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RESEARCH ARTICLE

Effects of canopy openness on diversity and distribution of invasive alien plants in an Indo-Burma biodiversity hotspot region

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Abstract

Invasive alien plants (IAPs) perturb the ecosystem functioning and endanger plant biodiversity, which is inadequately explored in global biodiversity hotspots. The present study, therefore, aimed to analyze the vegetation dynamics and plant diversity in the urban forest of Aizawl, Mizoram, an integral landscape of the Indo-Burma biodiversity hotspot. The study was conducted from 2020 to 2023. We evaluated the phytosociology of IAPs along the anthropogenic disturbance gradient (highly disturbed, moderately disturbed and less disturbed sites), which were distinct in the urban forest. We also investigate the ecology of IAPs in the area by determining habitat attributes such as forest canopy openness, leaf area index (LAI) and photosynthetically active radiation (PAR). LAI is the total surface area of leaves per unit of ground area (m^2 m^{-2}) and PAR is the portion of the electromagnetic spectrum (400-700 nm) that green plants may employ to power their photosynthesis. Moderately disturbed site recorded the highest number of plant individuals (n = 1158) with an importance value index (IVI) ranging from 1.60 to 32.16. Further, the disturbed site recorded a total of n = 595 plant individuals with IVI ranging from 2.09 to 31.38. Whereas the less disturbed site has the least plant individuals (n = 146) with IVI ranging from 7.89 to 36.53. Notably, IAPs such as *Ageratum conizoides* L., *Calyptocarpus vialis* Less., *Chromolaena odorata* (L.) R.M. King & H. Rob. have the highest IVI at all sites. The canopy openness was more pronounced in disturbed habitats (87.42 %) when compared with moderately disturbed (25.92 %) and less disturbed (37.24 %) habitats. Maintaining the intact forest canopy by increasing native plant species richness and less human intervention on the pristine environment can result in sustainable management of IAPs. Therefore, sustenance of dense canopy regulate the invasive spread and alteration of species dynamics of biodiversity hotspot region.

Keywords: canopy openness; diversity indices; importance value index; invasive alien plants; leaf area index; photosynthetically active radiation

Introduction

Invasive alien plants (IAPs) are one of the major threats in the Anthropocene, which disrupts the homeostasis of the biosphere, perturbs environmental sustainability and jeopardizes the achievement of United Nations Sustainable Development Goals (SDGs) (1, 2). Plant invasion threatens human survival and negatively impacts ecosystem health and biodiversity in several ways (3, 4). Globalization, urbanization and population growth of humans have led to an alarming increase in biological invasions (5, 6). These invasions have complex effects on biogeographic realms, native species abundance, extinction risk and genetic composition (7). It is often noticeable only when IAPs are well-established, colonized, become abundant and attain landscape spread (8). India is well known for its rich plant diversity, which is highly influenced by the country's diverse topography, climate and ecosystems. India is also home to many IAPs that have colonized the global landscapes and are now posing a serious threat by altering socioeconomic conditions, fragmenting habitats and contributing to climate change as well as biodiversity loss (6, 9). Invasive plant species can negatively affect the native vegetation composition of a large area and their movement beyond natural boundaries alters the distribution of native biodiversity (10, 11). Therefore, understanding which alien species will naturalize and increase or which alien species will adversely impact biodiversity or other resources is one of the main challenges associated with invasion ecology (12, 13).

Native ecosystems have suffered significant harm in terms of their structure and functionality as a result of plant invasions. Since IAPs can release certain secondary metabolites or chemicals that can have an allelopathic effect on the coexisting native plants, they can successfully invade specific environments (14, 15). Hence, this supports the Novel Weapon Hypothesis (NWH) and Enemy Release Hypothesis (ERH). NWH stated that IAP could gain an advantage over native species by using novel biochemical weapons, which are potential secondary metabolites (16) and ERH stated that IAP has an advantage in new regions where native species are less familiar with them (17). Therefore, it is crucial that we take measures to control the spread of IAPs in India through effective management strategies such as early detection and eradication, monitoring and surveillance programs and public awareness campaigns (18).

Timely application of these control and containment strategies of IAPs can protect our natural resources and ensure a sustainable future (19). The early detection and sustainable management of IAPs are especially relevant in threatened global biodiversity hotspots, rich in endemic plant species (1, 20). To this end, phytosociological assessment of IAPs in Mizoram, underlying an Indo-Burma biodiversity hotspot, can facilitate their early detection and concomitantly elucidate the effects on vegetation and forest canopy openness. In this respect, the effects of IAPs on vegetation need to be explored along the disturbance gradient to visualize the impacts of anthropogenic perturbation on the biodiversity of this region. Past studies also demonstrated the linkages of canopy openness with the success of IAPs (21). Wide canopy gaps caused by human disturbances impact these forests by encouraging the invasion of other opportunistic species and indirectly altering soil attributes (22, 23). The study sites chosen for the present study were suburban and urban forests experiencing a wide range of anthropogenic disturbances such as stone quarries, agricultural activities, constructions and increased population. Further, the urban/peri-urban forests are ideal sites for phytosociological studies, which is attributed to the existence of explicit disturbance patterns, unlike less disturbed forest patches. Therefore, in the present study, we performed ecological investigations such as (i) vegetation analysis along the anthropogenic disturbance gradient (ii) assessment of phytosociology and diversity indices (iii) elucidate the role of forest canopy openness, Leaf Area Index (LAI) and Photosynthetically Active Radiation (PAR) on the diversity and distribution of IAPs.

Materials and Methods

Study sites

The study site selected was Aizawl district, Mizoram, Northeast India (Fig. 1). Mizoram is located in the Northeastern region of India and has an international boundary with Myanmar and Bangladesh. Mizoram is an integral component of the Indo-Burma biodiversity hotspot with dense forests, diverse species of flora and fauna and a rich diversity of medicinal plants (24). Mizoram plays an important role in biodiversity conservation and vegetation analysis. In summer, the temperature ranges from 20 to 30 °C and in the winter, 11 to 21 °C. Three sites (highly disturbed, moderately disturbed and less disturbed) were selected for the study along the disturbance gradient (Fig. 1). The disturbance gradient was determined based on their proximity to the various anthropogenic disturbances, which were evaluated in terms of assigning impact factors (IF) (25) (Table 1). The site with the highest distance from the road, agricultural land, market and habitation was given the impact factor 1 (lowest IF). IF for other sites was calculated as ratios of the distance from the road of the site with the lowest IF to the distance of the other sites. Other impacts were determined through visual estimation (Table 1).

Phytosociology

The interactions between invasive and native plant species along disturbance gradient (i.e. disturbed, moderately disturbed and less disturbed) areas have been studied through methodologies prescribed for vegetation analysis (26). In this context, the phytosociological parameters such as the percentage, frequency, density and abundance of each species present in quadrats have been recorded and analyzed as per the methods of Misra (26) and Kershaw (27):

Density

Density is an expression of the numerical strength of species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied.

$$\text{Density} = \frac{\text{Total no of individuals of a species in all quadrats}}{\text{Total no. of quadrats studied}}$$

Frequency (%)

This term refers to the degree of dispersion of individual species in an area and is usually expressed in terms of percentage occurrence. It will be studied by sampling the study area at several places at random and recording the name of the species that occurred in each sampling unit.

Table 1. Sites selected on the area invaded by invasive alien plants along the disturbance gradient with their coordinates, elevations (m), light intensity (LUX) and description

Site	Coordinates	Elevation (m)	Light intensity (LUX)	Description	Source of impact (relative impact)						
					Road	Agricultural land	Habitation	Market	Grazing	Soil erosion	Rockiness
Highly disturbed site	N 23°43′11.06″ E 092°41′50.71″	944	3758±1093.061	It is in close proximity to roads, habitation and frequent anthropogenic disturbances.	4.95	1	3	3	2	3	1
Moderately disturbed site	N 23°44′30.98″ E 092°41′20.82″	927	1017.60±243.47	It is located in close proximity to home gardens and habitats which are not frequently disturbed by heavy anthropogenic activities.	2.45	2	2	2	1	1	3
Less disturbed site	N 23°42′40.34″ E 092°42′10.24″	778	414.87 ± 191.88	The site is distant from road network as compared to the other two sites. It is surrounded by a thick forested area with negligible invasion.	1	3	1	1	3	2	2

Each value represents the mean (± standard deviation) of three replicates.

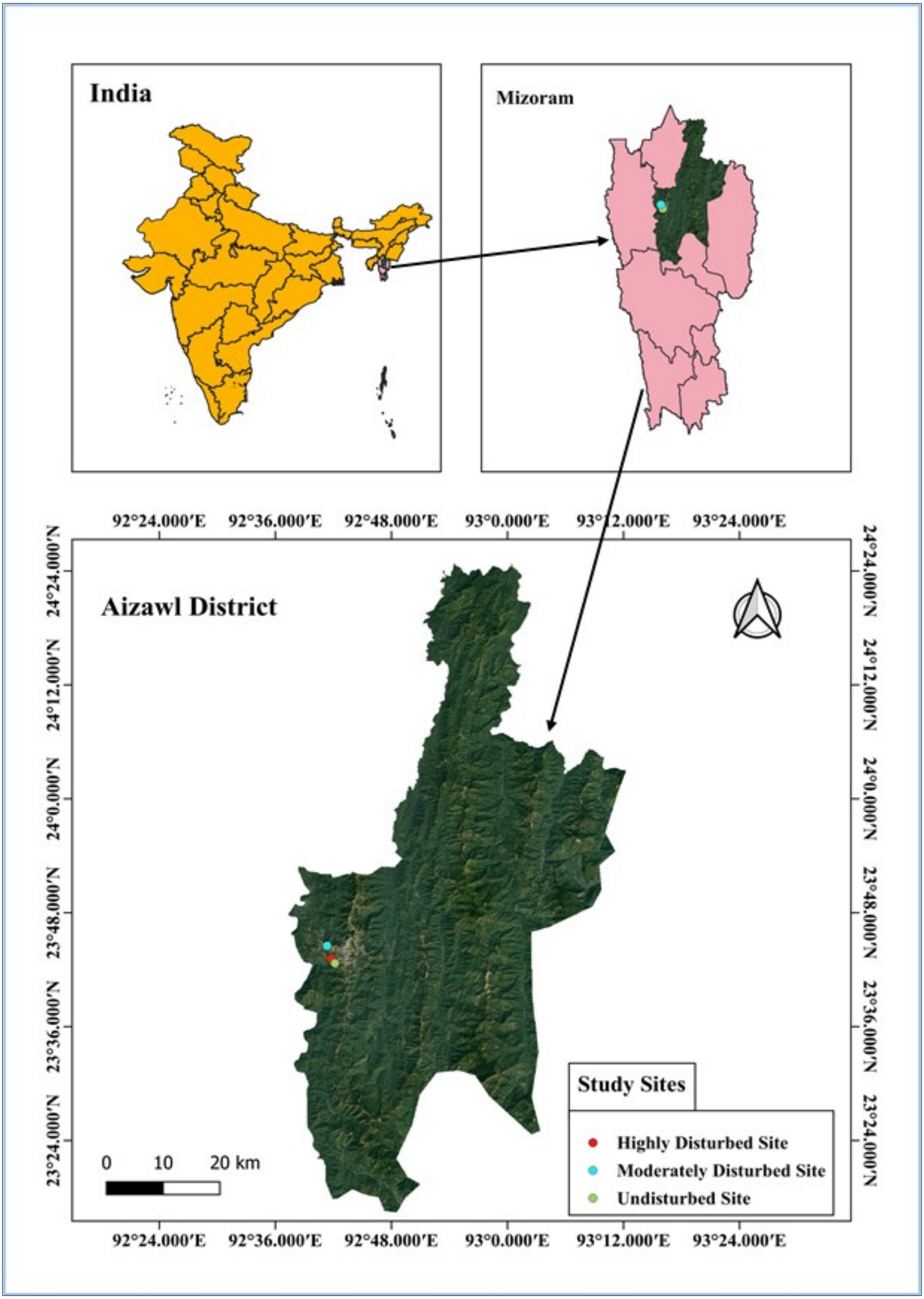

Fig. 1. Map of the study sites (highly disturbed, moderately disturbed and less disturbed) where invasive alien plants were present in Aizawl District, Mizoram, Northeast India located in the Indo-Burma biodiversity hotspot.

$$\text{Frequency (\%)} = \frac{\text{No. of quadrats in which species occurred}}{\text{No. of quadrats studied}} \times 100$$

Abundance

It is the study of the number of individuals of different species in the community per unit area, by quadrat method, samplings are made at random at several places and the number of individuals of each species were summed up for all the quadrats divided by the total number of quadrats in which the species occurred. It is represented by the equation:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrat}}{\text{Total number of quadrats in which the species occurred}}$$

Relative density

Relative density is the study of the numerical strength of the species in relation to the total number of individuals of all the species and can be calculated as:

$$\text{Relative density} = \frac{\text{Density of a species}}{\text{Total density of all species}} \times 100$$

Relative frequency

The degree of dispersion of individual species in an area in relation to the number of all the species occurred:

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$$

Relative abundance

The abundance value of a species with respect to the sum of abundance of all the species in the area. It is represented by the equation:

$$\text{Relative abundance} = \frac{\text{Abundance of a species}}{\text{Total abundance of all species}} \times 100$$

Importance value index (IVI)

IVI will be computed by adding the values of relative density, relative frequency and relative dominance for that species:

IVI = Relative density + Relative frequency + Relative dominance

Also, the following diversity indices have been used at different sites to further assess the impact of invasion on species richness and evenness.

Measurement of diversity

The type of diversity used here is α-diversity which is the diversity of species within a community or habitat. The diversity index was calculated by using the Shannon-Wiener diversity index (28).

$$\text{Shannon-Wiener diversity index(H')} = -\sum_{i=1}^{s} \left(\frac{n_i}{N}\right) l_n \left(\frac{n_i}{N}\right)$$

Where,

Pi = S/N S = number of individuals of one species

N = total number of all individuals in the sample

In = logarithm to base e

Measurement of species richness

Margalef's index was used as a simple measure of species richness (29).

$$\text{Margalef's index (R)} = \frac{(S - 1)}{\ln N}$$

Where,

S = total number of species

N = total number of individuals in the sample

In = natural logarithm

Measurement of species evenness

For calculating the evenness of species, Pielou's Evenness Index was used (30).

$$\text{Pielou's Evenness Index (E)} = \frac{H'}{\ln S}$$

Where,

H' = Shannon-Wiener diversity index

S = total number of species in the sample

Forest canopy openness, leaf area index (LAI) and photosynthetically active radiations (PAR)

The Gap Light Analyzer (GLA) software and hemispherical photography were used to analyze the canopy openness (31). The hemispherical photos were captured in triplicates using a smartphone mounted with a 10mm fisheye lens (Skyvik Signi One) pointed skyward and perpendicular to the earth in five locations on each site. The recorded hemispherical photographs from disturbed, moderately disturbed and less disturbed sites were analyzed on GLA software for canopy openness (Fig. 2). Colored photos are registered photos used for analysis on the GLA software and black and white photos are working/processed photos. Magnetic correction and declination were obtained from the National Oceanic and Atmospheric Administration (NOAA) website (32). The coordinates and elevation were recorded by a global positioning system (GPS) (Garmin GPSMAP 64s). The photosynthetically active radiation (PAR) and leaf area index (LAI) were determined using a plant canopy analyzer (Integration of portable and Software from Kaizen Imperial and Quantum Sensors from Apogee Instruments, USA) from five random points each on the study sites (33). Three data of PAR and LAI were recorded from each point and a mean value was noted.

Results and Discussion

Phytosociology

Vegetation analysis from the three sites viz. disturbed, moderately disturbed and less disturbed, recorded 23 species (Table 2). The disturbed site has the highest number of 23 species (Table 3), whereas, the less disturbed site has the lowest number of 15 species (Table 4). The density of each plant species from the three sites ranged from 0.1 to 8.9 at the disturbed site (Table 3), 0.1 to 15.3 at the moderately disturbed site (Table 5) and 0.2 to 2.2 at the less disturbed site (Table 4) respectively. IAPs such as '*Lantana camara* L., *Ageratum conyzoides* L., *Chromolaena odorata* (L.) R.M. King & H. Rob. and *Mikania micrantha* Kunth' were dominant at the disturbed site. The moderately disturbed site has a high

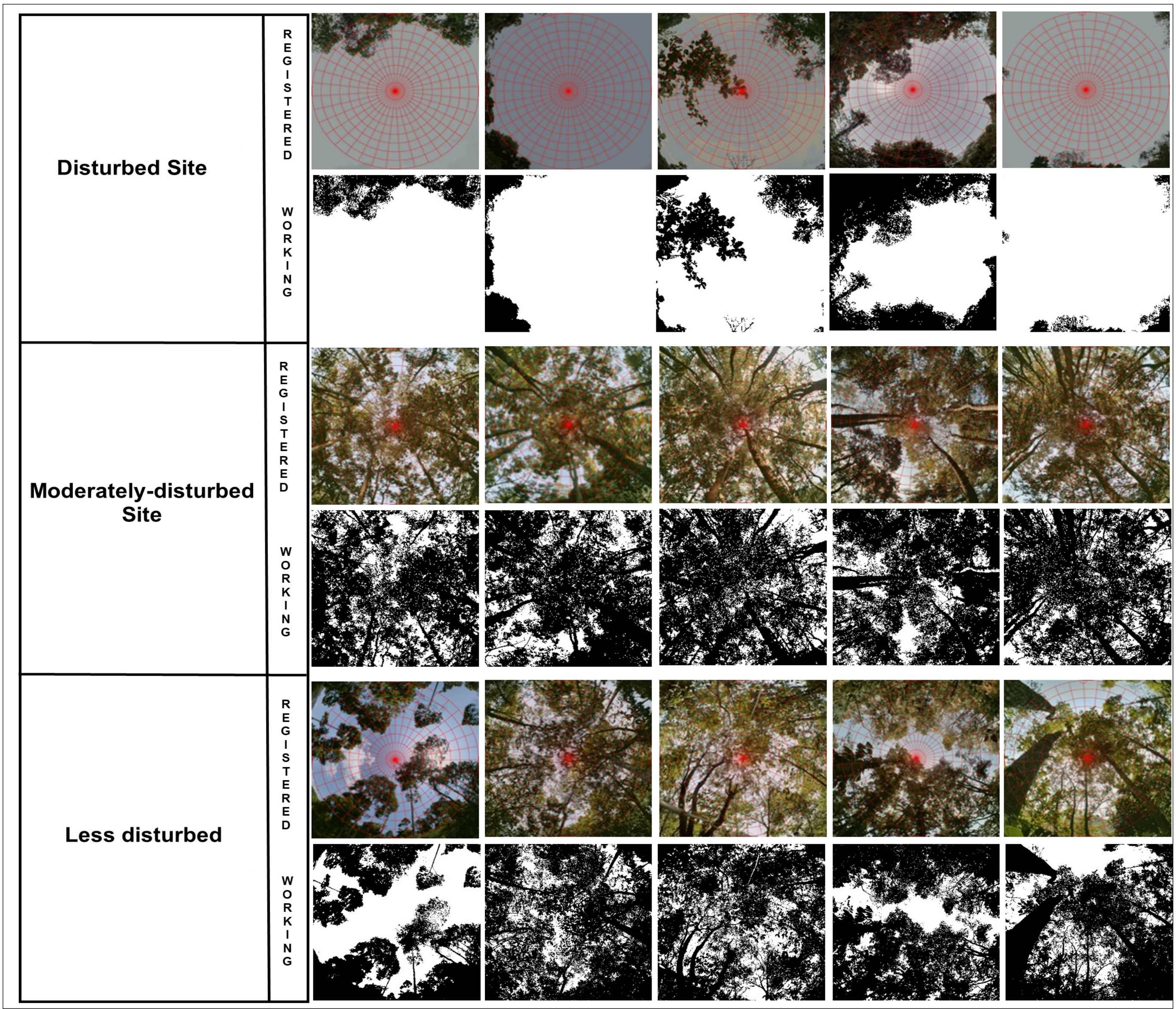

Fig. 2. Hemispherical photographs were taken and analyzed from disturbed, moderately disturbed and less disturbed sites. Colored photos are registered photos used for analysis on the gap light analyzer software and black and white photos are working/processed photos.

Table 2. List of the plant species reported from the study area in Aizawl, Mizoram, Northeast India

Name of species	Family	Nativity	Habit
Ageratum conizoides L	Asteraceae	Tropical America	H
Bidens biternate (Lour.) Merr. & Sherff	Asteraceae	China, Uganda, Kenya, Tanzania	H
Calopogonium mucunoides Desv.	Fabaceae	Tropical America, West Indies	C
Calyptocarpus vialis Less.	Asteraceae	Mexico, Central America and the Caribbean	H
Chromolaena odorata (L.) R.M. King & H. Rob.	Asteraceae	Tropical and subtropical regions of the Americas	S
Clerodendron infortunatum L.	Limiaceae	Tropical regions of Asia including India	S
Clerodendrum glandulosum Lindl.	Limiaceae	Tropical and subtropical regions of Asia including India	S
Cyrtococcum accrescens (Trin.)	Poaceae	Tropical and subtropical regions of Asia including India	H
Galinsoga parviflora Cav.	Asteraceae	Central America	H
Gynura bicolor (Roxb. ex Willd.)	Asteraceae	China, Taiwan, Thailand and Myanmar	H
Imperata cylindrica (L.) P.Beauv.	Poaceae	Tropical and subtropical Asia	H
Kyllingia brevifolia Rottb.	Cyperaceae	Tropical America	H
Lantana camara L.	Asteraceae	Central and south America	S
Leucaena leucocephala (Lam.) de Wit	Fabaceae	Tropical America	S
Merremia umbellata (L.) A.R.Simões & Staples	Convolvulaceae	Tropical America and West Africa	C
Mikania micrantha (L.) Kunth ex H.B.K.	Asteraceae	Central and south America	C
Mimosa pudica L.	Fabaceae	Central and South America	H
Panicum conjugatum Roxb.	Poaceae	Tropical and subtropical America	H
Solanum torvum S. W	Solanaceae	India	S
Spermacoce alata Aubl.	Rubiaceae	South America	H
Spilanthes oleracea (L.) Hook.f.	Asteraceae	Tropics of Africa and America	H
Stellaria media (L.) Vill	Caryophyllaceae	Europe	H
Urena lobata L.	Malvaceae	China and South East Asia	S

H: Herb; S: Shrub; C: Climber.

Table 3. Quantitative/phytosociological analysis of vegetation at disturbed site in Aizawl district, Mizoram, Northeast India

Name of species	Density	Frequency	Abundance	Relative density	Relative frequency	Relative abundance	IVI
Ageratum conizoides L.	6.3	100	6.3	10.59	10.99	5.18	26.75
Bidens biternate (Lour.)	3.1	60	5.17	5.21	6.59	4.24	16.05
Calopogonium mucunoides Desv.	0.3	20	1.5	0.5	2.2	1.23	3.93
Calyptocarpus vialis Less.	0.8	20	4	1.34	2.2	3.29	6.83
Chromolaena odorata (L.) R.M. King & H. Rob.	6.9	90	7.67	11.6	9.89	6.3	27.78
Clerodendron infortunatum L.	0.1	10	1	0.17	1.1	0.82	2.09
Clerodendrum glandulosum Lindl.	0.1	10	1	0.17	1.1	0.82	2.09
Cyrtococcum accrescens (Trin.)	3.7	20	18.5	6.22	2.2	15.2	23.61
Galinsoga parviflora Cav.	1.1	20	5.5	1.85	2.2	4.52	8.56
Gynura bicolor (Roxb. ex Willd.)	0.2	20	1	0.34	2.2	0.82	3.36
Imperata cylindrica (L.) P.Beauv.	8.3	70	11.86	13.95	7.69	9.74	31.38
Kyllingia brevifolia Rottb.	3.1	30	10.33	5.21	3.3	8.49	16.99
Lantana camara L.	0.6	50	1.2	1.01	5.49	0.99	7.49
Leucaena leucocephala (Lam.) de Wit	0.1	10	1	0.17	1.1	0.82	2.09
Merremia umbellata (L.) A.R.Simões & Staples	0.1	10	1	0.17	1.1	0.82	2.09
Mikania micrantha (L.) Kunth ex H.B.K.	4.8	100	4.8	8.07	10.99	3.94	23
Mimosa pudica L.	1	40	2.5	1.68	4.4	2.05	8.13
Panicum conjugatum Roxb.	6.1	50	12.2	10.25	5.49	10.02	25.77
Solanum torvum S.W	0.4	20	2	0.67	2.2	1.64	4.51
Spermacoce alata Aubl.	0.9	20	4.5	1.51	2.2	3.7	7.41
Spilanthes oleracea (L.) Hook.f.	8.9	70	12.71	14.96	7.69	10.44	33.09
Stellaria media (L.) Vill	2.4	60	4	4.03	6.59	3.29	13.91
Urena lobata L.	0.2	10	2	0.34	1.1	1.64	3.08

Table 4. Quantitative/phytosociological analysis of vegetation at less disturbed site in Aizawl district, Mizoram, Northeast India

Name of species	Density	Frequency	Abundance	Relative density	Relative frequency	Relative abundance	IVI
Ageratum conizoides L.	2	60	3.33	16	10.91	9.6	36.51
Bidens biternate (Lour.)	0.9	40	2.25	7.2	7.27	6.48	20.95
Calyptocarpus vialis Less.		50	4.2	0	9.09	12.09	21.18
Chromolaena odorata (L.) R.M. King & H. Rob.	2.2	60	3.67	17.6	10.91	10.56	39.07
Clerodendron infortunatum L.	0.2	20	1	1.6	3.64	2.88	8.12
Clerodendrum glandulosum Lindl.	0.3	30	1	2.4	5.45	2.88	10.73
Cyrtococcum accrescens (Trin.)	1.2	40	3	9.6	7.27	8.64	25.51
Galinsoga parviflora Cav.	2.1	50	4.2	16.8	9.09	12.09	37.98
Imperata cylindrica (L.) P.Beauv.	1	30	3.33	8	5.45	9.6	23.05
Lantana camara L.	0.2	20	1	1.6	3.64	2.88	8.12
Mikania micrantha (L.) Kunth ex H.B.K.	0.4	30	1.33	3.2	5.45	3.84	12.49
Spermacoce alata Aubl.	0.7	30	2.33	5.6	5.45	6.72	17.77
Spilanthes oleracea (L.) Hook.f.	0.2	20	1	1.6	3.64	2.88	8.12
Stellaria media (L.) Vill	0.7	40	1.75	5.6	7.27	5.04	17.91
Urena lobata L.	0.4	30	1.33	3.2	5.45	3.84	12.49

Table 5. Quantitative/phytosociological analysis of vegetation at moderately disturbed site in Aizawl district, Mizoram, Northeast India

Name of species	Density	Frequency	Abundance	Relative density	Relative frequency	Relative abundance	IVI
Ageratum conizoides L.	5.7	100	5.7	4.92	8	4.08	17
Bidens biternate (Lour.)	5.5	90	6.11	4.75	7.2	4.37	16.32
Calyptocarpus vialis Less.	12.9	100	12.9	11.14	8	9.23	28.37
Chromolaena odorata (L.) R.M. King & H. Rob.	4.8	100	4.8	4.15	8	3.44	15.58
Cyrtococcum accrescens (Trin.)	14.8	100	14.8	12.78	8	10.59	31.38
Galinsoga parvviflora Cav.	14.2	100	14.2	12.26	8	10.17	30.43
Gynura bicolor (Roxb.ex Willd.)	0.1	10	1	0.09	0.8	0.72	1.6
Imperata cylindrica (L.) P.Beauv.	9.6	90	10.67	8.29	7.2	7.64	23.13
Kyllingia brevifolia Rottb.	12.2	80	15.25	10.54	6.4	10.92	27.85
Lantana camara L.	0.2	20	1	0.17	1.6	0.72	2.49
Mikania micrantha (L.) Kunth ex H.B.K.	3.8	100	3.8	3.28	8	2.72	14
Mimosa pudica L.	0.5	40	1.25	0.43	3.2	0.89	4.53
Panicum conjugatum Roxb.	4	60	6.67	3.45	4.8	4.77	13.03
Solanum torvum S.W	0.2	20	1	0.17	1.6	0.72	2.49
Spermacoce alata Aubl.	9.4	80	11.75	8.12	6.4	8.41	22.93
Spilanthes oleracea (L.) Hook.f.	2.5	50	12.5	2.16	4	8.95	15.11
Stellaria media (L.) Vill	15.3	100	15.3	13.21	8	10.95	32.16
Urena lobata L.	0.1	10	1	0.09	0.8	0.72	1.6

number of species like '*Stellaria media* (L.) Vill., *Cyrtococcum accrescens* (Trin.), *Kyllingia brevifolia* Rottb. and *Galinsoga parvviflora* Cav'. The less disturbed site has a lower density of plant species such as *Calyptocarpus vialis* Less. and *K. bervifolia* while it has sparse distribution of IAPs.

The frequency of each plant species from the three sites ranged from 10 to 100 at the disturbed and moderately disturbed sites (Table 3 and 5). However, the frequency ranged from 20 to 60 at the less disturbed site (Table 4). Invasive plants such as '*L. camara*, *A. conyzoides*, *C. odorata*, *M. micrantha*, *Bidens biternate* (Lour.) Merr. & Sherff., *Spermacoce alata* Aubl., *G. parviflora*, *S. media* and *C. accrescens*' were abundantly present at both the disturbed and moderately disturbed sites, while they were sparsely distributed at the less disturbed site. The abundance of each plant species from the three sites ranged from 1 to 18.5 at the disturbed site (Table 3), 1 to 15.25 at the moderately disturbed site (Table 5) and 1 to 4.2 at the less disturbed site (Table 4), respectively. Plants such as '*C. accrescens*, *Panicum conjugatum* Roxb., *Imperata cylindrica* (L.) P.Beauv., *K. brevifolia*, *A. conyzoides*, *C. odorata*, *M. micrantha* and *L. camara*' were dominant at the disturbed site as well as moderately disturbed sites. The less disturbed site on the other has a dispersed collection of plant species such as *A. conzyoides*, *C. odorata*, *C. accrescens* and *C. vialis.*

The relative density was observed highest in the case of *C. odorata* [17.60], followed by *A. conyzoides* [16], at the less disturbed site (Table 4) followed by *Spilanthes oleracea* (L.) Hook.f. [14.96], *I. cylindrica* [13.95] in highly disturbed site (Table 3). The relative frequency was recorded highest in the case of *M. micrantha* [10.99], *A. conyzoides* [10.99] at the disturbed site (Table 2) followed by *C. odorata* [9.89], *C. vialis* [9.90], *G. parviflora* [9.90] from the less disturbed site (Table 5). The relative abundance among the species was highest in *S. media* [10.95] followed by *K. brevifolia* [10.92] and *C. accrescens* [10.59] at the moderately disturbed site (Table 5) and *C. odorata* [10.56] at the less disturbed site (Table 4). The plant species with the least relative abundance was found to be *L. camara* [0.72] from the moderately disturbed site (Table 5).

In moderately disturbed site, the species recorded a total of 1158 plant individuals belonging to different species with IVI ranging from 1.60 to 32.16. However, in the disturbed site, a total of 595 plant individuals were recorded, with IVI ranging from 2.09 to 31.38. Similarly, the least number of plant species, with 146 individuals, were recorded in less disturbed with IVI ranging from 36.53 to 7.89. The IVI for the three sites was found to be high in plants like *G. parviflora*, *C. vialis*, *S. media*, *C. accrescens*, *C. odorata* and *A. conyzoides* with IVI ranging from 23.00 to 36.53 (Fig. 3) which are among the list of top 100 worst biotic invaders (34). On the other hand, plant species such as *G. bicolor*, *C. glandulosum*, *U. lobata*, *C. infortunatum*, *L. camara*, *L. leucocephala* and *S. torvum* were plants having lower values of IVI ranging from 1.60 to 2.49 (Fig. 3). Similarly, a phytosociological study recorded dominant species such as *A. conyzoides*, *M micrantha*, *C. odorata* and *L. camara* along the disturbance gradient, which are all IAPs belong to Asteraceae (35).

The study on phytosociological attributes of all species at the three sites revealed the varying degrees of dispersion and species with low important value index indicated that they were of rare occurrence at the selected study sites. In the present study, the number of individuals of different species was recorded maximum at the moderately disturbed site [1158], which follows the 'Intermediate Disturbance Hypothesis' (IDH), which states that a moderate level of disturbance gives an equal opportunity for every plant individual to flourish (36, 37). Whereas the less disturbed site [146] provides opportunities to few dominant plant individuals, therefore, they have recorded a lesser number of individuals compared to disturbed sites [595].

The maximum diversity index using the Shannon-Wiener diversity index was observed at the disturbed site [2.54], followed by the moderately disturbed site [2.47] and the less disturbed site showed the lowest diversity index [2.42] (Table 6). The higher values of the species diversity index indicate the variability in the type of species and heterogeneity in the communities, whereas the lesser values point to the homogeneity in the community (38).

Table 6. Shannon-Wiener diversity index, Margalef's index and Pielou's evenness index in disturbed (D), moderately disturbed (MD) and less disturbed sites (LD)

Indices	Sites		
	D	MD	LD
Shannon-Wiener Diversity index H	2.54	2.47	2.42
Margalef's index SR	3.60	3.26	4.62
Pielou's Evenness Index E	0.40	0.35	0.49

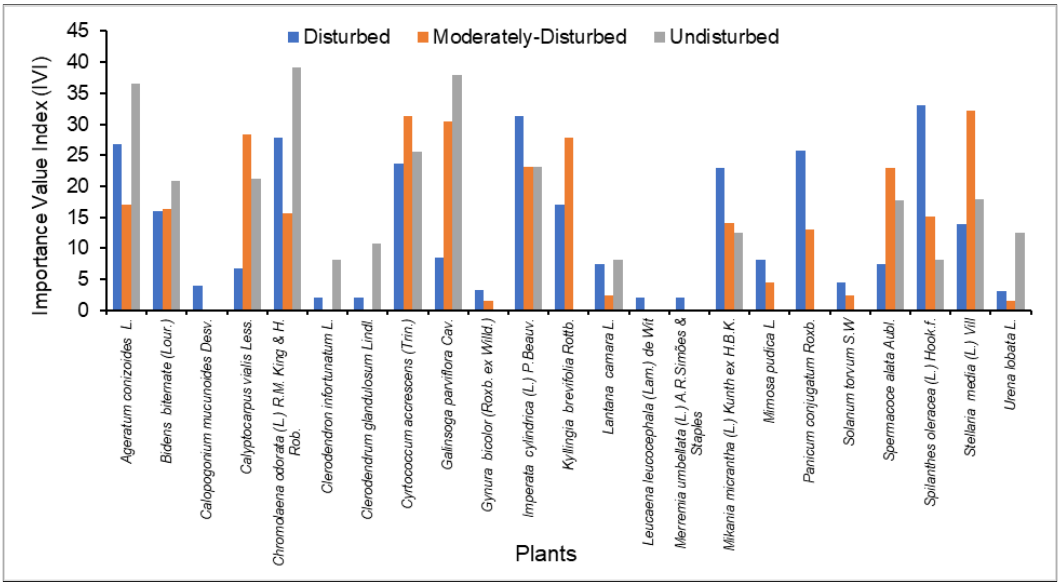

Fig. 3. Importance value index (IVI) of all the species presents in disturbed, moderately disturbed and less disturbed sites.

The decrease in species diversity depended on the complex interactions and variations among the species found within the community in response to disturbance factors (39). Margalef's index-based species richness was highest at the less disturbed site [4.62], followed by the disturbed site [3.6] and the moderately disturbed site [3.2] has the lowest species richness (Table 6). The decrease in species richness in the study sites depended on the types of plant species found within the community and species-specific differences in cover between the species (39). The lower species richness at disturbed and moderately disturbed sites is attributed to the high population density of IAPs which suppress the growth of neighboring native plants, thereby reducing the species richness and anthropogenic disturbances often increase the abundance of IAPs, especially in the Indian tropical wet forests (40). The evenness index was higher in the less disturbed [4.62], showing that the species are evenly distributed, whereas the lesser values in weed-infested regions showed patchiness in the distribution of plant species (Table 6). Present results on evenness indices at different sites along the disturbance gradient following previous ecological investigations (38). Similarly, another study also observed significant differences in the species evenness along the disturbance gradient (41).

Canopy openness, leaf area index (LAI) and photosynthetically active radiation (PAR)

The canopy openness was highest at the disturbed site (87.42 %) while it was lowest at the moderately disturbed site (25.92 %) (Table 7). The incoming PAR, which is the total incoming solar radiation received by the area above the forest canopy, was highest at the moderately disturbed site at 1355.6 ± 195.93 µmol m^{-2} s^{-1}whereas, the diffused PAR, which is the total solar radiation received by the area under forest canopy was highest at the disturbed study site 562.6 ± 368.38 µmol m^{-2} s^{-1} (Table 7). The highest LAI, which is the leaf area index of a particular site was observed at the less disturbed study site (4.36 ± 0.43), while it was noted as the lowest (1.65 ± 1.30) at the disturbed site (Table 7). Statistical analysis, demonstrated through the correlation matrix (Table 8), revealed that canopy openness showed a highly significant negative relationship with LAI (r = -0.817), while a highly significant positive relationship with diffused PAR (r = 0.875) and Shannon-Wiener diversity index (0.825). The diffused PAR also showed a highly significant positive relationship with the Shannon -Wiener diversity index (r = 0.995). However, LAI showed a highly significant negative relationship with diffused PAR (r = -0.994) and Shannon-Wiener diversity index (r = -1). Similarly, incoming PAR showed a highly significant negative relationship with Margalef's index (r = -0.993) and Pielou's evenness index (r = -0.972).

The highly significant negative relationship between canopy openness and LAI signifies that the density of foliar forest cover is independent of the canopy gaps. Higher canopy openness was found at the disturbed study site when compared with the less disturbed site, indicating that the area is more likely to experience disturbances, which may facilitate IAP infestation. Similarly, LAI showed a highly significant negative relationship with diffused PAR and species diversity index. High LAI (foliar cover) decreased the light penetration (diffused PAR) at the forest floor, resulting in low species diversity. The total radiation received by the area beneath the forest canopy was highest at the disturbed site, whereas the incoming solar radiation received by the area above the canopy was highest at the moderately disturbed site. This demonstrates how plant invasion can be accelerated by the presence or lack of forest canopy in a given area and it offers valuable insights for managing IAPs and the invasion process (42). Similar results were also reported in previous studies (31, 33), which observed that plant invaders were prevalent in areas with high canopy openness and light intensity. The correlation matrix also revealed that the PAR showed a highly significant negative relationship with Margalef's index and Pielou's evenness index, indicating that with increased solar radiation, the species richness and evenness reduced. High PAR levels frequently facilitate the invasion of IAPs by offering more favorable conditions for their development than native plants that are adapted to shaded environments (43, 44). The germination, growth and establishment of IAPs are directly influenced by light intensity and canopy cover, which are critical factors in plant invasions (45, 46). Therefore, monitoring canopy openness can help detect IAP in their early stage of invasion and efforts to maintain the intact canopy by increasing native plant species richness to achieve environmental sustainability in the urban forest of this Indo-Burma biodiversity hotspot region (47, 48).

Table 7. Canopy openness, Leaf Area Index and Photosynthetically Active Radiation (PAR) of the forest cover along the disturbance gradient (Disturbed, Moderately Disturbed and Less Disturbed)

Site	Canopy openness (%)	Leaf Area Index	PAR	
			Incoming µmol m^{-2} s^{-1}	Diffused µmol m^{-2} s^{-1}
Disturbed	87.42±13.24	1.65±1.30	1228.2±57.14	562.6±368.38
Moderately Disturbed	25.92±3.08	3.20±0.36	1355.6±195.93	206.2±62.01
Less disturbed	37.24±11.08	4.36±0.43	400.8±66.49	29.6±7.09

Each value represents the mean (± standard deviation) of five location on each sites.

Table 8. Correlation of Canopy openness, Leaf area index (LAI), Photosynthetically Active Radiation (PAR), Shannon-Wiener diversity index, Margalef's index and Pielou's Evenness Index in the study area along the disturbance gradient

Correlation	Canopy openness	LAI	Incoming PAR	Diffused PAR	Shannon-weiner Diversity index H'	Margalef's index SR	Pielou's Evenness Index E
Canopy openness	1						
LAI	-0.817**	1					
Incoming PAR	0.225	-0.745*	1				
Diffused PAR	0.875**	-0.994**	0.668*	1			
Shannon-Wiener Diversity index H'	0.825**	-1.000**	0.737*	0.995**	1		
Margalef's index SR	-0.107	0.661	-0.993**	-0.575	-0.651*	1	
Pielou's Evenness Index E	0.010	0.568	-0.972**	-0.475	-0.557	0.993**	1

*Significance; **highly significance.

Conclusion

Vegetation analysis at the three distinct study sites along the disturbance gradient in an Indo-Burma hotspot region of NE India revealed varying degrees of dispersions and species diversity. Native and IAPs with low IVI values indicated their rare occurrence. On the contrary, the plants with high IVI values were marked as dominant (*G. parviflora*, *C. vialis*, *S. media*, *C. accrescens*, *C. odorata* and *A. conyzoides*), which all are IAPs. The diversity indices were recorded highest at the disturbed study site and lowest at the less disturbed study sites, which corroborate that anthropogenic disturbances enhance IAP infestations, the majority of which are among the list of top 100 worst biotic invaders. The canopy openness was more pronounced and significant in the disturbed habitats when compared with less disturbed habitats. The Pearson correlation matrix also validated that the canopy openness demonstrated a highly significant negative interrelationship with LAI, while a highly significant positive correlation was noted with the Shannon-Wiener diversity index. The presence of large canopy gaps in the disturbed area increases solar radiation reaching the forest floor, which ultimately results in the formation of an ideal habitat for various IAPs. The observed variability in the floristic composition along the disturbance gradient demonstrated heterogeneity in the plant communities. Furthermore, an intact canopy can be maintained and regulated by sustainable development approaches and less human intervention in the urban forest of Aizawl, NE, India. Therefore, efforts to maintain the intact canopy by increasing native plant species richness can regulate the invasive spread to maintain the environmental sustainability in the urban forest of this Indo-Burma biodiversity hotspot region.

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Authors' contributions

SL contributed to conceptualization, data curation, formal analysis, investigation, methodology, resources, validation and writing original draft. PKR contributed to conceptualization, funding acquisition, methodology, project administration, supervision, visualization and writing review and editing. RBS contributed to data curation, formal analysis, investigation, methodology, software, validation and writing original draft. V contributed to data curation, formal analysis, validation and writing original draft. STL contributed to data curation, formal analysis and validation. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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