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M. Sundararajan, D.Litt., Professor, Senior Principal Scientist and Professor (CIMFR-AcSIR)
Natural Resources and Environment Management
CSIR-CIMFR, Dhanbad, Jharkhand, India, 826015
V. Vambol, DSc, Associate Professor, Professor of the Department
S. Vambol, DSc, Professor (Full), Head of the Department
National University of Civil Defence of Ukraine
Chernyshevska Str., 94, Kharkiv, Ukraine, 61023
N. Kumari, M.Tech Student
Department of Civil and Environmental Engineering
BIT Mesra, Jharkhand, India, 835215
I. Ansari, Ph.D. Research Scholar
Academy of Scientific and Innovative Research (AcSIR)
CSIR-CIMFR, Dhanbad, Jharkhand, India, 826015

NUTRIENT DISPERSION MODELING OF COAL OVERBURDEN DUMPS FOR RECLAMATION AND SUSTAINABLE MANAGEMENT

This study presents an innovative approach for the effective reclamation and management of coal overburden dumps. The study reveals that the existing and liberated nutrients due to natural phenomena are washed away by the run-off in the form of leachate during resting period of 5 years. The concentration of organic matters and organic carbon are also decreasing and as the result of these phenomena, the electric conductivity also decreases. The nutrients on the top layer starts increasing during 6th years while nutrient amendment was done just before plantation by means of bio-degradable manures on the top-soil amended on the dump materials for reclamation purpose. After plantation, it has been observed that the nutrient loss on the top-layer is very less due to plantation as the roots control the soil erosion. However, there is no significant improvement in the nutrient refilling the dump as the leaves fall is not much. The nutrient status of the dump after plantation has been studied for different ages 6…10, 11…15, 16…30 years using the predictive model and the probable reasons have been well discussed. The study concludes that there are no soil amendments after 10 years but the plants are found to be capable to significantly refill the nutrients as there is a huge quantity of leaf-drops from the planted trees and become compost after going through the process of decaying to serve the plants. In this way, the plants survive without requirements of nutrient amendments meeting its nutrients themselves and such a capability of self-satisfying characteristics of plants through nutrient transaction between soil and plants go on as a cyclic phenomenon through the natural process due to recurrent seasonal changes. As a result of the combined effect of penetrated plant roots in all the directions across the soil and dump materials and the increased organic matter decreases the bulk density and increases the water holding capacity.

Keywords: reclamation of coal overburden dumps; nutrient dispersion modeling; overburden dump management.

1. Problem statement.

Opencast mining leads in removal of huge quantities of overburden, dumping and buckling of the excavated area. The newly created coal overburden dumps are physically, chemically and biologically imbalanced and lack nutrients for supporting the regeneration of vegetation potentially on the dumps. As the result of the nutrient deficiency in the dumps' materials, the chances of survival of the plant species is hindered and the survival rate is significantly minimized. Further, the nutrients of coal overburden dump are considerably washed away by the run-off and drain to the nearby water bodies in the form of leachate and contaminates severely. In some cases, the leaching effluents may flow to the groundwater aquifers through porous medium and contaminates drastically if the dumps are laid over faults or fractures without proper selection of the sites through a scientific study. Hence the poor management of overburden dumps causes not only the instability of slope in an opencast mine but also pollutes the surface water as well as groundwater quality. Therefore, there is a need for developing an appropriate nutrient dispersion model for predicting the nutrient status at different ages of the future so that suitable strategies might be devised for protecting the plants growing over the surface of the overburden dumps for an enhanced environmental management in the mining areas. The main objective of the present study is to carry out nutrient dispersion modeling for the coal overburden dumps, which would be useful for applying biotechnological treatments to stimulate the plants' growth over the dumps. The various tasks of the above objective are (i) to carry out sampling and analysis of the physico-chemical parameters of one of the coal overburden dumps of Vishwakarma Opencast Coal Mining Project in the Jharia Coalfields in order to establish mathematical relationships between the physic-chemical characteristics of the dumps and (ii) to predict nutrient status of the dumps of different ages through nutrient dispersion model.

2. Analysis of the recent researches and publications.

Surface mining activity cause several ecological problems like change in landuse pattern, land degradation, alteration of topographical features, disturbance to plant communities and may create biological deserts. Mining operations by open method creates the need to remove removal of huge quantities of overburden, dumping and buckling of the excavated area. Mine spoil poses unfavourable conditions for the soil microbe and plant growth, due to its low organic matter and adverse soil chemistry, poor structure (either coarse or compact) and high isolation from vegetation (Singh, 2015; Ghose, 1996). A study reports that the growth rates of the plants in height, diameter and volume increments are positively related to foliar N and P concentration (Singh, 2006). Substantial increase in rate of accumulation of waste materials in recent years has resulted in greater height of dumps to minimize ground cover area. Consequently, this has given rise to the danger of dump failures, gully erosion and various associated environmental problems (Campbell, 1992; Rai et al., 2009). To rehabilitate such drastically disturbed ecosystem to achieve sustainable development is a challenging global problem. Reclamation is the process of accelerating the recovery of land from disturbed conditions. In India, the reclamation of mined out areas, especially the overburden dumps is a new area of research and very little work has been done so far. The shape, size, slope and method of formation of the mine spoil heaps have an effect on the infiltration of rain water, oxygen transport, oxidation of pyritic and carbonaceous materials and natural process. Under India condition where the temperature during summer goes as high as 45 °C and as low as 3…4 °C during winter and in between one may have heavy rains to the tune of even 300…400 mm in 24 hrs during monsoon, causing high risk of physical, chemical and biological changes followed by leaching of metallic ions from acidic dumps. Such environmental factor often cause higher rate of discharge of pollutants in the runoff system.Revegetation is one of the widely used techniques for controlling erosion and stabilization of dump slope (Akers and Muter, 1974) and thereby maintaining ecological equilibrium in the area (Jorgensen, 1994).

In Indian mining areas, biological stabilization of a dump slope has specify that biological reclamation with grass and vegetation should be considered for long term stability of this coalmine dump. Grasses have superior soil binding capacity and its help to manage soil erosion and recover soil stability. During the characterization of different coal overburden dumps with the specific age, the account of nitrogen (N), phosphorus (P) and potassium (K) ratio is considered. This gives the fertility status of the overburden dump. It has been found that low availability of N, P and K are also the cause of poor plant growth. During opencast mining various mine spoils or overburdens are created which lacks in nutrients and have low water holding capacity. These are also chemically, physically and biologically unstable and deficient. Due to heavy metal toxicity of mine spoils it inhibit uptake of nutrients, plant growth and microbial population. Hence it requires to develop a separate management plans for restoration or reclamation of varying kinds of landscapes and finally post mine land use planning (Maiti and Saxena, 1998; Singh and Jha, 1993). Study has been conducted in different aged reclaimed coalmine overburden dumps of Jharia Coalfield to show the effect of mine soil characteristics, host specificity, age of plantation and profile depth on spore density (Mukhopadhyay and Maiti, 2010). A study assess the changes on nutritional and microbial characteristics brought about by afforestation on overburden dumps of coal mine spoil at Jhingurda, Singrauli of Madhya Pradesh. The results were found encouraging with respect to amelioration of sites undertaken for rehabilitation activity. (Chaubey et al., 2012). A study reports that revegetation facilitates the development of N-fixing bacteria and mycorrhizal association, which are vital for maintaining the soil quality by mediating the processes of organic matter turnover and nutrient cycling (Sheoran et al., 2010). Productivity of soil can also be increased by adding various amendments such as hay, saw dust, bark mulch, wood chips, wood residues, sewage sludge, animal manures as they stimulate the activities of bacteria and mycorrhiza that provide the nutrients such as N, P, organic matters (OM) and organic carbon (OC) to top soil.

Mathematical modeling is the most important tool to understand the complexity of the soil-plant relation, which would lead the bio-reclamation experts to devise suitable nutrient budget for successful reclamation of coal overburden dumps. Because, several case studies on reclaimed coal overburden dumps reveals the truth that 40…60 % of species only survive after plantation even after proper care and suitable soil amendments. After investing a huge amount of project fund, 60…40 % failure is always being faced by the mining industries. Therefore, for a long period of time, the mining industry has felt the need for modeling the nutrient dispersion through appropriate mathematical approach for achieving optimized survival rate of the species in reclaiming the coal overburden dumps in effective and economic means. Therefore, an attempt has been made to develop a nutrient dispersion model.

3. Statement of the problem and its solution.

3.1. Study area.

One of the opencast projects in Kusunda area of Bharat Coking Coal Limited in Jharia Coalfields, namely Vishwakarma Opencast Project has been chosen for the present study. The study site is located as shown in figure 1. The dump is situated in Dhanbad district of Jharkhand state of India with longitude and latitude of 86˚24’00”E and 23˚46’00”N respectively. The topography of the area is undulating. The dump was formed by backfilling a mine quarry in 1995 with a shovel-dumper combination. Maximum dump height and slope angle are 30 m and 35° respectively.

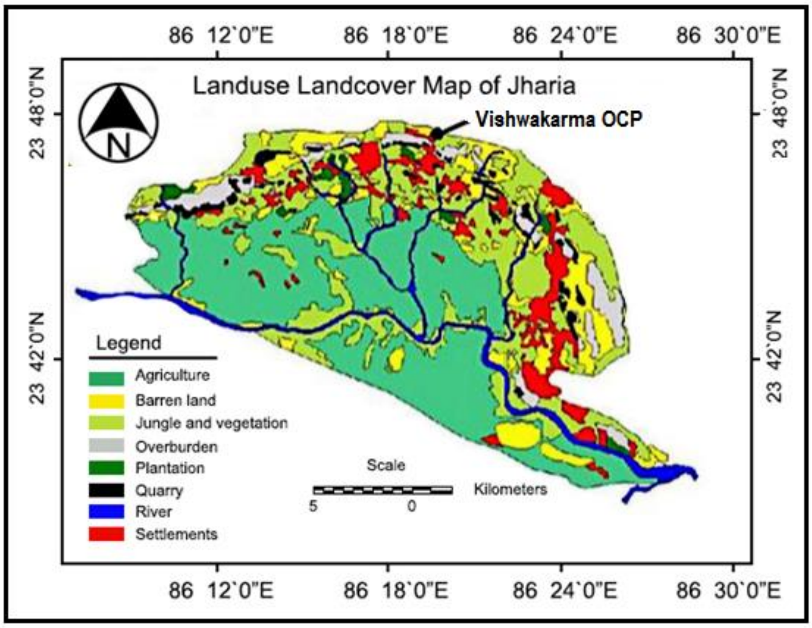

Figure 1 – Location map of study area

3.2. Spoil and Soil sampling.

Each age series mine overburden was divided into 5 blocks and from each block; five mine spoil samples were collected randomly from 0…15 cm soil depth, by digging pits (15 × 15 × 15) cm^3 size. Samples collected from each block were referred as 'sub-samples', and were thoroughly mixed to form one 'composite sample', obtained from each overburden site. Similar strategy has been followed for sampling from different age series of coal mine overburden. The sampling method of spoils commonly followed by many researchers has been adopted for the present study (Kujur and Patel, 2013; Jitesh Kumar, Amiya Kumar, 2013; Patel and Behera, 2011). All the samples were taken to laboratory air dried, mixed thoroughly, sieved and used for physico-chemical analysis.

3.3. Overburden dump characteristics.

Coal overburden dump consists of material from the sedimentary strata adjacent to the coal seams, waste produced from the sinking of shafts and other works, dirt and fragments of coal, sometimes, materials from demolished building, railway sidings and other wastes are also mixed with overburden materials. The combination of these results in considerable heterogeneity of physical, chemical and biological characteristics of most coal overburden dumps. Use of heavy equipment during mining subjects the overburden materials to a variety of compaction; which results in both desirable and undesirable changes depending upon the nature of overburden. Analysis of dump material is essential to know the status of physical structure as well as nutrients and essential chemical properties for establishment of vegetation cover. Once status is known, various amendments are possible. The secondary data of physico-chemical parameters such as bulk density (BD), water holding capacity (WHC), pH value, electrical conductivity, OC, available macro-nutrients (N, P, K) and micro-nutrients such as calcium, sodium and heavy metals were collected from available source and presented in tables 1.

The pH and electrical conductivity (EC) of the dump material and soil were determined in a suspension of 1 : 2.5 (spoil: water) using pH meter and conductivity meter respectively. The OC was determined by Walkley and Black method (Potassium dichromate reduction and titration with ferrous ammonium sulphate). Available nitrogen was estimated by alkaline permanganate method. Available phosphorus from overburden dump was extracted by Bray's reagent (spoil to the ratio of 1: 5). Analysis of Available Phosphorus, Available Potassium, Calcium, Sodium, Heavy Metals were measured using (ICP-MS) following standard methods.

3.4. Nutrient dispersion modelling.

The nutrient dispersion model is based on the mass balance equation, which is applied for the top layer where the soil and nutrient amendments are usually carried out prior to plantation. Maiti and Saxena (1998) reported the possibility of reclamation without top soil through amendments with domestic raw sewage and grass-legumes mixture. There are four major components that govern the nutrient dispersion of a coal overburden dump:

– the nutrients available naturally in the dump initially at its zero age when the dump is physically, chemically and biologically unbalanced;

– the nutrients added to the dumps through soil and nutrient amendments by means of different manures and fertilizers;

– the nutrients added to the top soil through decayed leaves from the plants and removal of nutrients from the top layer through uptakes of plants by means of roots, stumps, stems, branches and leaves.

The roots penetrate even beyond the assumed top layer thickness and uptakes nutrients and helps the plants grow up. The nutrients uptake by the leaves added to the top soil through decaying phenomenon. When the plants grow and become larger in size, the quantity of the nutrients that the plants uptake from the top soil is very negligible while compared with the quantity of nutrients uptake from the depth beyond the assumed thickness. Usually, the thickness of the layer has been assumed to be about 1.5 … 3 m as it has been observed from the field survey reveals that the minimum and maximum penetration of roots in coal overburden dumps is about 1.5 m and 3 m respectively.

The mass balance of nutrient in a coal OB dump at any time involves the following factors:

– quantity of nutrient initially existing in the dump;

– quantity of nutrient in manures applied;

– quantity of nutrient in the decayed leaves/grass/organisms found along with the top-soil after bio-reclamation;

– quantity of nutrient-uptakes by the plants and found in the plant roots, stumps, stems and leaves.

Usually the nutrients are categorized into two groups – macro-nutrients and micro nutrients. The macro-nutrients are large in quantity whereas the micro-nutrients are very rare but serious impact would caused by them on the environment. The quantity of nutrients from the first three factors are mingled together and found on the top-soil of the dump and it is assumed to be uniformly distributed in the top-soil. The forth factor incorporates the uptake quantity of nutrients by the plants growing on the dump. Let us consider a coal overburden dump as shown in figure 2.

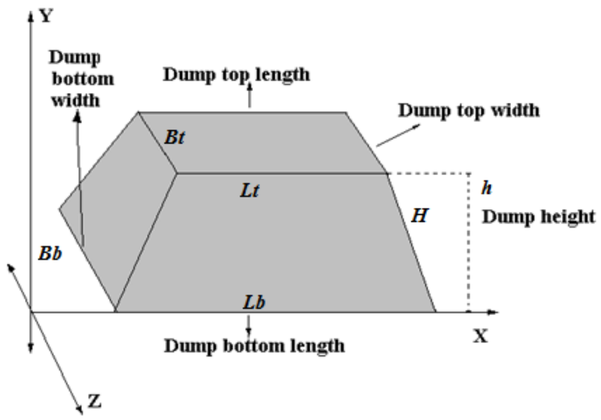

Figure 2 – Structure of coal overburden dump

If the total surface area of the dump is S and the depth of the soil amended on the dump surface is λ, then the volume of the top-soil (V_t) is approximately equals to λS. The mass of the top-soil is approximately equals to $V_t D_t = \lambda S D_t$. The mass of the decayed leaves, grass and organisms may be approximately assumed to be equal to $V_t \beta = \lambda S \beta$, where β is the concentration of decayed leaves, grass and organisms (mass/unit volume) found in the top-soil at particular time t. If the mass of the total manures or fertilisers of i^{th} year m_i, then total mass of the manure added to the top-soil till n^{th} year is equal to $M = m_1 + m_2 + m_3 + \ldots + m_n$.

Let τ be the no. of years that the dump was kept annulled for nutrient development by means of microbial and natural mechanism before plantation. The nutrient balance in the top-soil of the dump after the reclamation when the plants are healthy and having the significant volume of canopy at the age t may be given by the following equation:

$$C(t) - \frac{\alpha_t \lambda S D_t + \alpha_m \sum_{i=1}^{n} m_i + \alpha_c \lambda S \beta - \sum \alpha_i \Psi_i \gamma_i}{\lambda S D_t + \sum_{i=1}^{n} m_i + \lambda S \beta - \sum \Psi_i \gamma_i}. \quad (1)$$

The third and the fourth term vanishes when $t > \tau$. The second term also vanishes before amendment of manures with top-soil. Thus, the mass balance equation prior to the amendments of manures is $C(t) = \alpha_t$. This means the concentration of particular nutrient in the top-soil before the amendments of manures and plantation is α_t. In equation (1), all the terms in both numerator and denominator are not constant but vary with respect to the time. All the terms in the denominator represent the total mass of respective domains at particular time. But it varies with respect to the time as the plants grow stretching its roots and stems in different directions. Therefore, it is essential to convert the nutrient balance equation to be true with respect to the increase in age of the dump by incorporating suitable factors along with the terms that represent different volumes. The significance of the terms and the factors that change its value with respect to the time is given in table 2.

3.4.1. Rainfall intensity factor (term 1).

A study has presented an approach to define the month-wise rainfall intensity for estimating the number of rainfall days for each month and year (Singh, et al., 2007). The rainfall intensity r_i for the i^{th} month, which would be used as an exponent in the above mentioned factor $\exp(-r_i t)$ may be estimated adopting the same approach. Rainfall intensity of i^{th} month, r_i (where i = 1, 2, 3, …, 12) can be defined as ratio of the total rainfall in the month to the total rainfall month of the year. But the rainfall pattern varies years to years. Therefore, the monthly average rainfall of at least five years may be considered for the calculation of the rainfall intensity.

Thus

$$r_i = \Omega_i \Big/ \sum_{i=1}^{12} \Omega_i \; ; \; \Omega_i = \frac{1}{N} \sum_{j=1}^{N} \omega_{ij}, \quad (2)$$

where ω_{ij} – the average rainfall for i^{th} month of j^{th} year while the rainfall data for N years are considered.

Therefore, the rainfall factor that alters the top-soil quality is given by

$$\exp(-r_i t) = \exp\left(\frac{-\Omega_i}{\sum_{i=1}^{12} \Omega_i} t \right). \quad (3)$$

As the number of rainfall days is directly proportional to the intensity of the rainfall of the month, the approximate no. of days of a rainfall month may be rudely estimated as follows:

$$\eta_i = \frac{r_i}{\max\{r_i\}} X \, n_i, \quad (4)$$

where n_i – the no. of days in the calendar year.

Thus, number of days (N) in a rainfall year is the sum of days in each rainfall month. i.e.

$$N = \sum_{i=1}^{n} \eta_{ii} . \quad (5)$$

The value of N may vary place to place depending upon the intensity of the rainfall of the area. The leachate of a coal overburden dump flows out through run-off during the rainy season only.

3.4.2. Soil amendment factor (term 2).

In nutrient balance equation (1), n represents the frequency of soil amendments were done till the time t by means of manures/fertilizers recommended by the reclamation experts. The frequency of soil amendments varies with respect to the age of the dump. Therefore, instead of the constant n, a frequency variable n(t) as a function of time has been incorporated in the nutrient balance equation (1).

3.4.3. Leaves Generation Potentiality (term 3).

The leaves generation potentiality μ for the i^{th} month of the age t, which would be used as an exponent in the factor, The factor, $\exp(\mu_i t)$ may be estimated assuming that the leaves generation potentiality of the plant directly proportional to the ratio of canopy height to the canopy dia, and also to the ratio of the shadow area at noon time to the canopy area. Figure 3 may be referred to understand the rout, stump, stem/branch, canopy height, canopy slant height and leaves etc.

$$\mu = \left(\frac{h_c}{D}\right)\left(\frac{A}{\pi \frac{D^2}{4}}\right) = \frac{4Ah_c}{\pi D^3} , \quad (6)$$

where h_c – the canopy height, D is the canopy dia, and A is the shadow area of the canopy at noon time.

The first and second factors govern the fact that the no. of leaves that would be dropped down to the surface increases when their product increases. Thus we obtain the leaves generation potentiality factor with the time t is given by

$$\exp(\mu_i t) = \exp\left(\frac{4Ah_c}{\pi D^3} t\right) . \quad (7)$$

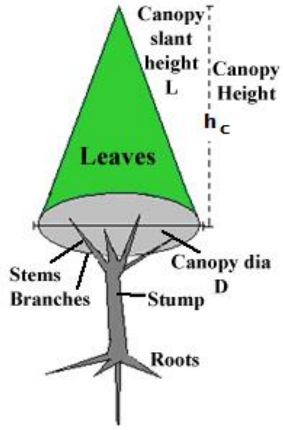

Figure 3 – Parts of a plant

3.4.4. Nutrient Uptake Factor (term 4).

The nutrient uptake capacity ϕ is directly proportional to the ratio of total biomass of roots, stump, stems and leaves to the total volume of the plants. i.e.

$$\phi_i = \frac{M_r + M_s + M_b + M_l}{V_r + V_s + V_b + V_l} ; \text{ i= 1, 2, 3, …, } \xi . \quad (8)$$

In the above equation, the volume of different parts may be calculated using geometrical formulas for calculating the volumes of standard geometrical structures. For examples, roots - cones, stumps and stems – cylinders, In fact, practically it is not possible to estimate the volumes but it is estimated approximately using suitable statistical methods and volume measuring techniques for non-symmetric structures. The integrated nutrient uptake capacity of all plants is obtained by taking the average of all the values estimated for each plant as follows:

$$\phi = \frac{1}{\zeta} \sum_{i=1}^{\xi} \phi_i . \quad (9)$$

Thus the nutrient uptake capacity factor is derived as

$$\exp(\mu_i t) = \exp\left(\left(\sum_{i=1}^{\xi} \phi_i\right) t\right) . \quad (10)$$

Thus, finally the nutrient dispersion model of a very complex form is obtained by substituting all these four factors such as rainfall that washes away the soil nutrients, nutrient amendments using manures and fertilizers, nutrient uptake by plants and leaves generation potentiality in nutrient balance equation (1) as follows:

$$C(t) = \frac{\alpha_t \lambda S D_t . \exp\left(\frac{-\Omega_i}{\sum_{i=1}^{12} \Omega_i} t\right) + \alpha_m \sum_{i=1}^{n(t)} m_i + \alpha_c \lambda S \beta . \exp\left(\frac{4Ah_c}{\pi D^3} t\right) - \left(\sum_{k=1}^{\xi} \alpha_k \Psi_k \gamma_k\right) . \exp\left(\sum_{k=1}^{\xi} \varphi_k\right) t}{\lambda S D_t . \exp\left(\frac{-\Omega_i}{\sum_{i=1}^{12} \Omega_i} t\right) + \sum_{j=1}^{n(t)} m_j + \lambda S \beta . \exp\left(\frac{4Ah_c}{\pi D^3} t\right) - \left(\sum_{k=1}^{\xi} \Psi_k \gamma_k\right) . \exp\left(\sum_{k=1}^{\xi} \varphi_k\right) t} \quad (11)$$

where t – time in month; C(t) – concentration of the nutrient at time «t»; N – total number of plants surviving at time t; ξ – No. of parts considered in plant such as root, stump, stem, branch and leaf etc.; α_t – concentration of nutrient in top soil; α_m – concentration of nutrient in manure; α_c – concentration of the nutrient in compost of leaves/grass/organisms; α_k – concentration of the nutrient in kth part of the plants; λ – top soil layer thickness of the dump; S – total surface area of the dump; Dt – bulk density of the top soil; β – quantity of decayed leaves in the top soil per unit volume; N – number of years for which the rainfall data considered for modeling; Ω_j – intensity of rainfall for j^{th} month; m_i – total mass of the manures added uniformly to the top soil during ith month; A – average area of the shadow of the plants when sun is above the plant; h_c – average canopy height of the plants; D – average canopy dia of the plants; φ_k – average nutrient uptake capacity of k^{th} part of the plants; γ_k – density of k^{th} part of the plants.

3.4.5. Input Data.

In general, the coal overburden dumps are very lengthy in dimension and occupying a huge surface area. A small dump of age 20 years with 63511 m^2 total surface area, rest-angle of 30°, length 300 m and breadth 200 m at bottom level, and length 250 m and breadth 150 m at the top level with height of 29 m has been considered. It had been kept 5 years for rest in order to restore the physical, chemical and biological imbalance. As there was no record of soil and nutrient amendments, the current practice of the reclamation scientists were considered as the input of the model. In fact, there is no soil over the dump materials and the plantation is not possible without soil amendments. Hence, normally the top soil is preserved somewhere nearby the proposed dump or good surface soil is brought and amended over the dump materials up to at least 0.5 m depth level to vegetate after the due nutrient amendments. Initially, i.e., at the zero age of the dump, the soil amendments with dump materials possess very low quantity of nutrients as presented in table 1. Further, these nutrients are washed away by the run-off during rainy seasons (table 2, 3).

Table 1 – Secondary data of the nutrients status of the coal overburden dump

S. No.	Properties	15 years (2009) (Planted)		10 Years (2004) (Planted)		5 Years (1999) Just Before Plantation)		0 Years (1994) (Plain)	
		μ	σ	μ	σ	μ	σ	μ	σ
1.	BD (g/cm^3)	1.616	0.160	2.046	0.820	2.059	0.061	1.753	0.049
2.	WHC (%)	34.703	2.610	32.003	1.870	29.923	1.390	27.530	1.121
3.	pH	6.831	0.380	6.846	0.250	7.017	0.137	6.189	0.030
4.	EC (ms/cm)	0.164	0.002	1.037	0.051	0.103	0.043	0.449	0.020
5.	OM (%)	1.455	0.017	1.012	0.014	1.315	0.052	1.603	0.060
6.	Av. N (%)	0.845	0.070	0.083	0.006	0.093	0.010	0.441	0.070
7.	Av. P (ppm)	27.262	0.016	24.021	1.270	25.953	0.170	26.990	0.002
8.	Av. K (ppm)	15.992	0.003	13.235	2.010	16.311	0.280	16.818	0.160
9.	Ca (ppm)	32.489	0.009	26.221	0.770	32.460	0.005	35.422	0.064
10.	Na (ppm)	0.302	0.091	0.392	0.001	0.511	0.0210	0.204	0.014
11.	Cu (ppm)	0.082	1.000	0.028	0.250	0.313	0.060	0.121	0.001
12.	Zn (ppm)	0.876	0.110	0.897	0.003	1.456	0.170	2.226	0.005
13.	Fe (ppm)	5.541	0.190	7.460	0.090	12.177	0.040	14.216	0.048
14.	Mn (ppm)	5.639	0.040	7.779	0.160	6.012	47.197	56.103	0.150
15.	OC (%)	0.616	0.020	0.676	0.024	0.838	0.010	0.602	0.012

Table 2 – Factors involve in nutrient balance at different ages of the dump

Term	Significance	Factor that alters the top-soil quality	Factor that incorporates the variation in the term
1st	Total mass of the top-soil	Rainfall	$e^{-r_i t}$ where r_i is the rainfall intensity factor of the i^{th} month of the dump age t
2nd	Total mass of manures / fertilizers added to the top-soil so far	Soil amendments by means of manure/fertilizers	n(t) that represents the no. of times the soil amendments were done till the time t by means of manures/fertilizers
3rd	Total nutrient added to the top-soil by means of the decayed bio-mass after plantation	Increase in canopy volume and horizontal circular canopy area that increases the leaf drops	$e^{\mu t}$ μ the leaves generation potentiality of the plants with the age of the dump
4th	The total volume of the biomass generated from the sources mentioned in the terms 1 to 3	The increase in biomass density of the plant's canopy that increases nutrients uptake	$e^{\phi t}$ ϕ represents the average nutrient uptake capacity

Table 3 – Month-wise rainfall and statistical measures

Months	Month-wise rainfall for five years (in mm)					Statistical measures			
	2008	2009	2010	2011	2012	Mean	r_i	n_i	η_i
January	0	0	7	0.9	13.4	4.26	0.00398	31	0.48
February	0	0	0	0	1.9	0.38	0.00035	28	0.04
March	0	0	0	13.4	1.2	2.92	0.00273	31	0.33
April	0	0	4.6	3	17.5	5.02	0.00469	30	0.54
May	0	0	28.1	29.9	13.5	14.3	0.01336	31	1.60
June	165.9	81.8	152.8	313	80.1	158.72	0.14824	30	17.17
July	442.1	257.2	171.2	180.9	326.4	275.56	0.25737	31	30.81
August	195.3	284.1	171.5	470.6	264.9	277.28	0.25898	31	31.00
September	174.5	272.9	253.4	285.7	336.2	264.54	0.24708	30	28.62
October	39.7	102.1	49.1	18.6	21.3	46.16	0.04311	31	5.16
November	0	1.5	3.7	0	54.9	12.02	0.01123	30	1.30
December	0	0	38.5	0	9.1	9.52	0.00889	31	1.06
					Total	1070.68		Total	118.11

The rainfall data of the area was collected from the district statistical department for five years and the statistical analysis of the same for estimating average rainfall, rainfall intensity, rainfall days of different months and number of days for the rainfall year have been calculated and the same have been presented in table 4 adopting the method given in a research study (Singh, et al., 2007).

Table 4 – Physico-Chemical parameters of a 20 yrs old coal overburden dump during Jan 2015

S.No.	Parameter	S1	S2	S3	S4	S5	μ	σ
1.	BD (g/cm^3)	1.563	1.650	2.242	1.560	1.664	1.736	0.287
2.	WHC (%)	35.128	34.746	35.637	34.700	33.724	34.787	0.703
3.	pH	6.680	6.294	7.173	6.289	5.545	6.396	0.598
4.	EC(ms/cm)	0.082	0.082	0.880	0.081	-0.342	0.157	0.444
5.	OM (%)	1.434	1.699	2.203	1.417	1.625	1.675	0.319
6.	Av. N (%)	0.042	0.053	0.754	0.042	-0.804	0.018	0.552
7.	Av. P (ppm)	26.927	27.142	27.389	26.491	25.565	26.703	0.717
8.	Av. K (ppm)	16.034	16.282	16.470	15.959	15.136	15.976	0.511
9.	Ca (ppm)	32.520	32.486	33.208	32.486	32.186	70.657	0.042
10.	Na (ppm)	0.248	0.580	0.334	0.213	-0.372	3.725	0.021
11.	Cu (ppm)	0.027	0.024	0.030	0.012	0.100	0.350	0.004
12.	Zn (ppm)	0.965	0.709	0.949	0.702	-0.077	0.108	0.014
13.	Fe (ppm)	5.688	5.964	5.817	5.639	5.021	11.820	0.010
14.	Mn (ppm)	20.849	21.368	21.535	20.841	20.376	5.421	0.006
15	OC (%)	0.669	0.722	0.562	0.667	0.530	1.594	0.007

Usually, 1 kg of farm yard manure (FYM) which consists 90 % organic carbon and 5 % microbial, 0.25 kg of suphala, which consists of 15 % nitrate nitrogen (NN), 15 % phosphorus (P) and 15 % potassium (K), and 0.25 kg of di-ammonium phosphate (DAP) which consists 8 % ammonal nitrogen (AN) and 12 % phosphorus (P) are being applied on the layer of top-soil up to 0.3 m depth level amended over the dump materials per 1 m^2 surface area. There are many other fertilizers for nutrient amendments available such as: single super phosphate (SSP), which consists of 16 % phosphorus (P); urea, which consists of 46 % NN; muriatic potal, which consists of 31 % K; earthworm fertilizer; compost, and (vi) leaf mold etc.

The plant species such as D*albergia sissoo Roxb, Pongamia pinnata L. Pierre, Gmelina alborea Roxb, Azadirachta indica A., and Terminalia belerica (Gaertn) Roxb* are normally grow well over the coal overburden dumps. But only the plant, namely D*albergia sissoo Roxb* has been planted.

The total numbers of planted species were 2540. The volume of the top-soil is 31755 m^3. It has been observed from the secondary data that the average height of the plant was 1.5 m in which the average heights of stump and canopy were 0.5 m and 1m respectively. The slant height and diameter of the canopy were 1.12 m and 1 m respectively. The average volume of the canopy was 0.86 m^3 and the area of canopy shadow is 0.785 m^2. The leaf mold generated from the 2540 plants during the eighth year was approximately estimated to be 7.98 kg. The growth and generation of the leaves are not same as others in the same dump although the species' variety, the treatment applied and climate condition are the same as the nutrient distribution in the soil, the physical condition and the efficiency of nutrient uptake of the plants varies plant to plant.

The data concerning with average total mass of the leaves generated at different ages of the dump from 5 healthy plants and 5 unhealthy plants were estimated to be 0.003 kg at the age of 3 years, 0.022 at 5 years, 0.035 kg at 7 years, 0.055 at 9 years, 0.062 at 11 years, 0.081 kg at 13 years, and 0.085 kg at 15 years. No record were maintained by the concern department of the mine but these data were generated from different coal overburden dumps of different ages in Jharia coalfield for the same variety of species. Only the total mass of leaves at the age of 15 years old plant was collected from the selected dump of the present study. The average mass of the leaves generated per plant has been simulated using the following statistical equation.

$$y = 0.092 \log_e(\tau + x) - 0.1915 , \qquad (12)$$

where y is the average mass of leaves generated per plant in kg and τ is the resting period of the dump for preliminary treatment of dump materials and x is the age of the plant in years. In this case, the resting period is 5 years. The equation (12) has been used for simulating the total mass of the leaves generated from 2540 species that undergoes the natural phenomena of decaying over the years as compost. This equation has been incorporated in the present nutrient dispersion model. The equation cannot be an appropriate to be used in this nutrient dispersion study as the equation may vary depending upon the physico-chemical characteristics of the dump as well as the kind of species selected for the plantation. However, the equation has been used to illustrate the application of the model with some error in the predicted results.

4. Results.

The prediction of available N has been graphically shown in the graph (a) of figure 4. Similarly other nutrients such as available P, available K, Ca, OM and OC have been shown in (b), (c), (d), (e) and (f) respectively in figure 4. The predictions of Na, Cu, Zn, Fe and Mn have been shown in the graphs (a), (b), (c), (d) and (e) respectively in figure 4. The plots of electric conductivity (EC), pH value, bulk density, water holding capacity (WHC) have been shown in the graph (f) of figure 5.

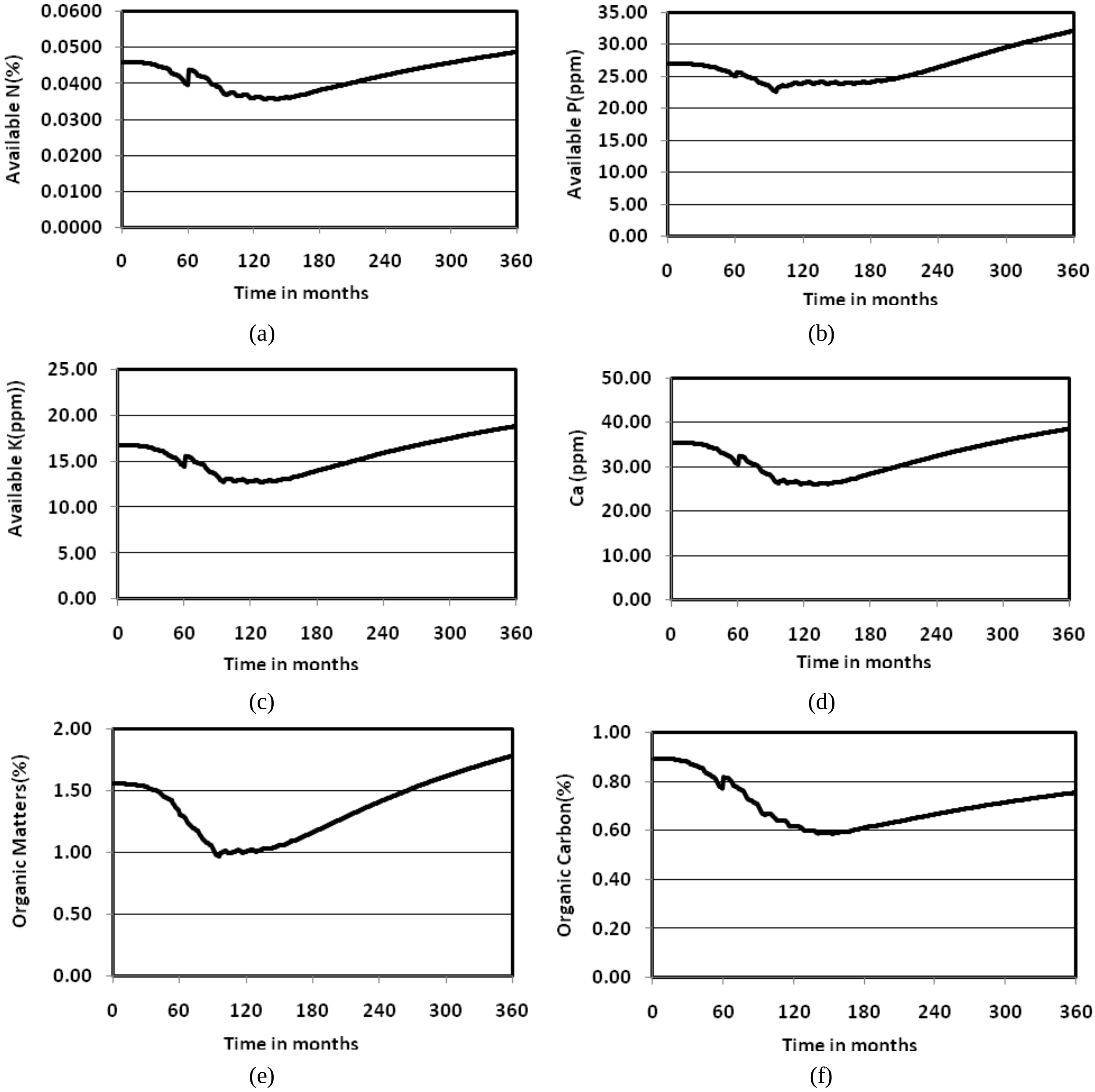

Figure 4 – Prediction of nutrients for 30 years: (a) av. N, (b) av. P, (c) av. K, (d) Ca, (e) OM and (f) OC

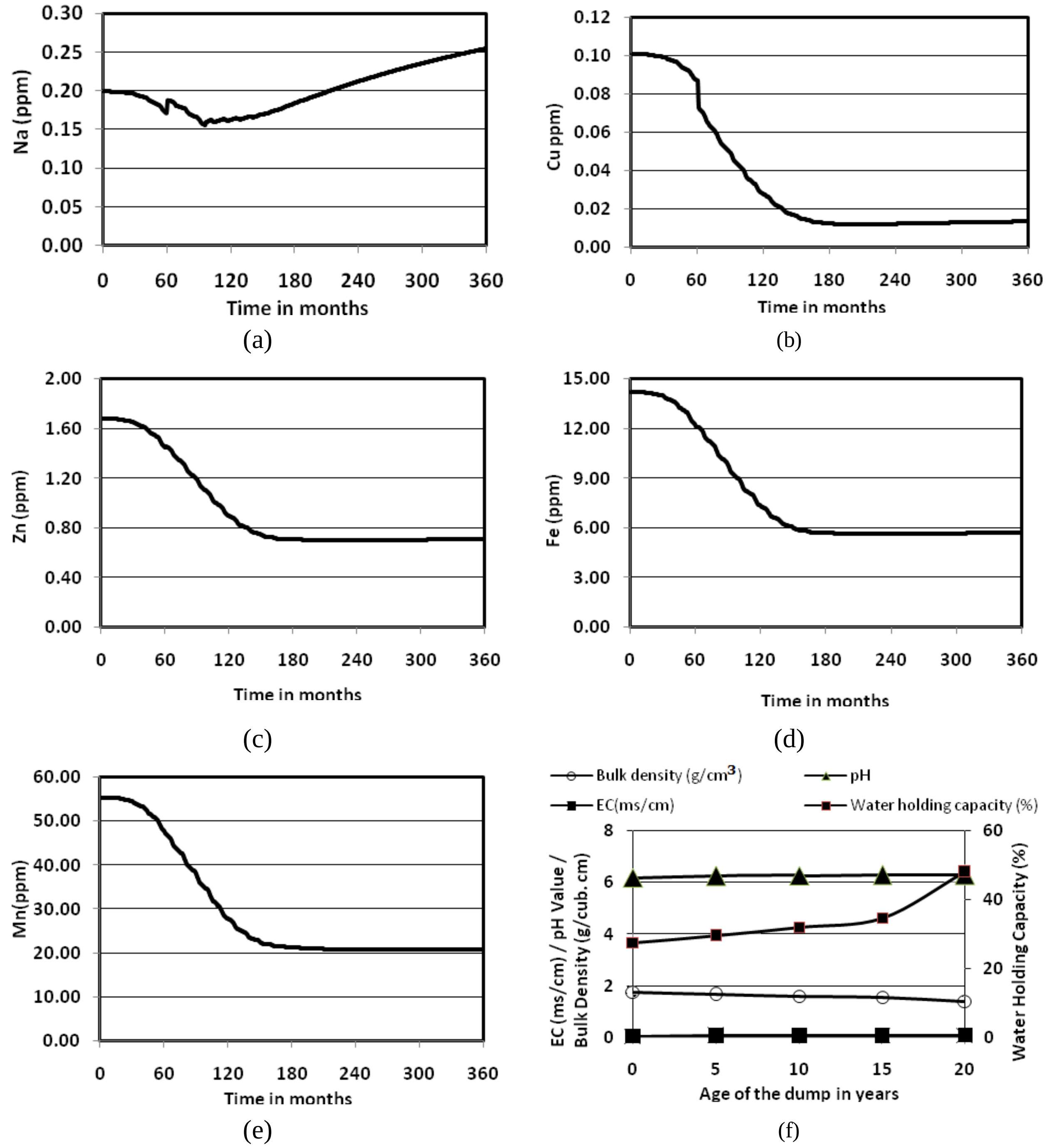

Figure 5 – Prediction of nutrients: (a) Na, (b) Cu, (c) Zn, (d) Fe and (e) Mn for 360 months, and (f) plots of data of EC, pH, bulk density (shown in primary axis) and WHC (shown in secondary axis) for twenty years

It can be observed from all the graphs of figures 4 that the curves gradually go down during the first 5 years of resting period kept for restoration of physical, chemical and biological parameters from the imbalanced condition to normal condition up to the level of suitable for plantation after appropriate nutrient amendments. During 6th year after the nutrient amendments with manures on the top soil, the curves slightly go up for a short period and again come down after plantation till the end of 8 to 10 years. The nutrients such as available N, available P, available K, Ca, OM, OC in Figure 4 and Na level in graph (a) of figure 4 gradually increases from 10th years onwards while curve of predicted Cu, Zn, Fe and Mn in the graph (b), (c), (d) and (e) of figure 5 come downward from 6th year onwards. Since the present model has been constructed on the basis of mass balance of the dump before and after the plantation, the model cannot be applied for the prediction of parameters such as electric conductivity, pH and water holding capacity. Therefore only the plots of analyzed data of electric conductivity, pH and bulk density have been shown in primary axis and the water holding capacity in secondary axis for twenty years. The electric conductivity and pH value gradually increase while the water holding capacity increases significantly with the decrease in bulk density.

The prediction study has been carried out only for 10 years duration as the age of the dump was 20 years during sampling of dump materials and top-soil and collecting other physical parameters such as dump height, widths and breadths at both bottom and top levels, rest-angle, data concerning with soil amendments with dump materials, and nutrient amendments and water spray along with their frequency. The analyzed data and the predicted data have been presented in table 5 only for the predictable parameters along with results of statistical analysis of standard deviations for each predictable parameter.

Table 5 – Comparison of predicted data (P) with analyzed data (A)

S. No.	Properties	20^{th} year		15^{th} year		10^{th} year		5^{th} year		0^{th} year		σ
		A	P	A	P	A	P	A	P	A	P	
1.	OM (%)	1.675	2.062	1.455	1.417	1.012	1.012	1.315	1.311	1.603	1.559	0.1750
2.	Av. N (%)	0.018	0.044	0.845	0.042	0.083	0.036	0.093	0.0438	0.441	0.046	0.4015
3.	Av. P (ppm)	26.703	26.833	27.262	26.491	24.021	23.979	25.953	25.646	26.990	26.98	0.3762
4.	Av. K (ppm)	15.976	16.336	15.992	15.959	13.235	12.864	16.311	15.609	16.818	16.800	0.3902
5.	Ca (ppm)	70.657	70.855	32.489	32.486	26.221	26.221	32.460	32.415	35.422	35.389	0.0920
6.	Na (ppm)	3.725	4.269	0.302	0.213	0.392	0.163	0.511	0.188	0.204	0.199	0.3035
7.	Cu (ppm)	0.350	0.786	0.082	0.012	0.028	0.027	0.313	0.073	0.121	0.101	0.2249
8.	Zn (ppm)	0.108	0.695	0.876	0.702	0.897	0.893	1.456	1.456	2.226	1.680	0.3669
9.	Fe (ppm)	11.820	12.308	5.541	5.639	7.460	7.291	12.177	12.172	14.216	14.213	0.2351
10.	Mn (ppm)	5.421	5.958	5.639	5.639	7.779	7.291	6.012	5.990	56.103	55.415	0.4473
11.	OC (%)	1.594	1.896	0.616	0.667	0.676	0.612	0.838	0.819	0.602	0.894	0.1916

5. Discussion.

In figures 4 and 5, there is a gradual decrease in the predicted minerals and nutrients of the dump during the first 5 years of restoration period. Probably, the initially existing and liberated nutrients on time course might have been washed away by the run-off in the form of leachate. The curves micro and macro-nutrients go up during 6^{th} years while nutrient amendment was done just before plantation by means of bio-degradable manures on the top-soil amended on the dump materials for reclamation purpose as the manures contain abandons of nutrients to support the plants to grow up with increased canopy and micro-organisms to mineralize on organic matters (Smith and Doran 1996). After plantation, it has been observed that the nutrient loss on the top-layer is very less due to plantation as the roots control the soil erosion. However, there is no significant improvement in the nutrient refilling the dump as the leaves fall is not much. After 10 years, there are no soil amendments but the plants are found to be capable to significantly refill the nutrients as there a huge quantity of leaf-drops from the planted trees and become compost after going through the process of decaying to serve the plants. In this way, the plants survive without requirements of nutrient amendments meeting its nutrients themselves. Such a capability of self-satisfying characteristics of plants through nutrient transaction between soil and plants goes on as a cyclic phenomenon through the natural process due to recurrent seasonal changes. Nevertheless, the micro nutrients such as Cu, Zn, Fe and Mn notably decrease in the top soil as the plants uptake these nutrients and accumulate in its body. Since the leaves contain the micro-nutrients in less quantity, the stop soil regains the micro-nutrients very gradually by means of leaves fall. The organic matters and OC in the top soil provokes the new leaves dropped from the plants in decaying phenomena and support the plats to grow as influential compost. After 15 years, the roots enter through the rock materials and uptakes the heavy metals which are liberated from the rock materials through natural phenomenon and accumulate in its parts. Now the need of the nutrients of the plants are mostly met by the liberated minerals at depth level through routs but the nutrient at top-soil is gradually increasing as the decayed leaves add on the nutrients to the top-soil and minerals are constantly accumulated. This may also be the reason for increase of micro-nutrients in top soil after 15 years onwards. The water holding capacity gradually increases after reclamation up to 15 years and thereafter, there is an appreciable increase. The predicted micro and macro-nutrients in the coal overburden dump have been plotted and presented in figures 4 and 5. In figure 5, the variation of EC, pH value, bulk density and water holding capacity have been visualized at the last graph from the analyzed data. It can be observed that the EC and pH value increases with respect to the age of the dump. A study also reports that the electrical conductivity increases as the concentration of OM and OC increases on the dump (Carter, 2002). The water holding capacity is increasing significantly whereas the bulk density decreased. This shows that the combined effect of plant roots that are passing through the dump materials and the increased organic matter decreases the bulk density and increases the water holding capacity.

Conclusions.

Mathematical modelling is the most important tool to understand the complexity of the soil-plant relation, which would lead the bio-reclamation experts to devise suitable nutrient budget for successful reclamation of coal overburden dumps. Because, several case studies on reclaimed coal overburden dumps reveals the truth that 40…60 % of species only survive after plantation even after proper care and soil amendments. After investing a huge amount of project fund, 40…60 % failure is always being faced by the environmentalists of the mining industries. Therefore, for a long period of time, the environmentalists have felt the need for modelling the nutrient dispersion through appropriate mathematical approach for achieving maximum survival rate of the species while reclaiming the coal overburden dumps in effective and economic manner. Therefore, the present nutrient dispersion model would be a useful tool for understanding the nutrient status at different ages and reclaiming the overburden dumps successfully. The results have established the fact that the planted species are capable of self sufficient after 10 years as the plants spread their roots around its dump materials to uptakes the nutrients liberated from the dump due to natural phenomena and dropping its own leaves to go through the decaying phenomena to prepare the compost of good worth to meet their needs. The predicted data was compared with analyzed data and it was observed that the predicted data was deviating from 0.092 to 0.447, the average standard deviation (σ) is 0.291 and the maximum error in the predicted data is 9.9 %, which may be accepted.

Notations.

S. No	Parameters	Nota-tion	Unit
1.	Bottom length of the dump	L_b	m
2.	Bottom breadth of the dump	B_b	m
3.	Top length of the dump	L_t	m
4.	Top breadth of the dump	B_t	m
5.	Area of the top surface of the dump	S_t	m^2
6.	Area of the slant surface associated with length of the dump	S_1	m^2
7.	Area of the slant surface associated with breadth of the dump	S_b	m^2
8.	Total surface area of the dump	S	m^2
9.	Top-soil layer thickness of the dump	λ	m
10.	Volume of the top soil of the dump	V_t	m^3
11.	Dump rest angle	θ	Radian
12.	Dump height	h	m
13.	Slant/inclined height	H	m
14.	Total mass of the manure added uniformly to the top-soil as a nutrient amendment during the year i (i=1,2,3,…)	m_i	kg
15.	Age of the dump	n	year
16.	No. of times the nutrient amendments were done till the time t in year	n(t)	year
17.	Concentration of decayed leaves/grass/ organisms found in the top-soil	β	kg/m^3
18.	Concentration of the nutrient in the top soil	α_t	kg/m^3
19.	Concentration of the nutrient in manures	α_m	kg/m^3
20.	Concentration of the nutrient in compost of leaves/grass/ organisms	α_c	kg/m^3
21.	Initial concentration of the nutrient	C_o	kg/m^3
22.	Concentration of the nutrient at time t	C(t)	kg/m^3
23.	Bulk density of the top soil	D_t	kg/m^3
24	Volume of the roots in the top-soil	ψ_r	m^3
25.	Volume of the roots under the rock matters	ψ_R	m^3
26	Volume of the stump of the plants	ψ_S	m^3
25.	Volume of the stems/branches of the plants	ψ_b	m^3
26.	Volume of the leaves/grass/organisms of the tree planted on the dump	ψ_l	m^3
27	Density of roots in the top-soil	γ_r	kg/m^3
28.	Density of the roots under the rock	γ_R	kg/m^3
29.	Density of the stump	γ_S	kg/m^3
30.	Density of the stems/branches	γ_b	kg/m^3
31.	Density of the leaves/grass/ organisms	γ_l	kg/m^3
32.	Concentration of the nutrient found in the roots in the top-soil	α_r	kg/m^3
33.	Concentration of the nutrient found in the roots under the rock matters	α_R	kg/m^3
34.	Concentration of the nutrient found in stump	α_S	kg/m^3
35.	Concentration of the nutrient found in the stems/branches	α_b	kg/m^3
36.	Concentration of the nutrient found in the leaves/ grass/ organisms	α_l	kg/m^3

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Conflicts of Interest.

None of the authors have any potential conflicts of interest associated with this present study.

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М. Сундараджан, В. Вамболь, С. Вамболь, Н. Кумарі, І. Ансарі

МОДЕЛЮВАННЯ ДИСПЕРСІЇ ПОЖИВНИХ РЕЧОВИН У ВІДВАЛАХ РОЗКРИВНИХ ПОРІД ВУГІЛЛЯ ДЛЯ МЕЛІОРАЦІЇ ТА СТАЛОГО УПРАВЛІННЯ

У цьому дослідженні подано інноваційний підхід до ефективної рекультивації й управління відвалами розкривних порід вугілля. Дослідження показує, що існуючі поживні речовини під дією природних факторів вимиваються у вигляді фільтрату протягом п'яти років. Концентрація органічних речовин і органічного вуглецю також зменшується, і в результаті спостерігається зниження електропровідності. Поживні речовини на верхньому шарі починають утворюватися через шість років. З метою меліорації ґрунту на відвальних породах, в верхній шар були внесені добрива, що біологічно розкладаються, безпосередньо перед насадженням дерев. Після насадження було відзначено, що втрата поживних речовин на верхньому шарі значно зменшилася, оскільки коріння контролюють ерозію ґрунту. Тим не менш, не спостерігалося істотного поліпшення живлення рослин, висаджених на відвалах, оскільки падаючого листя не було багато. Стан поживних речовин на відвалі після насадження дерев вивчалося з використанням моделі для прогнозування для різних вікових груп: 6...10, 11...15, 16...30 років. При цьому були добре проаналізовані вірогідні причини нестачі поживних речовин. У дослідженні встановлено, що після 10 років без внесення добрив, рослини здатні значно збільшити кількість поживних речовин, оскільки з посаджених дерев опадає величезна кількість листя, які перетворюються у компост. Таким чином, рослини виживають без потреби у внесенні додаткових поживних речовин. Така здатність самодостатніх характеристик рослин за допомогою перенесення поживних речовин між ґрунтом і рослинами відбувається як природне циклічне явище, обумовлене повторюваними сезонними змінами. В результаті комбінованої дії проникаючих коренів рослин у всіх напрямках в ґрунті відвальних порід і органічної речовини, що утворюється, зменшується об'ємна щільність і збільшується вологоємність ґрунту.

Ключові слова: рекультивація відвалів розкривних порід вугілля; моделювання дисперсії поживних речовин; управління розкривними відвалами.

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М. Сундараджан, В. Вамболь, С. Вамболь, Н. Кумари, И. Ансари

МОДЕЛИРОВАНИЕ ДИСПЕРСИИ ПИТАТЕЛЬНЫХ ВЕЩЕСТВ В ОТВАЛАХ ВСКРЫШИ УГЛЯ ДЛЯ МЕЛИОРАЦИИ И УСТОЙЧИВОГО УПРАВЛЕНИЯ

В этом исследовании представлен инновационный подход к эффективной рекультивации и управлению отвалами вскрыши угля. Исследование показывает, что существующие питательные вещества под воздействием природных факторов вымываются в виде фильтрата в течение пяти лет. Концентрация органических веществ и органического углерода также уменьшается, и в результате наблюдается снижение электропроводности. Питательные вещества на верхнем слое начинают образовываться через шесть лет. В целях мелиорации грунта на отвальных породах, в верхний слой были внесены биологически разлагаемые удобрения непосредственно перед насаждением деревьев. После насаждения было отмечено, что потеря питательных веществ на верхнем слое значительно уменьшилась, поскольку корни контролируют эрозию почвы. Тем не менее, не наблюдалось существенного улучшения питания растений, высаженных на отвалах, поскольку падающих листьев не было много. Состояние питательных веществ на отвале после насаждения деревьев изучалось с использованием модели для прогнозирования для разных возрастов: 6…10, 11…15, 16…30 лет. При этом были хорошо проанализированы вероятные причины недостатка питательных веществ. В исследовании установлено, что после 10 лет без внесения удобрений, растения способны значительно увеличить количество питательных веществ, поскольку с посаженных деревьев опадает огромное количество листьев, которые превращаются в компост. Таким образом, растения выживают без потребности во внесении дополнительных питательных веществ. Такая способность самодостаточных характеристик растений посредством переноса питательных веществ между почвой и растениями происходит как естественное циклическое явление, обусловленное повторяющимися сезонными изменениями. В результате комбинированного действия проникающих корней растений во всех направлениях по почве отвальных пород и образующемуся органическому веществу, уменьшается объемная плотность и увеличивается влагоемкость почвы.

Ключевые слова: рекультивация отвалов вскрыши угля; моделирование дисперсии питательных веществ; управление вскрышными отвалами.