Diversity, distribution patterns, and ethnobotanical utilizations of aromatic plant species in Sitakunda Botanical Garden and Eco-park, Bangladesh

Shourav Dutta and Mohammed Kamal Hossain

Correspondence

Shourav Dutta[1,2*] and Mohammed Kamal Hossain[3]

[1]Golisano Institute for Sustainability, Rochester Institute of Technology, Rochester, New York, 14623, USA.
[2]Department of Forestry and Environmental Science, Rangamati Science and Technology University, Rangamati-4500, Bangladesh.
[3]Institute of Forestry and Environmental Sciences, University of Chittagong, Chattogram-4331, Bangladesh.

*Corresponding Author: shourav.forestry@gmail.com; sd1548@rit.edu

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Research

Abstract

Background: Sitakunda Botanical Garden and Eco-park is a biodiversity-rich hill forest in the Chattogram district, Bangladesh that harbors a wide range of aromatic plant species. However, the diversity of these species is facing a serious onslaught due to multiple anthropogenic disturbances. This study was carried out to evaluate the current status, diversity, distribution patterns, and ethnobotanical uses of aromatic plant species in this eco-park.

Methods: Field data were collected using the random quadrat method across 48 plots at various elevations. Ethnobotanical data were gathered through Focus Group Discussions (FGDs) with local communities and categorized into five use categories based on plant habit. Community structure was assessed using biodiversity indices, including Shannon's Index, Simpson's Index, Species Diversity Index, Margalef's Richness Index, and Species Evenness Index.

Results: A total of 1284 individuals representing 27 aromatic plant species from 26 genera and 22 families were documented. The families Asteraceae and Lauraceae were the most represented each with three species, followed by Zingiberaceae with two species. The calculated biodiversity indices were Shannon's Index (4.07), Simpson's Index (0.84), Species Diversity Index (3.08), Margalef's Richness Index (0.97), and Species Evenness Index (2.05).

Conclusions: This study revealed that medicinal aromatics performed a significant role in supporting biodiversity, preparing traditional medicines, sustaining religious and cultural heritage. Findings of the study recommended that the sustainable management of these plant resources is urgently needed to counteract the impact of human activities and to preserve the ethnobotanical heritage of the region.

Keywords: Aromatic plant; Bangladesh; Conservation; Importance Value Index; Plant diversity; Potential utilizations.

Background

Forest ecosystems have a positive impact on biological diversity (Mori *et al*. 2016). However, it is unfortunate that the floral diversity of tropical hill-forests of south Asia, which gradually resides in herbs, shrubs and small trees, has been facing a serious onslaught over the past four decades in numerous ways due to over exploitation, land-use change, climate change, anthropogenic disturbances and unscientific management (Dutta *et al.* 2014, Franklin *et al*. 2016, Hassan 1995, Nath *et al.* 2000, Vitousek 1994).

Bangladesh, lies within the northwestern edge of the Indo-Burma floristic zone of south Asia, is one of the most populous tropical countries of the world. It possesses a wide diversity of flora and fauna with enormous genetic variations due to its unique geophysical location and acts as a breeding and resting ground of several angiosperms, vertebrates, and microorganisms (Dutta & Hossain 2020, Dutta *et al*. 2015, Hossain 2009, Nishat *et al*. 2002). Researchers reported that immediate actions are required to effectively preserve the existing forests as well as the genetic variations of indigenous and exotic plant species in Bangladesh through intensive management (Alam 2001, Hossain 2004). Several protected areas, e.g., Botanical Garden, Eco-park, National Park, Wildlife Sanctuary, Game Reserve, etc. have been established by Bangladesh Forest Department to conserve the country's biological diversity (Mukul 2007). As part of these exertions, Bangladesh Forest Department implemented an ecological rehabilitation of its denuded natural forests by establishing the first eco-park at Sitakunda in the south-eastern Chattogram hill region under the Southern Sitakunda Reserved Forest of the Chattogram North Forest Division (Misbahuzzaman & Alam 2006).

Established in 2000 by the Bangladesh Forest Department, the eco-park was designed to preserve and develop the gene pool of both native and exotic plants along with various aromatic, ornamental and avenue plant species through ecological rehabilitation and plantation efforts (Alam 2001, Misbahuzzaman & Alam 2006, MoEFCC 2000). From the religious and ecotourism perspectives, Sitakunda Botanical Garden and Eco-park plays a significant role. Floral variety and the presence of several waterfalls and pilgrimage sites in this hilly region serve as special attraction for eco-tourists, pilgrims and casual visitors (Dutta *et al*. 2014, Rahman & Fakir 2015). Numerous aromatic plants and two threatened native gymnosperms of Bangladesh - *Cycas pectinata* and *Gnetum latifolium* are naturally harbored in different locations of Sitakunda Eco-park due to its unique habitat and rich biodiversity (Dutta *et al*. 2014). This eco-park is not only significant for conserving biological diversity but also vital for sustaining the traditional knowledge among local residents, specifically concerning the utilizations of aromatic plant species. These species are extensively woven into the fabric of rural and indigenous life, serving as key components in culinary practices, folk medicines, natural perfumery and spiritual rituals (Devi *et al*. 2014, Merry & Shahjahan 2013).

Aromatic plants inhabit a culturally esteemed space in South Asian societies, particularly in Bangladesh (Merry & Shahjahan 2013). Aromatic plants are a special class of flora utilized for their aroma and flavor. Generally, those plants release sweet fragrance or pungent smell due to odorous volatile compounds found in one or more of their organs (Devi *et al*. 2014). Many are exclusively used for medicinal purposes in aromatherapy as well as in various traditional systems of medicine. Over millennia, aromatic plants have been utilized as drugs and fragrance materials to support human health and well-being. They form the basis of traditional and indigenous health systems used by the majority of the population of developing country like Bangladesh (Merry & Shahjahan 2013). Similarly, several aromatic plants also produce essential oils as well as being widely used for perfumery (Maiti & Geetha 2013, Rahman & Fakir 2015). In addition, many of the aromatic plant species have special chemical compounds that function as natural preservatives (Merry & Shahjahan 2013).

From the ethnobotanical points of view, aromatic plants perform a significant role in cultural, ecological, economic and social aspects of local residents (Devi *et al*. 2014). Apparently, these plants are considered essential in the daily life of human society. Several species are commonly utilized in traditional remedies by the local herbal healers (Devi *et al*. 2014). Meanwhile, these plants are dominantly associated with cultural activities and religious ceremonies (Merry & Shahjahan 2013). These are often burned as incense during religious ceremonies, infused in oils for therapeutic massages, and consumed as herbal decoctions in traditional healing. Furthermore, aromatic plant species are widely used in culinary practices for augmenting aroma and flavor. Such practices reveal deep-rooted ethnobotanical knowledge passed down through generations, and focus the connection of ecological richness and cultural heritage in Chattogram region, Bangladesh (Merry & Shahjahan 2013, Rahman & Fakir 2015).

The diversity of different plant species as native trees, exotic plants, medicinal plants and non-wood forest species in Sitakunda Botanical Garden and Eco-park has already been documented (Alam 2001, Dutta *et al*. 2014, Dutta *et al*. 2015, Misbahuzzaman & Alam 2006, Rahman & Fakir 2015, Rahman & Uddin 1997, Roy *et al*. 2024, Uddin *et al*. 2005). Dutta *et al*.

(2014) documented 332 vascular plant species, representing 266 genera and 93 families, in the Sitakunda Botanical Garden and Eco-park. More recently, Roy *et al*. (2024) reported that the eco-park possesses 321 plant species with approximately 382,992 trees having a diameter at breast height (DBH) of 5 cm or above. However, the literature concerning assessment of aromatic plant species, their distribution patterns, utilizations and conservation measures is not well addressed in the southeastern Bangladesh, particularly in the Sitakunda Botanical Garden and Eco-park. There is also a lack of quantitative assessment regarding their diversity, natural populations and distribution patterns along the elevation gradient of the hill forests. In this study, an attempt has been made to investigate the status and distribution patterns of aromatic plant species in the Sitakunda Botanical Garden and Eco-park of Bangladesh. Additionally, categorizing the recorded aromatic plant species based on their habit forms and potential ethnobotanical uses was another key aim of this study.

Materials and Methods

Study area

Sitakunda Botanical Garden and Eco-park is situated at the north-western part of Chattogram district under the jurisdiction of Chattogram North Forest Division, Bangladesh. The area was classified as semi-evergreen forest with wide floral diversity (Misbahuzzaman & Alam 2006). It lies between 22°36´ - 22°39´N latitude and 91°40´ - 91°42´E longitude (Alam 2001, Nandi & Vacik 2014).

The climate of the study area is sub-tropical. Eco-park area resides under the tropical climatic zone and located in the east of the Bay of Bengal, 6-7 km from the coast that helps to get heavy rain as the winds of the southwest monsoon blow in this direction. Eco-park area remains dry for 4 to 5 months during summer (Dutta *et al*. 2014, Nandi & Vacik 2014, Misbahuzzaman & Alam 2006). This forest area adores moist tropical climate of 29.6°C mean annual temperature. Moreover, the average annual rainfall and mean monthly humidity of this eco-park are about 2872 mm and 66.5% - 88.6%, respectively (Dutta *et al*. 2014, Dutta *et al*. 2015, Uddin *et al*. 2005).

Soil, drainage and topography of the study area

The soils of Sitakunda hills are developed on Tertiary hill sediments of Tipam-Surma series. These are well structured, brown, acidic, loamy soils resting on hard rock within 100 cm depth. Soils are yellowish brown to yellowish red in color and are sandy loam to clay loam with moderately alkaline to widely acidic in reaction (Misbahuzzaman & Alam 2006, Nandi & Vacik 2014). The topography of the park area consists of very steep hills and numerous V-shaped valleys. The degrees of slopes range from 40-90 degrees. Therefore, land use planning in the high hills has to take into account - (1) steep slope of the terrain (> 30% slope), (2) shallow depths of soil, (3) severe seasonal drought (January - May), (4) large access of seasonal rainfall (July - October), and (5) difficult and poor accessibility of the landscape (Alam 2001).

Reconnaissance survey

The secondary information about the eco-park area, status of forest coverage, and density and accessibility of the whole study area was collected from the respective forest offices and conversation with key informants (Bangladesh Forest Department officers and local people). Principally, a reconnaissance survey/pre-fieldwork (field observation) in the study area before the main research is effective to gain an overall idea regarding the physiographic and general environmental conditions of the study site (Dutta *et al*. 2021). Reconnaissance also provides a basis for conducting the comprehensive main investigation (Ray *et al*. 2024). Hence, a reconnaissance survey was conducted prior to fieldwork to have a general idea of the site, topography, vegetation coverage, boundary, and species composition. The experience gained from the reconnaissance survey was used to design the survey.

Experimental design

To assess the distribution patterns of aromatic plant species of the Sitakunda eco-park, field work was done through random quadrat method. A total of 48 sample quadrats were selected in the whole study area (Fig. 1). The quadrat size: 2m×2m for herbs and grasses, 5m×5m for shrubs and 10m×10m for trees were standardized on the basis of species-area-curve method (Cain 1938). For all plots, the size used was 10m × 10m. However, the actual location of plots depended on the accessibility of the site. Generally, 10 meters is the longest distance that can be accurately surveyed in a dense forest. Plants inside the 10m × 10m quadrat were identified and then counted accordingly. A 2m × 2m sub-plot was laid out inside the 10m × 10m quadrat for the inventory of herbs, vines, and seedlings. Similarly, a 5m×5m subplot was laid out inside the 10m × 10m quadrat for the enumeration of shrubs.

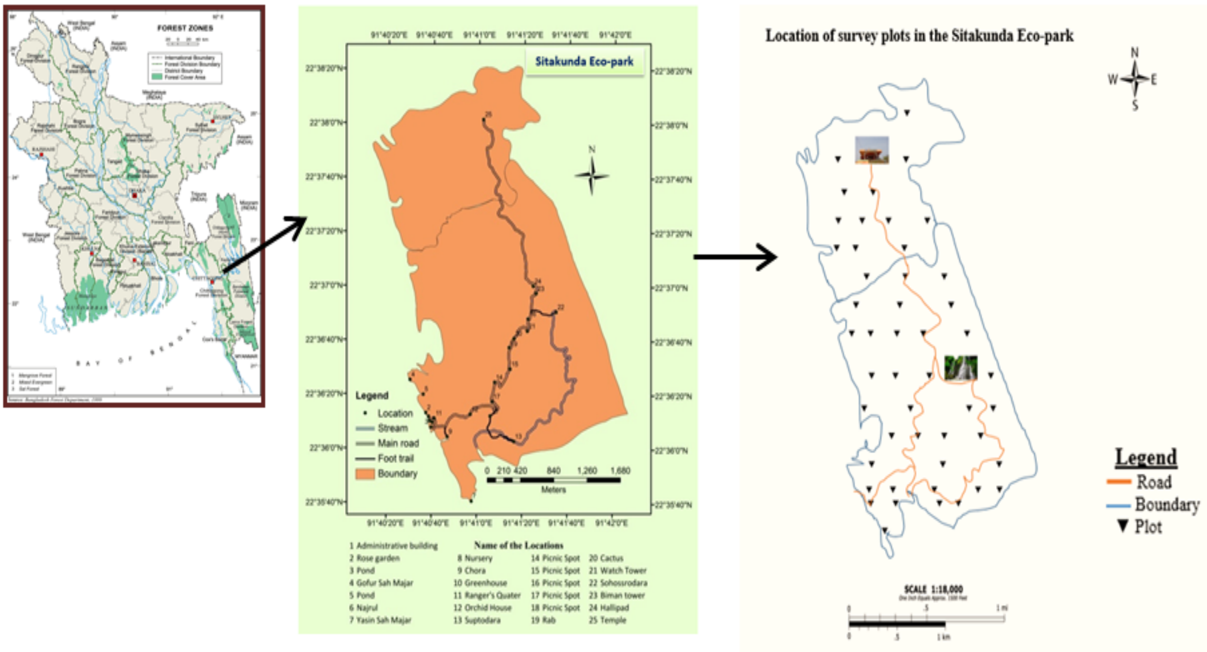


Figure 1. Map showing the locations of 48 survey quadrats in the study area.

In the 48 sample quadrats, regeneration of various plant species were also found and recorded. Among 48 sample quadrats, the hill top, mid hill and the valley (bottom-hill) were represented by 16 plots each. At each of the three hill positions (hill top, mid hill and valley), four quadrats were laid out on each of the four aspects (southern, northern, eastern and western). Such distribution results in a total of 12 quadrats per aspect (3 hill positions × 4 aspects = 12 quadrats in each aspects) (Table 1).

Table 1. Number of sample plots taken in the study area

Slope	Number of plots	Aspect	Number of plots
Hill Top	16	Southern	12
Mid Hill	16	Northern	12
Bottom of hill	16	Eastern	12
		Western	12
Total	48	Total	48

Data collection and compilation

The observed aromatic plant species were identified, recorded, and tagged in the field. Fertile parts of unknown aromatic plant species were collected for herbarium preparation and taxonomic identification. These specimens were dried, pressed, and mounted on standard-sized sheets (29.21 cm × 41.91 cm or 11.5" × 16.5"), then identified using standard floras and cross-verified with the Bangladesh Forest Research Institute Herbarium and relevant literature. Identification was carried out with reference to Ahmed *et al.* (2008), Das and Alam (2001), and Prain (1903). Endangered and rare aromatic plant species were categorized using Ara *et al*. (2013), Khan *et al*. (2001), Merry and Shahjahan (2013), and Uddin and Hassan (2010). Voucher specimens were deposited in a referenced herbarium and assigned identification numbers (101 to 127) for traceability.

In this study, a plant species was considered 'aromatic' if it met at least one of the following criteria: (i) it possessed a noticeable scent or aromatic property in any part of the plant (e.g., leaf, flower, bark, oil, or sap) as confirmed independently by at least two local informants during field surveys and FGDs; (ii) its aromatic nature was cited in established literature, ethno-botanical reports and floristic references (Ahmed *et al*. 2008; Das & Alam 2001, Merry & Shahjahan 2013). For instance, *Cocos nucifera* was involved due to its traditional aromatic utilizations. Floral sap of *Cocos* is known for a characteristic sweet scent, and coconut oil derived from its fruit, which is usually used in perfumery, cooking, and therapeutic applications due to its distinct fragrance. This amalgamated approach confirmed the robustness of species inclusion criteria and minimized subjectivity.

Focus Group Discussion

The information about the aromatic plant resources, uses, and their impacts on the local residents was collected and gathered through Focused Group Discussion (FGD) including local residents, residing around the botanical garden and eco-park. FGD is extensively used in clarification and validation of information obtained (Dutta *et al*. 2021). FGD was carried out in the surrounding villages of the study area involving the direct participation of local residents. A total of four FGDs were carried out that covered the whole study area. Both male and female participants were selected randomly from the adjacent villages for FGDs, targeting local residents with recognized knowledge of medicinal or aromatic plant uses. Each FGD consists of minimum 8-10 persons, upholding at least 40% female participants, and including local community leader, local villagers, resource collectors, and resource dependent persons. In addition, male participants were found to be dominant, when FGDs were conducted at the local market. The FGDs involved those who were knowledgeable about aromatic and medicinal plant resources, and also who were familiar with the utilizations of different aromatic plant species for healthcare purposes. During the survey, local knowledgeable persons and herbal healers were interviewed and information on indigenous uses of the aromatic plants was collected.

Moreover, selection of the informants was based on their experience, willingness to participate, and familiarity with the vegetation of the study area. The respondents were the residents as they have been living in the area for more than 15 years. Primary data (i.e., gender, age, education level, frequency of aromatic plant collection, and consumption pattern of resources, etc.) were collected from the field level for the analysis of the dependency and consumption patterns. The informants were also categorized into four major groups based on the distance between the park area and their residents. Further, information about aromatic and medicinal flora of the study area was also collected through personal communication with various personnel (e.g., range officers, researchers, foresters, conservators, and local key informers), following the approaches prescribed by Dutta *et al*. (2015), Dutta and Hossain (2016). Alongside the cosmetic-producing plants, numerous perfume- and oil-yielding plant species were recorded from the eco-park and subsequently categorized into five major use categories - cosmetics, flavoring, food, medicine, and perfumery.

Data analysis

During the study, different phytosociological attributes (relative density, relative frequency, relative dominance and Importance Value Index) were calculated for all the plots. The equations used for calculating phytosociological characteristics are listed in Table 2.

Table 2. Equations used for calculating the phytosociological characteristics of aromatic plant species

Phytosociological characters	Formula	Reference
Density	$D = \frac{a}{b}$	Shukla & Chandal 2000
Relative density (RD) (%)	$RD = \frac{n}{N} \times 100$	Dallmeier *et al.* 1992, Mori *et al*. 1983
Frequency (F)	$F = \frac{c}{b}$	Shukla & Chandal 2000
Relative frequency (RF) (%)	$RF = \frac{Fi}{\sum_{i=1}^{s}(Fi)} \times 100$	Dallmeier *et al.* 1992, Mori *et al*. 1983
Abundance (A)	$A = \frac{n}{c}$	Shukla & Chandal 2000
Relative abundance (RA) (%)	$RA = \frac{Ai}{\sum_{i=1}^{s}(Ai)} \times 100$	Misra 1968
Relative Dominance (%)	$RDo = \frac{Basal\ area\ of\ one\ species}{\text{Total basal area}}$	Dutta *et al*. 2015, Hossain *et al*. 2013
Importance value index (IVI)	$IVI = RD + RF + RDo$	Dutta *et al*. 2015, Hossain *et al*. 2013; Hossen *et al*. 2021

a: total number of individuals of a species in all the quadrats; *b*: total number of quadrats studied; *c*: total number of quadrats in which the species occurs; *n*: total number of individuals of the species; *N*: total number of individuals of all the species; F_i: frequency of one species; A_i: abundance of one species.

Family importance value index (FIVI) was calculated by applying the formula proposed by Rahman *et al.* (2011).

$$\textit{Family Importance Value Index (FIVI)} = \textit{Family relative density } (FD_e) + \textit{Family relative diversity } (FD_i)$$

The formula for calculating Family relative density is $FD_e = \frac{Ni}{Ti} \times 100$, where N_i is number of individual in a family and T_i is the total number of individuals.

On the other hand, Family relative diversity (FD_i) $= \frac{Ns}{Ts} \times 100$, where, N_s means number of species in a family and T_s indicates total number of species (Mori *et al*. 1983).

The relative abundance of a species is illustrated by species diversity and not indicates just its occurrence. If a community is composed of few species, or if few species are abundant, the species diversity will be low. High species diversity indicates the presence of a complex ecological community (Rahman *et al*. 2019). To make a relationship between species composition and species diversity, a number of methods exist. In this study, biodiversity indices such as Shannon's index, Simpson's diversity index, Species evenness index, etc. were assessed and the equations used for the calculation are listed in Table 3. Species diversity index (S_{DI}) starts from 1 when there is only one individuals of one species, the value reach to maximum with the increase of species number (Odum 1971).

Shannon-Wiener diversity index value is highest when the number of individuals of all species is equal; value is zero (0) if there is only one species (Michael 1984). Margalef's index (R) is high in communities that include a greater number of species and in which the number of individuals of each species decreases relatively slowly on passing from more abundant to less abundant ones (Kent & Coker 1992). With Simpson's diversity index (D), 0 represents infinite diversity and 1 indicates no diversity (Magurran 1988). Species Evenness index (E) is known as Shannon's equitable index, adopts a value between 0 and 1 with 1 being complete evenness (Pielou 1966).

Table 3. Specification of biodiversity indices for aromatic tree species in the Sitakunda Botanical Garden and Eco-park

Biodiversity indices	**Formula**	**Reference**
Species diversity index (S_{DI})	$S_{DI} = \frac{S}{N}$	Kohli *et al.* 1996, Odum 1971
Shannon-Wiener's diversity index (H)	$H = -\sum_{i=1}^{n} Pi \times ln\ Pi; Pi = n/N$	Michael 1984, Shannon & Wiener 1963
Margalef's species richness index *(R)*	$R = \frac{S-1}{LN(N)}$	Margalef 1958
Simpson's diversity index (D)	$D = \frac{1}{\sum_{i=1}^{n} Pi^2}; Pi = n/N$	Magurran 1988
Species evenness index *(E)*	$E = H/log(S)$	Pielou 1966

N: total number of individuals of all the species; P_i: number of individuals of i^{th} species/total number of individuals in the samples; S: total number of species; n is the number of individuals of each species; H: Shannon's index.

Use Value (UV) of aromatic plant species was calculated using the formula proposed by Phillips *et al.* (1994) -

$$UV = \sum Ui / N$$

Where, *"UV"* refers to the use value of an aromatic species; "U_i" refers to the number of uses reported by each informant for that plant species; and "N" refers to the total number of informants interviewed in the survey. If a plant secures a low UV score indicates fewer use reports cited by the informants, while high UV score indicates that there are many use reports for that medicinal plant.

Frequency of citation (CF) index score was calculated using the following equation proposed by Friedman *et al*. (1986) -

$$CF\ (\%) = \frac{Ns}{Nt} \times 100$$

Where, "N_s" referred to the number of times a particular species was mentioned and "N_t" referred to the total number of times all species were mentioned.

The relationship between ecological dominance and cultural significance of aromatic plant species was evaluated. The correlation between Importance Value Index (IVI) and Use Value (UV), as well as Citation Frequency (CF) was explored applying Spearman's rank correlation. Due to the ordinal nature of the ranks and non-normal distribution of values, this nonparametric method was preferred. The analysis was implemented applying SPSS v16.0, with significance evaluated at $p < 0.05$.

Evaluating species richness across elevations

The elevation range data were collected from the local range office of Bangladesh Forest Department and Alam (2001). Species richness is demarcated as the total number of species found in each 100 m elevation band (Grytnes & Vetaas 2002). But, in this study the total elevation gradient between 0 and 410 m was divided into 50-m elevation intervals (vertical elevation band) to examine the relationship between species richness and elevation. We have used Generalized Linear Model (Dobson 1990, McCullagh & Nelder 1989) to examine the relationship between species richness and elevation. The response variable, species richness, is a discrete data type (counts) and also follows a Poisson error distribution (McCullagh & Nelder 1989). The models were checked with up to third-order polynomial regressions according to Bhattarai and Ghimire (2007).

Data compilation and result presentation

All the recorded data/information (qualitative and quantitative) was gathered and compiled using spread sheet (Microsoft Excel, version MS 2013). Statistical techniques, such as frequency analysis, descriptive statistics, etc. were applied during the study for analyzing the collected data. Regressions were performed using SPSS v16.0. Data were processed using statistical software, e.g., Microsoft Excel 2013 and R 3.0.2. The major findings of this research were summarized cautiously and disclosed scientifically in the form of graphs, tables and pictures.

Results

Aromatic plant species composition and their habit forms

The study enumerated a total of 1284 individuals belonging to 27 aromatic plant species (4 monocots and 23 dicots) representing 26 genera and 22 families from the Sitakunda Botanical Garden and Eco-park, Bangladesh. The number of individuals and species distributed in 48 quadrat plots is shown in Fig. 2.

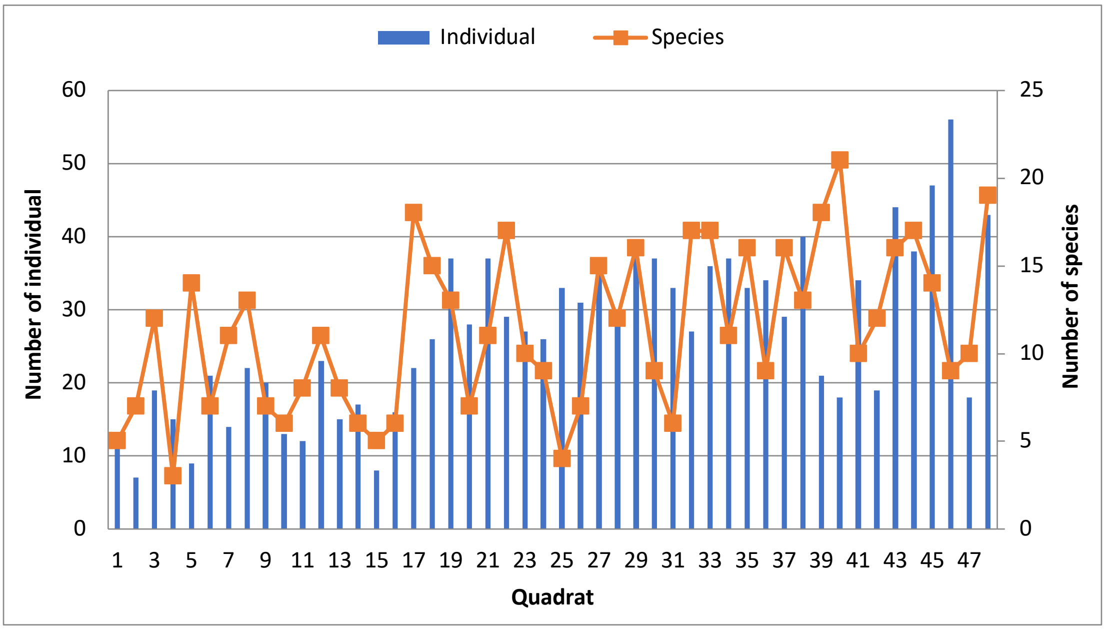


Figure 2. Number of individuals and species (per quadrat) of aromatic plants recorded from 48 study plots

All the plant species were categorized based on plant type, habit form and classified under genus and family. Magnoliopsida (dicot) were represented by 23 species under 22 genera and 19 families. In Magnoliopsida (dicot), Asteraceae and Lauraceae families were represented by maximum 3 species. Liliopsida (Monocot) were represented by 4 species under 4 genera and 3 families (Table 4).

Among the 27 aromatic plant species, trees constitute the major category (11 species) and occupying 41% of all the recorded aromatic species followed by shrubs (29%), herbs (26%) and climbers (4%) (Table 5). The botanical name, local name, family, habit form, mode of origin, habitat and voucher (herbarium) code of each aromatic plant species are provided in Table 6.

Table 4. Categorization of aromatic plant species recorded from the Sitakunda Botanical Garden and Eco-park, Chattogram, Bangladesh

Family	Genus	Species	Plant type
Arecaceae	1	1	L*
Asteraceae	3	3	M
Caesalpiniaceae	1	1	M
Fabaceae	1	1	M
Labiatae	1	1	M
Lauraceae	2	3	M
Liliaceae	1	1	L
Lythraceae	1	1	M
Magnoliaceae	1	1	M
Myrtaceae	1	1	M
Oleaceae	1	1	M
Piperaceae	1	1	M
Rosaceae	1	1	M
Rubiaceae	1	1	M
Rutaceae	1	1	M
Santalaceae	1	1	M
Sapindaceae	1	1	M
Scrophulariaceae	1	1	M
Solanaceae	1	1	M
Thymelaeaceae	1	1	M
Verbenaceae	1	1	M
Zingiberaceae	2	2	L
Total: 22	**26**	**27**	

*L= Liliopsida (Monocot), M= Magnoliopsida (Dicot)

Table 5. Aromatic plant species recorded from Sitakunda Botanical Garden and Eco-park

Plant Category	Species	Genus	Family	Percentage
Tree	11	10	9	41
Shrub	8	8	8	29
Herb	7	7	6	26
Climber	1	1	1	4

Table 6. List of aromatic plant species recorded from the eco-park area with their name, family, habit, mode of origin, habitat and voucher (herbarium) code

Scientific name	Local name	Family	Habit	Mode of origin	Habitat	Voucher code
Aloe vera (L.) Burm.f.	Grheeta kumari	Liliaceae	h*	P[#]	Mid-hill	114
Aquilaria agallocha Roxb.	Agar	Thymelaeaceae	t	P	Top-hill	127
Cassia occidentalis L.	Kasundi	Caesalpiniaceae	s	P, N	Mid-hill	102
Cestrum nocturnum L.	Hashnahena	Solanaceae	s	P	Bottom-hill	119
Cinnamomum camphora (L.) Prest.	Korpur	Lauraceae	t	N	Mid-hill	105
Cinnamomum glaucescens (Nees) Meiss	Tej-bohol	Lauraceae	t	P, N	Mid-hill	124
Citrus aurantifolia (Christm. & Panzer)	Lebu	Rutaceae	s	N	Bottom-hill	109
Cocos nucifera L.	Narikel	Arecaceae	t	P, N	Mid-hill	108
Curcuma longa L.	Holud	Zingiberaceae	h	N	Bottom-hill	130
Dahlia variabilis Cav.	Dahlia	Asteraceae	h	P	Bottom-hill	103
Gardenia angusta (L.) Merr.	Gandha-raj	Rubiaceae	s	P	Bottom-hill	120
Gliricidia sepium (Jacq.) Kunth.	Gliricidia	Fabaceae	t	P	Bottom-hill	126
Helianthus annuus L.	Surjomukhi	Asteraceae	h	P	Bottom-hill	112
Jasminum sambac (L.) Aiton.	Bon-mollika	Oleaceae	s	N	Bottom-hill	115
Lawsonia inermis L.	Mehedi, Henna	Lythraceae	s	N	Mid-hill	100

Litsea glutinosa (Lour.) C.B. Rob.	Meda-patta	Lauraceae	t	P	Bottom-hill	117
Melaleuca leucodendron L.	Melaluka	Myrtaceae	t	P	Top-hill	118
Michelia champaca L.	Champaphul	Magnoliaceae	t	P, N	Mid-hill	123
Nyctanthes arbor-tristis L.	Shefali	Verbenaceae	t	N	Mid-hill	107
Ocimum sanctum L.	Tulshi	Labiatae	s	N	Top-hill	125
Piper betel L.	Pan	Piperaceae	c	P	Bottom-hill	101
Rosa chinensis L.	Golap, Rose	Rosaceae	s	P	Bottom-hill	104
Santalum album L.	Shweta-chandan	Santalaceae	t	P	Top-hill	128
Sapindus mukorossi Gaerth.	Ritha, Soap nut	Sapindaceae	t	N	Mid-hill	106
Scoparia dulcis L.	Bondhoney	Scrophulariaceae	h	N	Mid-hill	111
Zingiber zerumber Sm.	Pola	Zingiberaceae	h	N	Top-hill	110
Zinnia elegans Jacq.	Jinnia	Asteraceae	h	P	Bottom-hill	113

(*h = herb, c = climber, s = shrub, t = tree); [#P = Planted, N = Natural]

The study recorded 11 aromatic tree species under 10 genera and 9 families from Sitakunda Botanical Garden and Eco-park, where Lauraceae was represented by maximum (3) tree species. *Cinnamomum camphora* and *Sapindus mukorossi* were found as very common natural tree species in Sitakunda eco-park. A total of 8 aromatic shrub species belonging to 8 genera and 8 families were recorded from Sitakunda Eco-park. The aromatic shrub species that naturally occurred in Sitakunda eco-park were *Citrus aurantifolia*, *Jasminum sambac*, *Lawsonia inermis* and *Ocimum sanctum*.

The study recorded 7 aromatic herb species belonging to 7 genera and 6 families in Sitakunda Botanical Garden and Eco-park. Among the 6 families, Asteraceae was represented by 3 herb species and the remaining 5 families had only one species each. Among the 27 aromatic plant species, 10 plant species (37%) were recorded from the natural forests and 13 species (48%) from the plantation. Only four species were found to grow naturally as well as in the plantation. The abundance of species under different families disclosed wide variation, whereas, 30% species were represented by 3 dominant families and rest of the 70% species by 19 families. Among the dominant families, Asteraceae and Lauraceae contain maximum number of species (3 species) followed by 2 in Zingiberaceae and the remaining families had one species each (Fig. 3).

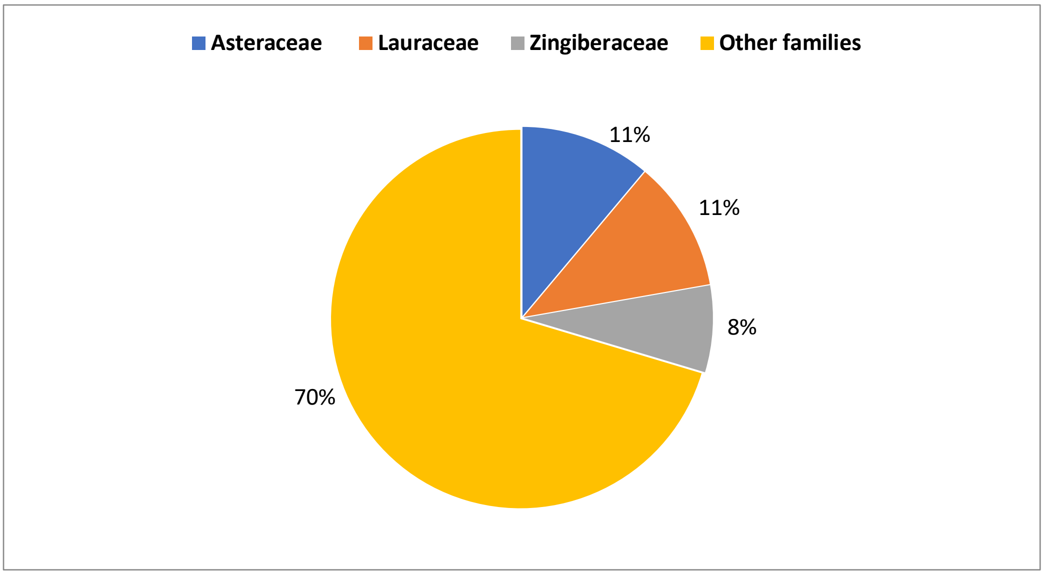


Figure 3. Abundance of aromatic plant species belonging to three dominant families

Distribution pattern of aromatic plant species in the study area

A total of 12 plant species (44%) were recorded from the Bottom-hills (valley), where 2 species were trees, 5 were shrubs, 4 were herbs and only 1 was climber. The study recorded 37% plant species (6 trees, 2 shrubs and 2 herbs) from the mid-hills and only 19% plant species (3 trees, 1 shrub and 1 herb) from the top-hills of the Sitakunda Eco-park (Fig. 4).

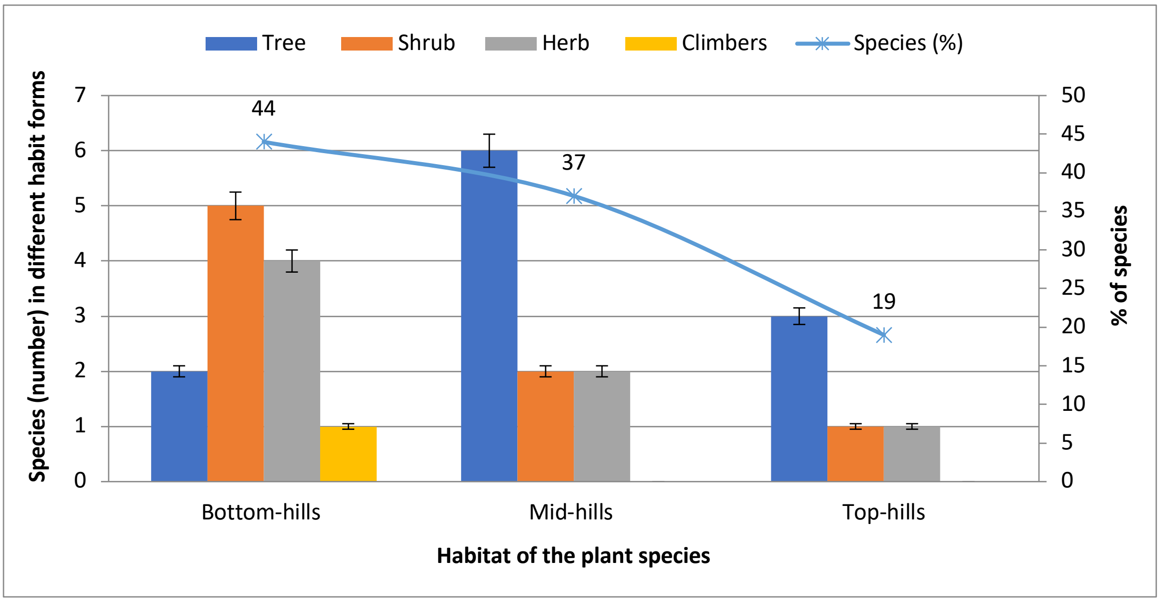


Figure 4. Distribution of aromatic plant species in various topographical locations of Sitakunda Eco-park, Bangladesh

Phytosociological attributes of aromatic tree species

Among the aromatic tree species, the relative density was found highest for *Melaleuca leucodendron* (24.70%) followed by *Cocos nucifera* (16.41%) and *Nyctanthes arbor-tristis* (16.03%). Maximum relative frequency was calculated for *Nyctanthes arbor-tristis* (27.20%) followed by *Cocos nucifera* (18.09) and *Melaleuca leucodendron* (16.02%). Maximum relative dominance was calculated for *Melaleuca leucodendron* (21.09%) followed by *Cocos nucifera* (16.23%) and *Nyctanthes arbor-tristis* (14.11%). The maximum Importance Value Index (IVI) was estimated for *Melaleuca leucodendron* (61.81) followed by *Cocos nucifera* (59.84) and *Nyctanthes arbor-tristis* (48.23) in the Sitakunda Botanical Garden and Eco-park (Table 7).

Table 7. Phytosociological attributes of aromatic tree species in the study area

Scientific name	Local name	RD(%)	RF(%)	RDo(%)	IVI
Aquilaria agallocha Roxb.	Agar	10.08	9.01	7.83	26.92
Cinnamomum camphora (L.) Prest.	Korpur	9.01	11.01	8.41	28.43
Cinnamomum glaucescens (Nees) Meiss	Tej-bohol	11.23	8.65	7.18	27.06
Cocos nucifera L.	Narikel	16.41	18.09	16.23	59.84
Gliricidia sepium (Jacq.) Kunth.	Gliricidia	1.90	2.04	2.01	5.95
Litsea glutinosa (Lour.) C.B. Rob.	Meda-patta	1.35	1.79	2.64	5.78
Melaleuca leucodendron L.	Melaluka	24.70	16.02	21.09	61.81
Michelia champaca L.	Champaphul	2.11	2.90	13.08	18.09
Nyctanthes arbor-tristis L.	Shefali	16.03	27.20	14.11	48.23
Santalum album L.	Shweta-chandan	1.09	2.20	4.01	7.30
Sapindus mukorossi Gaerth.	Ritha, Soap nut	6.09	1.09	3.41	10.59
Total		**100**	**100**	**100**	**300**

RD: Relative Density(%), RF: Relative Frequency(%), RDo: Relative Dominance(%), and IVI: Importance Value Index

The hilly forest of Sitakunda Eco-park is commonly classified as a semi-evergreen forest. Findings from the family importance value analysis indicated that Myrtaceae and Arecaceae were the most species-rich families, followed by Magnoliaceae and Fabaceae, which together constitute the majority of the aromatic plant composition (Fig. 5). Both naturally occurring and planted aromatic plant species were recorded in the study area.

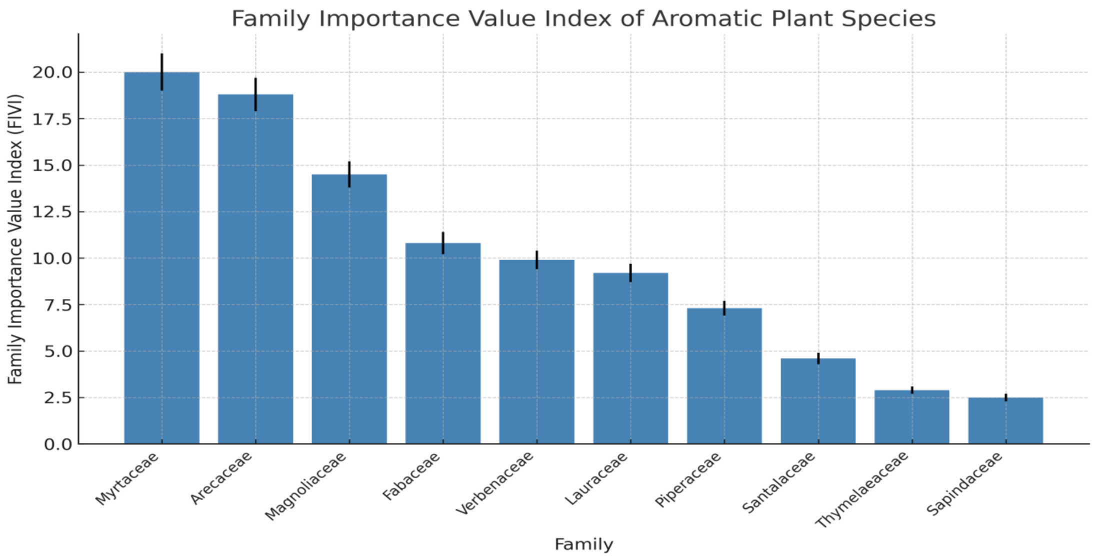


Figure 5. Family Importance Value Index (FIVI) of aromatic plant species in the study area

Biological diversity indices of aromatic plant species in the Sitakunda Eco-park

Biological diversity indices are helpful to better understand the community structure and also prescribe baseline information about the composition and status of aromatic vegetation in the study area. Different biological diversity indices, i.e., Species diversity index (SDi), Shannon-Winner index (H), Species evenness index (E), Simpson's diversity index (D), and Margalef's species richness index (R) were calculated for Sitakunda Eco-park to illustrate the status of recorded aromatic tree species (Table 8). The findings of this study revealed that the species were almost evenly distributed.

Table 8. Different biodiversity indices of aromatic tree species for Sitakunda Eco-park area

Biodiversity indices	Total for Eco-park area
Species diversity index (S_{DI})	3.08
Shannon-Wiener's diversity index (*H*)	4.07
Margalef's species richness index *(R)*	0.97
Simpson's diversity index (*D*)	0.84
Species evenness index *(E)*	2.05

Distribution of aromatic plant species along the elevation

The study revealed the distribution of aromatic plant species between ground level (0 m) to highest peak (410 m) of the Eco-park areas. All habit groups (trees, shrubs, herbs and climbers) of aromatic plant species when regressed separately and in amalgamation against elevation, significant trend was perceived in the GLM and ensured the hump shaped relationship along the elevation gradient of the hills of Sitakunda Eco-park (Table 9). Thus, the pattern of distribution along the elevation gradient is almost similar for all habit forms.

The aromatic plant species belonging to trees life form group are found up to 410 m, whereas the aromatic shrub groups are found up to 350 m. In the study, aromatic climber species was not recorded between 100-150m and 150-200m elevations. The aromatic species richness decreases with increasing the elevation up to certain elevation range and then increases with further increasing the elevation. Optimum aromatic species richness observed at the middle of the gradient. This optimum richness site is different for different life forms of aromatic plant species. Aromatic trees and shrubs were found optimum at 100 m. On the other hand, maximum number of aromatic herb species was recorded at 350 m elevation. The variation in the occurrence and richness of the species belonging to each life forms group is shown in Fig. 6.

Table 9. Summary of Generalized Linear Model (GLM) for each habit forms of aromatic plants in the study area

Habit form	P.O.	df	R.De.	R^2	*p-value*
Tree	2	7	11.27	0.705	0.009
Shrub	2	7	30.07	0.523	0.028
Herb	2	7	32.02	0.121	0.050
Climber	2	7	67.11	0.460	0.009

Note- P.O.: polynomial order; df: degree of freedom; R.De: Residual deviance

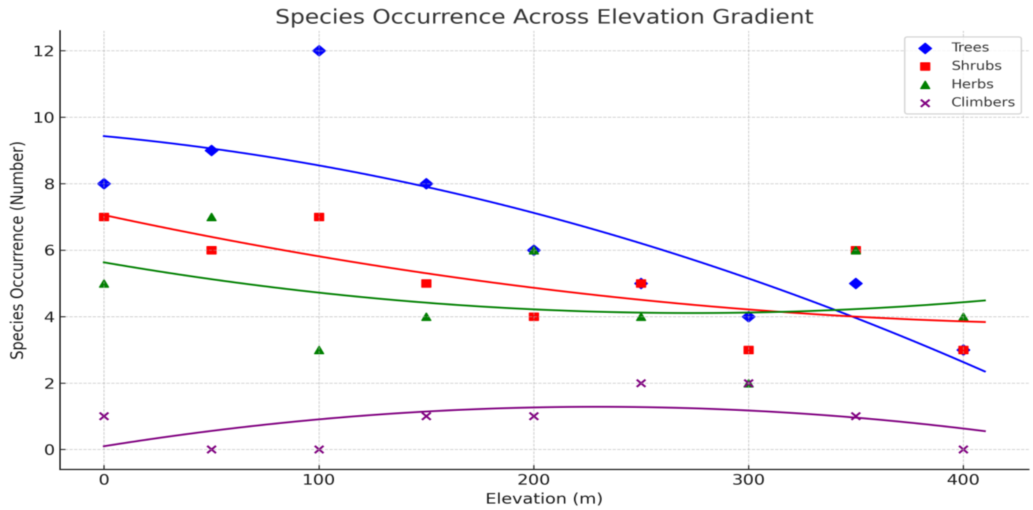
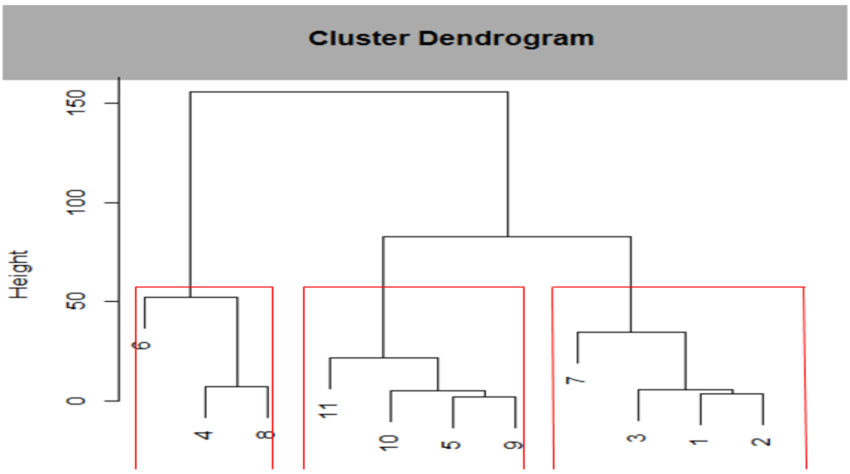


Figure 6. Scatter plot shows the relationship between aromatic plant species (belongs to different life forms) and elevation gradient in the study area

Hierarchical cluster analysis based on dominance of the recorded tree species

Cluster analysis using ward linkage of the groups of tree species indicated that the recorded aromatic tree species could be assembled into six hierarchical clusters depending on their dominance in the study area. The findings from the cluster analysis revealed that *Melaleuca leucodendron* is the most dominant species, which formed separate cluster. There are a number of plantations of *Melaleuca* in the park area, providing it dominance over others. *Michelia champaca* and *Sapindus mukorossi* formed the next two clusters. The remaining species, forming one cluster, are quite similar (Fig. 7).



*1: *Aquilaria agallocha;* 2: *Cinnamomum camphora;* 3: *Cinnamomum glaucescens;* 4: *Cocos nucifera,* 5: *Gliricidia sepium;* 6: *Litsea glutinosa;* 7: *Melaleuca leucodendron;* 8: *Michelia champaca;* 9: *Nyctanthes arbor-tristis;* 10: *Santalum album;* 11: *Sapindus mukoross*

Figure 7. Hierarchical cluster of aromatic tree species in the study area

Demographic information of the informants

The investigation on human-aromatic plant interactions as well as plant influences on human welfare were conducted through FGDs at the different locations, specifically at the adjacent communities in the study area, where numerous communities, i.e., Bengali, Tripura, etc. reside. Most (62.5%) of the informants were male; and high percentages (35%) of informants were around 31 to 40 years old; and about 60% informants were educated up to primary (elementary) level (Table 10). Meanwhile, about 42.5% respondents opined that they harvested aromatic plant species with the highest collection frequency being 1 to 2 times per month. As not all the data and information collected through the focus group discussions (FGDs) were relevant to the objectives of this study, only the key findings related to aromatic plant resources, their sustainable utilization, and ethnobotanical practices have been presented. Analyses deemed non-essential were excluded.

Table 10. Demographic information of the informants

Variables	Categories	Number of person	Percentage
Informants type	Aromatic plant harvesters	25	62.5
	General people	15	37.5
Gender	Male	22	55
	Female	18	45
Age class	20-30	9	22.5
	31-40	14	35
	41-50	7	17.5
	51-60	6	15
	> 60	4	10
Education Levels	Able to read and write	7	17.5
	Primary (elementary)	24	60
	Secondary to higher	9	22.5
Frequency of aromatic plants collection	1-2 times/month	17	42.5
	2-3 times/month	10	25
	3-4 times/month	7	17.5
	> 5 times/month	6	15

Utilizations of aromatic plant species

Most of the aromatic plant species are extensively used in the preparation of cosmetics and perfumes. Some of the aromatic plants are directly consumed as food, while others are used for flavoring foods or as spices that have special function to prolong table life and enhance the palatability of foodstuffs. Several plant species also serve as important raw materials in traditional medicinal systems, such as Unani, Ayurvedic, and Homoeopathic medicine. In addition, certain aromatic plants with woody stems like *Santalum album*, emit natural fragrances that are utilized to refresh room air. Cosmetics, flavoring, food, medicine, and perfumery were the major use categories considered for grouping the recorded aromatic plant species. Some oil yielding plants were classified under both the perfumery and cosmetics categories (Table 11).

Table 11. Uses of recorded aromatic plant species in the park area along with their useable parts

Scientific name	Category	Usable parts	Uses
Aloe vera	Cosmetic, Medicine	Leaves, whole plants	Leaves contain gel (polysaccharides), used in cosmetic industries and the leaf exudates contains aloins and aloe emodine, which are used as pain killer and purgative; skin diseases
Aquilaria agallocha	Cosmetic, Perfumery	Wood	Agar oil; base materials in perfumery; soap
Cassia occidentalis	Food, Medicine	Fruits, leaves	Spices; flavoring; Unani medicine
Cestrum nocturnum	Perfumery	Flowers	Flower oil; perfume
Cinnamomum camphora	Food, Medicine	Fruits, leaves	Spices; flavoring curry
Cinnamomum glaucescens	Food	Leaves	Spices; flavoring curry; bark oil
Citrus aurantifolia	Flavoring	Fruits, leaves	Flavoring curry; soap
Cocos nucifera	Cosmetic, Food	Fruits	Food; medicine; raw materials of hair oil
Curcuma longa	Cosmetic, Food	Rhizome	Food; flavoring curry; pharmacological applications
Dahlia variabilis	Cosmetic	Flowers	Fragrance; perfume
Gardenia angusta	Cosmetic	Flowers	Fragrance; perfume; soap materials
Gliricidia sepium	Cosmetic	Flowers	Fragrance; base materials in perfumery
Helianthus annuus	Cosmetic	Seeds	Seed paste in leaf juice is as ointment on head for one sided head-ache; oil is used for massage in body-pain
Jasminum sambac	Perfumery	Flowers	Natural flower oil (Jasmine oil); perfume
Lawsonia inermis	Cosmetic	Leaves	Hand and hair dying
Litsea glutinosa	Flavoring	Leaves	Flavoring; folk medicine
Melaleuca leucodendron	Medicine	Leaves	Melaluka oil; anti-bacterial; oil used to treat cough, pains and infections; herbal medicine
Michelia champaca	Perfumery	Flowers	Perfumery; soap
Nyctanthes arbor-tristis	Perfumery	Flowers	Perfumery

Ocimum sanctum	Flavoring, Medicine	Leaves, whole plants	As flavoring agent; treatment of fever & cough
Piper betel	Flavoring	Leaves	Elachi flavor
Rosa chinensis	Perfumery	Flowers	Fragrance; base materials in perfumery; fixative; soaps, cosmetics and incense
Santalum album	Perfumery	Wood, bark	Sandalwood; base materials in perfumery; fixative; soaps; refresh room air
Sapindus mukorossi	Cosmetics	Fruits	Shampoo
Scoparia dulcis	Food	Leaves	Food; flavoring curry
Zingiber zerumber	Cosmetic, Medicine	Rhizome	Sinusitis; stomach upset; to treat cough and cold; cosmetics
Zinnia elegans	Perfumery	Flowers	Natural flower oil; base materials in perfumery; soaps, cosmetics and incense

Four Focused Group Discussions (FGDs) made in the surrounding communities comprising participants from the surrounding residences shown that more than 75% of the food, flavoring and spices requirements of 85% participants were met by the fruits, leaves and rhizomes collected from the Sitakunda Botanical Garden and Eco-park. The study revealed 10 cosmetic-yielding aromatic plants in Sitakunda Botanical Garden and Eco-park. In addition, 8 aromatic plant species (4 trees, 3 shrubs and 1 herb) were found to yield perfume/ fragrance. Moreover, a total of 6 aromatic plant species under food category were recorded, where trees were represented by maximum 3 species. Aromatic plant species utilized for medicinal purposes were 6, where trees, shrubs and herbs were represented by 2 species each. Only 4 aromatic plants (1 tree, 2 shrubs, and 1 climber) were recorded from the study area that used for flavoring curry (Fig. 8).

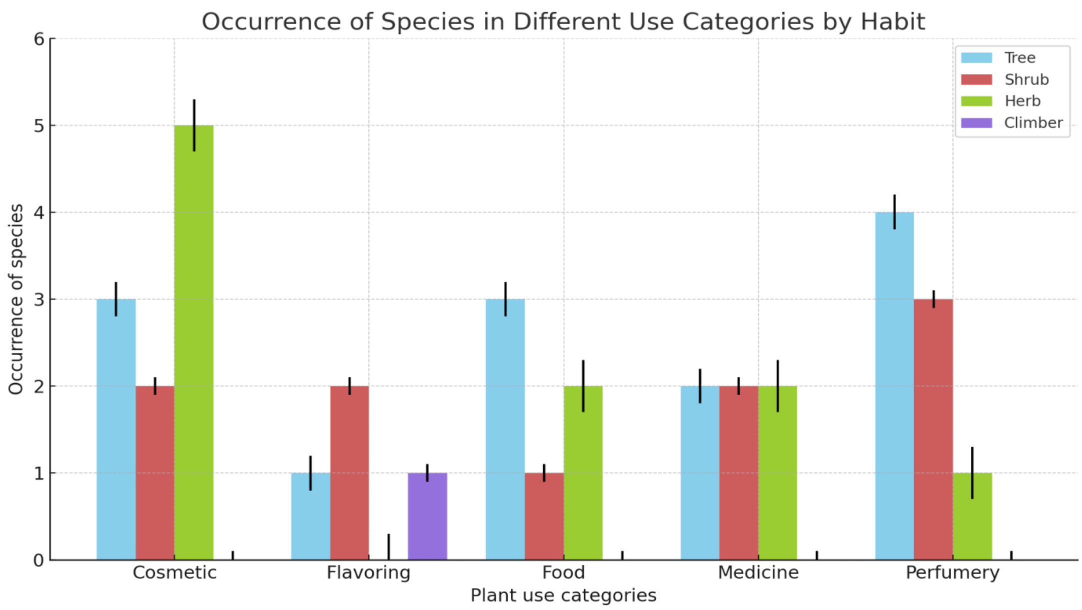


Figure 8. Categorization of aromatic plant species under five different use categories according to their habit form

Use Value and Citation Frequency (%) of the recorded aromatic plant species

The average Use Value (UV) score for aromatic plant species was calculated as 0.091, ranging from 0.03 to 0.23. The findings of the research revealed that *Santalum album* (UV = 0.23) was the most commonly utilized and processed aromatic plant species, followed by *Melaleuca leucodendron* (UV = 0.18) and *Aloe vera* (UV = 0.15) (Table 4). On the other hand, species such as *Lawsonia inermis* (UV = 0.03), *Nyctanthes arbor-tristis* (UV = 0.03), *Piper betel* (UV = 0.03), and *Sapindus mukorossi* (UV = 0.03) recorded the lowest UV scores, indicating limited reported uses. Aromatic plant species with higher UV scores were frequently cited for their multiple and diverse applications, such as cosmetics, incense production, perfumery, traditional medicine, and as raw materials in household and cultural practices (Table 12).

Citation Frequency (CF) among the investigated aromatic plant species ranged from 2.38% to 5.30% (Table 4). The analysis revealed that *Cocos nucifera* (5.30%) was the most frequently cited aromatic species, followed by *Santalum album* (5.03%) and *Citrus aurantifolia* (5.03%). These species were widely reported by informants for their diverse aromatic and therapeutic applications. Particularly, these species are traditionally utilized for purposes such as the preparation of perfumes, body oils, and incense, as well as for treating ailments. Several communities also emphasized their use in cultural rituals, religious ceremonies, and as natural insect repellents, underlining their multifaceted value within the local communities (Table 12).

Table 12. Use Value and Citation Frequency (%) of the recorded aromatic plant species utilized in the study area

Scientific name	UV	Number of informants citing species	CF (%)
Aloe vera (L.) Burm.f.	0.15	36	4.77
Aquilaria agallocha Roxb.	0.10	28	3.71
Cassia occidentalis L.	0.08	27	3.58
Cestrum nocturnum L.	0.05	29	3.84
Cinnamomum camphora (L.) Prest.	0.05	19	2.52
Cinnamomum glaucescens (Nees) Meiss	0.08	34	4.50
Citrus aurantifolia (Christm. & Panzer)	0.05	38	5.03
Cocos nucifera L.	0.13	40	5.30
Curcuma longa L.	0.13	22	2.91
Dahlia variabilis Cav.	0.05	21	2.78
Gardenia angusta (L.) Merr.	0.08	22	2.91
Gliricidia sepium (Jacq.) Kunth.	0.08	18	2.38
Helianthus annuus L.	0.10	26	3.44
Jasminum sambac (L.) Aiton.	0.08	22	2.91
Lawsonia inermis L.	0.03	29	3.84
Litsea glutinosa (Lour.) C.B. Rob.	0.05	22	2.91
Melaleuca leucodendron L.	0.18	37	4.90
Michelia champaca L.	0.05	33	4.37
Nyctanthes arbor-tristis L.	0.03	21	2.78
Ocimum sanctum L.	0.10	33	4.37
Piper betel L.	0.03	27	3.58
Rosa chinensis L.	0.20	21	2.78
Santalum album L.	0.23	38	5.03
Sapindus mukorossi Gaerth.	0.03	26	3.44
Scoparia dulcis L.	0.05	27	3.58
Zingiber zerumber Sm.	0.13	29	3.84
Zinnia elegans Jacq.	0.13	30	3.97

Correlation between ecological and ethnobotanical values of aromatic plant species

The Spearman's rank correlation revealed a weak but positive correlation between IVI and UV ($\rho = 0.376$, $p = 0.24$), and a moderate correlation between IVI and CF ($\rho = 0.485$, $p = 0.11$), although neither reached statistical significance. Despite of having low IVI (7.30), *Santalum album* demonstrated the maximum UV (0.23), indicating a great cultural significance. However, *Melaleuca leucodendron* showed both high IVI (61.81) and high UV (0.18), representing alignment between ecological and cultural significance. Such findings underscore that rare or less abundant aromatic plant species of the study area may grasp inconsistent ethnobotanical values, and should be prioritized in enrichment planting and conservation efforts.

Utilization of various plant parts

This study revealed that both above-ground and below-ground plant parts of aromatic plants are used in the study area. *Aloe vera, Cocos nucifera* and *Ocimum sanctum* are three important aromatic plant species and all parts of those species are useful. The oil extracted from the *Cocos* is utilized as a significant component in remedies for skin infections. The oil extracted from the mature *Cocos* tree is also used to manufacture marine soaps and hair oil. On the other hand, oils from *Ocimum* leaves are used as an ingredient to produce antiseptic and antimicrobial medicines and also used for antibacterial treatments by the local Unani and Ayurveda. Aboveground plant parts are used more often (85.5%) than below-ground parts (8.4%), and whole plants are rarely used (7.1%). Leaves (32%) of the various aromatic plant species are used by the local communities in the study area. Flowers (28%) and fruits (16%) of the aromatic species are utilized for the aromatherapy and religious purposes. Wood (6%), rhizome (6%), seed (3%) and bark (3%) of aromatic plants are also used for various purposes (Fig. 9).

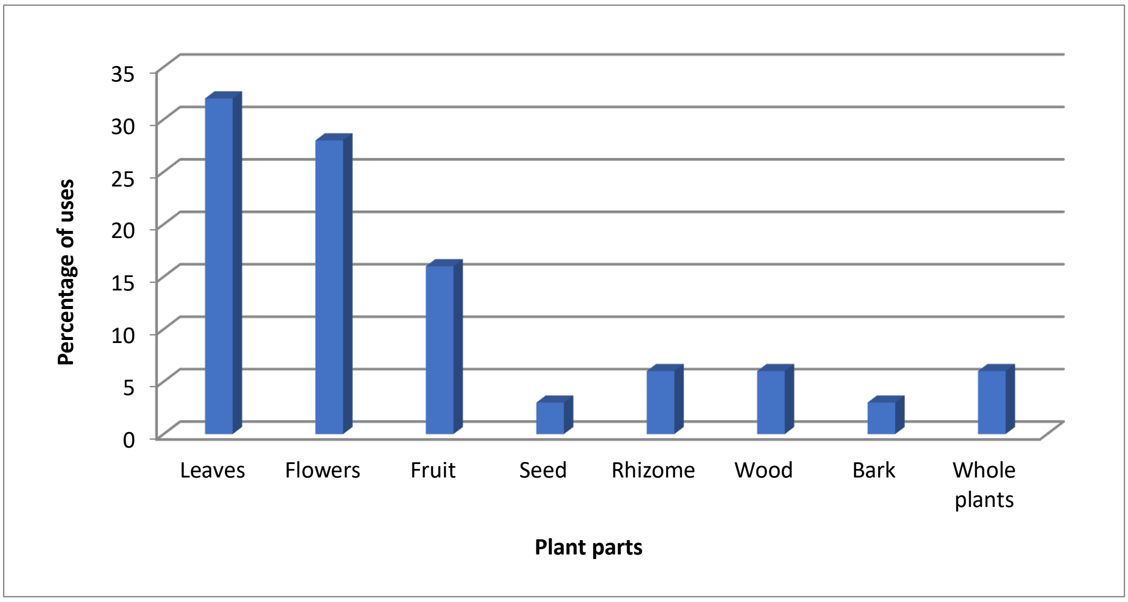


Figure 9. Uses of aromatic plant parts for various purposes in the eco-park and surrounding areas

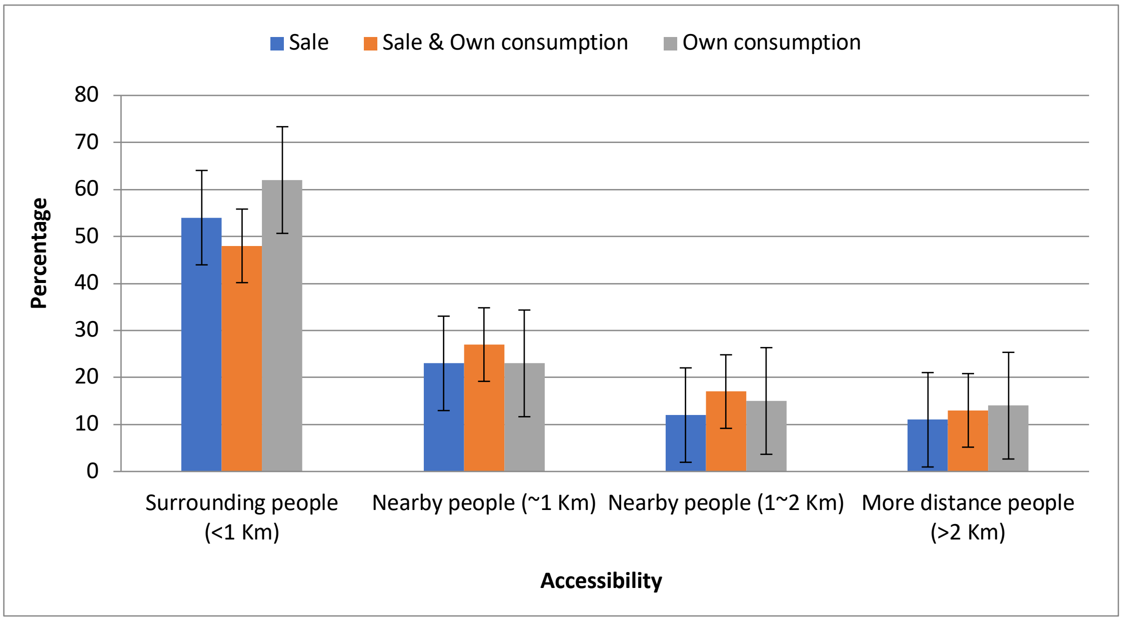


Figure 10. Consumption patterns of aromatic plants by local communities (with their accessibility) in the eco-park area

Consumption and income derived from aromatic plant species

Focused Group Discussions (FGDs) and the personal communications with knowledgeable persons indicated that the local inhabitants exploit the commercially-viable aromatic plants from the eco-park area for income generation. They are traded either in the local markets of the state or in the national markets. Most of the collectors' collected aromatic plants along with other medicinal species from the park area, primarily for commercial (selling) purposes, while some community members collected them for personal use (own consumption). The collection of aromatic plant species was found to be impacted by the proximity of local communities to the eco-park, specifically depends on the distance between the park area and the location of local communities. This study revealed that nearby communities (within 1 Km) collected more aromatic plant species compared to the communities residing away from the eco-park. Specifically, people living in close proximity to the eco-park collected and consumed the highest proportion (62%) of aromatic plants, compared to an average of 27% among communities located at greater distances (Fig. 10). The present study also revealed that local collectors earned an average of 2,500 Bangladeshi Taka (BDT) (~20USD) per month by selling aromatic plant species along with other non-wood forest products. Such amounts of money provide a meaningful contribution to their total income and also play a significant role in supporting their daily livelihoods.

Discussion

In this study, the status of the aromatic plant species excluding all other timber and non-woody plant species of the eco-park area was only evaluated. The IVI indicating overall dominance of the aromatic tree species showed that two tree species (*Melaleuca leucodendron and Cocos nucifera*), amongst the 11, were highly dominant with 60% of the total IVI. The results indicated that plantations of several exotic tree species raised by Bangladesh Forest Department resulted in the dominance of two aromatic trees- *Melaleuca leucodendron and Cocos nucifera* in the Sitakunda Eco-park area. Other than these two species, *Nyctanthes arbor-tristis* and *Cinnamomum camphora* were naturally occurring aromatic species in the study area. The high IVI exhibited by *Melaleuca leucodendron* is due to its higher relative frequency, density, and dominance compared to other species. The alarming findings of the study evidenced that the Sitakunda Botanical Garden and Eco-park is dominated by several exotic plant species, which may alter the ecological functioning in near future.

Plant researchers and ecologists have identified five or six clusters or groups of species in the natural forests of Bangladesh based on dominance and occurrence of the species (Das *et al*. 2018). In the present study, five distinct clusters of aromatic tree species were identified in the study area, aligning with similar findings by other researchers. Das *et al*. (2018) and Sajib *et al*. (2016) each identified five clusters of vascular tree species in the Fasiakhali Wildlife Sanctuary and Sandwip Island, respectively, both located in the Chattogram region of Bangladesh.

The findings of this study revealed that the biodiversity status of aromatic plant species is still in better condition than other government managed forests in Bangladesh. The diversity of aromatic plant species in the Sitakunda Eco-park is quite higher in comparison to other forests and protected areas of Bangladesh. The Shannon-Wiener diversity index (4.07) and Simpson's Dominance index (3.08) is higher than that of the Fashiakhali Wildife Sanctuary (2.07), Sitapahar Reserve Forests (2.98), and Chunati wildlife sanctuary (3.58) of Bangladesh according to the findings of Das *et al.* (2018), Nath *et al*. (2000), Hossain and Hossain (2014), respectively.

Religious and cultural utilizations of aromatic plants by local communities

Due to inherent and remedial pharmacological properties, aromatic plants are often utilized as natural medicines (Samarth *et al*. 2017). However, most of the local communities do not know the proper use of several aromatic plant species. For this reason, aromatic plants are not absolutely utilized by the local communities in the study area. Flowers of aromatic plants considered as the symbol of grace and elegance by the surrounding local communities of the eco-park area. Over time, the use of these flowers has become integral to religious ceremonies. Local communities' frequently used these flowers on all religious occasions. Generally, flowers are offered by devotees in the temple. In the local mosques, flowers are used as a floral decoration. Flowers of different aromatic plants such as *Michelia champaca, Nyctanthes arbor-tristis*, *Gardenia angusta, Rosa chinensis, Helianthus annuus*, etc. are used for religious purposes by the local Hindu and Buddhist communities (Fig. 11). This study revealed that leaves of *Ocimum sanctum, Piper betel*; rhizome of *Curcuma longa*; and fruits of *Cocos nucifera* are also used for religious rituals by the surrounding Hindu and Tripura communities, a practice common in other parts of Bangladesh as well. Rana *et al.* (2010) reported the use of these species in religious (spiritual) activities by the Manipuri ethnic group and local Hindu communities in the Chittagong Hill Tracts of Bangladesh.

(a) (b) (c)

Figure 11. Flowers of three common aromatic plants used for religious purposes, (a) *Gardenia angusta,* (b) *Rosa chinensis,* and (c) *Helianthus annuus*

Cultivation of aromatic plant species

Findings of the study disclosed that aromatic plants play an important role in the socio-cultural, health care and spiritual arena of rural people of Chattogram, Bangladesh. Those species may affect quality of life, productivity and wellbeing of future generations. Not only in the park area, but also in the surrounding communities, several aromatic and medicinal plant species are cultivated and planted. Most of the aromatic plants are collected from forest or uncultivated wild sources but with increasing abiotic and biotic pressures on natural habitat; a number of species are becoming endangered or threatened. Further, aromatic plant species are correlated with livelihood of the local communities.

Cultivation of various aromatic plants, i.e. *Lawsonia inermis, Piper betel* etc. has become common practice in the Sitakunda eco-park area. Local communities of the Sitakunda eco-park also cultivated various aromatic plant species alongside timber species in their home gardens. A significant number of local residents are involved in the cultivation of *Citrus aurantifolia,* and *Melaleuca leucodendron* in their homesteads. Several betel-leaf farms were observed around the Eco-park area during the study (Fig. 12). Moreover, Eco-park authority introduced various aromatic plant species in the garden to enhance the aesthetic appeal of the park area. *Dahlia variabilis* and *Rosa chinensis* are two common aromatic plant species that cultivated by the eco-park authority to improve the scenic beauty of the park area**.** A flower garden containing numerous varieties of roses is located along the boundary of the eco-park (Fig. 12).

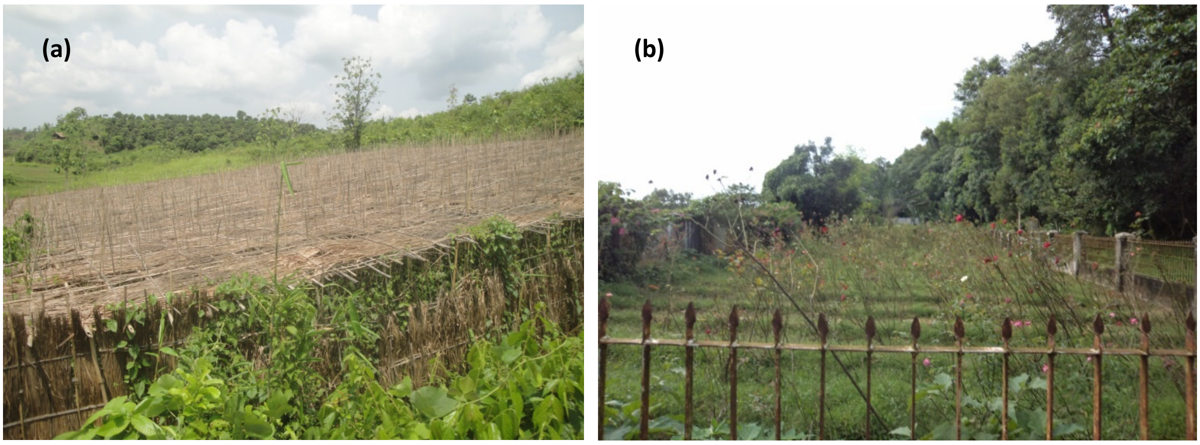


Figure 12. Photographs showing (a) a betel leaf farm located near the eco-park area, and (b) a rose garden cultivated along the boundary of the Sitakunda Botanical Garden and Eco-park

Endangered and rare aromatic plant species in the study area

Sitakunda Botanical Garden and Eco-park is the first eco-park in Bangladesh, where a number of native and exotic aromatic plant species along with medicinal and ornamental plants were conserved by the Bangladesh Forest Department (BFD) (Dutta *et al.* 2015). In this study, aromatic plant species of eco-park area were enumerated, which may provide baseline information for conserving several threatened species and formulating management strategies for the hilly forests of Bangladesh. This study revealed the occurrence of 7 endangered and rare aromatic plant species in the eco-park area. Among them, 1 herb species (*Aloe vera*)*,* 2 shrub species (*Cassia occidentalis, Jasminum sambac*) and 1 tree species (*Santalum album*) were recorded as rare. Besides, a total of 3 tree species (*Aquilaria agallocha, Cinnamomum glaucescens* and *Michelia champaca*) were documented as endangered.

Plant utilization and conservation measures

Commonly, different distillation processes are used to isolate necessary oils from aromatic plant species (Kumar & Jnanesha 2016). Brenes and Roura (2010) reported that flowers, buds, seeds, leaves, twigs, bark, wood, fruits, roots and even whole plant body of aromatic plant species are used to produce essential oils and those oils are used to manufacture a wide variety of products (e.g. detergents, cosmetics, soaps, toilet products, pharmaceuticals, perfumes, confectionery food products, soft drinks, distilled alcoholic beverages and insecticides). This study showed that numerous aromatic plant species are very useful to manufacture essential oils and ingredients, which are used in perfumes, cosmetics, oil formulations, soaps and hair care products to provide conditioning and a pleasant aroma and shine. This finding supports the report of Aburjai and Natsheh (2003). Aburjai and Natsheh (2003) reported that modified coconut oil containing polyunsaturated fatty acids in the form of mono-, di-, and tri-glycerides, is useful as a constituent of a barrier lipid mixture in cosmetic and pharmaceutical formulations to protect and prevent drying of the skin.

During the study, it was observed that degradation and destruction of habitat of plant communities by human settlement, over-exploitation, agricultural expansion, road networks and shifting cultivation are the major issues for the conservation of aromatic plant composition in the park area. A significant number of eco-tourists, pilgrims and devotees visit this eco-park on a regular basis. Local communities are either fully or partially dependent on the resources of this eco-park for their livelihoods. Hence, the eco-park faces a serious onslaught and loses its aromatic plant diversity faster along with other non-wood forest resources. Such findings support the research results of Dutta and Hossain (2016). A research conducted by Dutta and co-researcher (2016) reported that natural ecosystems and biological functioning of the eco-park area are deteriorated as well as in great threat due to severe extractions of natural resources by the surrounding residents in the forms of grazing, fuel-wood collections, illicit felling, and forest-product exploitations.

Mukul *et al.* (2018) reported that awareness gap at various levels from policymakers to grass root people lead to misappropriation of existing law. In developing country like Bangladesh, lack of appropriate implementation of existing biodiversity laws and regulation are very common scenarios. In this study, researchers also found the knowledge gaps and lack of consciousness among the local communities and eco-tourists in the surrounding eco-park area. In such case, Bangladesh Forest Department (BFD) should come forward to inform the importance of aromatic plant species to the local communities. Community-based and sustainable nature management approaches should take into account involving local residents to protect the growth and regeneration of aromatic plant species in the study area. Several research conducted by other researchers (Dutta & Hossain 2016, Nandi & Vacik 2014) in the same study area recommended that sustainable management of diversity, distribution, and regeneration of floral resources in the eco-park area along with financial amelioration of the local residents can be possible through effective implementation of community-based forestry approach.

During the study, a considerable number of destitute hills, and Sungrass/ Chhan (*Imperata cylindrica*) infested areas were observed in the eco-park area. BFD should be brought those degraded forest areas under plantation programs of native species, specifically aromatic plant species. On the other hand, illicit felling, collection of aromatic plants along with other woody species by the local communities should minimize. Alternative income generating activities are considered effective, which may diminish the dependency of local residents on natural resources as well as forest lands. A considerable number of conservation measures should be implemented with the involvement of relevant stakeholders to conserve the existing aromatic plant resources in the Sitakunda Eco-park. A list of conservation initiatives, along with associated stakeholders and proposed conservation measures, is presented in Fig. 13.

Conclusion

Bangladesh Forest Department established the Sitakunda Botanical Garden and Eco-park with the aim of preserving remnant forests, conserving biological diversity, and restoring degraded forest lands through the plantation of various medicinal and aromatic plant species. This eco-park has played a significant role not only in the ex-situ conservation of floral diversity but also in supporting the livelihoods of local communities who highly rely on plant resources for food, medicine, perfumery, and spiritual practices. This study recorded 27 aromatic plant species across various ecological niches and elevations within the eco-park, indicating noteworthy variation in species richness and habit forms. Ethnobotanical analysis disclosed that *Santalum album* has the maximum Use Value (UV), representing its cultural and medicinal significance regardless of its ecological rarity. The findings of the study indicated that aromatic plant composition in the park area is rapidly declining due to severe human pressure and multiple anthropogenic disturbances, such as over-harvesting, habitat degradation, and unregulated tourism. Aromatic plant species of this eco-park need to be conserved through implementing sustainable management approaches. The low representation of naturally occurring (natural origin) aromatic plant species in the study area further highlights the significance of conserving native aromatic flora to preserve ecological and cultural heritage. Further research should be carried out to enhance understanding and refine management strategies for rehabilitating aromatic plant species in this biodiversity-rich eco-park of Bangladesh. While this study provides baseline information for understanding the diversity, distribution, and cultural significance of aromatic plant species in Sitakunda Eco-park, future study is recommended to explore the ecological-cultural linkages in greater depth.

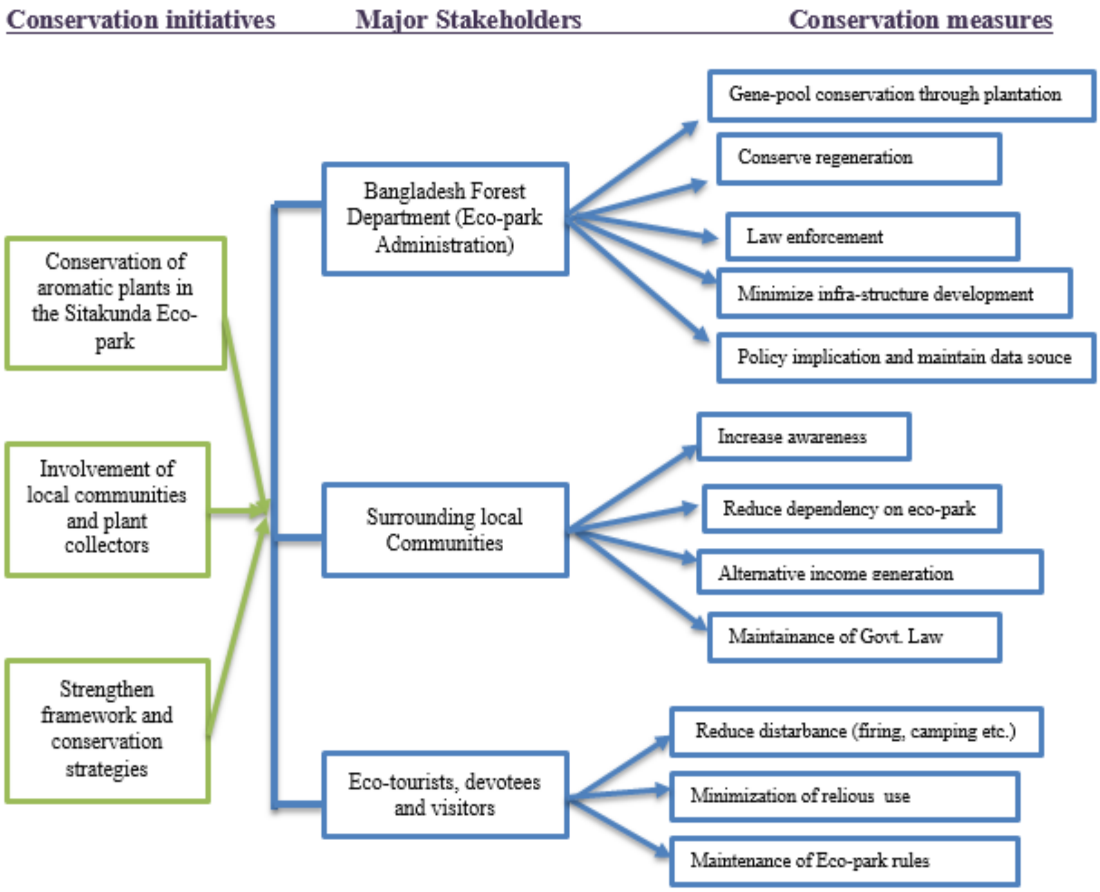


Figure 13. Conservation initiatives along with relevant stakeholders and proposed conservation measures to preserve aromatic plant composition in the study area

Declarations

List of abbreviations: BFD -Bangladesh Forest Department; CF -Citation Frequency; DBH -Diameter at Breast Height; FGD - Focus Group Discussion; FIVI -Family Importance Value Index; GLM -Generalized Linear Model; IVI - Importance Value Index; N -Natural; PO - Polynomial Order; RF - Relative Frequency; USD - United States Dollar; UV -Use Value

Ethics approval and consent to participate: The development of the study followed the ethical and legal guidelines for the development of research on traditional knowledge. The participation of informants was subject to the acceptance of the Free and Informed Consent Form. Respondents' written consent has been collected and preserved by the author(s) as per international standard or university standard. Confidentiality of participants' data was strictly maintained.

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Literature cited

Aburjai T, Natsheh FM. 2003. Plants used in Cosmetics. Phytotherapy Research 17:987-1000.

Ahmed ZU, Begum ZNT, Hassan MA, Khondker M, Kabir SMH. 2008. Encyclopedia of Flora and Fauna of Bangladesh, Asiatic Society of Bangladesh, Dhaka.

Alam MK. 2001. Development Plan for Sitakunda Botanical Garden and Eco-park. Office of the Director and Conservator of Forests, Chittagong Circle, Forest Department, Chattogram, Bangladesh. Pp. 4 -15.

Ara H, Khan B, Uddin SN (eds.). 2013. Red Data Book of Vascular plants of Bangladesh. Volume 2. Bangladesh National Herbarium, Dhaka, Bangladesh. 280 pp.

Bhattarai KR, Ghimire M. 2007. Commercially important medicinal and aromatic plants of Nepal and their distribution pattern and conservation measure along the elevation gradient of the Himalayas. Banko Janakari 16(1):3-13.

Brenes A, Roura E. 2010. Essential oils in poultry nutrition: Main effects and modes of action. Animal Feed Science and Technology 158(1-2):1-14.

Cain SA. 1938. The Species-area Curve. American Midland Naturalist 19: 573-581.

Dallmeier F, Kabel M and Rice R. 1992. Methods for long term biodiversity inventory plots in protected tropical forests. *In:* Dallmeier F (ed.). Long term monitoring of Biological Diversity in Tropical Forest Areas: Methods for Establishment and Inventory of Permanent plots. 11-46, UNESCO, Paris, France.

Das DK, Alam MK. 2001. Trees of Bangladesh. Bangladesh Forest Research Institute, Chittagong, Bangladesh. Pp. 10-301.

Das SC, Alam MS, Hossain MA. 2018. Diversity and structural composition of species in *Dipterocarp* forests: a study from Fasiakhali Wildlife Sanctuary, Bangladesh. Journal of Forestry Research 29(5):1241-1249.

Devi AD, Devi OI, Singh TC, Singh EJ. 2014. A Study of Aromatic Plant Species Especially in Thoubal District, Manipur, North East India. International Journal of Scientific and Research Publications 4(6):1-12.

Dobson AJ. 1990. An introduction to generalized linear models. Chapman and Hall, London.

Dutta S, Chowdhury P, Ray TK, Das S, Hoque ME. 2021. Biodiversity of the Medir Haor wetland ecosystems of Bangladesh. International Journal of Fisheries and Aquatic Studies 9(3):45-55.

Dutta S, Hossain MK, Hossain MA, Chowdhury P. 2014. Floral diversity of Sitakunda Botanical Garden and Eco-park in Chittagong, Bangladesh. Indian Journal of Tropical Biodiversity 22(2):106-118.

Dutta S, Hossain MK, Hossain MA, Chowdhury P. 2015. Exotic Plants and their Usage by Local Communities in the Sitakunda Botanical Garden and Eco-Park, Chittagong, Bangladesh. Forest Research 4:136. doi:10.4172/21689776.100013

Dutta S, Hossain MK. 2016. Infestation of *Imperata cylindrica* L. and its Impacts on Local Communities in Secondary Forests of Sitakunda Botanical Garden and Eco-Park, Chittagong, Bangladesh. International Journal of Conservation Science 7(1):167-180.

Dutta S, Hossain MK. 2020. Bringing back the Chakaria Sundarbans mangrove forest of South-east Bangladesh through sustainable management approach. Asian Journal of Forestry 4(2):65-76. doi: 10.13057/asianjfor/r040204

Franklin J, Serra-Diaz JM, Syphard AD, Regan HM. 2016. Global change and terrestrial plant community dynamics. PNAS (Ecology) 113(14):3725-3734.

Friedman J, Yaniv ZA, Dafni A, Palewitch D. 1986. A preliminary classification of the healing potential of medicinal plants, based on a rational analysis of an ethnopharmacological field survey among Bedouins in the Negev Desert, Israel. Journal of Ethnopharmacology 16(2-3):275-287.

Grytnes JA, Vetaas OR. 2002. Species richness and altitude: A comparison between null models and interpolated plant species richness along the Himalayan altitudinal gradient, Nepal. The American Naturalist 159:294-304.

Hassan MM. 1995. Biodiversity Conservation and Management in Bangladesh: A state of the art, Review. ICIMOD, Kathmandu, Nepal Hill.

Hossain A, Chowdhury MAS, Islam MSTT, Malakar PK, Iqbal SM. 2009. Plant diversity of the horticultural farm of Bangladesh Agricultural University. Bangladesh Journal of Agricultural Research 34(2):189 -204.

Hossain MA, Hossain MK, Salam MA, Rahman S. 2013. Composition and diversity of tree species in Dudhpukuria-Dhopachori wildlife sanctuary of Chittagong (south) forest division, Bangladesh. Research Journal of Pharmaceutical, Biological and Chemical Sciences 4(2):1447-1457.

Hossain MK, Hossain MA. 2014. Biodiversity of Chunati Wildlife Sanctuary: Flora. Arannayk Foundation and Bangladesh Forest Department, Dhaka, p 176.

Hossain MK. 2004. Final report on National Biodiversity Specialist (Flora), Biodiversity Strategy and Action Plan Project, 197p.

Hossen S, Hossain MK, Hossain MA, Uddin MF. 2021. Quantitative assessment of tree species diversity of Himchari National Park (HNP) in Cox's Bazar, Bangladesh. Asian Journal of Forestry 5(1):1-7. doi: 10.13057/asianjfor/r050101

Kent M, Coker P. 1992. Vegetation description and analysis. Baffins Lane, Chichester, West Sussex, England: John Wiley and Sons Ltd.

Khan MS, Rahman MM, Ali MA. 2001. Red Data Book of Vascular Plants of Bangladesh. Bangladesh National Herbarium, Dhaka, Bangladesh, pp. 1-171.

Kohli RK, Singh HP, Rani D. 1996. Status of floor vegetation under some monoculture and mixculture plantations in North India. Journal of Forest Research 1(4):205-209.

Kumar A, Jnanesha AC. 2016. Medicinal and aromatic plants biodiversity in India and their future prospects: a review. Indian Journal of Unani Medicine IX(1): 10-17.

Magurran AE. 1988. Ecological diversity and its measurement. New York: Chapman and Hall Publishers, USA.

Maiti S, Geetha KA. 2013. Country Status Report on Medicinal and Aromatic Plants in India. *In:* Paroda R, Dasgupta, Mal B, Ghosh SP, Pareek SK (eds.) Proceedings of Expert Consultation on Promotion of Medicinal and Aromatic Plants in the Asia-Pacific Region, Bangkok, Thailand. pp. 101-123.

Margalef R. 1958. Information theory in ecology. General Systematics 3:36-71.

McCullagh P, Nelde JA. 1989. Generalized linear models. 2nd edition, Chapman and Hall, London.

Merry SR, Shahjahan M. 2013. Country Status Report on Medicinal and Aromatic Plants in Bangladesh. *In:* Paroda R, Dasgupta, Mal B, Ghosh SP, Pareek SK (eds.) Proceedings of Expert Consultation on Promotion of Medicinal and Aromatic Plants in the Asia-Pacific Region, Bangkok, Thailand. pp. 75-89.

Michael P. 1984. Ecological methods for field and laboratory investigations. New Delhi, India: Tata Mc Graw Hill Publishing Co. Ltd. pp. 404-424.

Misbahuzzaman K, Alam MJ. 2006. Ecological Restoration of Rainforest through Aided Natural Regeneration in the Denuded Hills of Sitakunda, Chittagong, Bangladesh. International Journal of Agriculture & Biology 8(6):778-782.

Misra R. 1968. Ecology work book. New Delhi, India: Oxford and IBH Publ. House.

MoEFCC (Ministry of Environment, Forest and Climate Change) 2000. Project Document on Establishment of Sitakunda Botanical Garden and Eco-park, Chittagong, Government of the Peoples' Republic of Bangladesh.

Mori SA, Boom BM, Carvalino AM, Santos D. 1983. The ecological importance of Myrtaceae in Eastern Brazilian wet forest. Biotropica 15:68-70.

Mori SA, Lertzman KP, Gustafsson L. 2016. Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. Journal of Applied Ecology 2017(54): 12-27.

Mukul SA, Biswas SR, Rashid AZMM. 2018. Global Biodiversity Volume 1: Selected Countries In Asia, Chapter: 3, Publisher: Apple Academic Press and CRC Press, Canada, pp.93-107.

Mukul SA. 2007. Biodiversity Conservation Strategies in Bangladesh: The State of Protected Areas. Tiger Paper 34(3): 28 -32.

Nandi R, Vacik H. 2014. Regeneration and tree species diversity of Sitakund Botanical Garden and Eco-park, Chittagong, Bangladesh. Journal of Mountain Science 11(4):950-958. doi: 10.1007/s11629-013-2886-z

Nath TK, Hossain MK, Alam MK. 2000. Assessment of tree species diversity of Sitapahar Forest Reserve, Chittagong Hill Tracts (South) Forest Division, Bangladesh. The Indian Forester 126 (7):727-740.

Nishat A, Huq SMI, Barua SP, Reza AHMA, Khan ASM. 2002. Bio-ecological zones of Bangladesh. The World Conservation Union, Dhaka, Bangladesh.

Odum E. 1971. Fundamentals of Ecology. Philadelphia: W.B. Saunders Co., USA.

Phillips O, Gentry AH, Reynel C, Wilkin P, Galvez-Durand BC. 1994. Quantitative ethnobotany and amazonian conservation etnobotánica cuantitativa y la conservación de la amazonia. Conservation Biol.ogy 8:225-248.

Pielou EC. 1966. Species-diversity and pattern-diversity in the study of ecological succession. Journal of Theoretical Biology 10(2):370-383.

Prain D. 1903. Bengal Plants, Botanical Survey in India, Calcutta, India. 1-1103.

Rahman MA, Uddin SB. 1997. Angiospermic flora of Sitakunda in Chittagong, Bangladesh. Journal of Plant Taxonomy 4:17-36.

Rahman MH, Khan MASA, Roy B, Fardusi MJ. 2011. Assessment of natural regeneration status and diversity of tree species in the biodiversity conservation areas of Northeastern Bangladesh. Journal of Forestry Research 22(4):551-559.

Rahman MM, Fakir MSA. 2015. Biodiversity of Medicinal Plants in Bangladesh: Prospects and Problems of Conservation and Utilization. International Journal of Minor Fruits, Medicinal and Aromatic Plants 1(1):1-9.

Rahman MR, Rahman MM, Chowdhury MA. 2019. Assessment of natural regeneration status: the case of Durgapur hill forest, Netrokona, Bangladesh. Geology, Ecology, and Landscapes 1-10.

Rana MP, Sohel MSI, Akhter S, Islam MJ. 2010. Ethno-medicinal plants use by the *Manipuri* tribal community in Bangladesh. Journal of Forestry Research 21:85-92.

Ray TK, Dutta S, Das S, Chakma K. 2024. Ethno-botanical study on medicinal plant species utilized by Marma community of Wagga Union in Rangamati Hill District, Bangladesh. Asian Journal of Ethnobiology 7(2):105-114.

Roy J, Melon M, Alam S, Rahman MA, Mainuddin SM, Haider R, Sultana N, Rahman MS, Akther R, Azad AK, Sarker CS, Yasmin F. 2024. Valuation of ecosystem services in Sitakunda Botanical Garden and Eco-park, Chattogram, Bangladesh. Bangladesh Forest Research Institute, Chattogram. Bulletin 6, Forest Economics Division. Pp. XI+97.

Sajib NH, Uddin SB, Islam MS. 2016. Vascular plant divrsity and their distribution pattern in Sandwip Island, Chittagong, Bangladesh. Journal of Biodiversity Management 5:2.

Samarth RM, Samarth M, Matsumoto Y. 2017. Medicinally important aromatic plants with radioprotective activity. Future Science OA 3(4): FSO247.

Shannon CE, Wiener W. 1963. The Mathematical Theory of Communities. University of Illinois Press, Urbana, USA. Pp. 111-117.

Shukla R, Chandal PS. 2000. Plant ecology and soil science (9th edition). New Delhi, India: Ramnagar S. Chamda and Company Limited.

Uddin MS, Hossain MK, Huda SMS. 2005. Distribution pattern of Medicinal Plant species in Sitakunda Botanical Garden and Eco-park of Chittagong, Bangladesh. Hamdard Medicus 48:118-124.

Uddin MZ, Hassan MA. 2010. Angiosperm diversity of Lawachara National Park (Bangladesh): a preliminary assessment. Bangladesh Journal of Plant Taxonomy 17(1):9-22.

Vitousek PM. 1994. Beyond global warming: Ecology and global change. Ecology 75(7):1861-1876.