International Journal of Environmental Engineering– IJEE
Volume 2 : Issue 1 [ISSN : 2374-1724]
Publication Date: 30 April, 2015

Stabilization of Integrated Sponge Iron Plant Waste Dump through Ecological Restoration Approach- A Field Study

S. K. Maiti[1*], D. Maiti[1], P. S. Rana[2], M. L. Sahu[2]

Abstract— **The dump material consists of fly ash- slag- dolochar, accretion, drain dust which is highly alkaline, very loose and powdery, causing massive pollution to the surrounding. The run-off water was totally black, nearby vegetation was fully dust coated and always there was cloud of dust moving along the wind direction. The dump height was 35-40 m (in some places even 60 m), with steep slope (>70-80^o), no space was available for regrading/terracing so that dump slope could be reduced. The total area of waste dump was 14 ha, which has to be ecologically restored. During technical restoration, 75-100 cm thick topsoil was spread and blanked with high tensile strength coir-mat. Once slope was blanketed with topsoil and coir-mat, grass-legume seed mixture was sown. Seed mixture was consist of both annual and perennial fast growing legumes, grasses and high biomass yielding annual shrubs. About 3^o slope was given in the top of the dump to collect run-off, and developed community park and fruit orchards. Now part of the community park is being developed as "Helipad" because, landing surface is above the canopy height of tree. Average cost ecorestoration was US$ 11900 ha^{-1}, out of which 41% contributed by excavation of transportation of topsoil, 23% for coir-mat and 16% was running cost of for heavy earth moving machinery. The study concluded that waste dump with loose steep slope can be restored by seeding with grass-legumes mixture blanketed with topsoil and coir-mat.**

Keywords*- Topsoil; coir mat; grass legume seeds; cost of ecorestoration.*

1. Introduction

India ranks first and produced more than 27% of the world's DRI (Direct-reduced iron) of 23.4 million tons (Mt). Worldwide DRI production is increasing with tremendous pace, e.g., in 2013, DRI production was 75 Mt which was more than 85% greater than that of 2001[(1)]. The principal raw materials used for the sponge iron production are iron ore, non-coking coal, and dolomite and solid waste produced as slag, dolochar and fly ash, which is dump in the vicinity of plant.

In the present study, a challenging task was undertaken to ecologically restored a huge waste dump covering 14 ha ground area, height of 35-40 m, without any intermediate benching with steep slope (> 70^o). Practically no space was available to reduce the slope. The sequence of restoration operation was (i) regrading of dump, (ii) blanketing with topsoil, (iii) covering the slope with coir-mat, (iv) sowing of grass-legume mixture on the slope, (v) construction of drainage, (vi) watering arrangement, and (viii) aftercare and maintenance of site for 3 yrs.

Use of good quality of topsoil is essential for ecorestoration success, and sources are either stockpiled or simultaneously excavate and reuse[(2)]. In the present study topsoil was used in a concurrent manner. Generally, geotextiles/coirmat is used to protect slopes by preventing erosion and creating favourable soil conditions for revegetation, especially in the initial stage of slope restoration, and the natural geotextile mat (jute mat or coir-mat) is preferred since it is more effective and more environmental friendly[(3)]. It can markedly increase vegetation cover and protects surfaces against evapo-transpiration and conservation of moisture, which increases survival of young seedlings during hot summers. In the present project, as there was no scope exists to reduce slope of the dump, entire slope was covered with high tensile strength coir-mat (slope length 50-70 m).

Use of grass-legume mixtures to stabilise steep slopes has now become a widely used technique. Studies have shown that *Pennissetum pedicellatum* along with a forage legume *Stylosanthes humulis* can successfully restore a degraded site [(4,5)]. This mix plantation creates a nitrogen balance in the soil, and decomposition of dry plant parts creates nitrogen rich litter and mulch. Grasses have extensive fibrous root systems which can reduce erosion by holding the loose soil particles, can tolerate adverse soil conditions and form mulches after drying[(4)]. Generally perennial forage type legumes are used but native species show greater improvement in soil fertility [(6)]. Legume litter has a high N concentration, thus has high early decomposition rates, which underscores its distinctive role in ecosystems and nutrient cycling. Its presence also improves litter quality and decomposition[(7)] and certain legume species assist nitrogen transfer to co-occurring non-leguminous plants. In nutrient-poor soils, legumes have a competitive advantage over the other species in the community. Study confirmed a higher decomposition rate of legumes over grasses. Therefore, in this project, during the seeding of grass-legume mixture, a higher percentage of legumes seeds were used, which will accelerate nutrient

[1]Department of Environmental Science & Engineering,
Centre of Mining Environment, Indian School of Mines, Dhanbad 826 004, India[2]Nalwa Steel and Power Limited (NSPL), Taraimal, Raigarh, Chattisgarh, India *Corresponding author:

cycling, improve the quality of soils, biodiversity and sustainability of the plant community. Mulching can facilitate seedling establishment, break seed dormancy and low mulch rates can increase native plant establishment during critical first year, as they are able to overcome microsite limitations [(8)]. In addition, formations of mulch create organic matter for soil and conserve moisture [(3)].

Most of the integrated DRI plants in India are located in the remote area within the forest. Due to loose and homogeneous nature of waste, stabilization of waste dump always a challenging task. At the same time, scientific eecorestoration is essential for building the company image to the neighborhood and regulatory bodies. In the present study, the end land use has been developed as Community Park (top of the dump) by covering soil, slope was stabilized by blanketing with coir-mat and revegetated with grass-legume mixture, and entire run-off was collected by through a drainage system. The aim of this study are: (1) to investigate the changes in physical and chemical properties of waste dump surface due to growth of grass-legume mixture, (2) effectiveness of use of coir-mat and grass legume seeds for stabilization of steep slope, and (3) cost estimation for ecological restoration.

2. *Materials and methods*

2.1 Study area

The waste dumps of an integrated sponge iron unit was located in Raigarh district, Chattisgarh, India, falls between latitudes 22°00'51"N and 22°02'10"N and longitudes 83°22'35"E and 83°23'27"E, covering an area approximately 14 ha. Wastes generated during the processes were dumped at the outskirts of plant surrounded by the Protected Forest. The height of dump ranged between 40-50 m with steep slope (> 70-80°), unstable, causing serious environmental problems. An aerial photograph of the original waste dump is shown in **Fig. 1**. The characteristics of waste sample are given in **Table 1**.

Fig.1: Aerial view of waste dump before ecological restoration

TABLE 1 CHARACTERISTICS OF WASTE MATERIALS (N=7)

Parameters	Composite sample	fly ash
pH (1:1); (w:v)	12 ± 0.2* (11.8-12)	8.7 ± 0.3 (8.4-9)
EC (1:1), dS/m	4.5 ± 0.2 (4.4-4.7)	2.0 ± 0.1 (1.9-2.1)
Na (ppm) (1:10)	464 ± 14 (454-484)	257 ± 5 (251- 264)
K (ppm) (1:10)	84 ± 3 (81-88)	211 ± 22 (180-227)
Ca (%) (1:10)	2.7 ± 1 (2.62-2.82)	2.6 ± 0.3 (2.3-3)

*Mean ± SD; (Minimum- Maximum). EC: electrical conductivity

Grass-legume seeds consisting of *P. pedicellatum*, *S. hamata*, *C. juncea* and *S. sesban*, *H. sabdariffa* (high biomass yielding non-leguminous under shrub) were used for the revegetation of slopes of the waste dump. As slope was very steep, initially covered with coir-mat, then topsoil was spread over it to create a substratum for germination and growth of seeds. Three rows of tillers of *Cymbopogon citratus* were planted along the berm (edge) of the dump. Additionally, one row of *Azadirachata indica* seeds was sown at a spacing 3 m interval on the berm. All these activities were carried out before the onset of monsoon to protect the soil and seed mixture from erosion. Seed germination test for grass-legume mixture was conducted in the laboratory controlled conditions to test the viability of seeds and time taken for germination by standard test method [(3)]. Leguminous seeds has low dormancy period and within 6 days, 60% of seeds were germinated and rest within 10 days. Whereas, grass seeds takes longer time to germinate. Approximately 3350 kg of seed mixture was used and sown in 3 times at an interval of one week. The composition of grass-legume seed mixture is given in **Table 2**. Coir-mat having high tensile strength, rich in lignin (46%), about 1.5 - 2 cm thick, inter-weaved with coconut-coir, fixed by nylon net; about 1 m width and 30 m/ 50 m length rolls were used for the stabilization of the slope, shown in **Fig. 2**.

Fig.2. View of the slope of waste dump after covering with soil and blanketing with coir-mat.

TABLE 2. COMPOSITIONS OF GRASS-LEGUMES MIXTURE

Botanical Name (Common name)	Plant characteristics	Shoot length (cm)	Root length (cm)
Stylosanthes hamata (Caribbean stylo)	Perennial creeper shrub, N fixing	75 ± 4*	15 ± 1
Crotalaria juncea Lam.) (Shon)	Tall herb, annual, nitrogen fixing	214 ± 12	27 ± 2
Cymbopogon citratus (Lemon grass)	Aromatic grass, perennial	289 ± 17	29 ± 1
Sesbania sesban (Egyptian pea)	Shrub, annual, N fixing	64 ± 4	24 ± 1
Hibiscus sabdariffa (Rosemallow)	Under shrub, annual	27 ± 1	24 ± 1
P. pedicellatum (Dinanath grass)	Grass, annual	263 ± 11	25 ± 1

*(Mean ± SE)

Slope was blanketed with soil, seeded with grass-legume mixture and covered with coir-mat. Again seeds of grass-legume mixed with soil and farm yard manure (FYM) (soil: FYM; 1:1) were respread. All these activities were carried out before monsoon. About 2000 nos of tillers of *C. citratus* were planted along the berm of the dump in a 1-m interval, and towards inner side, one-row of *A. indica* plantation was developed by seeding. The vegetated slope was irrigated in the summer months. Plant growth monitoring, soil sampling and analysis were done seasonally. Reinforced concrete drainage was provided to drain runoff from top-surface of the dump, while seepage from the slope was drain-out through earthen channel.

2.2 Sampling and analysis

Sampling sites were selected at the top and bottom portion of slope and berm of the dump. The rhizospheric soil samples (0–15 cm) were collected randomly from rhizosphere of grass and legumes by laying random quadrates (1 m x 1m). A reference site (here nearby forest dominated by *S. robusta*) was selected. Samples were air dried for a week, sieved through a 2-mm sieve, reweighted to record the proportion of soil fraction (< 2mm size), labeled and kept in air tight sampling bags for further analysis[9]. The soil pH and electrical conductivity (EC) were determined in soil: water suspension (1:1; w/v) with a pH and a conductivity meter respectively[9]; field moisture by gravimetric method[9]; Organic carbon by rapid dichromate oxidation technique [10]; available nitrogen by the alkaline potassium permanganate method[10]; available phosphorous by Bray's method [10]; exchangeable cations (Na, K, Ca) were extracted by 1 N ammonium acetate solution (1:10 w: v;) and determined by flame photometer[10]; cation exchange capacity (CEC) by Na saturation method (10); base saturation was calculated as the proportion of the CEC occupied by basic cations[10]. Total carbon and nitrogen were determined in the CHNS elemental analyser (Euro EA) using CRM soil # 3 as standard reference material. Soil dehydrogenase activity (DHA) was determined as pre the method of Casida et al. [11], and the activity was expressed as the amount of tri phenyl formazon (TPF) released.

Growth measurement of plants species *S. hamata*, *C. juncea*, *P. pedicellatum*, *C. citratus* were expressed as dry biomass per m^2. Seven replicates of each species were randomly sampled by laying random quadrate of $1m^2$. Plants were uprooted, shoot and root length was measured, and biomass of each plant was determined dry weights basis (80^{o}C for 48h).

2.3. Statistical analysis

Soil properties were grouped and summarized according to the vegetation type. Statistical differences were tested using one-way and two-way analysis of variance (ANOVA) of SPSS (version 20.0 for Windows). Duncan's multiple range tests was used for mean separation when ANOVA showed statistically significant difference at ($p < 0.05$) and ($p < 0.001$). Mean values of all properties along with their standard error (SE) are shown in relevant tables.

3. Result and discussion

3.1. Growth of grass-legume mixture

Entire slope was covered, stabilized and erosion is controlled with lash green growth of *Stylosanthes* legume. It was observed that, creeper nature of *Stylosanthes* formed 30-40 cm carpet above the coir-mat, and underneath decomposition of leaves contributes organic matter and humus**.** Dominance of *Stylosanthes* on the slope was observed, after 2nd yr onwards and substantially reduces abundance of *P. pedicellatum*. *C. citrates* and *S. sesban* produced maximum total biomass followed by *P. pedicellatum* and *S. hamata* **(Fig. 3)**. Decomposition of biomass provides nutrients and dead stem acts as mulch materials, which ameliorate microclimate of the slope-surface. Re-germination and luxurious growth of *H. sabdariffa*, a prickly annual herb, at the toe of restored dump during rainy season also observed. Decomposition of biomass of *Sesbania* and *Hibiscus* provides nutrients and dead stem acts as mulch materials, which ameliorate microclimate of the slope-surface**.** Dense vegetation covers development on the berm of restored dump is essential for direct draining of rainwater to the slope, which will also adds protection and stabilization slopes. At the berm of restored dump, 2-rows of Lemon grass which has been planted in previous year, which are growing excellently. In the 2nd years itself, thick vegetative barrier has developed by healthy growth of lemon grass (2 rows) and *S. sesban*. Invasion of open space available at the top surface of dump by *Stylosanthes* was observed after 2nd yr onwards. Berm of the dump was stabilized with massive growth of *C. citrates*, *C. juncea* and *A. indica.*

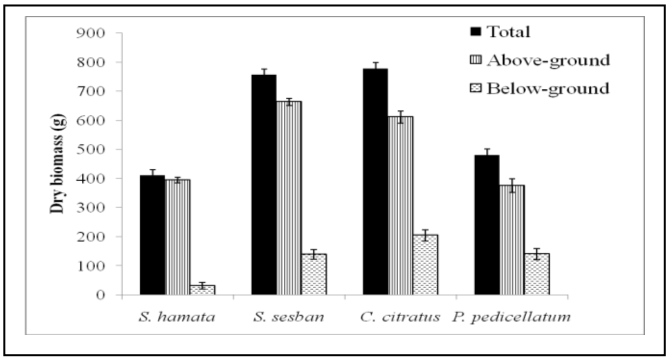

Fig. 3. Distribution of biomass of grass-legume species

3.2. Soil Characteristics in restored site

Soil fraction ranged between 48 - 56% which is lesser than nearby reference forest site (73%). Field moisture was found between 3.2 - 4.6% and highest was observed under *S. hamata* (4.6%) due to formation of dense green cover over the surface which is still less than forest soil. however, during post monsoon sampling, as high as 16% moisture content was observed under *S. hamata*. Soil pH (1:1) was found in the acidic range due to acidic nature of the blanketing topsoil material. Highest SOC was observed in forest soils; 9.7 g kg^{-1} and that of the *C. citratus* and *S. hamata* rhizosphere (4 g kg^{-1}). The mineralizable N content in the soil was also affected by the species used for vegetation, and highest was found in *S. hamata* rhizosphere; (72 mg kg^{-1}), which is still lower than forest soils (98 mg kg^{-1}). There is a significant variation of

Indian School of Mines, Dhanbad, India

available N in soil under grasses and legumes. Total N constitutes more than 90% of the soil N pool; while in forest soil total N constitutes more than 97% of the N pool. Higher percentage of mineralisable N in the restored dump is due to the higher microbial activity and N fixation by legumes. Nitrogen accumulation is controlled by OC input and N fixation, while P content is determined by the SOM, pH of the soil substrate and weathering process. Under all the grass legume species, available P was found lesser than the forest soil (3.26 µg g^{-1}) and were found to differ significantly at 5% level. Available K ranged between 114 and 153 mg kg^{-1} which indicates medium fertility.

3.3 Development of soil horizon

Development of soil horizon formation was studied by changes in soil profiles of 0-5, 5-10 and 10-20 cm. Increase in soil fraction and moisture content was found in lower slope region due accumulation of fine soil particles, soil organic carbon (SOC) and increase in legume cover. Growth of grass-legumes significantly changed SOC content and available N restored dump. In the 0–5 cm, the SOC in the *S. hamata* in the lower slope part of the waste dump was 33% higher than that in the upper slope region but 25% less than reference forest soil. In the 5-10 and 10-20 cm soil profile, no significant difference was observed in SOC accumulation. Significant increase in the concentration of easily mineralizable N was found in 0-5 cm profile and close to a value of reference site indicates importance of legumes for restoration of nitrogen economy in the waste dump. Increasing soil depth reduces soil dehydrogenase activity (DHA) as highest microbial activity is observed in the surface layer of soil profile (Mukhopadhyay et al., 2013).

3.5. Amelioration of soil temperature due to mulch and litter accumulation

Accumulation of dry mulch in a quantity 13 -15 tons ha^{-1} was observed on the waste dump, which was higher than the reference forest site (8.16 tons ha^{-1}) **(Table 3).** Higher accumulation of dry mulch was due to massive growth of the leguminous species (*S. sesban* and *C. juncea*). A significant reduction in the rhizospheric temperature of 12 - 17% was observed under mulches cover, while it was hardly 4% decrease on bare surfaces. Nearby reference forest site also showed 12% reduction in soil temperature under litter (at 10 cm depth). This indicates dry mulches not only in enhance soil organic carbon but also their dry parts ameliorate surface temperature during summer and help conserving moisture.

TABLE 3 ACCUMULATION OF DRY MULCH (N=9)

Location	Vegetation cover	Quantity (ton ha^{-1})
Mulch in upper slope	*S. hamata,C. juncea*	14.76 ± 1.27
Mulch in lower slope	*S. hamata, S. sesban*	12.62 ± 1.08
Litter fall in forest floor	*S. robusta*	8.16 ± 0.81

3.7 Estimation of the cost of ecological restoration

Topsoil regarded as strategic resource for successes of any ecological restoration project. Before salvaging operation of topsoil for concurrent use, inventory (quality and depth) and time of scrapping is essential. In the present study, topsoil was excavated (about 1m deep) from newly constructed dumping site and transport to the waste dump, which constituted 41% of total cost. Running cost of Heavy Earth Moving Machinery (HEMM) accounts 16% of total cost, which again depends on efficiency of use of HEMM and supervision. Third major cost involved purchasing of coir-mat @ US$ 1.3/ m^2, which depends of technical requirement and type of coir-mat. In present project, major challenge was stabilize the very slope (>70 ^{o}) with 50-60 m straight height without any bench. Slope could have been easily stabilize, if dump slope is reduced to <28-30^o by creating 2 additional benches of 15 m height. Total biological restoration components constituted 17% of total cost, which includes aftercare and maintenance for 3 years. Details break-up of activities and cost incurred is given in **Table 4**.

TABLE 4. COST OF ECOLOGICAL RESTORATION

Activity Quantity	Cost (US$)
Technical or Engineering restoration	
[1]. Running cost of dozers, loader, pockland for grading of dump surface, salvaging of topsoil, transportation, topsoil application on slopes, compact soil on the dump surface and provision of drainage	26,667 (16*)
[2]. Blanketing of waste dump with topsoil, flat surface of dump (80-100 cm thick) and in slope (20-50 cm thick) - 50,000 m^3 (approx)	68,333 (41)
[3]. Blanketing of slope with Coir-mat: 1.5 - 2 cm thick, inter-weaved with coconut-coir, fixed by nylon net; 1 m width with 30 m/ 50 m length- 30,000 m^2 (approx)	39,000 (23)
[4]. Hooks used to anchor coir-mat on slopes; "U" shaped iron nails, used at an interval of 1 m on the slope of the dump to fix the coir-mat.	3,333 (2)
Biological Restoration	
[5]. Grass-legume seeds: *S. hamata, C. juncea , H. sabdariffa, S. sesban, P. pedicellatum* etc. - 3350 kg; Tillers of *C. citrates* -10,000 nos; Seeds of *A. indica* -5 kg.	10,217 (6)
[6]. Aftercare and maintenance of site for 3 years which includes, watering arrangement during lean seasons, provision of watch guard, day to unskilled labour charges, expert advice etc.	19,167 (11)
Total cost	166,717

*as % of total cost; conversion 1US$ = Indian Rs 60

4. Conclusion

The ultimate aim of any ecological restoration work is to stabilize the slope as well as dump, mimic the landscape to the surroundings, reduce air and water pollution and regenerate economy from the waste site to make the project sustainable. The restored site now becomes the demonstration sites to many scientists, regulatory bodies and steel industry. Presently 5 ha surface area is used as community parks, picnic spots, as well as helipad (because the height of flat surface is above the tree canopy line) and rest is developing as fruit orchards. View of ecologically restored dump is shown in Fig. 4. Conclusions of this study are as follows:

Fig.4 Distance view of ecologically restored dump

1) Grass-legume mixture can be used as an initial coloniser for stabilisation of very steep slope, after blanking with topsoil and coir-mat. Addition of fast growing, annual, high biomass producing yielding species is essential to increase the soil organic matter and moisture.
2) Fast growing species can form massive green cover in very short time and plays important role to reduce erosion and conserve moisture.
3) Initial year both *Stylosanthes- Pennisetum* colonise together, but after second years onwards, *Stylosanthes* cover the entire slope surface and eradicate the *Pennisetum*. Natural colonisation of other herbaceous leguminous species also observed.
4) Short life cycle of *S. sesban* and *C. juncea* can play a role of green manure for the soil as it would add organic carbon and nitrogen to the soil after drying. This in turn would also be economic.
5) *S. hamata* is very effective forage legume which uplifts the nitrogen economy of degraded soils in a short period of time. These legumes can effectively influence the nitrogen cycling in soils due to presence of root nodules which fixes atmospheric nitrogen from air.
6) Aftercare and maintenance of the ecorestored site, particularly watering and protection of cattle is essential.

5. Acknowledgement

The authors would like to thank the Indian School of Mines (ISM), Dhanbd for providing her research fellowship and other research facilities during this study. The authors are grateful Nalwa Steel and Power Limited (NSPL), Raigarh, India, Chattisgrah Environmental Conservation Board (CECB), Raipur, M/s Sri Venkateshwara Fibre Udyog Pvt Ltd, Bangalore.

References

[1]. Midrex. “World direct reduction statistics 2013”, 2014. www.midrex.com/uploads/documents/Statsbook2013.6.5.14.pdf
[2]. Maiti, S. K., Ecorestoration of the Coalmine Degraded Lands. Springer, New York, 2013.
[3]. Shao, Q., Gu, W., Dai, Q., Makoto, S., Liu, Y., “Effectiveness of geotextile mulch for slope restoration in semi-arid northern China”. Catena, 116, pp.1-9, 2014.
[4]. Maiti, S. K., Saxena, N. C., “Biological reclamation of coal mine spoils without topsoil: an amendment study with domestic raw sewage and grass legumes mixture”. Int. J. Surf. Min. Reclamat. Environ. 12, pp. 87 – 90, 1998.
[5]. Araujo, I.C.S., Costa, M.C.G. “Biomass and nutrient accumulation pattern of leguminous tree seedlings grown on mine tailings amended with organic waste”. Ecol Eng. 60, pp. 254-260, 2013.
[6] Ledgard, F. S., Steele, W. K. “Biological nitrogen fixation in mixed legume/grass pastures”. Plant Soil, 141, pp. 137 – 153, 1992.
[7]. Scherer-Lorenzen, M., “Functional diversity affects decomposition processes in experimental grasslands”. Funct. Ecol. 22, pp. 547–555, 2008.
[8]. Mollard, P. O. F., Naeth, A. M., Cohen-Fernandez, A.”. Impacts of mulch on prairie seedling establishment: Facilitative to inhibitory effects”. Ecol. Eng. 64, pp. 377-384, 2014.
[9]. Maiti, S. K., Handbook of Methods in Environmental Studies (Vol 2), ABD Pub, Jaipur India. 2003.
[10]. Jackson, M. L.. Soil chemical analysis, PHI Pvt. Ltd., New Delhi, 1973.
[11]. Casida, L. E. Jr. “Microbial metabolic activity in soil as measured by dehydrogenase determinations”. Appl. Environ. Microbiol. 34(6), pp. 630–636, 1977.
[12]. Mukhopadhyay S., Maiti S.K., Masto R. E. “ Use of Reclaimed Mine Soil Index (RMSI) for screening of tree species for reclamation of coal mine degraded land”. Ecol. Eng. 57, pp. 133-142, 2013.

About Authors (s):

Dr S.K Maiti, working as Professor at ISM, Dhanbad, India since 1988. Published one book on “Ecorestoration of coalmine degraded lands (Springer 2013). Published more than 150 papers and guided several Ph.D on ecological restoration.

Deblina Maiti, working as Junior Research Fellow (JRF) at Indian school of Mines, Dhanbad. She did her Msc. Biotechnology and Gold medalist of the year 2012. Qualified GATE in 2012.

Shri P S Rana, Director, Nalwa Steel and Power Limited (NSPL), Raigarh, India. He did M. E (Power System) from Roorkee University, have 38 years of rich experience in the power and steel industry in India.

Shri Manik Lal Shau, Head-OHSE, NSPL, Raigarh, India since 2004. He did M. Tech (Env. Sc. & Engg.), MBA and PDIS. He has expertise in Water & Wastewater Mgmt., Environment Mgmt., Improvement in Industrial Safety Status, and Utilization of Solid Waste in Environmentally Sustainable manner.