parameter. The water qualities have been calculated and generated the digital map by interpolating the quality results (quality index). Finally, the ESA of the Noamundi area has been mapped by using the quality index, empirical model (weight overlay) and analysis. Indices are defined as a rating or normalising values that reflect the composite influence of a parameter with respect to all parameter. It may be Surface water Quality Index or Ground water Quality Index etc. The detailed methodologies of ESA, description of the environmental parameter, adopted environmental indices and index calculation are described below.

2.1 Surface and sub-surface water quality

The fresh water is the matrix of life (Franks, 2000). As the ground water is the fundamental need of life, around 1/3 of the world's population depends on that due to availability of 95 percent fresh water of our planet (Pandit et al., 2014; Mohrir et al., 2009). Today rapid growth in urbanisation, industrialisation and other development activity may affect the ground water and decrease their quality. Therefore, the Ground water quality has been considered as an environmental parameter for mapping and assessment the sustainability of the Noamundi area. Ground water quality decrease with to the changing of their natural amount of substances due to removing or adding some certain substances (Ramesh et al., 2001). Water becomes polluted when in contact with toxic elements, not visible to the open eye. Therefore, it is important to test the water quality, with respect to its standards.

Twelve locations were identified in study area. Noamundi, Bara Baljori, Katamati and Thakurani villages were used for ground water quality study. The GW1 and GW2 locations are Noamundi railway station and Noamundi Basti respectively. Other locations are GW3 (Bara Baljori Mines Office), GW4 (Merelgora Village), GW5 (Bara Baljori Village), GW6 (Chhota Baljori Village) of Bara Baljori area. GW7 (Talasai-Murga) and GW8 (Rabrusai-Mahadevnasa) are in Katamati area. GW9, GW10, GW11 and GW12 are near mine office, mining area, Murgabeda and Deojhar correspondingly of the Thakurani area.

WQI was computed using weighted index method (Singh et al., 2014), firstly the weight (*wi*) of each water quality parameter has been assigned in respect to its importance of water quality. For example, nitrate and arsenic have been categorised by maximum weight (5), due to its more importance in drinking water. Similarly pH, iron, fluoride, sulphate, chlorides, calcium, magnesium, etc., were weighted as to their importance and harmfulness. After weights assigned, the relative weights (*Rwi*) has been computed by the below equation (1):

$$Rwi = \frac{\mathrm{wi}}{\sum_{i=1}^{n} \mathrm{wi}} \tag{1}$$

where *n* is the number of parameters and *wi* is the weight of each parameter. Computed relative weight (*Rwi*) results of each water quality parameter are presented in Table 1.

Table 1 Relative weight of water quality parameters

Parameters	*wi*	*Rwi*	*Minimum standard*
pH	4	0.08163	6.5
Total hardness (as $CaCO_3$), mg/l	2	0.04082	300
Iron, ppm	4	0.08163	0.3
Fluoride, ppm	4	0.08163	1
TDS, g/l	4	0.08163	500
Sulphate	4	0.08163	200
Nitrate	5	0.10204	45
Chlorides (as Cl), mg/l	3	0.06122	250
Calcium, ppm	2	0.04082	75
Magnesium, ppm	2	0.04082	30
Arsenic, ppm	5	0.10204	0.05
Manganese, ppm	4	0.08163	0.1
Zinc, ppm	2	0.04082	5
Chromium, ppm	2	0.04082	0.05
lead, ppm	2	0.04082	0.05

In the next step, the quality rating scale (Qi) of each parameter was calculated by the equation as given below (2):

$$Qi = \frac{Ci}{Si} \times 100 \tag{2}$$

where Qi is quality rating scale, Ci is concentration of each parameter, Si is drinking water standard and the result multiplied by 100. The Sub index (SI) has calculated by using Relative weight (Rwi) and (Qi) of ith parameters and finally, the sub index (SI) has been used to determine the water quality index (WQI) by the equation below (equations (3) and (4)):

$$SI = Rwi \times Qi \tag{3}$$

$$WQI = \sum_{i=1}^{n} SI \tag{4}$$

The spatial interpolation technique ware conducted to generate the ground water quality map in the following way. Firstly, the calculated ground water quality results and corresponding geographical location were imported into GIS environment using the ARC/INFO (ArcGIS) software. Then the spatial interpolation technique was conducted, which are available in the Geostatistical Analyst toolbar of ArcGIS software package. After that, such thematic symbols were used to visualise the results. Finally, the soil map is superimposed over the interpolation map to analyse the results.

Surface water is the necessary element for the survival of life (fisheries, agricultural domestic uses) on the planet (Jena et al., 2013). River, canal etc are the sources of water play a significant role in development activity, fulfil the agricultural requirement, ecological balance and other necessary uses. Some time the growing population, Industries discharge and human activities add or remove the toxic or polluted elements to the river through surface water flow.

The lack of awareness, municipal industrial wastewater output may pollute the surface water. That water may run-off and distributed through surface slope or drainage to agricultural land, river basins etc and may pollute the surface water (Bordalo et al., 2001). As a result, surface water quality is an important parameter for environment and living hood balance and quality. Therefore, it is important to identify the surface water quality, with respect to its standards. Surface water quality index (SWQI) of the study area is compute through following steps.

The weighted index method has been used for estimation of the SWQI (Jena et al., 2013; Sharda and Sharma, 2013). The calculation of quality rating or sub index and the SWQI has been computed by the equation below (equations (5)–(7)):

$$Qr = \frac{Cn - I}{Sn - I} \times 100 \tag{5}$$

$$Uw = \frac{K}{Sn} \tag{6}$$

$$SWQI = \frac{\Sigma QrUw}{\Sigma Uw} \tag{7}$$

where *Qr* is the quality rating or sub index of the nth parameter, *Cn* is the concentration of the *n*th parameter, *Sn* is the standard value of the *n*th parameter, *I* is the ideal value (pure water) of the *n*th parameter, *K* is the proportionality (concentration). The ideal values for pH, dissolved oxygen and others are '7', '14.6' and '0' respectively (Gangwar et al., 2013).

2.2 LU/LC

Duveiller et al. (2018) reported that the land cover is the biophysical phenomenon of the earth surface. Silva et al. (2006), Fonji and Taff (2014); described the land use, which form by influence of environmental process and human activities, etc. Since both LU/LC are closely related and are not mutually exclusive, they are interchangeable as the former can be inferred based on land cover and on the contextual evidence. Land cover may change due to natural processes or human activity (Anwar, 2014). Accordingly, land use can also be assessed as the result of development/sustainable development. The active mines may stains landscape and disturbed the natural ecosystems due to change the physio-chemical properties that may effect on productivity, soil fertility, etc. (Board, 2007). Monty and Patel (2013), found the higher water holding capacity, organic contents, amount of clay material, moisture content etc at forest soil area with respect to iron mine area of Noamundi. That means natural ecosystems may stress situation due to mining activities. The mining, forest, built up; spatial data can also have attributed and terrain conditions have been subjected to spatial analysis using the LU/LC information system. In this context the LU/LC has been considered as an Environmental sustainability parameter.

2.2.1 Drainage density

Drainage density is the total length of channels per unit area of the basin that affects on earth, such as soil moisture, runoff and water resources, agriculture and ecosystems, society climate change, etc. (Daba et al., 2018; Dragičević et al., 2018). The good drainage density may imply good soil moisture and a good ecosystem. The dependency of ecosystems is associates with presence of agriculture and vegetation. Agriculture and vegetative cover depends upon soil moisture, drainage system and other geo-physical factors (El-Nashar, 2017). The characteristic of drainage density, drainage networks and drainage pattern are totally dependent upon geologic and geomorphic conditions (Rai et al., 2018; Altaf et al., 2013). Therefore, the drainage density is being considered as an important parameter for the study.

2.2.2 Road and rail density

Noamundi is involved in rural and industrial development; it also relies heavily on existing road and rail connectivity for its necessity and safety. The roads are frequently used to carry or transfer the mining or industrial material. The dust material, vehicle crowdedness, sound may disturb the local environment. Road may affect environment directly or indirectly like biodiversity loss, noise, dust, water pollution, run-off, social impacts and safety etc. The high road density may influence the local environments more.

Accordingly, the road density has been considered as an environmental sustainable parameter. The density of the road or rail has been calculated in length of road or rail per unit area.

2.3 Slope

A DEM is not a true representation of a ground surface, but a model of the digital earth's surface that is commonly used to generate topographic maps, ortho-rectified image data, slope, drainage, hydrological planning and different type of engineering work etc. DEMs are used in many cartographic and GIS applications (Murthy et al., 2008). Slope is the one of parameter to analyse the surface topography. An important benefit of the degree of slope angle is to represent the overland flow and direction, corresponding to the surface (Dunn and Hickey, 1998). Accordingly, the slope has been considered as an environmental parameter. The slope is the angular distance between two places (equation (8)). Slope is a number that tells us how quickly a line rises or falls (Hickey, 2000).

$$\text{Slope in Percent} = \frac{\text{Rise}}{\text{Run}} \times 100 \tag{8}$$

A circular neighbourhood with three map unit or cell is taken into action over DEM to smooth the DEM. The average values of the 3-cell circle neighbourhood have been assigned into the cell centre of the three circular matrixes. The model was created by using ArcGIS 10.1 software module and run over each pixel value of the DEM.

2.4 Population

Population density, distribution and growth are related with existing facility like available resources, fresh water, good communication facility, scope of occupation, etc. The population growth may increase the use of water resources, industrial production and activities, crowdedness etc, influence the environmental degradation. The effect of environment, not only depends on number of population, also effect by lifestyle, human thinking, energies consumption etc. (O'Brien, 1990). So the population characteristic has been used for this study as a secondary parameter. In 1990, Frank uses the population density or crowdedness to explain the physical crowding or density in his study. Billari (2015) and Lu (2015) defines the importance of human use of space in demography study.

Some villages are cross the boundary of the study area and maximum populations are concentrated at little part of each village due to forest area. But on the other hand population density represents the density of whole village. In this situation population density is not suitable method for this study. Therefore, the crowdedness observations have been considered for this study. The population density and settlement density of each village are used to observing the crowdedness of the area. Crowdedness has been calculated by the equation below (equation (9)).

$$\text{Crowdedness} = \left(\frac{Pop_{vill}}{Pop_{Tvill}} \right) \times \left(\frac{Sett_{ivill}}{Vill_i} \right) \times 100 \tag{9}$$

where Pop_{vill} and Pop_{Tvill} are the population of the *i*th village and Total population of all villages which are fall in the study area respectively. The $Sett_{ivill}$ *and* $Vill_i$ are the settlement area of the *i*th village and total area of the corresponding village respectively.

2.5 Land surface temperature (LST) and human comfort index (HCI)

Bear surface may affect surface moisture balance, net radiation or energy balance, surface temperature, etc. LST is essential physical parameters of the relations between the terrestrial surface and atmosphere for energy exchange system (Ming et al., 2009; Van et al., 2009). On the other hand, biophysical factors are altering with changing LST (Van et al., 2009; Ibrahim et al., 2012). The rapid growing of mining industry may change the surface cover that effect on surface energy balance and many other environmental issues. As the study area has situated at the active surface mine area, is an important indicator to change the surface cover (vegetated areas to bear surfaces) with increasing the LST that can affect on net radiation, water balance and surface heat budget (albedo) etc. These are influence to change the local weather, LST and change of biophysical factors such as vegetation cover (Ibrahim et al., 2012), etc.

LST has been derived from the corrected Landsat 8 TIR10 band, dated 17 April, 2013 (summer season). Landsat 8 has two thermal bands, TIR10 and TIR11. Here, TIR10 has been used due to larger calibration uncertainty associate with TIR11 band (Landsat 8 Data Users Handbook). The pre-launch calibration constant, K1 and K2 are used from image Meta data of Landsat-8 (Landsat 8 Data Users Handbook). The step wise procedure of LST retrieval from Landsat-8TIR11 data has been presented below (Table 2 and equations (10)–(15)).

- DN to at-sensor spectral radiance reconvention
- Spectral radiance to brightness temperature
- Emissivity corrected LST.

The at-satellite brightness temperature (i.e., blackbody temperature, B_T) also called radiometric temperature. Van de Griend and Owe (1993), achieved a high correlation between land surface emissivity (LSE) and NDVI. They suggest the relation follows as above (Table 2, ii). NDVI has been calculated to derive the emissivity (Є). NDVI may reflect the spatial distribution of green space. The result (vegetation and soil as mixed pixels) of NDVI varies between –1.0 to 1. On the other hand, the result of LSE varies between 0 and 1. But the relation is only valid for the areas large patches which covered by vegetation or soil (Van de Griend and Owe, 1993; Van et al., 2009). As the Noamundi fall in Chaibasa South Forest Division, the method has been applied for emissivity (Є) calculation. The emissivity corrected (LST) were computed through above equation (Valor and Casells, 1996). In Kelvin (*k*) scale, the absolute zero is equivalent to –273.15°C. So the emissivity corrected LST has been converted into Celsius (°C) by subtracting of 273.15.

Table 2 Detail of stepwise procedure of LST calculation

S. No.	*Procedure*	*Index*
1	DN to at-sensor spectral radiance reconvention $$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{\text{calmax}} - Q_{\text{calmin}}}\right)(Q_{\text{cal}} - Q_{\text{calmin}}) + LMAX_\lambda \quad (10)$$	L_λ: Spectral radiance [W/(m2sr μm)], Q_{cal}: Quantised calibrated pixel value [DN], Q_{calmin}: Minimum quantised calibrated pixel value corresponding to LMIN_λ [DN],
2	At sensor Brightness temperature (B_T) in degrees Kelvin (K), $$B_T = \frac{K2}{In\left(\frac{K1}{L_\lambda} + 1\right)} \quad (11)$$	Q_{calmax}: Maximum quantised calibrated pixel value corresponding to LMAX_λ [DN], $LMIN_\lambda$: Spectral at sensor radiance that is scaled to Q_{calmin} [W/(m2sr μm)] and
3	Emissivity corrected LST i. $NDVI = \left(\frac{NIR - R}{NIR + R}\right)$ (12) ii. $\epsilon = 1.0094 + 0.047 * NDVI$ (13) iii. $T_k = \frac{B_T}{\epsilon^{1/4}}$ (14) iv. C = (Kelvin value – 273.15) (15)	$LMAX_\lambda$: Spectral at sensor radiance that is scaled to Q_{calmax} [W/(m2sr μm)], from Image meta data. $K1$ and $K2$ are the pre-launch calibration constant value (Source: Landsat 8 Data Users Handbook) NIR: Near IR band R: Red band (light reflected) ϵ: Emissivity T_k: Kinetic temperature or emissivity corrected surface temperature in Kelvin. C: LST in °C

The temperature may have affect on quality of human and animal life (Pranoo et al., 2015). The Ming et al. (2009); use the human comfortness as a physiological indicator of climatic environment. In the present study, the human comfort has been used as a physiological indicator of climatic environment (Ming et al., 2009). Similarly, in the present studies human comfort index (HCI) has been used for the rapid growing mine of Noamundi area. HCI has been calculated through the Ming et al.'s (2009) equation below (equation (16)).

$$HCI = 1.8(T_s - 273.15) - 0.55[1.8(T_s - 273.15) - 26](1 - f) - 3.2\sqrt{v} + 32 \qquad (16)$$

where HCI is the human comfort index based on LST (T_s) in Kelvin (K), f is the relative humidity and v is the mean wind speed (m/s). The HCI values have been classified into several classes based on human sensation (Ming et al., 2009). The Values below 31 are classified as very cold with uncomfortable, 31–56 Cold with uncomfortableness, 56–68 cold with comfort, 68–72 very comfort, 72–79 more warm with comfort, 79–82 hot with more uncomfortableness, 82–88 hot with uncomfortableness and more than 88 very hot with uncomfortableness.

3 Result and discussion

3.1 Ground water quality

In the present study the result of WQI ranges from 18.02 to 112.032. Therefore, the results of WQI have been presented in Table 3 and the graphical view has been presented in Figure 3. Table 3 indicates that the Location ID/Code GW14, GW15 and GW20 (Figure 3) locations are falling under poor water quality status with index value 100 to 200 at northern and western side of the study area due to high and moderate permeability of soil (Figure 3). As the higher slope and moderate permeability of soil shown in the southern and middle part of the study area, maximum surface waters are runoff. On the other hand, the high permeability of soil shown at lower slope (Northern and North-eastern) area, maximum surface water may penetrate and store as a ground water. Due to this reason, the ground water quality index result varies in between 100 to 200 (Figure 3).

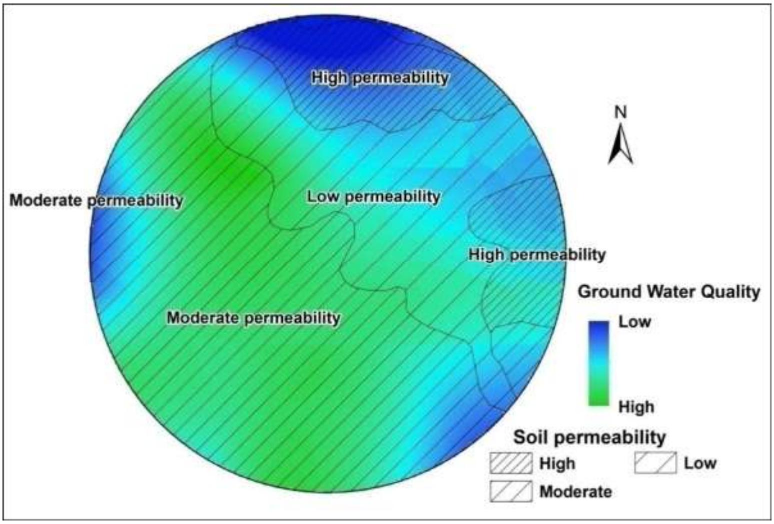
Table 3 Classification of ground water based on WQI (see online version for colours)

Location code	*WQI*	*Location code*	*WQI*
GW1	**31.5257**	GW13	**59.9072**
GW2	**27.1714**	GW14	**108.119**
GW3	**18.0228**	GW15	**116.062**
GW4	**25.3870**	GW16	**35.8400**
GW5	**19.1100**	GW17	**87.4500**
GW6	**29.0100**	GW18	**44.6900**
GW7	**24.3898**	GW19	**41.7193**
GW8	**23.2122**	GW20	**112.032**
GW9	**27.4016**	GW21	**32.2516**
GW10	**31.5581**	GW22	**61.6969**
GW11	**44.5453**	GW23	**39.9797**
GW12	**82.6309**		

Water quality index	*Water quality status*
<50	Excellent water quality
50-100	Good water quality
100-200	Poor water quality
200-300	Very poor water quality
>300	Unfit for drinking

From the Figure 3, the dark blue colour is indicating low ground water quality (near Bahada, Kothghar vill etc), while green colour indicated the good ground water quality (near Noamundi basti, Mahudi, Meralgara vill, etc.).

Figure 3 Layout of ground water quality map with soil permeability (see online version for colours)



3.2 Surface water quality

The computed results of surface water quality have been presented in Table 4. Table 4 indicates that the Location ID/Code (Figure 4) SWQ5, SWQ8 and SWQ10 locations are falling under very poor water quality status with index value 76 to 100. The area with the Location ID/Code SWQ3, SWQ6, SWQ9 and SWQ12 are falling under poor water quality status. The pH standard is 6.5 to 8.5 but the average 7 has been taken as a standard value. The pH of Location ID/Code SWQ8 is 6.90, which is less than seven and in between actual standard. Thus, the result of SWQ8 would be 82, falls into the category of very poor water quality.

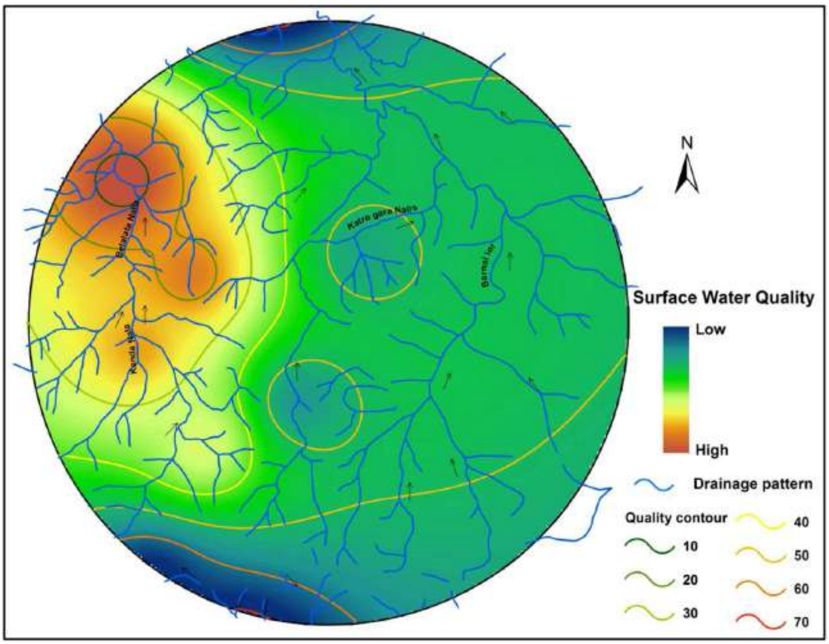
Table 4 Results of surface water quality (see online version for colours)

Location code	*ΣUw*	*ΣQrUw*	*SWQI*
SWQ1	1.07	17.78	16.61
SWQ2	1.13	07.28	06.43
SWQ3	1.16	61.64	53.12
SWQ4	1.15	56.74	49.27
SWQ5	3.12	289.66	92.94
SWQ6	1.41	98.11	69.80
SWQ7	2.22	46.35	20.88
SWQ8	1.04	85.21	82.09
SWQ9	2.93	162.05	55.35
SWQ10	2.83	225.14	79.70
SWQ11	2.48	76.03	30.64
SWQ12	3.31	179.19	54.11

Table 4 Results of surface water quality (see online version for colours) (continued)

Water quality index	*Water quality status*
0–25	Excellent water quality
26–50	Good water quality
51–75	Poor water quality
76–100	Very poor water quality
>100	Unfit for drinking

Figure 4 Layout of surface water quality map with contour (see online version for colours)

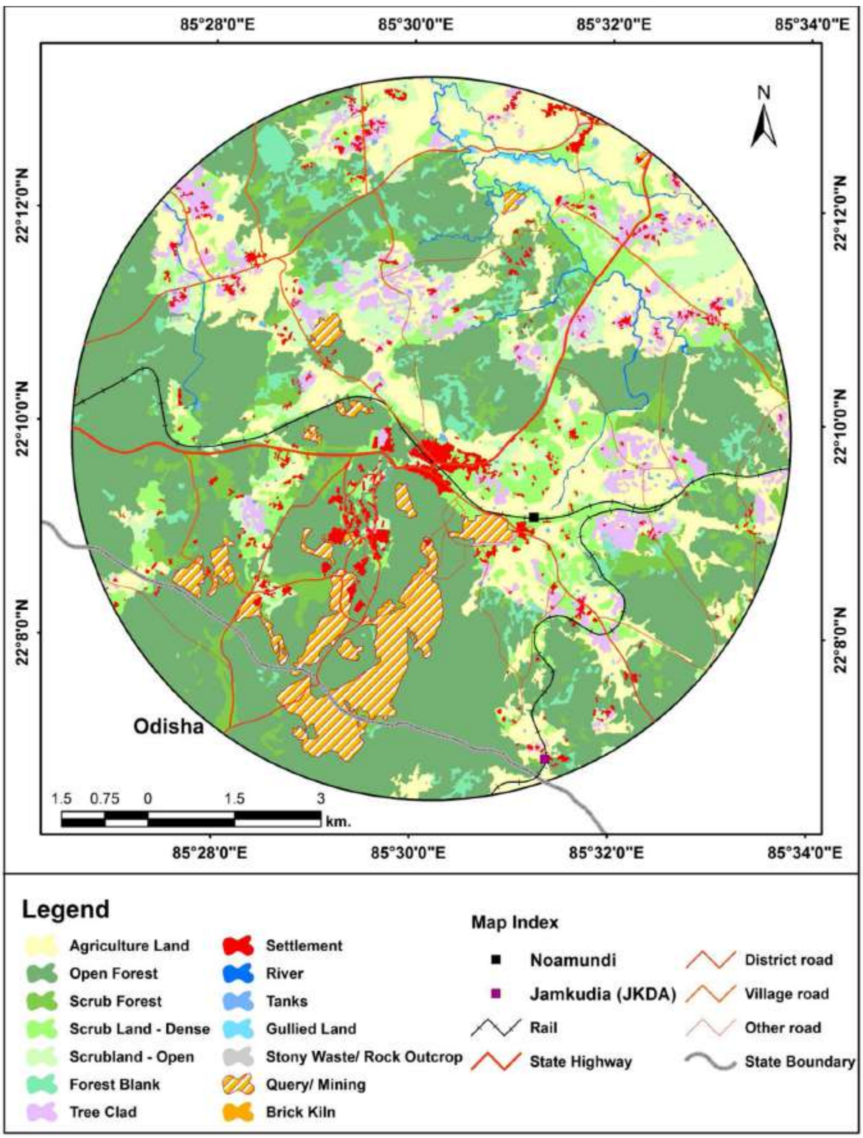


The surface water quality map (Figure 4) has been generated by following the same process of ground water quality map preparation. Water from river, canal, nala sources are used for surface water quality (SWQ). According to the available SWQ data, it is observed that the SWQ of western and north-western are better than Northern area (Figure 4). On the other hand, SWQ of Northern and southern portion of the study area are gradually increasing compared to middle and western area. From the slope analysis of the area, higher slopes are observed in southern, south-western and western part (due to hilly area). The lesser slopes are observed at North-western and south-eastern area. The lowest slopes are shown in Northern and North-eastern area. From the drainage pattern of the study area, it seems that the Koatrogara and Barnalor nalas have been flowing from Meralgara and Noamundi mines area to towards North-East and North direction through their natural slope, respectively. On the other hand, the Kanda and Betalata Nala flow from Thakurani and Bara Baljori mines area to in the way of north and North-western-north direction respectively. As all the drainage pattern follows the direction of northern site (Beterkea area) through mines area, SWQ is more or less poor in compared to other areas.

3.3 LU/LC

The LU/LC (2013) of the study area has been mapped from merge data of Resourcesat-2 and Cartosat-1 PAN (Panchromatic) data. Various LU/LC classes mapped in the area are shown in Figure 5. Noamundi, in the study area has the least forest cover, 8282.76 hectares with 533.84 hectares of quary/mining and 362.01 hectares of forest blank in 2010 (from previous study). In 2013, the study area has 8232.98 hectares of land classified as forests, 49.78 hectares of land has diverted mainly for mining or under working mines. On the other hand forest blank also increased from 362.01 hectares to 372.45 hectares in between the year 2010–2013.

Figure 5 Distribution of LU/LC classes (2013) of the study area (see online version for colours)

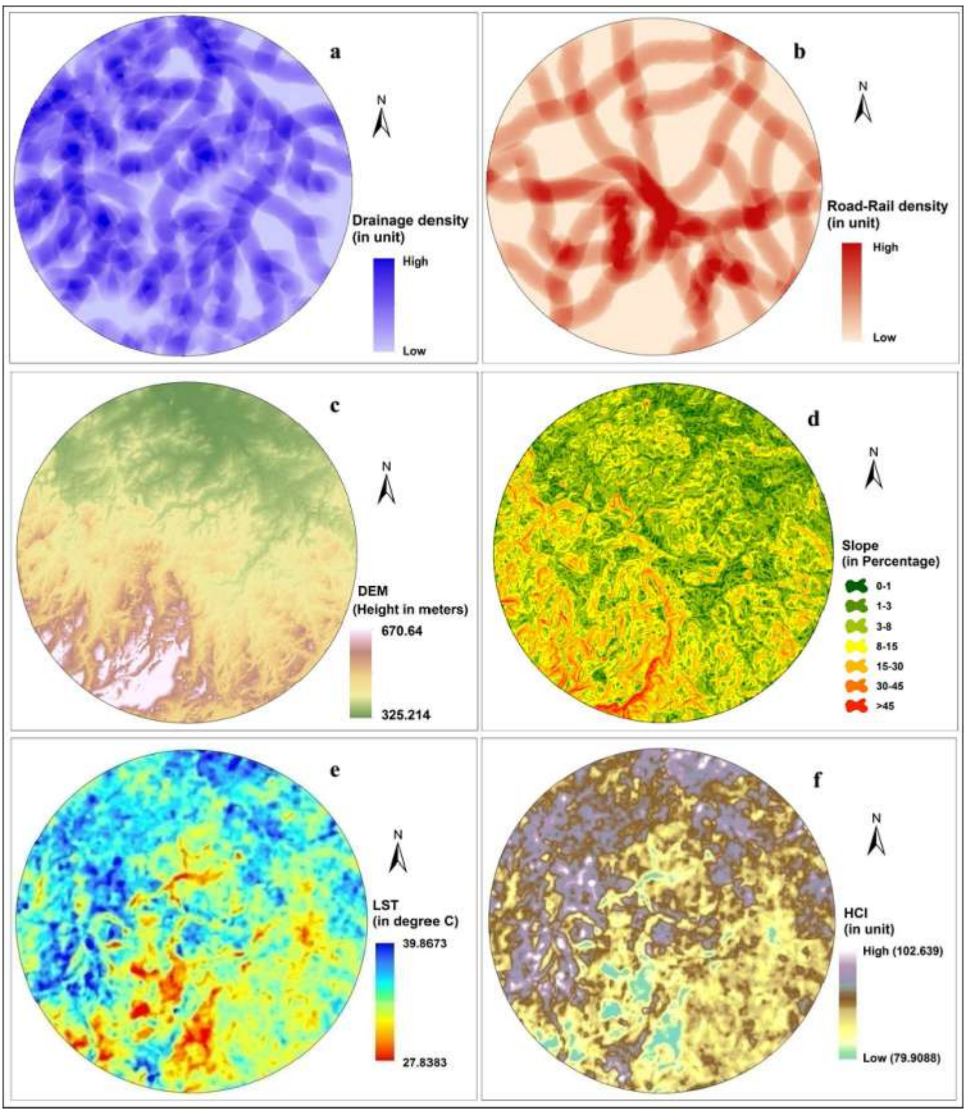


3.3.1 Rail, Road and drainage density

In the study area the less drainage density has been observed at north eastern part in respect to North-western, South and South-western parts as the mining and hilly areas are situated at South, west and South-western part (Figure 6(a)).

From the Figure 6(b), the highest density of rail, road has been found in the Noamundi (CT) area and the lowest density has been observed at northern part of the study area. Noamundi (CT) is the main centroid for the mining industry of the area, which may have affect on environment.

Figure 6 Aerial distributions of secondary environmental status (parameter): (a) drainage density, (b) road-rail density, (c) digital elevation model (DEM), (d) slope, (e) land surface temperature (LST) and (f) human comfort index (HCI) (see online version for colours)



3.4 Slope

The maximum and minimum elevations of the projected area are 325 m and 671 m, respectively (Figure 6(c)). The slope map generated from Cartosat-1 stereo DEM having values ranging from 0 to >45 degrees (Table 5). The slope map has been reclassified to six classes. More of them are steep to steeply sloping having slope 15 to 45 degrees. The area is sloping terrain, hence the runoff is more. The slope map and slope classes are showed in Figure 6(d).

Table 5 Classification of slope of the study areas

Slope classes	*Slope in percentage*
Nearly level	0–3
Gently slope	3–8
Moderately slope	8–15
Strongly slope	15–30
Steep slope	30–45
Very steep slope	>45

3.5 LST and human comfortness

The minimum LST of the study area are 27.83°C and maximum LST is around 40°C. The highest and lowest LST are depicted at non-vegetated and vegetated area respectively (Figure 6(e)). From the Figure 6(e), it has observed that the mining, rocky outcrop, build up, barren land or forest blank area are shown high LST which are more uncomfortable. These are only instantaneous results that the image was recorded in April but the LST may increase in May month (summer season). In the present study, the LST has been considering to derive the Human comfortness (HC).

The LST based on Landsat 8 TIR (Thermal Infrared) data; wind speed and relative humidity from metrology data have been used to evaluate the HCI of the study area (Figure 6(f)). Rests of the values are more than 79 that are indicating the uncomfortableness. Accordingly, these areas are uncomfortable in hottest months or summer time whereas the HCI values are ranging 79 to 103.

3.6 Population

The village wise population status and growth has been presented in Table 6. The maximum population increase has been observed (2001 to 2011) at Noamundi (CT) area with 1724 number of population. As Noamundi (CT), area is situated near industrial area (mining industry); the high population density has been observed due to sources of facility.

From the Figure 7, it has been observed that the maximum crowdedness observed at Noamundi (CT) area due to higher population and higher settlement area. Forest areas are indicating the less crowdedness due to non-availability of population or settlement area. The higher values are indicating more crowdedness and lower values are indicating lesser crowdedness in Figure 7.

Figure 7 Layout of crowdedness (index) map of the projected area (see online version for colours)

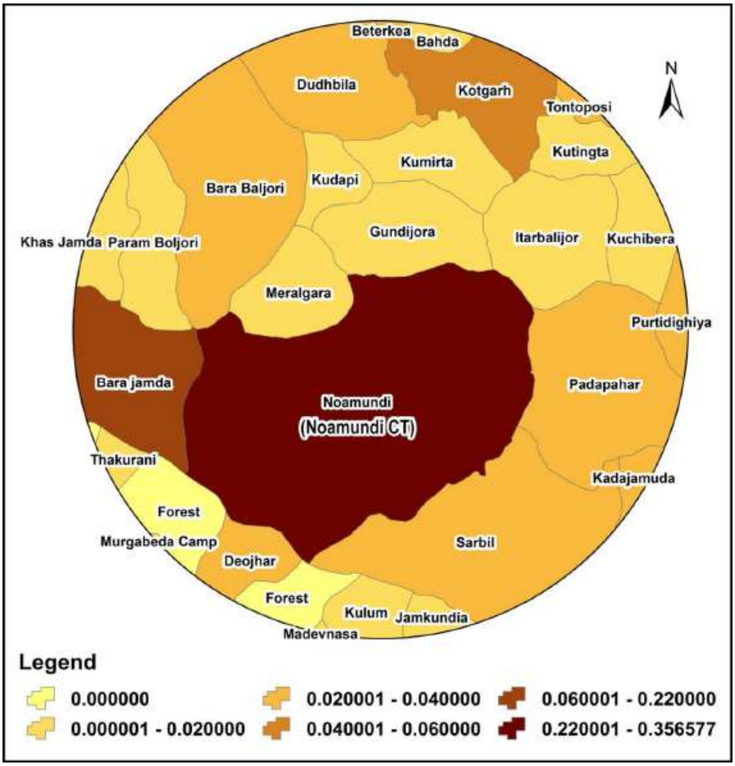


Table 6 Population status of the study area

State	*Village*	*Population (2001)*	*Population (2011)*	*Changes*
Jharkhand	Gundijora	761	887	126
	Meralgara	493	652	159
	Beterkea	968	1160	192
	Bahda	1049	431	–618
	Dudhbila	1493	1673	180
	Tontoposi	1351	1578	227
	Kotgarh	1844	2172	328
	Bara Baljori	983	1167	184
	Kutingta	659	816	157
	Khas Jamda	579	808	229
	Kumirta	462	491	29
	Param Boljori	325	438	113
	Kudapi	165	251	86
	Kuchibera	490	616	126
	Itarbalijor	668	804	136

Table 6 Population status of the study area (continued)

State	*Village*	*Population (2001)*	*Population (2011)*	*Changes*
Jharkhand	Purtidighiya	784	1124	340
	Padapahar	1323	1594	271
	Kadajamuda	1581	1763	182
	Sarbil	1209	1435	226
	Bara jamda	N/A	8629	0
	Noamundi (CT)	16,230	17,954	1724
Odisha	Thakurani	318	432	114
	Deojhar	818	1048	230
	Murgabeda Camp	508	519	11
	Kulum	455	513	58
	Jamkundia	507	644	137
	Madevnasa	661	752	91

Source: Census of India, 2001 and 2011

4 Environmental sustainability

Noamundi is a mining town, the environmental sustainability status is very important. The important elements of environment impacts are (1) impacts on land, (2) impacts on water regime, (3) impacts on ecology and (4) impacts on society. In the present study the Ground water quality, Surface water quality are considered as a primary environmental parameter.

The location of Merelgara, near Bara Baljori, Noamundi basti, Noamundi colony, Chatti Buru, etc. has good character (sustainable quality) of surface and ground water quality (Figure 8). The overall sustainability of the study based on the primary and secondary parameters has been observed towards the northwest.

The ES of the study area has been analysed through the integration of various environmental parameters like slope, crowdedness, road-rail density, drainage density, HCI, LU/LC etc, as a secondary parameter. Liao et al. (2013); used the AHP method base weight and score for environmental indices to analyse the ecological environmental impact assessment of coal mining area by using GIS technique. Radhakrishnan and Ramamoorthy (2014) used the ranks based on importance and weightages for all parameters to analyse the potential zones of ground water recharge. Recently, Bera and Ahmad (2016) used the simple weight overlay technique to delineate the ground water potential zone as an environmental parameter.

In the present study, ES model has been developed based on weighted overlay analysis by using geospatial technique. The weight (*Wi*) were assigned to the sub class of all environmental parameters based on their importance on environmental effect (Table 7 and Figure 9). The weights are ranging from 1 to 6. 1 indicating, good for environment and 6 indicates critical for environment. On the other hand the Theme weight has been assigned to all environment parameter based on environmental effects and importance, with in 100 scores (Table 7). The more theme weight indicates more importance for environment. The Arc GIS software package has been used to generate the result based on this environmental sustainability model.

Figure 8 Layout sustainable water resources quality (surface and ground) distribution (see online version for colours)

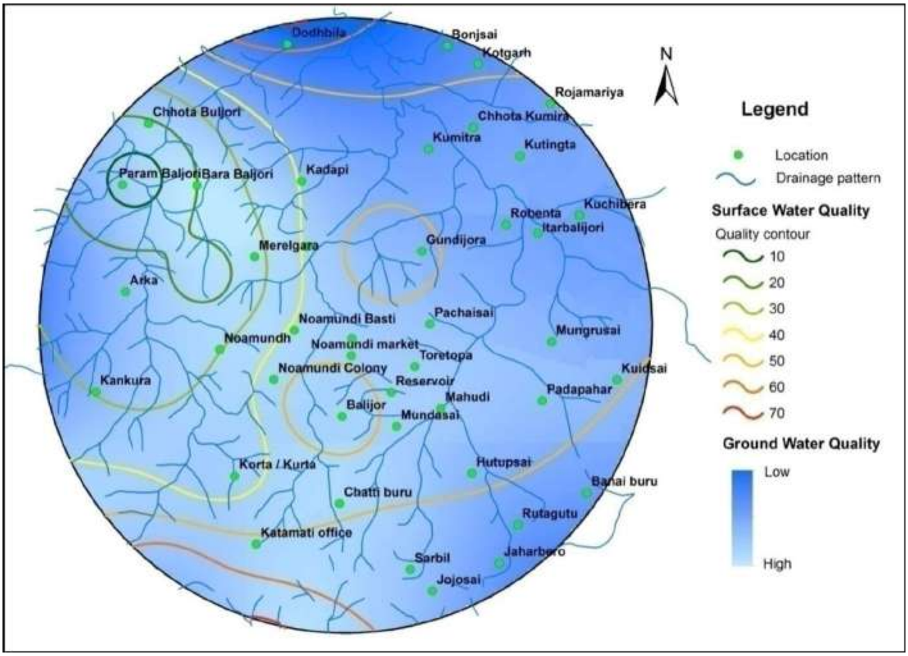


Figure 9 Ranges and weight base classification of secondary environmental status: (a) drainage density, (b) road-rail density and (c) human comfort index (HCI) (see online version for colours)

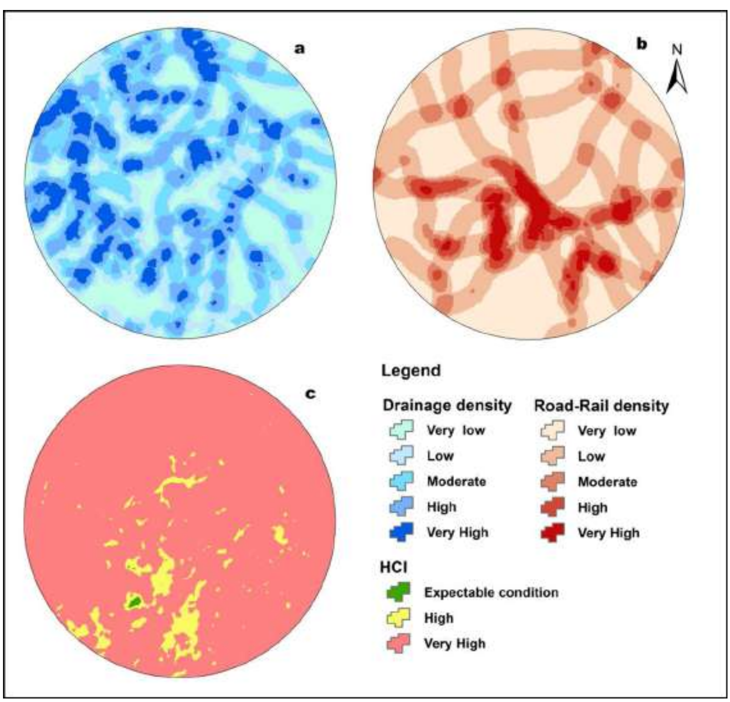
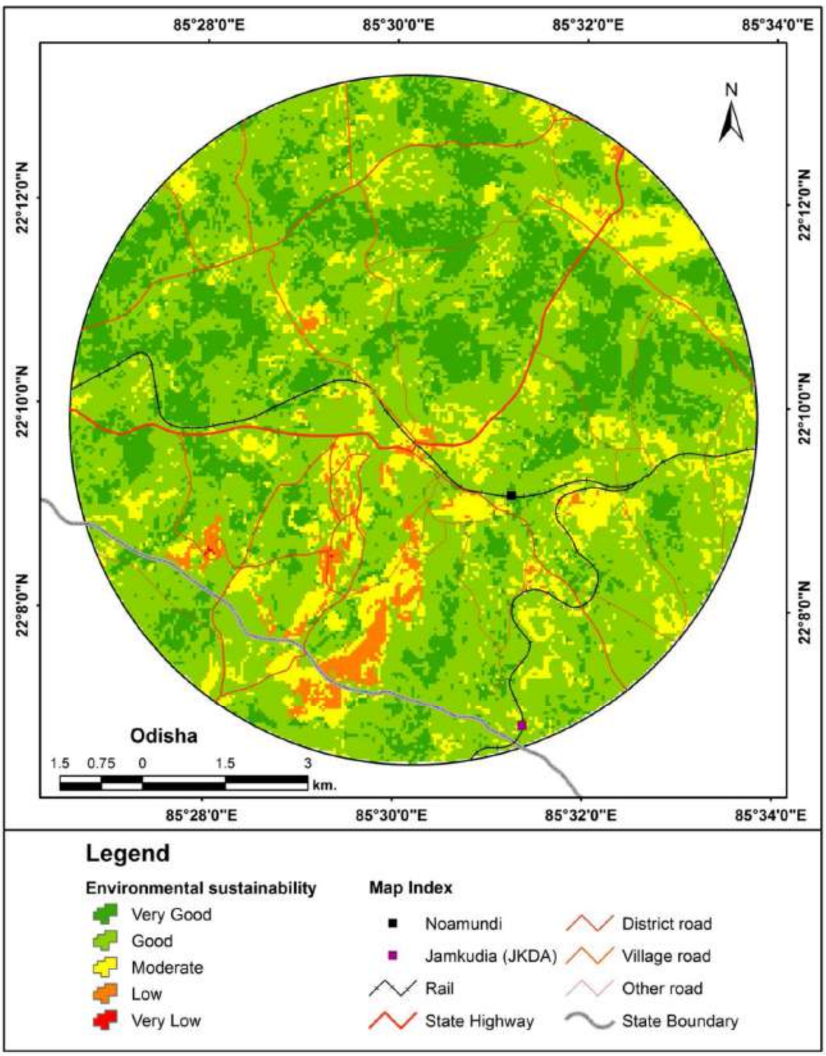


Table 7 Ranges and weight of parameter for ESA

Environmental parameter	*Sub classes*	*Ranges*	*Weighted (Wi)*	*Theme Weighted*
Slope	Nearly level	0–3	1	25
	Gently slope	3–8	2	
	Moderately slope	8–15	3	
	Strongly slope	15–30	4	
	Steep slope	30–45	5	
	Very steep slope	>45	6	
Crowdedness	No crowd	0	1	7
	Very low	0–0.02	2	
	Low	0.02–0.04	3	
	Moderate	0.04–0.06	4	
	High	0.06–0.22	5	
	Very high	>0.22	6	
Drainage density	Very low	0	6	20
	Low	0–0.1	5	
	Moderate	0.1–0.2	3	
	High	0.2–0.3	2	
	Very high	>0.3	1	
Road-rail density	Very low	<66	2	8
	Low	66–170	3	
	Moderate	170–260	4	
	High	260–360	5	
	Very high	>360	6	
HCI	Expectable condition	<83	4	10
	High	83–89	5	
	Very High	>89	6	
LU/LC	Agriculture land	Base on soil microbial communities, organic carbon and moisture in different dry tropical ecosystems (Noamundi) by Monty and Patel (2014)	2	30
	Scrub land – dense		1	
	Scrub forest		1	
	Open forest		1	
	Forest blank		4	
	Gullied land		3	
	Query/mining		6	
	Tree clad		4	
	Settlement		5	
	Stony waste/rock outcrop		5	
	River		3	
	Tanks		3	
	Scrubland – open		4	
	Brick Kiln		6	

The environmental sustainability distribution map shows in Figure 10. This map provides an idea about aerial distribution of environmental sustainability of the study area. The mines and rocky area shows very low sustainability due to high surface temperature, steep slope, low organic carbon and moisture, etc. The moderately sloppy, settlement, road-rail communication area shows moderate sustainability. On the other hand, the agricultural and forest cover area indicating high to very high sustainability due to low surface temperature, more organic carbon and moisture, etc.

Figure 10 The superposition layout of ESI classification result (see online version for colours)



Noamundi in the study area has the least forest cover, 8232.98 (Scrub Land – Dense: 930.66 ha., Scrub Forest: 672.08 ha. and Open Forest: 5489.94 ha.) hectares with 584.00 hectares query/mining and 372.45 hectares forest blank. The bare land or mining land related to high LST and high LST may increase uncomforted condition (environment), climatic environment. The mines, build up, settlement, rocky outcrop, etc., the non-vegetated area may uncomfortable because of less vegetation cover. Therefore, it is found the relationship between the spatial distribution of LU/LC, vegetation and mining are related to each other.

5 Conclusions

To accost all the reflection and discussed of this study, an integrated attempt in both primary and secondary environmental regime is necessary to evaluate the overall quality. The better sustainability of ground water can be seen in south-west part compare to other portion of study area. The water quality in the northern site is poorer than in other regions as the whole drainage pattern follows through the mining region towards the north (Beterkea area). The character of sustainability of water resources based on surface and sub surface water quality were good near Bara Baljori, Merelgara, Noamundi basti, Noamundi colony, Chatti Buru etc. The overall sustainability has been observed towards the north-west direction based on the initial environmental parameters of the study area. The major findings have been drawn through the GIS based weight overlay methods and quantitative analysis.

A conventional approach of EIA, which basically considers air and noise quality, water quality that characterises the surface and sub-surface water of the projected area, indicates limited relevance of environment. Environmental sustainability represents an inadequate opportunity for the environmental intensification of the small-scale mining area of Noamundi. This geospatial technique has extensively assessed environmental impacts at the local level. An environmental conceptual model influenced by geospatial technique has been developed using information from various environmental datasets for future sustainability assessment, mitigation and management. The use of GIS not only improves the overall EIA, management and mitigation process but also provides novel mapping techniques which include an ecological approach. Moreover, GIS is a software based meant that can analyse, manage and present all types of geo-physical and geo-environmental data. The type of model used in this study can also be implemented on same geo-environmental zones in small scale but large scale analysis needs extensive field survey along with other parameters.

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