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RESEARCH ARTICLE

Quantitative Assessment and Predicting the Effects of Soil Pollutants on Herbaceous Biomass Production in Reserved Forests

Gisandu K. Malunguja[1] · **Ashalata Devi**[1]

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Abstract Heavy metal concentrations in surface soils of Reserved Forests (RFs) have a significant impact on understorey herbaceous layer. However, research on their effects on herbaceous productivity and ecological risk in Assam's RFs is still scarce. Thus, we undertook an ecological study to gain a better understanding of this. Levels of ecological risks were assessed using geostatistical indices, and the impacts of metals on productivity were predicted using Pearson's correlation and regression analysis. Results identified a total of 64 herbaceous plants (13 grasses, 42 forbs, and 09 climbers) from 29 families and 61 genera. According to IVI, the dominating grasses, forbs, and climbers were *Cynodon dactylon*, *Datura stramonium*, and *Piper betle*, respectively. Herbaceous productivity was strongly negatively correlated with heavy metals (i.e. Cr (− 94%), Cd (− 83%), Pb (75%), Ni (− 65%), for grasses; and Ni (− 89%), Cr (− 74%), Pb (− 66%), Cd (− 59%) for forbs). This suggested that metals are strong predictors of herbaceous productivity with a significant impact. Meanwhile, the contamination and pollution levels ranged from slightly to severely contaminated and from moderately to highly polluted. Among the metals, Pb and Cd were highly contaminating with significant implications on productivity. Regression analysis found that metals exerted a considerable impact, accounting for approximately 43.4%, 61.7%, 80.0%, and 49.3% of the variances in Cd, Cr, Ni, and Pb, respectively. The empirical model for predicting metals' effects on productivity is: $\hat{Y} = 24.977 + 288.607\text{Cd} + (-149.635\text{Cr}) + (-6.534\text{Ni}) + (-6.656\text{Pb})$. Therefore, policymakers must devise efficient metal discharge mitigation techniques in the RFs.

Keywords Biodiversity · Ecological risk · Plant productivity · Indian Reserved Forest · Metal pollution

Introduction

Herbaceous species share the most significant proportion of plant diversity and are regarded as a pioneer ecological indicator due to their quick response to any change of environmental conditions [1]. They are characterized by completing their life cycle within a short period of time, which significantly influences any forest ecosystem's physical, chemical, and biological characteristics [2]. They provide a quick important information regarding the forest ecosystem's disturbances in terms of diversity and productivity potential. The accumulated heavy metals in soils greatly influence herbaceous layers than any other component of the forest ecosystem [2, 3] and has become a rising global issue [4]. Heavy metals originate from range of sources, including natural processes such as lithogenic inputs through geochemical and chemical processes, as well as anthropogenic activities such as urbanization, industrialization, agricultural, and development projects [5, 6].

Significance statement The study examined the concentrations of heavy metal in surface soils of Reserved Forest soils (RF) and anticipated their ecological effects on herbaceous biomass productivity potential and general forest ecosystems.

✉ Gisandu K. Malunguja
gmalunguja77@gmail.com

Ashalata Devi
ashalatadevi12@gmail.com

[1] Department of Environmental Science, School of Sciences, Tezpur University, Tezpur, Assam 784028, India

Conversely, roadways that run through protected forest habitats, such as Reserve Forests, have been identified as major environmental polluters. Highways' traffic is associated with a significant contribution to heavy metal discharge [7], which has synergistic impacts on understorey herbaceous layer production and total ecosystem functions and services [8]. Despite their potential impact on plant productivity, there is minimal information available about the impacts of heavy metals on herbaceous productivity and the ecological risk they pose to the Reserved Forest ecosystem. Heavy metal accumulation in soils has a substantial impact on physical and chemical components of the environment, including the forest ecosystem [2, 7]. They purely interfere the physiological processes by affecting enzyme selectivity, compromising cellular function [3], and decrease of soil quality [8]. Their most concern is due to their non-biodegradability, ecological danger, high toxicity, biogeochemical recycling, and long environmental persistence [6, 9]. Exposure to these heavy metals has a negative impact on herbaceous diversity and productive potential [4].

Even protected Reserved Forests (RFs) in India, particularly in the state of Assam, are under threat of pollution from anthropogenic activities such as urbanization, encroachment, agriculture, and development projects near RFs [10]. However, there is scarce information about heavy metal contamination levels, their effects on herbaceous species productivity, and the ecological consequences. The review of the relevant literature also revealed that the few studies that measured plant biomass productivity did not correspond with heavy metals' impacts, instead focusing on reporting biomass stocking potentials in various forests throughout the state [1, 10, 11].

Therefore, the present study was undertaken in Bhomoraguri Reserved Forests (RFs) of Assam, a state in the northeast region of India in order: (1) to quantify levels of heavy metal (Cd, Cr, Ni, and Pb) and assess their ecological risks; (2) to determine herbaceous species diversity and quantify their biomass productivity; (3) to examine and predict the impacts of heavy metals on herbaceous biomass productivity.

Material and Methods

Description of the Study Area

The investigation was undertaken in the Bhomoraguri Reserved Forest (RF) in the Sonitpur district of Assam, a state in the northeast region of India. The RF was chosen because it is adjacent to an urban area (Tezpur city) characterized by fast urbanization and industrial growth; it is intersected by one of the busiest National Highways (NH-15), which operates throughout the year, and it is surrounded by ongoing development projects (bridge construction) and periodic overflows (flooding) caused by the Brahmaputra River. Since these factors are connected with heavy metal release and contamination in the RF, the RF had to be chosen by the present study. The general characteristics of the selected RF, and its coordinates for sampling are indicated Table 1 and Fig. 1.

The district is situated in the northwestern Brahmaputra valley, between 92° 16′ E and 93° 43′ E longitudes and 26° 30′ N to 27° N latitudes, with an elevation of 70 to 75 m above mean sea level [12]. Reserved forests comprise roughly 935.38 km^2 [13], accounting for 17.57% of the area. The district is subtropical in climate and experiences monsoons. Summers are hot and humid, averaging 29 °C but ranging from 7 to 36 °C [14]. The rain begins in early April [12], and the average annual rainfall ranges from 170 to 220 cm, playing a significant influence in establishing the district's climate [13]. Rain is heavy, which is both a blessing and a curse for the inhabitants; a blessing because it gives natural irrigation to the farms, and a curse because it causes rivers to exceed their banks and produce floods [12, 13].

Field Design, Plots Layout, and Experimentation

Ground-based forest survey techniques were employed to determine phytosociological attribute, quantification of herbaceous productivity [15], as well as soil sampling. The herbaceous species were analysed for frequency (%), density, diversity, and biomass productivity (t DM ha^{-1}). To accomplish our objectives, we divided the RF into three sampling areas as follows:

Site 1: a control site: it was located distant from both the RF's boundaries and the roadside. Samples in this site were collected interior of the forest at a distance of around 200 m from the RF's boundaries and highway. In this case, the 200-m separation was deemed sufficient to ensure that metal discharges from road traffic or river overflows were either completely avoided or merely moderately exposed [16].

Site 2: the RF's edges: the periphery was considered as an experimental II, examining the role of adjusted household and the overflowing banks of the Brahmaputra River on heavy metals release in surface soils of RF.

Site 3: along the roadway (Highway): this site was chosen as an experimental III to determine whether road traffic-related activities contribute significantly to metal concentrations in soil surface throughout the RF.

In the present investigation, a total of 30 circular plots (each having a radius of 15 m) were systematically established. For each plot, four samples were collected using hand augers, making a total of 120 samples. The

Table 1 Sampling geo-coordinates characterizing the Bhomoraguri RF of Assam northeast India

Site 1 (i.e. inside the forest)			Site 2 (i.e. forest edge/boundary)			Site 3 (i.e. along Highway)		
Points	Latitude	Longitude	Points	Latitude	Longitude	Points	Latitude	Longitude
1	26.620871	92.862207	11	26.61635	92.84918	21	26.616609	92.851172
2	26.618859	95.862207	12	26.618711	92.853818	22	26.615353	92.851478
3	26.61707	92.861521	13	26.621946	92.860746	23	26.613884	92.852291
4	26.617465	92.858663	14	26.621629	92.864695	24	26.612752	92.852533
5	26.617255	92.856328	15	26.61790	92.867388	25	26.611601	92.852972
6	26.614705	92.855595	16	26.614994	92.863438	26	26.616962	92.852677
7	26.614077	92.859834	17	26.612227	92.86034	27	26.615565	92.853256
8	26.615768	92.862942	18	26.612185	92.856182	28	26.61400	92.853983
9	26.615909	92.854642	19	26.61262	92.851018	29	26.612399	92.853907
10	26.613973	92.851073	20	26.614568	92.849907	30	26.611967	92.854730

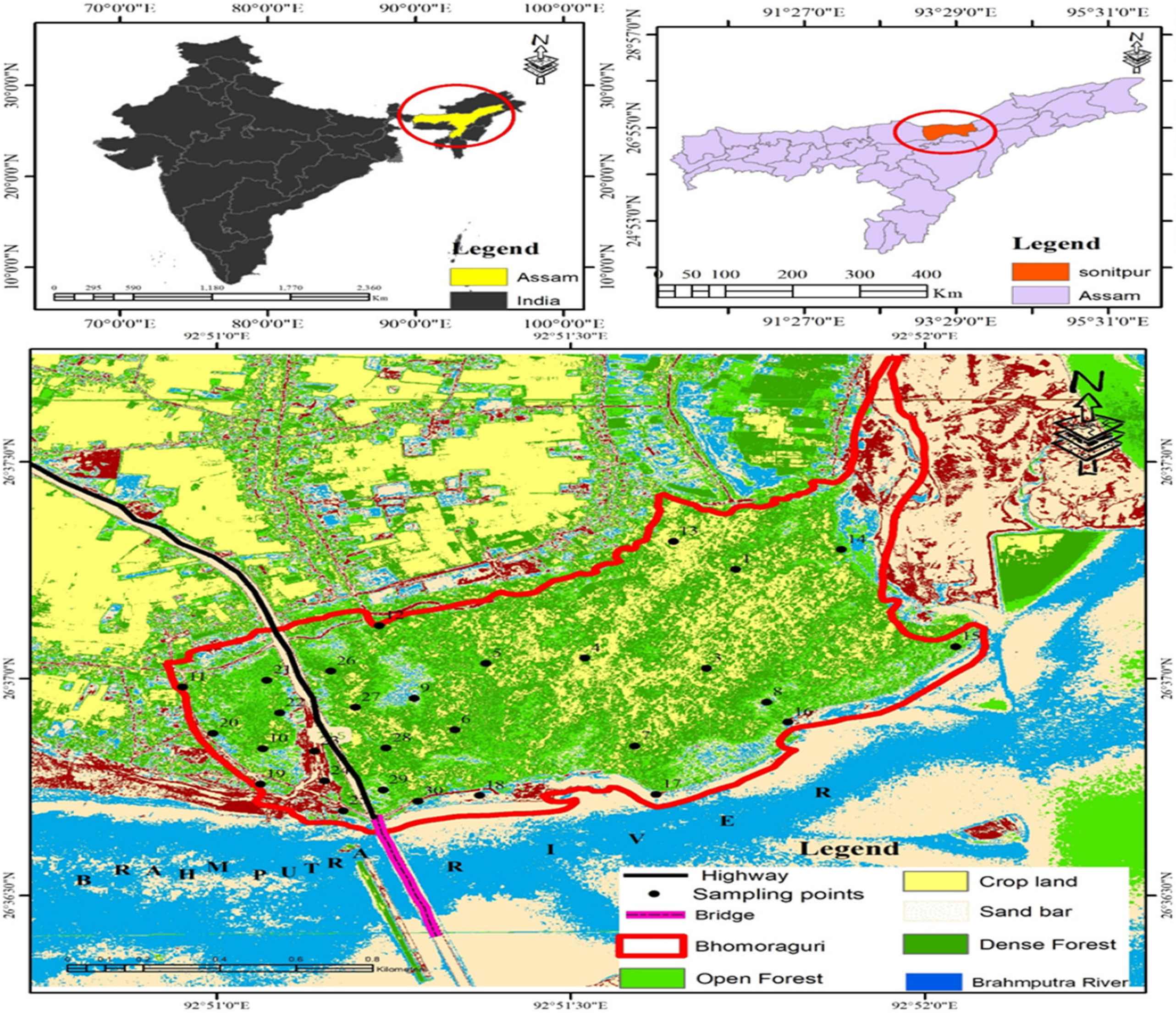

Fig. 1 The map showing the Bhomoraguri Reserved Forests of Assam, northeast India

herbaceous layer was trimmed with a hand sickle within each thrown metal quadrat. According to Czapiewska and Dyderski [11], whenever the frame fell on a previously sampled site, or on a dense shrub layer, or on animal pathways, we repeated the throw in order to reduce the impact of these factors. The clipped herbs were immediately transferred to pre-weighed labelled paper bags and quickly weighted for fresh weight, followed by 48 h of forced-air drying at 60 °C to constant weight to get dry matter (DM). Soil samples were similarly packaged, labelled, and brought at Tezpur University's Ecology and Biodiversity Laboratory. The soil samples were dried for two weeks at room temperature (25 °C) before being shattered. They were sieved and homogenized, then placed in plastic bags for further analysis.

Data Collection

Herbaceous Phytosociological Attributes and Diversity

Herbaceous phytosociological and ecological attributes such as frequency, abundance, density, basal area, and important value index (IVI) were determined by method proposed by Curtis and McIntosh [17]. Species diversity was calculated using the standardized diversity indices Eqs. (1–3).

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \tag{1}$$

$$C_D = \sum_{i=1}^{s} (p_i)^2 \tag{2}$$

$$J' = \frac{H'}{Ln(S)} \tag{3}$$

where H' is the Shannon–Wiener diversity index; P_i is the proportional abundance of species; C_D is Simpson diversity index; J' is the Evenness index; Ln is the natural logarithm; S is the species richness.

Determination of Herbaceous Biomass Production

Herbaceous biomass production data were collected using the harvest method, a disruptive procedure that includes clipping herbaceous plants with a thrown metal quadrat at ground level. Equation 4 was used to calculate the herbaceous biomass productivity per hectare in accordance with Chambers and Brown [18]:

$$\begin{aligned}&\text{Herb productivity}\left(\text{t DM ha}^{-1}\right)\\&\quad=\frac{\text{Total dry weight (DM.)}}{\text{Total number of quadrats}}\times\text{Quadrat per area}\end{aligned} \tag{4}$$

Determination of Soil Physico-Chemical Properties and Heavy Metals Concentration

The pH and the EC (µS/cm) of the soils were measured in 1:2 soil water suspensions using digital pH and EC metres, respectively. As reported in Gupta [19], standard procedures were employed to test characteristics such as organic carbon (SOC), N, P, and K levels. Heavy metals (Cd and Ni) in soil were extracted using 5 mM DTPA/10 mM $CaCl_2$/100 mM triethanolamine at pH 7.3. Similarly, at pH 7.0, Cr and Pb were extracted with 0.05 M, EDTA, and ammonium nitrate. The concentrations of the investigated heavy metals in an aliquot of the filtrates were determined using inductively coupled plasma-mass spectrometry (ICP-MS).

Ecological and Environmental Risk Assessments

Several geostatistical indices were employed to account for the level of contamination and pollution induced by heavy metals. Each index applies a separate pollution scale for contamination [20–23]. Indices such as the geo-accumulation index (Igeo), pollution index (PI), pollution load index (PLI), and ecological risk index (RI) were used. Unfortunately, the normal background soil concentration value in India by region (state), and in especially for the study area, was not readily available. It was decided to use a set of average values used by previous researchers from the region and India in general [8, 24].

Geo-Accumulation Index (Igeo)

The geo-accumulation index (Igeo) quantifies the concentration of heavy metals in soil. It evaluates metal pollution in soils and compares current levels to background levels [23]. The geo-accumulation index is calculated using Eq. 5.

$$I_{\text{geo}} = \log_2\left[\frac{C_n}{1.5 \times B_n}\right] \tag{5}$$

where C_n denotes the concentration of a metal pollutant in soil and B_n denotes the concentration of a metal pollutant in the geochemical background. The contamination values levels were categorized into seven as per Adimalla [24]:

Indices categories	Level of classifications
(1) Igeo ≤ 0	Practically uncontaminated
(2) $0 <$ Igeo < 1	Uncontaminated to moderately contaminated
(3) $1 <$ Igeo < 2	Moderately contaminated
(4) $2 <$ Igeo < 3	Moderately to heavily contaminated
(5) $3 <$ Igeo < 4	Heavily contaminated

Indices categories	Level of classifications
(6) 4 < Igeo < 5	Heavily to extremely contaminated
(7) 5 < Igeo > 6	Extremely contaminated

Pollution index (PI)

Pollution index (PI) compares a soil's heavy metal contents to its natural background concentration [20]. Equation 6 was used to compute the PI.

$$\mathrm{PI} = \frac{C_{n-1}}{B_n} \tag{6}$$

where C_n denotes the measured concentration of the element in soil and B_n denotes the area's natural background value. Pollution index values was categorized into three levels:

Indices categories	Level of classifications	Reference
(1) PI $\leq$ 1.0	Low pollution	Dutta et al. [20]
(2) 1.0 < PI $\leq$ 3.0	Medium pollution	
(3) PI > 3.0	High pollution	

Pollution Load Index (PLI)

Pollutant load index (PLI) measures heavy metal pollution by multiplying the *n*th root of the factors multiplied together for each metal at each site. The quotient is obtained by dividing the metal concentrations by the background concentration [22]: Eq. (7).

$$\mathrm{PLI} = \sqrt[n]{C_r n_1 \times C_r n_2 \times C_r n_3 \times C_r n_4 \cdots \times C_r n_n} \tag{7}$$

where C_r signifies the pollutant's contamination factor and n denotes the number of metal pollutants evaluated. Tomlinson et al. [22] categorize the value of PLI into seven classes:

Indices categories	Level of classifications	References
(1) PI < 0.25	Slight contamination	Tomlinson et al. [22]
(2) 0.25 $\leq$ PI < 0.5	Moderate contamination	
(3) 0.5 $\leq$ PI < 1	Severe contamination	
(4) 1 $\leq$ PI < 4	Slight pollution	
(5) 4 $\leq$ PI < 8	Moderate pollution	
(6) 8 $\leq$ PI < 16	Severe pollution	
(7) PI > 16	Excessive pollution	

Ecological Risk Index (RI)

The ecological risk index (RI) was designed to measure the overall ecological risk induced by heavy metals in a specific ecosystem [21]. RI evaluates entire ecosystem by consideration its specific toxic response factors. Standardized toxic response factors of 30, 5, 2, and 5 for Cd, Pb, Cr, and Ni, respectively, as per Dutta et al. [20] were used to establish the RI. It was determined using Eqs. (8) and (9).

$$E_i = T_i \times f_i = T_i \left[\frac{C_{i-0}}{B_i}\right] \tag{8}$$

$$RI = \Sigma(E_i) \tag{9}$$

where E_i denotes the risk factor, T_i the toxic-response factor associated with a particular metal, and f_i the pollution index.

Hakanson [21], grouped levels of potential risk factors and ecological risk into the following groups:

Indices categories	Level of classifications	References
(1) Ei < 40	Low potential ecological risk	Hakanson [21]
(2) 40 $\leq$ Ei < 80	Moderate potential ecological risk	
(3) 80 $\leq$ Ei < 160)	Considerable potential ecological risk	
(4) 160 $\leq$ Ei < 320	High potential ecological risk	
(5) Ei $\geq$ 320	Very high potential ecological risk	
(1) RI < 180	Low ecological risk	
(2) 150 $\leq$ RI < 300	Moderate ecological risk	
(3) 300 $\leq$ RI < 600	Considerable ecological risk	
(4) RI $\geq$ 600	Very high ecological risk	

Statistical Analysis

A one-way ANOVA was used to determine the significance differences in physico-chemical properties, heavy metals concentration, and herbaceous biomass production between sampling sites. The Shapiro–Wilk and Levene tests were employed to ensure that the data were normal and homogeneous, respectively. The post hoc analysis using Fisher's Least Significant Difference (LSD) test was employed to check in whether the differences between means were statistically significant at $P < 0.05$. Pearson correlation coefficient analysis was used to investigate the relationship between herbaceous productivity and heavy metal concentrations. The impacts of heavy metals on herbaceous production were predicted using regression analysis. All statistical analyses were conducted at a significance level of = 0.05 using the SPSS Software package (ver. 20.0; SPSS, Chicago, IL).

Results and Discussion

Physicochemical Properties and Concentration of Heavy Metals in Surface Soils

The mean values for pH, EC, OC, available N, P, K, and the concentrations of heavy metals (Cd, Cr, Ni, and Pb) are summarized in Table 2. Analysis of variance (ANOVA) revealed that there was a significant difference in the physicochemical properties across sites (Site 1, Site 2, and Site 3 ($P < 0.05$)). However, the post hoc test using LSD revealed that Site 1 and Site 2 were not statistically significant ($P > 0.05$). The greatest pH values were found in soil samples collected from Site 3 (along Highway) with the mean value of 7.74. Similarly, EC was found to be elevated in Site 3, reaching to about 0.88 µS/cm. Conversely, the SOC in Site 1 was significantly higher (1.78%) than in Sites 2 and 3. The concentrations of heavy metals were found to be greater in soil samples taken from Site 3 (along Highway), followed by Site 2 (Edge of forest), and the lowest concentration was recorded in Site 1 (forest section). For instance, the concentration of Ni (mg kg^{-1}) was 0.64 ± 0.16 in Site 1; 4.37 ± 0.94 Site 2; and 78.01 ± 16.78 Site 3 (Table 2).

The high concentration of heavy metal along roadway (Site 3), than in the edges of the RF (Site 2), and in forest section (Site 1), could be due to vehicular emissions caused by traffic traversing through RFs. These activities contribute significant upon raising the concentration of heavy metal-related compounds [23]. Similarly, an increase of metals concentration observed in Site 2 (Edge of the forest) could be owing to the ongoing small-scale agriculture, outflow of the Brahmaputra River, and the bridge construction near the forests. The concentration of heavy metals in soils has a direct effect on plant productivity [6, 24]. Long exposure of plants to heavy metals could decrease photosynthetic pigments for CO_2 assimilation [5]. Heavy metals can induce chromosomal aberrations in plant cells even in low concentrations, which in turn cause growth and developmental problems with a significant effect on productivity potential [4, 25]. Although there was high variation of metals across sites, but the overall mean values of heavy metals were within the safe standard limits set by India [5], and other international guidelines [6, 24]. The observed frequent outflow of the river in the forest might also affect its soil nature by changing its chemical composition. Furthermore, vegetation type has an influence on physicochemical properties of the soil to a great extent, which can alter soil structure, performance of plants in terms of productivity, infiltration rate, and water holding capacity [26]. Thus, tree species dominating the forest (*Tectona grandis*) are characterizing by great nutrients holding with less return to the soils; this could have influenced the recorded low levels of macronutrients (i.e. N, P, and K) in the present study. Results of the present study confirm to the data reported by Mishra et al. [3], Shukla et al. [27], and Sharma et al. [28].

Herbaceous Phytosociological Attributes and Diversity

A total of 64 understorey herbaceous species (13 grasses, 42 forbs, and 09 climbers) belonging to 29 families (2 grasses, 20 forbs, and 7 climbers) and 61 genera (13 grasses, 39 forbs, and 9 climbers) were identified. The forest exhibited a significant variation in herbaceous species. The overall results on grasses, forbs, and climbers with their ecological characteristics (basal area, density, frequency, abundance etc.,) are presented in "Appendix 1". Among the recorded herbaceous species, the forbs recorded the highest density (38,309,787 forbs ha^{-1}) as compared to climbers (7,585,592 climber ha^{-1}) and grasses (9,660,175 grasses ha^{-1}). Based on the importance value index (IVI), the grass species that recorded high domination in the RF were *C.dactylon* (L.) Pers (40.27)., *Imperata cylindrica* (Linn.) Beauv (35.81)., *Brachiaria reptans* (L.) (33.56)., and *Axonopus compressus* (Sw.) P. Beauv (26.15). The dominant forbs were *D. stramonium* L. (20.21)., *Chromolaena odorata* (L.) RM (14.93)., *Alternanthera sessilis* L. (13.39)., and *Hydrocotyle sibthorpioides* Lam (13.11), while *Clitoria ternatea* L (50.20)., *P. betle* L (51.30)., *Cissus rotundifolia* Vahl (42.60)., *Paederia foetida* L (40.80)., and *Merremia umbellata* (L.) Hallier f (40.20) were dominant climbers (Table 3). Other herbaceous species that recorded relatively high IVI values were *Leersia hexandra* Sw., *Digitaria ciliaris* (Retz.) Koeler, *Lophatherum gracile* Brongn, and *Fimbristylis miliacea* (L.) Vahl., for grasses, while *Persicaria strigosa* (R.Br.) Nakai., *Leucas aspera* (Willd.) Link., and *Jussiaea suffruticosa*., for forbs.

In terms of diversity, analysis of variance (ANOVA) between herbaceous groups (grasses, forbs, and climbers)

Table 2 Descriptive statistics for soil physicochemical properties and heavy metals in Bhomoraguri RF of Assam, northeast India

Soil parameter	Sampling Sites									ANOVA	
	Site 1 (Control; interior of forest)			Site 2 (Edge of Forest)			Site 3 (Along the roadside)				
	Min	Max	Mean ± SD	Min	Mx	Mean ± SD	Min	Mx	Mean ± SD	*F*	Sig
pH	4.77	6.83	6.17 ± 0.20	5.98	6.50	6.14 ± 0.16	7.12	7.74	7.31 ± 0.19	$F_{(2,\ 137)} = 691.01$	$P < 0.001$
EC (µS/cm)	0.09	0.36	0.25 ± 0.11	0.18	0.44	0.26 ± 0.11	0.36	0.88	0.52 ± 0.21	$F_{(2,\ 137)} = 46.10$	$P < 0.001$
SOC (%)	0.29	1.92	1.78 ± 0.41	1.30	2.16	1.67 ± 0.35	1.01	1.69	1.3 ± 0.27	$F_{(2,\ 137)} = 22.75$	$P < 0.001$
Available N (mg kg − 1)	31.42	45.10	33.36 ± 2.39	29.40	35.7	32.64 ± 2.15	17.55	21.31	19.49 ± 1.28	$F_{(2,\ 137)} = 890.09$	$P < 0.001$
Available P (mg kg^{-1})	0.97	4.69	2.75 ± 1.23	0.77	3.87	2.94 ± 0.98	0.96	4.48	3.65 ± 1.22	$F_{(2,\ 137)} = 8.76$	$P < 0.001$
Available K (mg kg^{-1})	2.23	63.90	26.56 ± 22.83	1.44	63.85	27.44 ± 19.08	0.68	30.01	12.9 ± 8.97	$F_{(2,\ 137)} = 13.41$	$P < 0.001$
Cd (mg kg^{-1})	0.07	0.11	0.03 ± 0.02	0.13	0.46	0.2 ± 0.11	1.91	6.90	2.97 ± 1.66	$F_{(2,\ 137)} = 110.87$	$P < 0.001$
Cr (mg kg^{-1})	0.04	0.08	0.06 ± 0.02	0.29	0.58	0.39 ± 0.10	4.87	9.53	6.39 ± 1.59	$F_{(2,\ 137)} = 558.67$	$P < 0.001$
Ni (mg kg^{-1})	0.40	0.81	0.64 ± 0.16	2.83	5.67	4.37 ± 0.94	50.39	100.78	78.01 ± 16.78	$F_{(2,\ 137)} = 781.42$	$P < 0.001$
Pb (mg kg^{-1})	2.11	3.77	2.66 ± 0.65	8.43	15.08	10.27 ± 2.02	113.05	202.32	137.83 ± 17.14	$F_{(2,\ 137)} = 850.73$	$P < 0.001$
Limit values for heavy metals in Indian soils and References	Cd = 3–6	Kaur et al. [6]									
	Cr = 100–200	Sharma et al. [28]									
	Pb = 250–500	Sharma et al. [28]									
	Ni = 100	Dutta et al. [20]									

Table 3 Dominant herbaceous species, and diversity parameters in Bhomoraguri RF of Assam, northeast India

Herbaceous category	Dominant herbaceous species based on calculated IVI	*D* (No. ha^{-1})	SR	H'	*C*	J'	EF	WI	NF	NG
Grasses	*Cynodon dactylon* (L.) Pers (40.27)., *Imperata cylindrica* (Linn.) Beauv (35.81)., *Brachiaria reptans* (L.) (33.56)., and *Axonopus compressus* (Sw.) P.Beauv (26.15)	9,660,175 (743,090 ± 156,016)	13	2.34	0.11	0.91	9	0.06	2	13
Forbs	*Datura stramonium* L (20.21)., *Chromolaena odorata* (L.) RM (14.93)., *Alternanthera sessilis* L. (13.39)., and *Hydrocotyle sibthorpioides* Lam (13.11)	38,309,787 (912,137 ± 120,947)	42	3.42	0.04	0.9	25	0.09	20	39
Climbers	*Clitoria ternatea* L (50.20)., *Piper betle* L (51.30)., *Cissus rotundifolia* Vahl (42.60)., *Paederia foetida* L (40.80)., and *Merremia umbellata* (L.) Hallier f (40.20)	7,585,592 (842,843 ± 163,814)	9	2.05	0.14	0.93	7	0.09	7	9

D, number of herbaceous per hectare (No. ha^{-1}); SR, species richness; H', Shannon–Wiener diversity index; C_D, Simpson's index; J', Pielou's index of evenness; EF, effective number of species; WI, Whitford index; NF, number of families; NG, number of the genus

revealed no significant difference between sampling sites ($P > 0.005$). The Shannon–Wiener diversity index (H') was found to range between 2.05 and 3.42, while the Simpson diversity index (*C*) was found to range between 0.04 and 0.14. Forb species had the greatest diversity ($H' = 3.42$), followed by grasses (2.34) and climbers (2.05) (Table 3). Similarly, the Evenness index (J') was between 0.90 and 0.93. According to Giri et al. [7], a community with a higher H' value has a more diverse and evenly distributed population, whereas a community with a lower H' value has a less diversified population. Thus, the results of this study reveal a moderate diversity of herbaceous species with irregular patterns of distribution. The findings observed that, few species were found to predominate in the RF, specifically along the Highway (Site 3). According to Sheng et al. [29], species such as *Bidens Pilosa* L., and *Arundo donax* have the great ability to adapt and survive in metal-polluted habitats. In the present study, such species were more common beside the Highway (Site 3), indicating that soils in Site 3 were contaminated with heavy metals.

Conversely, domination of species such as *H. sibthorpioides* and *C. dactylon* in the forest section (Site 1 and 2) indicates that soils contain low levels of heavy metal contamination. Furthermore, other human activities such as forest encroachment, agriculture, and other forms of human-induced disturbances such as burning and grazing were also identified in this study and may have contributed to the condition documented in the examined RF. The domination of species such as *I. cylindrica* (Linn.) Beauv., and *Cymbopogon nardus* (L.) Rendle., for grasses; *D. stramonium* L., and *O. gratissimum* L., for forbs, as well as *P. betle* L., and *Mikania micrantha* Kunth, for climbers in the studied RF denotes disturbed habitat which could be attributed to certain forms of land degradation. *M. micrantha*, for example, is one of the most troublesome invasive species since it has an enormous capability for infiltrating the open forest boundaries of natural forest vegetation and progressively altering the entire ecosystem. The recorded grass species in this study, such as *Aristida* spp., and *Cenchrus* spp., suggested that the RF is highly disturbed, as these plants are good indicators of disturbed environments with harsh conditions. On the other hand, the Highway that runs through the RF may have led to the significant effects on regeneration and diversity of the understorey herbaceous species. These activities result in the emission of heavy metals, which may have a detrimental effect on species diversity.

Population growth and fast urbanization may have also contributed to the loss of biodiversity and jeopardized the remaining flora. The greater number of forb species documented in comparison with grasses and climbers could be attributed to the effect of tree canopy, which has a greater impact on grasses than forbs. Additionally, forb species exhibit a remarkable capacity for recovery and regeneration, indicating their greater diversity in the examined RF when compared to climbers and grasses. According to Ali et al. [1], tree density and canopy structure tend to dictate the amount of light and moisture available to the understory layer; hence, increased openness assures that appropriate resources are available for understory plant development.

Herbaceous Biomass Productivity Potential

Table 4 shows the total herbaceous biomass primary productivity potentials. Results of biomass in Site 1 were 10.43 t DM ha^{-1} (0.93 grasses, 2.39 forbs, 7.11 climbers); Site 2 was 13.43 t DM ha^{-1} (4.16 grasses, 2.76 forbs, 6.51

Table 4 Herbaceous biomass production (Mean ± SD) t DM ha^{-1} among sites in Bhomoraguri RF of Assam, northeast India

Plant category	Sampling sites						ANOVA	
	Site 1 (Control; interior of forest)		Site 2 (Edge of Forest)		Site 3 (Along the roadside)			
	Mean ± SE	%	Mean ± SE	%	Mean ± SE	%	*F*	Sig
Grasses	0.93 ± 0.70	8.92	4.16 ± 0.58	30.98	1.10 ± 0.26	30.98	$F_{(2,\ 137)} = 0.17$	$P = 0.85$
Forbs	2.39 ± 0.22	22.91	2.76 ± 0.89	20.55	2.04 ± 0.21	20.55	$F_{(2,\ 137)} = 0.78$	$P = 0.46$
Climbers	7.11 ± 1.99	68.17	6.51 ± 1.66	48.47	6.30 ± 1.67	48.47	$F_{(2,\ 137)} = 0.45$	$P = 0.64$
Total	10.43	100.00	13.43	100.00	9.44	100.00		

climbers), while, Site 3 was 9.44 t DM ha^{-1} (1.10 grasses, 2.04 forbs, 6.30 climbers). Due to variations in species compositions in different categories of herbaceous plants, analysis of variance (ANOVA) indicated that herbaceous biomass productivity potential varied significantly between individual herbaceous categories (i.e. grasses, forbs, and climbers), ($P < 0.05$). Despite the slight differences observed among herbs in biomass production, the overall comparisons of biomass productivity between sites were not significant ($F_{2,\ 137} = 0.17$, $P = 0.85$ for grasses; $F_{2,\ 137,} = 0.78$, $P = 0.46$ for forbs; and $F_{2,\ 137} = 0.45$, $P = 0.64$ for climbers), (Table 4). The highest biomass production was recorded in climbers from all the sampled sites (7.11 for Site 1; 6.51 for Site 2; and 6.30 for Site 3) which is equivalent to 68.17%; 48.47%; and 48.47%, respectively, of all herbaceous. Thus, among the studied herbaceous species, climbers contributed the greatest biomass production and stocking potential than grasses and forbs. Some herbaceous species recorded great biomass productivity in Site 1 (e.g. *Hemarthria compressa,* and *A. compressus*); others in Site 2 (e.g. *Panicum virgatum* L., *P. betle* L., *Paederia foetida* L., *Clerodendrum viscosum* Vent, and *Ocimum tenuiflorum* L); and Site 3 (e.g. *A. donax* L., and *Bidens Pilosa*).

The variations observed in biomass productivity potentials between herbaceous categories and across sites may be due to differences herbaceous adaptability on varying metal requirements. For instance, some species recorded

Table 5 Geo-contamination index (Igeo), pollution index (PI), and pollution load index values among sites in Bhomoraguri RF of Assam, northeast India

Sites	Metals (mg kg^{-1})	Geo-accumulation (Igeo)		Pollution index (PI)		Pollution load index (PLI)	
		Mean	Level	Mean	Level	Mean	Level
Site 1 (Control; interior of forest)	Cd	− 5.83	Uncontaminated	0.03	Low	3.05E-07	Slightly contaminated
	Cr	− 11.25	Uncontaminated	0.0006	Low		
	Ni	− 6.04	Uncontaminated	0.02	Low		
	Pb	− 2.91	Uncontaminated	0.21	Low		
Site 2 (Edges of Forest)	Cd	− 3.09	Uncontaminated	0.2	Low	6.18E-04	Slightly contaminated
	Cr	− 8.49	Uncontaminated	0.004	Low		
	Ni	− 3.28	Uncontaminated	0.16	Low		
	Pb	− 0.96	Uncontaminated	0.78	Low		
Site 3 (Along the roadside)	Cd	0.83	Uncontaminated to moderately cont	2.97	Medium	1.43	Severe contaminated
	Cr	− 4.44	Uncontaminated	0.07	Low		
	Ni	0.87	Uncontaminated to moderately cont	2.82	Medium		
	Pb	2.79	Moderately to heavenly contaminated	10.52	High		

Table 6 Risk factor (E_i) and ecological risk index (RI) values among sites in Bhomoraguri RF of Assam, northeast India

Sites	Metals (mg kg^{-1})	Ecological risk assessment			
		Risk factor (E_i)		Ecological risk index (RI)	
		Mean	level	Mean	Level
Site 1 (Control; interior of forest)	Cd	0.89	Low potential ecological risk	11.51	Low ecological risk
	Cr	0.0012	Low potential ecological risk	0.02	Low ecological risk
	Ni	0.12	Low potential ecological risk	1.52	Low ecological risk
	Pb	0.2	Low potential ecological risk	2.65	Low ecological risk
Site 2 (Edge of Forest)	Cd	5.88	Low potential ecological risk	346.88	Considerable ecological risk
	Cr	0.01	Low potential ecological risk	0.52	Low ecological risk
	Ni	0.78	Low potential ecological risk	46.71	Low ecological risk
	Pb	3.92	Low potential ecological risk	231.32	Moderately ecological risk
Site 3 (Along the roadside)	Cd	88.97	Considerable potential ecological risk	5249.32	Very high ecological risk
	Cr	0.14	Low potential ecological risk	8.37	Low ecological risk
	Ni	14.08	Low potential ecological risk	830.78	Very high ecological risk
	Pb	52.61	Moderately potential ecological risk	3103.7	Very high ecological risk

high biomass in Site 3 (along Highway) which is characterized heavy metals, while others recorded low productivity and vice versa. The increasing concentration of heavy metals on Site 2 and Site 3 as a result of traffic, regular road repair, and construction, as well as outflow of the river are associated with excellent disturbance on the understorey species and had a significant impact on species productivity. The findings from the present study noted a relatively high total herbaceous primary biomass production, which suggests that the herbaceous layer has a potential stocking and contributes in CO_2 sequestration for an enhanced climate change.

Ecological and Environmental Risk Assessment

Numerous ecological assessment indices were used to assess environmental in studied RF, and the results are summarized in Tables 5 and 6. Geo-accumulation index (Igeo) values recorded in Site 3 (along the Highway) was found to be higher than other sites (Site 1 and Site 2). Table 5 shows the geo-accumulation index (Igeo) values for Sites 1 and 2 which indicated uncontaminated ecosystem (i.e. Igeo $\leq$ 0), while Site 3 ranged from uncontaminated to moderately contaminated, and then from moderately contaminated to heavily contaminated. Pb was determined to have the highest levels of environmental risk among the examined metals, whereas Cr and Cd had the lowest levels. Similarly, pollution index value (PI), from Sites 1 and 2, portrayed low level of pollution, while in Site 3 ranged from low, medium to high polluted environment. This suggests that Site 3 was polluted by heavy metals, specifically Pb (PI = 10.52). Thus, Pb and Ni were the main environmental contaminants and polluters, which could have a significant effect on herbaceous biomass production. Results on pollutant load index (PLI) revealed that the analysed soils in both Site 1 and Site 2 indicated a slightly contaminated sites, while Site 3 was severely contaminated.

On the other hand, ecological risks index (RI) for the examined sites of the RFs differed significantly (Table 6). Results of RI in Site 1 revealed the category of low ecological risks, while Site 2 indicated low to moderately ecological risk; however, RI results for Site 3 ranged from low to very high ecological risk. Cd and Pb were found to be the most significant contributors to ecological risks of the examined RFs, while Cr contributed the negligible ecological risk, in the Bhomoraguri RF. Thus, vehicle emissions could be the primary sources of metal pollution into the environment.

Correlation Analysis Between Physicochemical Properties, Heavy Metals Concentrations, and Herbaceous Biomass Productivity

The degree of a relationship and the effects of heavy metals on herbaceous biomass productivity were determined and

Table 7 Correlation between heavy metals and herbaceous productivity potential among sites in Bhomoraguri RF of Assam, northeast India

	pH	EC	OC	Cd	Cr	Ni	Pb	GB	FB	CB
Control Site (i.e. Site 1 interior of forest)										
pH	1									
EC	0.75**	1								
OC	− 0.788**	− 0.15	1							
Cd	0.96**	0.53**	− 0.0067	1						
Cr	0.7896	− 0.12	− 0.84	0.94	1					
Ni	0.62*	0.66**	− 0.89	0.81**	0.90*	1				
Pb	0.98**	0.48*	0.69	0.98	0.94	0.77**	1			
GB	− 0.74**	0.45*	0.85*	− 0.62	− 0.74	− 0.89	− 0.03	1		
FB	− 0.63	0.05	0.78	− 0.52	− 0.65	− 0.82	− 0.58	0.98**	1	
CB	− 0.56**	− 0.26	0.89	− 0.73	− 0.85**	− 0.92	− 0.76	0.97**	0.94	1
Experimental sites (i.e. Site 2 (Edge of Forest) and Site 3 (Along the roadside)										
pH	1									
EC	0.18	1								
OC	− 0.78**	− 0.05	1							
Cd	0.95**	0.18	− 0.63	1						
Cr	0.93**	0.12	− 0.81**	0.94**	1					
Ni	0.80**	0.05	− 0.86**	0.74**	0.89**	1				
Pb	0.98**	0.19	− 0.67	0.98**	0.91**	0.76**	1			
GB	0.65**	− 0.09	− 0.75**	0.67	0.83**	0.65**	0.75**	1		
FB	0.90**	0.12	− 0.89**	0.83**	0.93**	0.92**	0.86**	0.79**	1	
CB	− 0.74**	− 0.09	0.75**	− 0.64**	− 0.77**	− 0.74**	− 0.85**	− 0.84**	− .89**	1

GB, FB, and CB stand for grasses, forbs, and climbers biomass production, respectively

**Correlation is significant at the 0.01 level (2-tailed)

Table 8 Regression equations to predict the effects of heavy metals on herbaceous productivity potential in Bhomoraguri RF of Assam, northeast India

Model	Predictors	Regression equations	*R* Square	Sig
1	Cd	$\hat{Y}_{\text{effCdBiomass}} = 6.177\text{–}86.392\mathbf{Cd}$	$R^2 = 0.434$	$P < 0.001$
2	Cr	$\hat{Y}_{\text{effCrBiomass}} = 10.445\text{–}120.573\mathbf{Cr}$	$R^2 = 0.617$	$P < 0.001$
3	Ni	$\hat{Y}_{\text{effNiBiomass}} = 12.684\text{–}14.336\mathbf{Ni}$	$R^2 = 0.80$	$P < 0.001$
4	Pb	$\hat{Y}_{\text{effPbBiomass}} = 10.957\text{–}2.817\mathbf{Pb}$	$R^2 = 0.493$	$P < 0.001$
4	Cd + Cr + Ni + Pb	$\hat{Y}_{\text{effCd,Cr,Ni,PbBiomass}} = 24.977 + 288.607\mathbf{Cd} + (-149.635\mathbf{Cr}) + (-6.534\mathbf{Ni}) + (-6.656\mathbf{Pb})$	$R^2 = 0.848$	$P < 0.001$

predicted using Pearson's correlation and regression analysis. Correlation analysis between heavy metals and herbaceous biomass productivity ranges from weak to strong relationship (Table 7). In forest section (Site 1), all the heavy metals correlated negatively to herbaceous biomass productivity (i.e. Cd ($r = -73\%$), Cr ($r = -85\%$), Ni ($r = -92\%$), and Pb ($r = -76\%$), for climbers; Cd ($r = -52\%$), Cr ($r = -65\%$), Ni ($r = -82\%$), and Pb ($r = -58\%$, for forbs), suggesting that the available heavy metals in soils are inversely related and have a significant negative impact on herbaceous biomass productivity. Thus, any increase of heavy metal levels in the soil samples of Bhomoraguri RF lowers herb productivity. Unfortunately, heavy metal concentration exhibited a positive correlation of Cr ($r = 83\%$), Pb ($r = 75\%$), Cd ($r = 67\%$), and Ni ($r = 65\%$) for grasses; and Cr ($r = 93\%$), Ni ($r = 92\%$), Pb ($r = 86\%$), Cd ($r = 83\%$) for forbs, in an experimental site (Site 2 and 3), while only climber showed a negative correlation with values of $r = -0.64$ for Cd; $r = -0.77$ for Cr; $r = -0.74$ for Ni; and $r = -0.85$ for Pb. The observed positive matrix between heavy metals, grasses, and forbs in experimental sites (both Site 2 and 3) suggest that species that produced high biomass were those adopted and prefer to produce more under polluted habitats. The study recorded few herbaceous species (e.g. *Arundo donax* and *Bidens Pilosa*). These species are characterized by better performance under polluted area. Thus, this could be the reason for positive correlation observed between grasses and forbs in experimental sites.

Table 8 shows the stepwise regression analysis results, which predicted the impacts of heavy metals on herbaceous biomass productivity. Using data from the control site (Site 1), it was observed that about 84.3% of the variances in herbaceous biomass productivity could have accounted by these heavy metals, collectively ($F_{4,\ 115} = 160.24$, $P = 0.000$). The available heavy metals in soils (Cd, Cr, Ni, and Pb) have a varying proportion of impacts on herbaceous biomass productivity. The uniqueness contributions of these heavy metals (predictors), results indicated significant for Cd ($\beta = 2.20$, $t = 5.05$, $P = 0.000$); Cr ($\beta = -0.98$, $t = -3.11$, $P = 0.02$); and Pb ($\beta = 1.16$, $t = -5.74$, $P = 0.000$), but not significant for Ni ($\beta = -0.41$, $t = -2.56$, $P = 0.12$). The regression equations predicting the herbaceous biomass production portrayed a close relationship between metals on empirical models, that follows a linear of: $\hat{Y} = 6.177–86.392\mathbf{Cd}$, $R^2 = 0.43$, $P < 0.01$ for Cd; $\hat{Y} = 10.445–120.573\mathbf{Cr}$, $\mathrm{R}^2 = 0.62$, $P < 0.01$ for Cr; $\hat{Y} = 12.684–14.336\mathbf{Ni}$, $R^2 = 0.43$, $P < 0.01$ for Ni; and $\hat{Y} = 10.957–2.817\mathbf{Pb}$, $R^2 = 0.43$, $P < 0.01$ for Pb, explaining about 43.4%, 61.7%, 80.0%, and 49.3% of the variances, respectively (Table 8). The overall empirical model for predicting the effects of the heavy metals on herbaceous biomass productivity can be represented by $\hat{Y} = 24.977 + 288.607\mathrm{Cd} + (-149.635\mathrm{Cr}) + (-6.534\mathrm{Ni}) + (-6.656\mathrm{Pb})$, suggesting that heavy metals are strong predictors and have a major impact on herbaceous biomass productivity potential.

Conclusions

Although the mean levels of the examined heavy metals (Cd, Cr, Ni, and Pb) were within the Indian permissible values, but soil samples from Site 3 (along Highway) exhibited considerably greater concentrations of these metals than those taken from Site 1 (control site) and Site 2. (Edge of the forest). This suggests that vehicles passing through protected and Reserved Forests (RFs) may enrich heavy metals in RF surface' soils. This could have a significant impact on the sustainability of forest species. Moreover, RFs not only support biodiversity but also contribute significantly to biomass production and carbon stocking for an enhanced climate change. However, anthropogenic pressures like as human encroachment, urbanization, and development projects near or within RFs, on the other hand, threaten herbaceous diversity, productivity, and their contribution to ecological dynamics.

The contamination and pollution levels in the study site (Bhomoraguri RF) ranged from moderately contaminated to heavily contaminated, as well as medium polluted to highly polluted ecosystem; also, RI showed a range of low to very high ecological risk. The values with the highest levels of ecological risk assessment were generally recorded along the Highway (Site 3), followed by the forest borders (Site 2), and the lowest was recorded within the forest (Site 1). Pb, Ni, and Cd were all severely contaminating, polluting, and harmful to the environment. Thus, were the most prominent polluter and contaminate of the environment posing an ecological risk.

The strong negative relationships revealed in this study between herbaceous biomass production and heavy metals showed that metals are key constituents that negatively affect herbaceous physiological functions, hence reducing their productivity. Thus, it is necessary to develop a database of heavy metal concentrations in soils along Highways that run through RFs.

Appendix 1. Phytosociological parameters of herbaceous species documented in Bhomoraguri RF of Assam, northeast India

Herbaceous category	S/no	Local name	Botanical name	Family	BA	*D*	*F*	Ab	RD	RF	Rd	IVI
Grasses	1	Duburi	*Cynodon dactylon* (L.) Pers	Poaceae	1.13	2,265,496	93.33	6.36	23.45	11.81	5.01	40.28
	2	Urukheli	*Imperata cylindrica* (Linn.) Beauv	Poaceae	2.55	1,310,933	86.67	3.96	13.57	10.97	11.27	35.81
	3	Lukosa	*Brachiaria reptans* (L.) C.A. Gardner & C.E. Hubb	Poaceae	2.94	967,290	83.33	3.04	10.01	10.55	13.00	33.56
	4	Labhori	*Axonopus compressus* (Sw.) P.Beauv	Poaceae	3.14	407,280	63.33	1.68	4.22	8.02	13.91	26.15
	5	Erali-bon	*Leersia hexandra* Sw	Poaceae	0.95	865,470	76.67	2.96	8.96	9.70	4.21	22.87
	6	keyabon	*Cyperus rotundus* L	Cyperaceae	0.79	967,290	70.00	3.62	10.01	8.86	3.48	22.35
	7	Bedaliya	*Centotheca lappacea* (L.) Desv	Poaceae	2.01	432,735	66.67	1.70	4.48	8.44	8.90	21.82
	8	Unknown grass	*Fimbristylis miliacea* (L.) Vahl	Cyperaceae	1.54	712,740	60.00	3.11	7.38	7.59	6.82	21.79
	9	Unknown grass	*Digitaria ciliaris* (Retz.) Koeler	Poaceae	1.54	483,645	60.00	2.11	5.01	7.59	6.82	19.42
	10	Unknown grass	*Hemarthria compressa* (L.f.) R.Br	Poaceae	2.55	216,368	36.67	1.55	2.24	4.64	11.27	18.15
	11	Unknown	*Poa angustifolia* L	Poaceae	0.79	407,280	46.67	2.29	4.22	5.91	3.48	13.60
	12	Unknown grass	*Eragrostis amabilis* (L.) Wight & Arn. ex Nees	Poaceae	1.13	343,643	30.00	3.00	3.56	3.80	5.01	12.36
	13	Gabnol	*Arundo donax* L	Poaceae	1.54	280,005	16.67	4.40	2.90	2.11	6.82	11.83
Forbs	14	Unknown forb	*Datura stramonium* L	Solanaceae	15.21	674,558	56.67	3.12	1.76	2.66	15.79	20.21
	15	Jarmoni ban	*Chromolaena odorata* (L.) R.M.King & H.Rob	Asteraceae	4.91	2,150,948	90.00	6.26	5.61	4.22	5.10	14.93
	16	Mati-Kaduri	*Alternanthera sessilis* (L.) R.Br. ex DC	Amaranthaceae	6.16	1,361,843	73.33	4.86	3.55	3.44	6.39	13.39
	17	Xoru-Maanimuni	*Hydrocotyle sibthorpioides* Lam	Araliaceae	0.13	3,410,971	86.67	10.31	8.90	4.06	0.13	13.10
	18	Unknown forb	*Urtica dioica* L	Urticaceae	9.08	343,643	43.33	2.08	0.90	2.03	9.43	12.36
	19	Dhekia 1	*Diplazium esculentum* (Retz.) Sw	Athyriaceae	0.79	2,621,866	90.00	7.63	6.84	4.22	0.82	11.88
	20	Dhania	*Coriandrum sativum* L	Apiaceae	1.13	2,774,596	70.00	10.38	7.24	3.28	1.17	11.70
	21	Unknown forb	*Ageratum conyzoides* L	Asteraceae	1.13	1,883,671	86.67	5.69	4.92	4.06	1.17	10.15
	22	Bonduaboni	*Bidens pilosa* L	Asteraceae	1.54	1,680,031	86.67	5.08	4.39	4.06	1.60	10.05
	23	Unknown forb	*Grona triflora* (L.) H.Ohashi & K.Ohashi	Fabaceae	0.50	1,870,943	80.00	6.13	4.88	3.75	0.52	9.16
	24	Unknown forb	*Ranunculus multifidus* Forssk	Ranunculaceae	5.31	598,193	43.33	3.62	1.56	2.03	5.51	9.11
	25	Duruni chaki	*Leucas aspera* (Willd.) Link	Lamiaceae	4.53	852,743	43.33	5.15	2.23	2.03	4.70	8.96
	26	Doron bon	*Leucas zeylanica* (L.) R.Br	Lamiaceae	1.54	1,132,748	80.00	3.71	2.96	3.75	1.60	8.31
	27	Kola Kosu	*Colocasia esculenta* (L.) Schott	Araceae	0.13	1,476,390	86.67	4.46	3.85	4.06	0.13	8.05
	28	Tengeshi-tenga	*Oxalis corniculata* L	Oxalidaceae	0.79	1,132,748	73.33	4.05	2.96	3.44	0.82	7.21
	29	Water-Agra	*Chamaecrista rotundifolia* (Pers.) Greene	Fabaceae	0.28	1,361,843	70.00	5.10	3.55	3.28	0.29	7.13
	30	Bor-Maanimuni	*Centella asiatica* L	Apiaceae	0.28	1,590,938	56.67	7.35	4.15	2.66	0.29	7.10
	31	Tulasi	*Ocimum gratissimum* L	Lamiaceae	2.01	916,380	53.33	4.50	2.39	2.50	2.09	6.98
	32	Hathisuri	*Achyranthes aspera* L	Amaranthaceae	1.54	967,290	60.00	4.22	2.52	2.81	1.60	6.94

Herbaceous category	S/no	Local name	Botanical name	Family	BA	*D*	*F*	Ab	RD	RF	Rd	IVI
	33	Khutura	*Amaranthus spinosus* L	Amaranthaceae	2.55	585,465	53.33	2.88	1.53	2.50	2.64	6.67
	34	Nilakantha	*Ajuga decumbens*Thunb	Lamiaceae	5.31	114,548	13.33	2.25	0.30	0.63	5.51	6.44
	35	Suka Xaak	*Rumex acetosa* L	Polygonaceae	4.16	292,733	26.67	2.88	0.76	1.25	4.31	6.33
	36	Tita-Mora	*Corchorus olitorius* L	Malvaceae	3.80	330,915	30.00	2.89	0.86	1.41	3.95	6.22
	37	Elapathi	*Ricinus communis* L	Euphorbiaceae	2.55	407,280	46.67	2.29	1.06	2.19	2.64	5.89
	38	Unknown forb	*Oxalis articulata* Savign	Oxalidaceae	1.13	521,828	60.00	2.28	1.36	2.81	1.17	5.35
	39	Dhekia	*Cyathea cooperi* (Hook. ex F. Muell.)	Cyatheaceae	0.50	992,745	46.67	5.57	2.59	2.19	0.52	5.30
	40	Dhapatita	*Clerodendrum viscosum* Vent	Lamiaceae	0.39	776,378	53.33	3.81	2.03	2.50	0.40	4.93
	41	Unknown forb	*Commelina benghalensis* L	Commelinaceae	0.50	610,920	53.33	3.00	1.59	2.50	0.52	4.62
	42	Unknown forb	*Arum maculatum* L	Araceae	2.55	216,368	30.00	1.89	0.56	1.41	2.64	4.61
	43	Unknown forb	*Cassia occidentalia* (L.) Link, 1829	Fabaceae	2.01	534,555	23.33	6.00	1.40	1.09	2.09	4.58
	44	Metekah	*Euryale ferox* Salisb	Nymphaeaceae	1.13	470,918	43.33	2.85	1.23	2.03	1.17	4.44
	45	Omoratha	*Ocimum tenuiflorum* L	Lamiaceae	0.50	712,740	43.33	4.31	1.86	2.03	0.52	4.41
	46	Unknown forb	*Tragia involucrata* L	Euphorbiaceae	2.01	292,733	30.00	2.56	0.76	1.41	2.09	4.26
	47	Usipakh	*Abelmoschus manihot* (L.) Medik	Malvaceae	2.01	292,733	26.67	2.88	0.76	1.25	2.09	4.10
	48	Maha-bhringoraj	*Sphagneticola calendulacea* (L.) Pruski	Asteraceae	1.13	458,190	36.67	3.27	1.20	1.72	1.17	4.09
	49	Helochi	*Enydra fluctuans* Lour	Asteraceae	1.54	369,098	30.00	3.22	0.96	1.41	1.60	3.97
	50	Guru-tulash	*Scoparia dulcis* L	Plantaginaceae	0.79	432,735	40.00	2.83	1.13	1.88	0.82	3.82
	51	Unknown forb	*Sphaeranthus indicus* L	Asteraceae	1.13	356,370	20.00	4.67	0.93	0.94	1.17	3.04
	52	Unknown forb	*Malva sylvestris* L	Malvaceae	1.54	165,458	20.00	2.17	0.43	0.94	1.60	2.97
	53	Unknown forb	*Cicuta virosa* L	Apiaceae	0.79	165,458	26.67	1.63	0.43	1.25	0.82	2.50
	54	Kopaliputha	*Physalis peruviana* L	Solanaceae	0.20	318,188	30.00	2.78	0.83	1.41	0.20	2.44
	55	Jati-lau	*Lagenaria siceraria* Hook.f	Cucurbitaceae	1.13	89,093	20.00	1.17	0.23	0.94	1.17	2.34
Climbers	56	Unknown climber	*Clitoria ternatea* L	Fabaceae	5.31	738,195	53.33	3.63	9.73	11.19	31.30	52.22
	57	Pan	*Piper betle* L	Piperaceae	1.54	1,769,123	90.00	5.15	23.32	18.88	9.08	51.28
	58	Beberi lota	*Cissus rotundifolia* Vahl	Vitaceae	4.53	521,828	43.33	3.15	6.88	9.09	26.67	42.64
	59	Bhedeli-lota	*Paederia foetida* L	Rubiaceae	0.79	1,361,843	86.67	4.12	17.95	18.18	4.63	40.76
	60	Goria-loti	*Merremia umbellata* (L.) *Hallier f*	Convolvulaceae	1.54	1,247,295	70.00	4.67	16.44	14.69	9.08	40.20
	61	Unknown climber	*Argyreia speciosa* (L.f.) Sweet	Convolvulaceae	1.13	521,828	43.33	3.15	6.88	9.09	6.67	22.64
	62	Bhati kerela	*Cucumis anguria* L	Cucurbitaceae	0.50	585,465	36.67	4.18	7.72	7.69	2.96	18.37
	63	Haghun-lota	*Tinospora sinensis* (Lour.) Merr	Menispermaceae	1.13	407,280	30.00	3.56	5.37	6.29	6.67	18.33
	64	Unknown climber	*Argyreia argentea* (Roxb.) Arn. ex Choisy	Convolvulaceae	0.50	432,735	23.33	4.86	5.70	4.90	2.96	13.56

BA, basal area of herbaceous (cm^2); D, density (No. ha^{-1}); F, frequency (%); Ab, abundance; RD, relative density (%); RF, relative frequency (%); Rd, relative dominance (%); IVI, importance value index.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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