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Ethnobotanical and ethnopharmacological survey of medicinal tree species used in the treatment of diseases by forest-fringe communities of Southwestern Ghana

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ABSTRACT

Demand for medicinal plant remedies is rising globally, while indigenous knowledge about medicinal plants is declining rapidly. The preservation of indigenous knowledge is critical in discovering and developing innovative drugs. The ongoing discussions on providing nature-based solutions to contemporary issues make it urgent to document indigenous knowledge about medicinal trees, especially in areas with limited or no studies such as our study area. Our study aimed to understand the use of medicinal trees among the communities fringing the Asukese and Amama Shelterbelt Forest Reserves. We administered structured questionnaires and interviewed 88 respondents who were selected using snowball and simple random techniques. The ethnobotanical survey data were processed and evaluated using parameters such as Indigenous Knowledge Index (IKI), Relative Citation Frequency (RCF), Species Use Value (SUV), Family Use Value (FUV), and Plant Part Value (PPV). We found that ethnobotanical knowledge about medicinal trees was higher in respondents who were widowed or had larger number of dependants. We found that the local communities used diverse medicinal trees (70 species belonging to 33 families) to treat 83 ailments. *Azadirachta indica* had the highest RCF (8.9) and SUV (23.4). The other top four species according to the SUV were *Alstonia boonei* (SUV = 11.1), *Khaya senegalensis* (SUV = 10.7), *Moringa oleifera* (SUV = 10.3) and *Cocos nucifera* (SUV = 10.2). The most-well represented and valuable families were Fabaceae, Anacardiaceae, Meliaceae, Arecaceae, Rubiaceae and Malvaceae. Medicinal trees had alternative uses such as food, fodder, fuelwood, and construction material. Indigenous knowledge about medicinal trees was transmitted to younger generations predominantly by parents. The results show that the most known botanical families and species with the most useful parts were the most useful plant families and species. Thus, the selection of medicinal trees was driven by their traits. Furthermore, results indicate that species diversity is critical to the healthcare needs of local communities and that their conservation and sustainable use and the preservation of indigenous knowledge are crucial to ensuring good health and the general well-being of local communities of all ages.

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1. Introduction

Medicinal plants are wild and cultivated plants or plant-based products containing active ingredients essential to relieve pain, manage, and cure different diseases [1]. Medicinal plants have historically played an indispensable role in human development globally. They were the primary approach to treating various ailments and are currently used as alternative medicines for several diseases ([2–4]). They are also widely recognized to have played a critical role in the development and advancement of modern medicine by serving as the precursors for the synthesis and discovery of new drugs ([5,6]). Despite recent advances in conventional medicine, medicinal plants are still the primary source of treatment for most local communities [7]. This is mainly because they are accessible, simple to use, affordable, and have minimal side effects compared to conventional medication ([2,4,6]).

Medicinal plants are of immense significance for the healthcare needs of people worldwide. It is estimated that between 50,000 and 80,000 of the world's plant species serve as primary sources of medicine for about 80 % of the world's population ([8–12]). According to the World Health Organization (WHO), more than 3.5 billion people in the developing world rely on medicinal plants for their primary health ([13,14]). Besides their healing abilities, medicinal plants are export commodities and alternative sources of income for indigenous people in developing countries ([8,10,13,15]). Wodah and Asase [8] estimate the global medicinal plant market at US $60 billion and a growing rate of 7 % per annum.

In Africa, the use of medicinal plants has been an ancient practice, with many people consulting traditional medical practitioners for their health challenges ([7,16,17]). The practice is still an integral part of the healthcare system of the continent, with an estimated 80 % of the continent's rural population still relying on such remedies for their primary healthcare needs ([4,7–9]). The almost exclusive dependence on traditional medicine in Africa is due to limited coverage of modern healthy services, inadequate healthcare professionals, high costs of conventional medication, and the cultural acceptability of traditional medicine ([17,18]).

Like other African countries, many communities use medicinal plants to manage various diseases in Ghana. Though conventional medicine is the widely recognized approach in the medical system of Ghana, socioeconomic conditions such as limited and poor medical infrastructure and human recourses have limited its acceptability, especially in local communities [8]. Consequently, most tribes in Ghana have historically developed elaborate traditional medicine knowledge of about 1360 species of medicinal plants for their primary health care [8]. It is estimated that around 70 % of healthcare in Ghana is provided by traditional healers using medicinal plants [19]. The government of Ghana has realized the importance of traditional medicine in the socioeconomic life and healthcare system of Ghana, and as a result established the Centre for Plant Medicine Research (CPMR) to conduct scientific research aimed at improving herbal medicines [2]. The activities of CPMR and other scientific studies confirming the efficacy of such herbal remedies have further promoted and increased the usage of herbal medicines in Ghana.

Despite the proven potential of medicinal plants in the healthcare and economic development in Ghana, human activities such as agricultural expansion, timber production, deforestation, fuel wood harvesting, overgrazing, overexploitation, population growth, and urbanization have been widely reported to pose a severe threat to their sustainability ([13,18,20]). According to 9, overharvesting and habitat destruction pose severe threats to about 15,000 medicinal plant species, with 20 % of their wild resources already, especially in Africa. Besides these threats, social issues such as the intergenerational verbal transfer of indigenous knowledge on medicinal plants, the recent underestimation of traditional values by the younger generation due to exposure to modern education have contributed to the gradual loss of this valuable knowledge ([1,2]).

In recent years, the rise in commercial value and demand for medicinal plants have made them a resource of significant interest to policymakers and the scientific community. As a result, global advocacy for increased research for documenting traditional medicinal knowledge and conservation of medicinal plants has also increased significantly in recent times ([2,11,19,21]). Though the study of medicinal plants has been explored from diverse perspectives, one area receiving increased research interest in recent times is the study of medicinal plants using ethnobotanical and ethnopharmacological approaches ([10–12,17,21,22]). These authors have argued that such knowledge is critical for developing medicinal plants and discovering new drugs ([11,12]). However, despite the varied vegetative coverage and culturally diverse knowledge on medicinal plants, imminent threats to medicinal plants and fast depletion of traditional medicinal knowledge in Ghana, limited ethnobotanical and ethnopharmacological studies have been conducted in the country. Particularly, medicinal tree species in the Asukese and Amama Forest Reserves have been largely unexplored. Moreover, a central question in ethnobotanical studies has been how and why do local people select plants for use? Therefore, this study collected and documented data on medicinal tree species used to treat diseases among the fringe communities of the Asukese and Amama Forest Reserves and analyzed what drives medicinal plants selection. Specifically, the study sought to: (i) provide vital information on the tree species, methods of preparation and administration of the traditional remedies, side effects of traditional remedies, and plant parts used; (ii) assess the variation of local knowledge about medicinal plants across socio-demographic characteristics; and (iii) examine whether plant selection for medicinal use is related to the demographic traits of the plant, including availability. Consequently, the hypotheses of the study were: (i) local knowledge about medicinal plants varies across socio-demographic characteristics (ii) highly known plant families (i.e., families with greater number of cited species); are the most useful plant families (i.e., have higher species use values); and (iii) highly available medicinal species (i.e., species with higher alternative sources of collection) and species with greater number of plant part use are the most useful species. At its inception the study hoped to preserve traditional knowledge to advance the ongoing discussion, provide nature-based solutions to contemporary issues, and contribute to achieving the SDGs (goals 1–3). It is also expected to help preserve and sustainably manage medicinal plants.

2. Methodology

2.1. Study area

The study was conducted in four forest-fringe communities (Kurosua, Atronie, Kufour camp and Nyamebekyere) of the Asukese and the Amama Shelterbelt Forest Reserves which are located in the Sunyani Forest District in the Bono Region of Ghana (Fig. 1). The two forest reserves constitute the Forest Management Unit 17 and form part of the Moist Semi-deciduous North West Forest Type ([23,24]). The Asukese Forest Reserve (7°05′ N and 7°15′ N and 2°24′W and 2°38′W) is 279 m above sea level and covers an area of 265 km^2. The Amama Shelterbelt Forest Reserve (7°00′ N and 7°15′ N and 2°05′W and 2°30′W) is about 12 km southwest of Sunyani, covers an area of 44 km^2 and it is 287 m above sea level. The reserves are highly degraded due to overexploitation and fires; thus, the ground flora is dominated by *Chromolaena* and *Maranthaceae*. Predominant tree species in the forests includes *Celtis mildbraedii*, *Triplochiton scleroxylon*, *Nesogordonia papaverifera*, *Cola gigantea*, *Mansonia altissima*, *Chrysophyllum albidum* and *Albizia zygia*. Common fauna species in the forests include antelopes, rats, deer and grasscutters. The study area has an average annual precipitation of 1270 mm during the major rainfall season (March–September) and 900 mm during the minor season (October-December) ([24,25]). The temperature is lowest in August and highest in March and April; with a mean monthly range between 23 °C and 33 °C. Relative humidity averages between 75 % and 80 % during the rainy seasons and 70 % and 80 % during the dry seasons.

The study area's population is approximately 76,937, and farming is the predominant economic activity. The major crops cultivated in the study area include maize, yams, cassava, vegetables, cocoa, citrus, mangoes and oil palm. The primary lighting source in the study district is electricity, while wood and charcoal are the primary sources of fuel for cooking. Rivers serve as the main water sources for domestic use in the study communities; other supplementary water sources include pipe-borne water and boreholes. Residents in the district and study communities were predominantly Christians, followed by Muslims and followers of Traditional religion. Regarding ethnicity, the communities consisted mainly of Akan-Bonos with a few Northern tribes (e.g., Dagaati, Kusaasi and Waala). The main language of the local communities was Twi, spoken by both the Akan-Bonos and the Northern tribes. The minor languages were spoken by the few Northern tribes and they included Dagaare, Waali, Kusal and Dagbanli. The traditional food of the Akan-Bonos is 'fufu' and it is enjoyed by all tribes in the study area. The most common festivals in the study region includes Kwafie, which is celebrated to "clean and feed the stool and gods" and Fordjour (Yam) Festival, an annual harvest festival to thank the gods for a good harvest. Thursdays was a taboo day; no one enters the forests or goes to farm on the taboo day. Predominant diseases reported in the district include malaria, ulcers, skin diseases, diarrhoea, cholera, anemia, infertility and gastrointestinal infections (e.g., 11; 26). Amid the advances in medical healthcare in Ghana, medicinal plants and traditional healers remain the main and first resort for health needs in most parts of the country, including the study communities. Thus, medicinal trees and traditional healers are central to the healthcare of local communities.

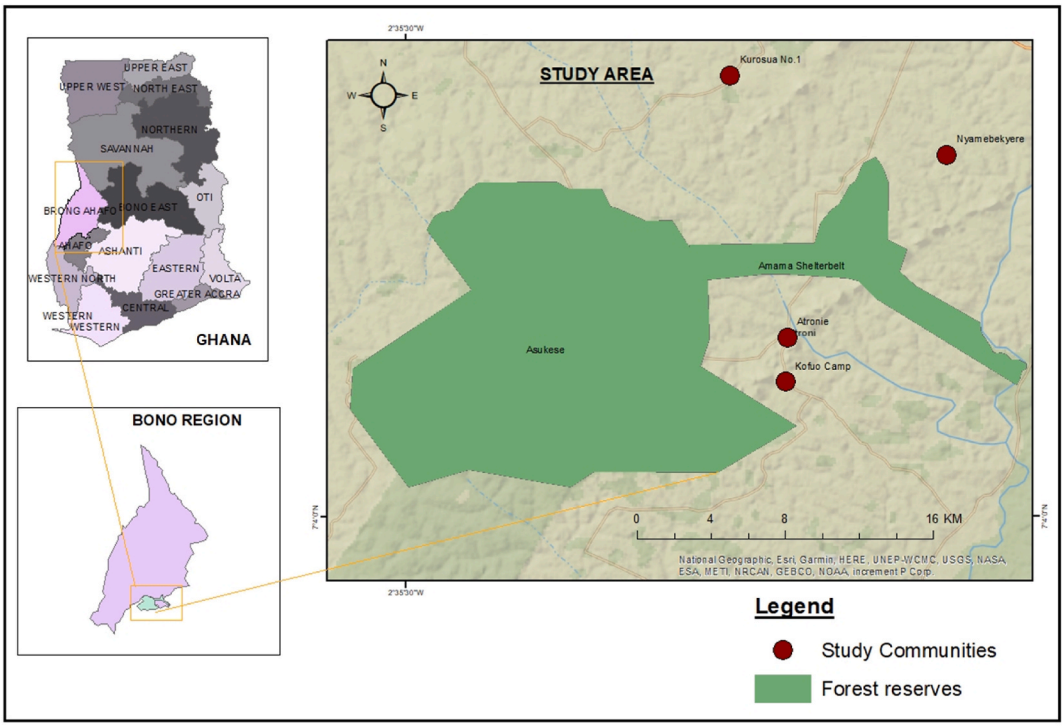

Fig. 1. Map of study area.

2.2. Sampling procedure

The survey was conducted from April to August 2022 to document indigenous knowledge of medicinal tree species in the selected communities. The two Forest Reserves were purposively selected because, to the best of our knowledge, no study on medicinal plants has been conducted in this area. Such information is urgently needed since medicinal plant use are site-specific ([27,28]). The four communities were randomly selected after generating a list of all peripheral communities. The study purposively selected respondents who were at least 20 years old because they were considered mature, knowledgeable and experienced and could provide insightful information about medicinal plants ([28,29]). Traditional herbalists were selected using the snowball sampling technique, while a simple random sampling approach was used to select residents in the selected communities ([28,30]). Structured questionnaires coupled with interviews and field tours ([30–32]) were employed in the survey of all 88 selected respondents by trained research assistants. Prior informed consent was obtained before respondents were engaged in the research. The nature of the study (for academic, not commercial, purposes) and its objectives were explained to the respondents before their oral consent was sought. Our study complied with the ethical standards of the Ethics Committee of the University of Energy and Natural Resources and with the Helsinki Declaration of 1975, as revised in 2000 [5]. Permission for field tours and collection of voucher specimens in the two Forest Reserves was obtained from the Sunyani Forest District. The questionnaires solicited information on socio-demographic traits, plant species used to treat diseases, condiments, side effects, methods of preparing and administering herbal remedies, tree parts used, and alternative uses of medicinal trees. In this study, sex defined as male/female based on biological attributes at birth. Questionnaires were administered in Twi because it is the principal language in the study area, and all the respondents and the trained research assistants were fluent in the dialect. Interviews, questionnaire administration, and field tours lasted 3–4 h per person.

2.3. Botanical identification

Medicinal tree species were first identified by their local names and confirmed during field tours. After this, the medicinal trees were identified with the help of local botanists and following Hawthorne and Jongkind [33]. The nomenclature of the trees followed the International Plant Names Index (IPNI, www.ipni.org). Finally, collected voucher specimens were compared with already identified specimens to authenticate the field plant identification; this was done for only unknown tree species [28].

2.4. Data processing and analysis

The collected survey data was processed and analyzed by estimating the following parameters for each species or taxon: Indigenous Knowledge Index (IKI), Relative Citation Frequency (RCF), Species Use Report (SUR), Species Use Value (SUV), Family Use Value (FUV) and Plant Part Value (PPV). IKI was estimated *per* respondent while RCF and SUV we estimated *per* medicinal plant species. Similarly, FUV was estimated *per* botanical family while PPV was estimated *per* plant part. Therefore, respondents with greater indigenous knowledge would potentially cite higher use reports *per* plant species and number of plant parts used *per* plant species. SUV is directly related to RCF. FUV depends on the SUV of plant species belonging to the specified family and the number of different plant species used to treat and manage diseases. Relative to the therapeutic and/or pharmacological effects and phytochemical composition of cited medicinal trees, a literature search was conducted ([27,31]). All data were processed and analyzed using Statistical Package for the Social Sciences version 23 and Microsoft Excel 2016. Prior to all analysis, where applicable, normality and homoscedasticity tests were conducted using Kolmogorov-Smirnov and Levene tests, respectively; non-normally distributed datasets were box-cox transformed.

2.4.1. Indigenous knowledge index

The indigenous knowledge index (IKI), introduced in this study, measures how knowledgeable an informant is in relation to medicinal plants. IKI is the sum of the scores reflecting an informant's ability to cite specific species, diseases treated by remedies made from the cited species, plant parts used, condiments and the side effects associated with using remedies made from the cited plant species. A score of one [1] was awarded for each citation. We considered that a respondent who can cite more plant species, diseases per plant species, plant parts per plant species, condiments per plant and side effects per plant species demonstrate a greater ethnobotanical knowledge and vice versa. Therefore, IKI reflects the ethnobotanical knowledge of an individual respondent. A one-way ANOVA (for normally distributed datasets) and Kruskal-Walli's test (for non-normally distributed datasets) were used to analyze if IKI varied across socio-demographic characteristics of the respondents; differences were considered significant at $\alpha = 0.05$. Where applicable, a Tukey-Kramer post-hoc test was conducted after the one-way ANOVA test to establish mean IKS differences. Spearman rank correlation test was used to determine the relation between age, number of dependants, family size, years of using medicinal plants and IKI.

2.4.2. Relative citation frequency

RCF was estimated as the ratio of the number of respondents who mentioned a particular species to the total number of respondents expressed as a percentage. It reflects the shared knowledge of the usefulness of a tree species [34]. It ranges between 0 and 100; higher RCF values show a greater proportion of the respondents have knowledge of and consider a certain species to be medically beneficial while lower RCF values suggest the opposite [34].

2.4.3. Species and family use values

The species use value (SUV) indicates the value of a specific species to the local communities relative to medicinal use [28]. It demonstrates the relative importance of medicinal tree species which are locally known [29]. SUV was estimated using equation (1):

$$SUV = \sum \left(\frac{SUR}{N}\right) * Ns \quad (1)$$

SUV is the species use value, SUR is the species use report from all respondents, N is the total number of respondents, and Ns is the respondents who indicated that a particular species is used to treat diseases in the community. Species use report (SUR) indicates the total number of medicinal uses for a particular tree species. The family use value (FUV) signifies the value ascribed to a particular plant family relative to their medicinal use by the local communities [28]. It is therefore an index of cultural importance that identifies plant families' significance. It was calculated using equation (2) [35]:

$$FUV = \frac{\Sigma SUVs}{ns} \quad (2)$$

where $\sum SUVs$ is the sum of the species use values for all cited species belonging to a particular plant family, and *ns* is the number of cited species belonging to that same plant family. Linear regression was used to test whether families with greater number of cited species had higher species use reports while variation in species use reports across sources of medicinal plants was assessed via one-way ANOVA.

2.4.4. Plant part value

The plant part used signifies the portion of a medicinal tree used as a bioresource in treating diseases in the local communities. It also shows the most preferred or dominant plant parts harvested for the treatment process of various diseases in the communities [29]. Plant part value was calculated using equation (3):

$$PPV\ (\%) = \frac{\text{PPUR per part}}{PPUR} X100 \quad (3)$$

where, PPUR per part is the sum of reported uses per part of the plant and PPUR is the overall number of uses reported for all parts. Linear regression was used to test whether species with greater number of plant part use were the most useful species.

3. Results

3.1. Socio-demographic characteristics of respondents vs. indigenous knowledge index

The respondents were predominantly natives of the study communities (68 %), males (70 %) and their main occupation was farming (61 %) (Table 1). The respondents' ages ranged between 21 and 80 years with the average age being 43 years. Most of the

Table 1
Ethnobotanical knowledge and socio-demographic characteristics of respondents in the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

Variable	Category	Total	Percentage (%)	Mean IKI	Medicinal plant use experience (years)
Gender	Male	62	70	13.77[a]	12.50[a]
	Female	26	30	15.08[a]	12.73[a]
Marital status	Married	56	64	13.96[ab]	12.82[b]
	Single	21	24	12.29[b]	7.62[c]
	Widowed	7	8	21.00[a]	24.38[a]
	Divorced	4	4	13.00[ab]	11.50[bc]
Religion	Christian	72	82	13.69[a]	12.56[a]
	Muslim	10	11	14.30[a]	9.50[a]
	Traditionalist	4	5	23.00[a]	19.25[a]
	Others	2	2	15.50[a]	13.50[a]
Educational level	SHS/TEC/VOC	33	38	14.36[a]	11.88[a]
	JHS	28	32	14.50[a]	12.36[a]
	Primary	16	18	13.63[a]	16.75[a]
	Tertiary	2	2	10.50[a]	8.50[a]
	None	9	10	14.11[a]	9.22[a]
Respondent category	Farmer	54	61	–	–
	Herbalist	18	21	–	–
	Trader/seller	14	16	–	–
	Homeopath	2	2	–	–
Respondent origin	Native	60	68	14.42[a]	13.20[a]
	Immigrant	28	32	13.61[a]	11.21[a]

Variables with different letters for each category implies significant differences between mean IKI and medicinal plant use experience values. IKI is indigenous knowledge index.

Table 2
Medicinal tree species used in the treatment of diseases by the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

Vernacular name	Family name	Botanic name	Plant part	Therapeutic properties	Condiments	Side effects	C. F	RCF	SUV
Nseduansehoma	Amaranthaceae	*Berlinia confusa* Hoyle	L, R	Menstrual pain	None	Headache	1	0.21	0.01
Atea	Anacardiaceae	*Anacardium occidentale* L.	L, R	Diarrhoea, Fertility, Piles, Pregnancy care	Honey, Efom wisa	Bitter mouth, Running stomach	9	1.91	1.02
Aprokuma	Anacardiaceae	*Antrocaryon micraster* A. Chev.	F, SB, WP	Pressure, Chicken pox, Stomach ache	Salt, Nunum	Bitter mouth	4	0.85	0.18
Kumanini	Anacardiaceae	*Lannea welwitschii* (Hiern) Engl.	SB, R, L	Aseram, Child fever, Piles	Lime	None	6	1.27	0.55
Mango	Anacardiaceae	*Mangifera indica* L.	SB, L	Ulcer, Bedwetting, Low sperm count, Measles, Fever	Alcohol, Pear leaves, Ginger	Stomach upset	9	1.91	1.74
Atoa	Anacardiaceae	*Spondias mombin* L.	L, F	Gonorrhoea	Alcohol	None	1	0.21	0.01
Nkyene ne ngo	Annonaceae	*Cleistopholis patens* (Benth.) Engl. & Diels	WP	Hernia, Typhoid fever, Piles	Cassava leaves, Alcohol	None	4	0.85	0.64
Hwentia	Annonaceae	*Xylopia aethiopica* (Dunal) A. Rich.	F, S	Anaemia, Cough	Akofem atiko	None	2	0.42	0.05
Oba	Annonaceae	*Xylopia villosa* Chipp	SB, S	Amenorrhoea	None	Dizziness	1	0.21	0.01
Nyamedua	Apocynaceae	*Alstonia boonei* De Wild	L, SB, R	Malaria, Hypertension, Asthma, Rashes, Chicken pox, Shingles	Funtum, Alcohol, Dry Cocoa/ Pawpaw	Bitter mouth, Itching skin Running stomach	25	5.30	11.08
Funtum	Apocynaceae	*Funtumia elastica* (Preuss) Stapf.	WP	Stop alcoholism, Stroke	Alcohol	Vomiting, Weakness	6	1.27	0.61
Kakapenpen	Apocynaceae	*Rauvolfia vomitoria* Afzel.	L, SB, R	Hernia, Chicken pox, Piles, Body pains	Ashes, Fam wisa, Alcohol, Glycerine	Allergic reaction	6	1.27	0.89
Kube	Arecaceae	*Cocos nucifera* L.	F, R, SB, L	Herpes, Erectile dysfunction, Ulcer, Bad breath, Heart disease	Alcohol, Food, Ginger, Kraman kote	Excessive drinking leads to low sperm count	23	4.87	10.19
Abe	Arecaceae	*Elaeis guineensis* Jacq.	R	Stroke, Wounds, Boils, Erectile dysfunction	Alcohol, Coconut, Moringa, Salt, Shea butter	None	10	2.12	1.14
Nufutin	Bignoniaceae	*Kigelia africana* (Lam.) Benth.	SB	Stomach ache	Garlic	None	3	0.64	0.10
Sesemesa	Bignoniaceae	*Newbouldia laevis* (P.Beauv.) Seem.	SB, L, R	Cough, Infertility, High blood pressure, Pregnancy care	Tweta, Salt	None	6	1.27	1.16
Akuakua Nisuo	Bignoniaceae	*Spathodea campanulate* P. Beauv.	L, SB	Typhoid, Stroke, Malaria, Wound	Fever grass, Fam wisa, Dry pear, Pawpaw Leaves	Weakness	10	2.12	1.93
Akatabena	Bombacaceae	*Bombax buonopozense* P. Beauv.	SB, WP	Bloody stool, Asthma, Anaemia,	Pepper, Moringa seeds	None	2	0.42	0.11
Pepea	Bromeliaceae	*Margaritaria discoidea* (Baill.)	FL	Stomach pain	Ginger	None	1	0.21	0.01
Brofere	Caricaceae	*Carica papaya* L.	L, S, R	Stomach ache, Cough, Ulcer, Easy delivery, Dewormer, Aseram, Cancer	Food, Ginger, Honey	None	12	2.54	3.14
Emire	Combretaceae	*Terminalia ivorensis* A.Chev.	SB	Piles	None	None	2	0.42	0.05
Ofram	Combretaceae	*Terminalia superba* Engl. & Diels.	R, SB	Convulsion	Food	None	6	1.27	0.41
Duamako	Euphorbiaceae	*Drypetes aubrevillei* Leandri	R	Easy delivery, Bad breath, Fracture, Herpes	None	None	3	0.64	0.10
Opam	Euphorbiaceae	*Macaranga barteri* Müll. Arg.	SB	Foot rot	None	None	4	0.85	0.18

(*continued on next page*)

Table 2 (*continued*)

Vernacular name	Family name	Botanic name	Plant part	Therapeutic properties	Condiments	Side effects	C. F	RCF	SUV
Nyanyafurowa	Euphorbiaceae	*Mallotus oppositifolius* (Geiseler) Müll. Arg.	L	Waist pain	Ginger, Alcohol	Allergic reaction, Hot burns	3	0.64	0.10
Onwamma	Euphorbiaceae	*Ricinodendron heudelotii* (Baill.) Heckel	L, R	Malaria, Waist pain, Piles	Lemon, Ashes, Afama, Toantini, Alcohol	Bitter mouth	5	1.06	0.34
Akasia	Fabaceae	*Acacia pycnantha* Benth.	SB	Wounds	Akyeampong, Nyankyerenee	None	5	1.06	0.28
Awiemfosamina	Fabaceae	*Albizia ferruginea* (Guill. & Perr.) Benth.	R, L	Waist pain, Diarrhoea, Anal sore	Shea butter, Alcohol, Ginger/ Cloves	Stomach pains, Excessive drinking leads to kidney failure, Frequent running	9	1.91	1.02
Kasia	Fabaceae	*Cassia fistula* L.	L, SB	Swollen eyes, Piles, Malaria	Teak	None	1	0.21	0.03
Otedua	Fabaceae	*Copaifera salikounda* Heckel	R, SB	High fever, Piles	None	None	4	0.85	0.18
Prekese	Fabaceae	*Tetrapleura tetraptera* (Schum. & Thonn.) Taub.	F, S	Asthma, Blood pressure, Typhoid, Arthritis, Blood tonic	Wediaba, Ginger, Pepper, Kaolin	Urinating	14	2.97	4.61
Sẽfufudua	Guttiferae	*Garcinia kola* Heckel	WP	Tooth cleaning, Piles, Chest pain	None	None	5	1.06	0.40
Teak	Lamiaceae	*Tectona grandis* Linnaeus. F	L, SB	Malaria	Prekese, Moringa, Neem	None	5	1.06	0.28
Paya	Lauraceae	*Persea americana* Mill.	L, F	Skin disease, Ulcer, Fever	Mango leaves	None	3	0.64	0.20
Asia	Lecythidaceae	*Petersianthus macrocarpus* (P. Beauv.) Liben	L, SB	Fibroid, Constipation, Menstrual pain	Salt	None	7	1.48	0.56
Okoro	Leguminosae	*Albizia zygia* (DC.) Macbr.	L, SB	Blood tonic, Stomach ulcer/ upset	Palm nut soup, Moringa	None	5	1.06	0.28
Owudifo Kete	Loganiaceae	*Anthocleista nobilis* G. Don	L, R, SB	Typhoid, Jaundice, Hernia, Piles, Diabetes, Syphilis	Nkrapan, Dried teak	Urinating, Headache	7	1.48	1.11
Onyina	Malvaceae	*Ceiba pentandra* (L.) Gaertn.	SB, F, FL	Measles, Sting removal	Shea butter, Nyenya, Palm wine/oil, Food, Tea, Prekese			15	3.18
Aprono	Malvaceae	*Mansonia altissima* (A Chev.) A Chev	L	Body pain	None	Bitter mouth	1	0.21	0.01
Neem	Meliaceae	*Azadirachta indica* A. Juss	L, R, SB	Malaria, Fever, Typhoid, Diabetes	Hwentia, Fever grass, Ginger, Lemon, Dry pear/ mango leaves	Bitter mouth, Dizziness, Sweating, Kidney failure	42	8.90	23.39
Gyenegyene	Meliaceae	*Cedrela odorata* L.	SB	Tooth decay, Migraines, Ear problems, Headache	Water	None	3	0.64	0.20
Mahogany	Meliaceae	*Khaya senegalensis* (Desv.) A.Juss.	L, SB	Male infertility, Waist pain, Piles, Sexual weakness, Blood tonic,	Hwentia, Toantini, Nyamedua, Okoro, Nyankyerenee leaves, Alcohol	None	23	4.87	10.72
Tannuru	Meliaceae	*Trichilia monadelpha* P. Browne	L	Piles, Heart burns	Ginger, Nunum, Otie	None	6	1.27	0.61
Chenchen	Moraceae	*Antiaris toxicaria* Lesch.	SB	Anaemia	Alcohol	Bitter mouth, Poisoning the liver,	2	0.42	0.05
Ɔdoma	Moraceae	*Ficus capensis* Thunb.	L, SB	Stomach ache	None	None	5	1.06	0.28
Nyankyerene	Moraceae	*Ficus exasperata* Vahl.	L, SB	Foetus disposition, Asthma, Wound, Shingles, Malaria	Soup, Ginger	Abdominal pain	14	2.97	3.34
Odum	Moraceae	*Milicia excelsa* (Welw.) Berg.	L	Stomach ache	Alcohol	Dizziness	1	0.21	0.01

(*continued on next page*)

Table 2 (*continued*)

Vernacular name	Family name	Botanic name	Plant part	Therapeutic properties	Condiments	Side effects	C. F	RCF	SUV
Moringa	Moringaceae	*Moringa oleifera* Lam	L, R, SB	Heart disease, Anaemia, Arthritis, Erectile, dysfunction	Milk, Ginger, Honey, Porridge	Bitter mouth, Upset stomach	22	4.66	10.25
Otie	Myristicaceae	*Pycnanthus angolensis* (Welw.) Warb.	SB	Fertility, Blood tonic, Piles, Pregnancy care	Ginger, Hwentea, Tweta	Urinating	4	0.85	0.36
Guava	Myrtaceae	*Psidium guajava* L.	F, L	Haemorrhoid, Heart disease, Constipation	Food, Cloves	None	7	1.48	0.72
Pampulo	Poaceae	*Bambusa vulgaris* Schrad. ex J.C. Wendl.	L	Malaria, Fever	Lemon, Teak, Neem, Oyaw, Kuakuanisuo leaves	Weight loss, Sweating	6	1.27	0.41
Kɔfe	Rubiaceae	*Coffea arabica* L.	L	Vomiting	None	None	1	0.21	0.01
Konkroma	Rubiaceae	*Morinda lucida* Benth.	L, R	Candidiasis, Stomach pain, Malaria	Lime, Tea leaves, Ginger, Pepper, Pawpaw leaves	Weakness, Urinating, Sleeping, Bitterness	11	2.33	1.38
Ntatiadupon	Rubiaceae	*Psydrax subcordata* (DC.) Bridson var. subcordata	WP	Fertility, Boils, Body pains, Skin disease	Water, Lime	Sharp pain	7	1.48	1.03
Ankaa twadeɛ	Rutaceae	*Citrus aurantiifolia* (Christm.) Swingle	L, R, F, S	Malaria, Diarrhoea, Fever, Cough, Burns fat, Typhoid	Honey, Fever grass, Food, Ginger, Cloves	Loss of weight, Urinating	15	3.18	3.58
Nkagyua	Rutaceae	*Citrus limon* (L.) Burm. f.	R, F	Migraines, Fever, Cough	Ginger, Prekese, Tea leaf			2	0.42
Sesadua	Rutaceae	*Clausena anisata* (Willd.) Hook.f. ex Benth.	L, F	Snakebite antidote, Scorpion bite antidote, Diabetes, Abdominal pains	None	None	1	0.21	0.06
Oyaa	Rutaceae	*Zanthoxylum leprieurii* Guill. & Perr	SB	Sickle cell anaemia, Rheumatism, Stomach ulcer	Pepper, Okuo, Nyamedua, Alcohol	Weakness	9	1.91	1.43
Odee	Santalaceae	*Okoubaka aubrevillei* Pellegr. & Normand	SB, F, R	Fertility, Pregnancy care	Palm oil, Salt, Lemon	None	7	1.48	0.80
Odwen	Sapindaceae	*Allophylus africanus* P. Beauv.	L, SB	Retarded growth, High blood pressure	Alcohol, Honey	Dizziness, Weakness	4	0.85	0.18
Agyehene	Sapindaceae	*Blighia sapida* K. D. Koenig.	R, SB	Stroke, Hernia	Alcohol	None	2	0.42	0.05
Akyekobri	Sapindaceae	*Blighia welwitschii* (Hiern) Radlk.	SB	Measles	Alcohol	Dizziness	1	0.21	0.01
Sanfena	Sapotaceae	*Pouteria altissima* (A Chev.)	L, SB	Stops bleeding	None	None	5	1.06	0.28
	Simaroubaceae	*Brucea antidysenterica* J. F.Mill	R	Wounds	Water	None	1	0.21	0.01
Watapuo	Sterculiaceae	*Cola gigantea* A. Chev.	R	Waist pain	None	None	1	0.21	0.01
Bese	Sterculiaceae	*Cola nitida* (Vent.) Schott & Endl.	F, SB	Easy delivery, Bad breath, Fracture, Herpes	Fam wisa, Charcoal, Ashes, Hwentea,	None	9	1.91	1.33
Wawabima	Sterculiaceae	*Sterculia rhinopetala* K. Schum.	R	Piles, Waist pain	None	None	1	0.21	0.02
Kookoo	Sterculiaceae	*Theobroma cacao* L.	L, R	Chest pain, Malaria, Cough, Blood tonic, Fever	Moringa seed, Awonwono, Coconut root, Alcohol	None	8	1.69	1.00
Esa	Ulmaceae	*Celtis mildbraedii* Engl.	SB	Hernia	None	None	1	0.21	0.01
Ogyama	Zygophyllaceae	*Balanites aegyptiaca* (L.) Del.	L, SB	Piles, Wound, Fever, Malaria, Constipation	Kakaweadwe, Ginger	Urinating, Bitter mouth	6	1.27	0.89

L = leaves, SB = stem bark, F = fruits, S = seeds, R = roots, FL = flowers, and WP = whole plant (saplings or seedlings).

respondents were either married or single (87 %) while few were either widowed or divorced (13 %). The family size of respondents ranged from 1 to 13 with an average family size of 5 members. The respondents were predominantly Christians (82 %), with a few being Muslims (11 %) or Traditionalists. Out of the 88 respondents, most had basic education (88 %), while only 2 % had tertiary education (Table 1). However, 10 % of the respondents had no form of education. There was a positive correlation between the number of dependants and IKS ($r = 0.23$, $p = 0.031$); the other parameters were not significantly related to IKI. Mean IKI was significantly different across marital status ($p = 0.035$), with higher values for widowed respondents than those who were single. Mean IKI values were similar across gender, educational level, religion, resident status, and type of family household head ($p > 0.05$). Experience in using medicinal plants (years of using medicinal plants) varied significantly across marital status ($p < 0.001$); a post-turkey test showed that respondents who were widowed had greater experience than respondents who were married or single (Table 1). However, experience in using medicinal trees was similar across gender, religion, educational level, and the origin of respondents ($p > 0.05$).

3.2. Medicinal tree species and tree parts used

The questionnaire-led interviews resulted in the identification of 70 medicinal tree species from 34 families that were utilized in treating diseases by the local communities (Table 2). These tree species were efficacious in managing and treating 83 different ailments. *Azadirachta indica* was the most frequently cited tree species which recorded a citation frequency (CF) of 42 and a relative citation frequency (RCF) of 8.898. This was followed by *Alstonia boonei* (CF = 25, RCF = 5.297), *Cocos nucifera* and *Khaya senegalensis* (each CF = 23, RCF = 4.873), *Moringa oleifera* (CF = 22, RCF = 4.661), *Ceiba pentandra* and *Citrus aurantiifolia* (each CF = 15 RCF = 3.178), *Tetrapleura tetraptera* and *Ficus exasperata* (CF = 14, RCF = 2.966), *Carica papaya* (CF = 12, RCF = 2.542), and *Morinda lucida* (CF = 11, RCF = 2.331). Different tree parts (stem bark, leaves, roots, seeds, flowers, and whole plants) were harvested and either used singly or incorporated in treating disease in the study area (Fig. 2). However, there were variations in the preference and use of these parts; the dominant and most frequently used part was the stem bark which represented 30 % of the plant parts identified. This was followed by the leaves (23 %), roots (18 %), seeds (17 %), flowers (9 %) and whole plants recorded the least (3 %).

3.3. Family distribution and species use value of medicinal trees

The 70 medicinal trees that were identified belonged to 33 botanical families (Table 2; Figs. 3 and 4; Supplementary Information 1). The ten most represented families in terms of the number of species were Fabaceae and Anacardiaceae (5 spp. each), Sterculiaceae, Rutaceae, Moraceae, Meliaceae and Euphorbiaceae (4 spp. each), and Sapindaceae, Rubiaceae, Bignoniaceae, Apocynaceae, and Annonaceae (3 spp. each) whiles the remaining families were either represented by two or single species. Based on the family use value index, the most cited families were Meliaceae (FUV = 34.9), Apocynaceae (FUV = 12.6), Arecaceae (FUV = 11.3), and Moringaceae (FUV = 10.3). The five top plants in terms of species use values were *Azadirachta indica* (SUV = 23.4), *Alstonia boonei* (SUV = 11.1), *Khaya senegalensis* (SUV = 10.7), *Moringa oleifera* (SUV = 10.3) and *Cocos nucifera* (SUV = 10.2) (Fig. 3). We found that mean RCF and SUR were directly related to the number of cited species per plant family (Fig. 5a–c), but SUV was not related to the number of cited species per plant family. However, RCF, SUR and SUV were all directly related to the number of plant parts used (Fig. 5d–f). RCF and SUV were significantly different across number of sources of medicinal plants, with multiple collection sources having greater RCF and

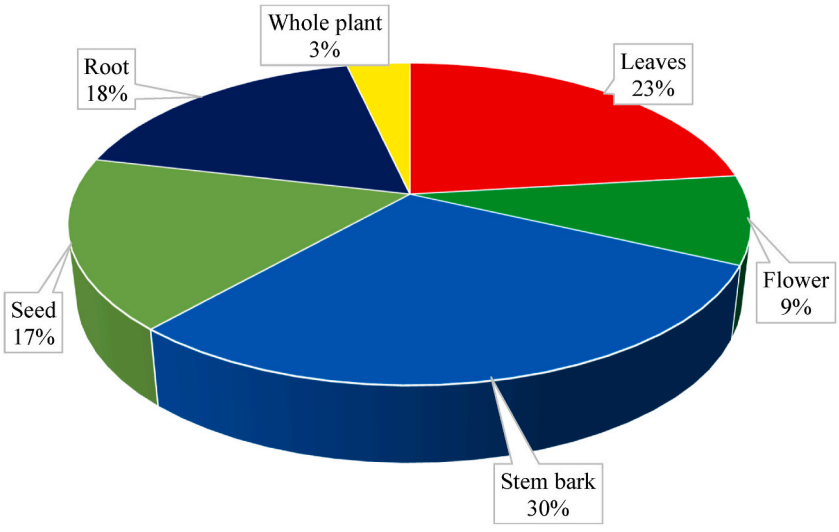

Fig. 2. Parts of medicinal tree species used in treating diseases by the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

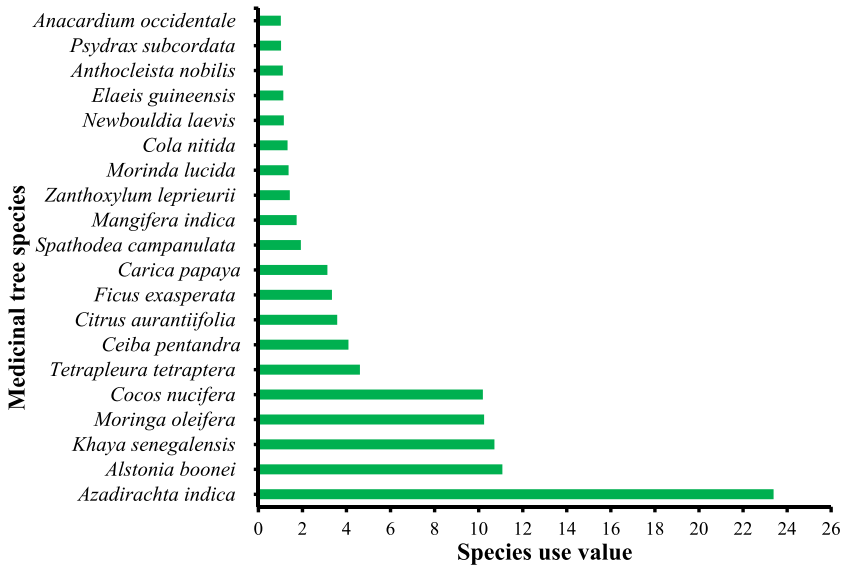

Fig. 3. Species use value of medicinal trees (top 20 species) used by the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

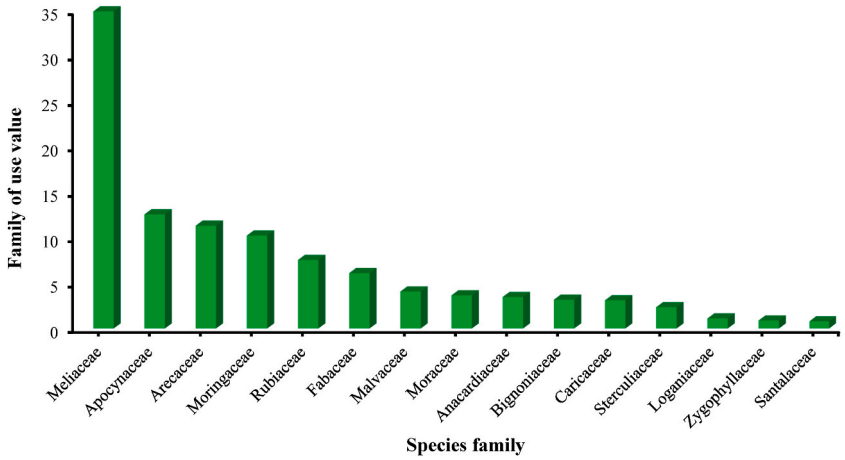

Fig. 4. Family use value of medicinal trees used by the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

SUV than single sources (Table 3), but SUR remained similar across sources of medicinal plants.

3.4. Mode of preparation and administration of plant medicine

The techniques employed by people in the study area in preparing the medicinal remedies and the routes of administration varied as indicated in Figs. 6 and 7, respectively. These variations were primarily dependent on the plant ingredients, the diseases it intended to cure, and the conservation of the active ingredients. The preparation methods included decoction, grinding, crushing, infusion and eating raw (ingestion). Nearly half of the remedies were prepared using decoction (Fig. 6); this was followed by grinding (22 %), crushing (15 %), infusion (9 %), and eating raw (7 %). Also, administration routes of the plant medicine included inhalation, oral, nasal/ear/eye drop, body massage, eating, and bathing or steam bathing. The oral route (65 %) was the most predominantly used, followed by body massage (21 %) (Fig. 7). The least route of administration was inhalation (1 %).

3.5. Condiments and side effects of medicinal plant medicine

The majority of the remedy preparations (80 %) included condiments, whiles a few (20 %) were prepared without the addition of any condiment (Table 2). Of all the condiments identified, 79 % were raw plants, while 21 % were finished products. Ginger (19 %) and Alcohol (33 %) were the highest raw plant and finished product condiments, respectively. Data on the side effects of plant medicine

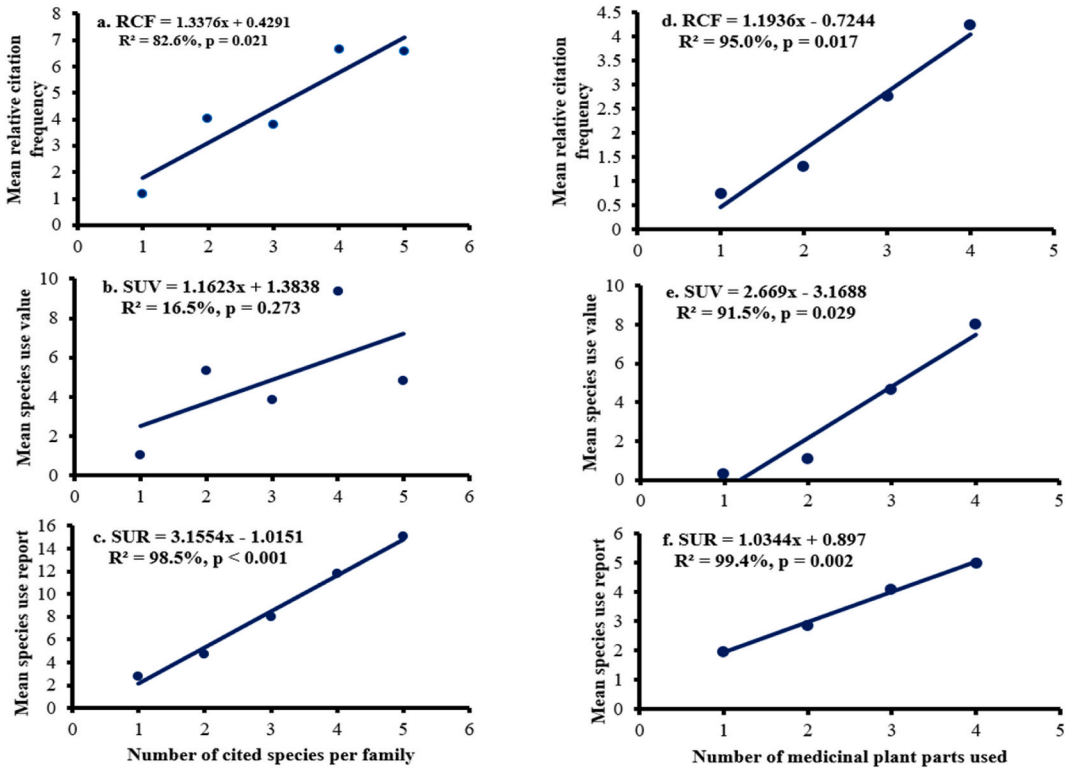

Fig. 5. Relationship between mean relative citation frequency, species use value and species use report and number of cited species per family (panel a–c) and number of medicinal plant parts used (panel d–f).

Table 3
Variation of mean relative citation frequency (RCF) and species use value (SUV) and report (SUR) across number of collection sources (one-way ANOVA). Different letters for each column indicate significant differences and the same letters indicate no difference.

Number of collection sources	N	Mean (95 % CI)		
		RCF	SUV	SUR
One collection source	39	0.42 (0.214, 0.841)[b]	0.016 (0.004, 0.066)[b]	6.081 (3.819, 9.660)[a]
Two collection sources	5	1.968 (0.851, 4.539)[a]	0.314 (0.054, 1.832)[a]	7.194 (4.083, 12.706)[a]
Three collection sources	26	1.66 (0.247, 11.194)[ab]	0.339 (0.006, 18.967)[ab]	19.724 (5.408, 71.945)[a]
df		2, 67	2, 67	2, 67
F-value		4.3	3.84	1.46
P-value		0.018	0.026	0.238

also indicated that a greater percentage (63 %) of the medicinal plants posed no side effects whiles only 27 % were reported to exhibit some side effects (Table 2). The side effects reported ranged from mild forms such as headache, dizziness, bitter mouth, urinating or sweating to more complicated forms like kidney failure, low sperm count, and liver poisoning. However, the most cited side effect was bitter mouth (20 %) followed by frequent urination (14 %), weakness and dizziness (10 % each), running stomach (6 %), stomach upset, loss of weight, sweating, abdominal pains, kidney failure, and headache (4 % each). The least reported cases were vomiting, allergic reaction, sleeping, liver poisoning, sharp pain, hot burns, itching skin and low sperm count (2 % each).

3.6. Alternative uses of medicinal tree species

Though medicinal plants are popularly known to be used in managing and treating diseases as the name suggests, the study revealed alternative uses of the medicinal tree species in fringe communities of Asukese and Amama Forest Reserves of Southwestern Ghana (Fig. 8). The alternative uses of medicinal tree species documented in the study communities include food, craftwork, fodder, fuel wood, construction, and others (e.g. chewing stick, fencing, sponge, rituals, and decoration). The most dominant alternative use of medicinal trees was fuel wood (30 %), followed by craftwork (24 %), and the least was fodder (5 %).

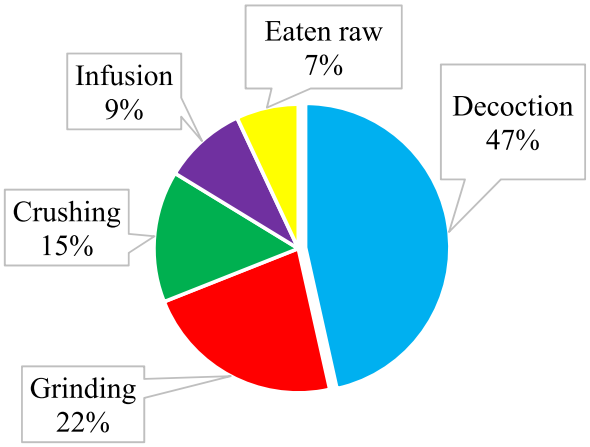

Fig. 6. Mode of preparation of remedies of medicinal trees.

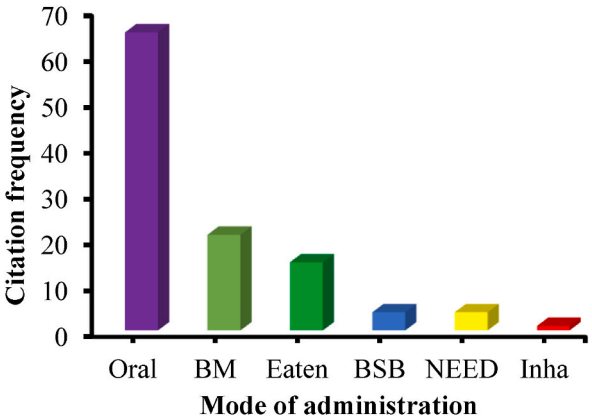

Fig. 7. Route of administration of remedies of medicinal trees. BM is body massage, BSB is bathing or steam bathing, NEED is nose, ear or eye drop, Inha is inhalation.

3.7. Sources of knowledge about medicinal trees and materials used in preparing remedies

The questionnaire-led interviews revealed that the medicinal tree materials were sourced from different places (Fig. 9). The major source of medicinal tree species was the forests (38 %); the other two sources mentioned by the respondents were farmland (34 %) and bush (28 %). The survey revealed that the respondents acquired knowledge about medicinal plants from different sources, including herbalists, parental training, media, formal training, apprenticeship, and shared knowledge in the area (Fig. 10). Nearly 60 % of the respondents cited either parental training or shared knowledge as their primary source of knowledge (Fig. 10). The least sources of knowledge transfer in the local communities were apprenticeship (4 %) and the media (7 %).

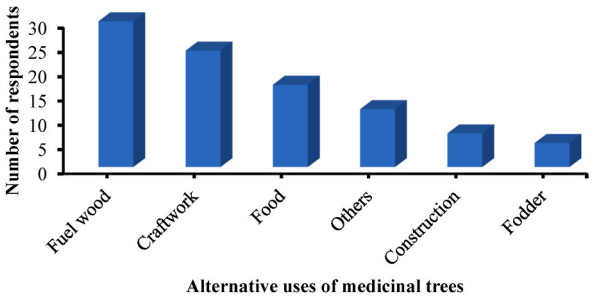

Fig. 8. Alternative uses of medicinal trees in the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

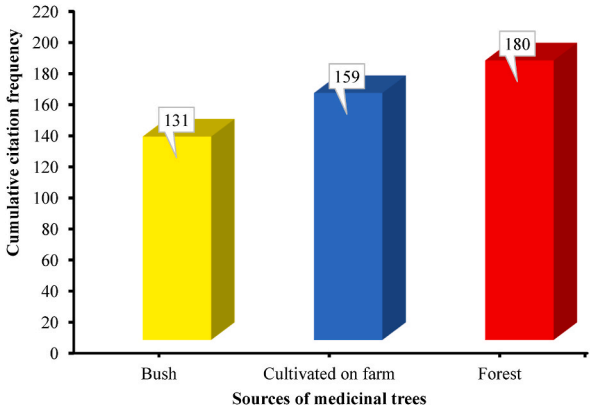

Fig. 9. Sources of medicinal trees used by the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

3.8. Comparison of ethnobotanical and published pharmacological uses of identified medicinal trees

Literature search on ethnopharmacological use of the identified medicinal trees were carried out to ascertain whether the tree species identified in the present study were used elsewhere for the treatment of similar or different ailments (Table 4). Results from the search showed that majority (78 %) of the tree species in were also used in other parts of the world for similar therapeutic purposes (Table 4). On the contrary, comparing results of the study with that of literature, sixteen tree species (22 %) are documented for the first time (or relatively rarely documented) for the treatment of diseases indicated by respondents in the study area. These species included; *A. zygia* (blood tonic, stomach pain), *A. toxicaria* (anaemia), *C. mildbraedii* (hernia), *C. limon* (migraines, fever, cough), *C. anisata* (snake and scorpion bite antidote, diabetes, abdominal pains), *C. arabica* (vomiting), *C. salikuonda* (high fever, piles), *F. capensis* (stomach ache), *K. africana* (stomach ache), *M. discoidea* (stomach pain), *M. excels* (stomach pain), *O. aubrevillei* (infertility, pregnancy care), *P. macrocarpus* (fibroid, constipation, menstrual pains), *S. mombin* (gonorrhoea), *S. rhinopetala* (piles, waste pain) and *X. villosa* (amenorrhoea) (Table 3). Most of the species (30 %) were used to treat multiple range of diseases compared to other parts of the world. Significantly, pharmacological information regarding the therapeutic use of plant such as *C. papaya*, *C. aurantiifolia*, *C. nucifera*, *K. senegalensis*, *M. oleifera*, *M. lucida*, *P. guajava*, *R. vomitoria* and *T. tetraptera* were abundant. Top five published pharmacological effects of the plants included anti-inflammatory, anti-malarial, anti-microbial, anti-bacterial and reproductive booster.

4. Discussion

4.1. Indigenous knowledge index and socio-demographic characteristics of respondents

Indigenous knowledge is central to health care in rural communities and a precursor to the discovery and development of novelties in drugs [32]. It is essential in the preparation and administration of herbal remedies and the isolation of bioactive constituents. The study revealed that demographic characteristics such as the number of dependants and marital status influenced respondents' knowledge of medicinal plants whiles gender, age, educational status, religion, resident status, years of using medicinal plants, and family size did not influence respondents' knowledge on medicinal plants (Table 1). This indicates that much of the ancestral knowledge that is part of the oral tradition has been transferred to the local population irrespective of socio-demographic features. Our results are contrary to findings which suggest that indigenes show more interest in traditional medicinal knowledge compared to migrants [12] and that men have better knowledge on medicinal plants than women ([8,12,32]). The similar ethnobotanical knowledge across several socio-demographic features may be because the predominant source of knowledge about medicinal plants

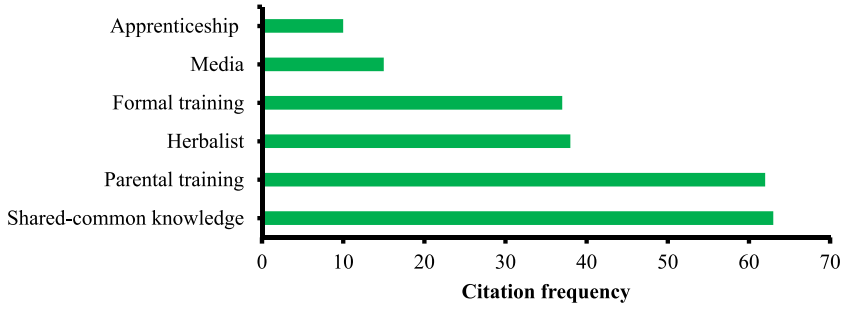

Fig. 10. Sources of knowledge about medicinal trees used by the forest-fringe communities of Asukese and Amama Shelterbelt Forest Reserves.

Table 4
Cross-reference in published literature on ethnobotanical use and pharmacology of medicinal tree species cited by respondents in the fringe communities of Asukuse and Amama shelterbelt Forest Reserves.

Botanical name	MOP	MOA	Therapeutic properties	Ethnopharmacological use reported in literature	Pharmacology
Acacia pycnantha	Grinding, Infusion	Body massage, Oral	Wounds	Wound ([36,37])	
Albizia ferruginea	Crushing, Decoction	Eaten, Body massage, Oral	Waist pain, Diarrhoea, Anal sore	Hermorrhoids and inflammation [38], Diarrhoea [38,39])	Anti-inflammatory [38]
Albizia zygia	Decoction, Grinding, Infusion	Oral, Body massage	Blood tonic, Stomach ulcer/upset		
Allophylus africanus	Infusion, Decoction	Oral	Retarded growth, High blood pressure		Galactogogues [40]
Alstonia boonei	Grinding, Infusion, Decoction, Crushing	Oral, Body massage, Eaten raw	Malaria, Hypertension Asthma, Rashes, Chicken pox, Shingles	Malaria ([41–44]); Hypertension [45]; Contraceptive performance [46]; Fever [47]; Henia ([48–50])	Antimalarial ([51–53]); Antihypertensive [54]; Reproductive performance [55]; Anti-inflammatory [56, 57]; Neuroprotective [58]
Anacardium occidentale	Decoction	Oral	Diarrhoea, Infertility, Piles, Pregnancy care, Haemorrhoids	Sexual dysfunction (59); Haemorrhoids (60; 61)	Infertility (62); Sexual dysfunction (59)
Anthocleista nobilis	Crushing, Decoction	Oral, Ear/Eye drop	Typhoid, Jaundice, Hernia, Piles, Diabetes, Syphilis	Diabetes (63)	Anti-diabetes (64)
Antiaris toxicaria	Decoction	Oral	Anaemia		
Antrocaryon micraster	Grinding, Decoction	Oral	Pressure, Chicken pox, Stomach ache	Arterial hypertension (65)	
Azadirachta indica	Crushing, Decoction	Oral, Inhalation, Bathing/Steam bathing	Malaria, Fever, Typhoid, Diabetes	Diabetes (66; 67; 68); Fever (39; 69)	Antimalarial (70); Antihyperglycemic (71); Hypoglycemic (72; 73); Antityphoid (74); Antibacterial (75); Antibacterial (76; 77)
Balanites aegyptiaca	Decoction, Grinding	Oral, Body massage	Piles, Wound, Fever, Malaria, Constipation	Malaria (78; 79); Mental disorder (80); Constipation (78; 79); Haemorrhoids (78; 79); Fever (78; 79)	Antiplasmodial (79); Antioxidant (81)
Bambusa vulgaris	Decoction	Oral	Malaria, Fever	Malaria (27); Fever (82)	Antimalarial (83; 84; 85)
Berlinia confusa	Decoction	Oral	Menstrual pain	Menstrual pain (86)	
Blighia sapida	Decoction	Oral	Stroke, Hernia	Hernia (87)	Antioxidant and anti-inflammatory (88)
Blighia welwitschii	Decoction	Oral	Measles	Measles (86)	
Bombax buonopozense	Decoction, Crushing	Oral	Bloody stool, Asthma, Anaemia, Candidiasis	Anaemia (89); Candidiasis, Asthma (86; 90)	Antimicrobial (91); Diarrhoea (90)
Brucea antidysenterica	Grinding	Body massage	Wounds	Wound healing (92; 93; 94)	Antibacterial (95); Anti-inflammatory (94)
Carica papaya	Decoction, Eaten raw, Grinding, Crushing	Oral, Eaten	Stomach ache, Cough, Ulcer, Easy delivery, Dewormer, Aseram, Cancer	Abortifacient (96); Cough (97); Stomach ache (98); Fever (97; 99); Worms (100); Glandular tumours (101), breast and prostate cancer (76)	Antimalarial (102; 103); Antimicrobial (104); Neuroprotective (105); Antiulcer (98); Antibacterial (106; 107; 108); Antihelminthic (109); Antipyretic (110); Analgesic and antipyretic (111); Antitumor (76)
Cassia fistula	Decoction	Oral	Swollen eyes, Piles, Malaria	Swellings (112; 113; 114); Malaria (112)	Antipyretic (115); Anti-inflammatory (116); Anti-inflammatory (116)
Cedrela odorata	Crushing, Infusion	Oral	Tooth decay, Migraines, Ear problems, Headache	Ear infection (117; 118)	Anti-inflammatory (119); Antioxidant (120)
Ceiba pentandra	Grinding, Decoction	Oral, Body massage, Eaten	Measles, Sting removal	Skin diseases (121); Chronic fever (122)	Anti-inflammatory (123); analgesic and anti-inflammatory (124);
Celtis mildbraedii	Decoction	Oral	Hernia		
Citrus aurantiifolia	Infusion, Decoction,	Oral, Eaten	Malaria, Diarrhoea, Fever, Cough, Burns fat, Typhoid	Kidney stones (125); Heart disease (126; 127); Cough (128; 129); Stroke (130),	Decrease calcium ratio to urine citrate (125); Hypocholesterolemic (136); Antibacterial (137; 138); Antioxidant (139); Antimicrobial (140)

(*continued on next page*)

Table 4 (*continued*)

Botanical name	MOP	MOA	Therapeutic properties	Ethnopharmacological use reported in literature	Pharmacology
	Grinding, Eaten raw			Mental disorder (80); Typhoid (131; 132; 133); Fever (134; 135)	
Citrus limon	Decoction	Oral	Migraines, Fever, Cough		Antioxidant (141)
Clausena anisata	Crushing	Oral	Snakebite antidote, Scorpion bite antidote, Diabetes, Abdominal pains		
Cleistopholis patens	Decoction, Grinding	Oral, Body massage	Hernia, Typhoid fever, Piles	Malaria (142); Typhoid (63); Fever (2)	Antimalarial (27; 143; 144); Antibacterial (145); Anti-inflammatory (146)
Cocos nucifera	Decoction, Eaten raw, Infusion	Eaten, Oral	Herpes, Erectile dysfunction, Ulcer, Bad breath, Heart disease	Bleeding (147; 148); Cardiovascular disease (149), Infertility (150; 151); Bronchial asthma (152); Stroke (153); Bleeding gum (154; 155); Hemorrhoidal bleeding (156; 157); Anaemia (158)	Antihypertensive (159); 160); Cardiovascular effect (161; 149); Sex hormones (162); Antimicrobial (163; 164); Antihypertensive (160); Dental ministration (156); Anti-inflammatory (159; 165; 166)
Coffea arabica	Infusion	Eye/Ear drop	Vomiting		
Cola gigantea	Decoction	Drinking	Waist pain		Anti-inflammatory [17]
Cola nitida	Grinding	Oral, Body massage, Steam bathing	Easy delivery, Bad breath, Fracture, Herpes	Antibacterial (168)	
Copaifera salikounda	Decoction	Oral	High fever, Piles		
Drypetes aubrevillei	Decoction	Oral	Easy delivery, Bad breath, Fracture, Herpes	Stroke (39; 130)	
Elaeis guineensis	Decoction, Crushing, Grinding	Oral, Body massage	Stroke, Wounds, Boils, Erectile dysfunction	Heart disease (169; 170); Aphrodisiac (171); Boil (86; 48; 172); Wound Healing (111; 174), Stroke (130)	Cardiovascular effect (175); Aphrodisiac activity (172); Wound healing (176); Neuroprotective (177)
Ficus capensis	Decoction	Oral	Stomach ache		
Ficus exasperata	Decoction, Grinding	Oral, Body massage, Steam bathing	Foetus disposition, Asthma, Wound, Shingles, Malaria	Abortifacient and ecbolic (178; 179); Rashes (180); Wound healing (178); Cough (181; 182); Asthma (86; 183; 184)	
Funtumia elastica	Decoction, Infusion	Oral	Stop alcoholism, Stroke	Stroke (130)	Antiplasmodial (185)
Garcinia kola	Crushing, Eaten raw, Decoction	Oral, Eaten	Tooth cleaning, Piles, Chest pain	Haemorrhoids (186; 187); Chest colds (188)	Anti-inflammatory and antipyretic (189); analgesic and anti-inflammatory (188)
Khaya senegalensis	Decoction, Crushing, Infusion	Oral, Nasal drop, Body massage	Male infertility, Waist pain, Piles, Sexual weakness, Blood tonic,	Hypertension (54); Anaemia (190); Infertility (39; 191; 192); Boils (190); Skin irritation (190; 193; 194); Seizure (195; 196), Epilepsy (80; 197); Stroke (130); Stomach-ache (190); Toothache (190); Diarrhoea (190); Tonic (190); Hermorhoids (190); Inflammation (190); Fever (190); Convulsing (173)	Antimalarial (198); Anti-anaemic (195); Antimicrobial (190; 199; 200); Neuroprotective (197); Antioxidant (44); Antiulcer (201); Anti-inflammatory (202; 203); Anti-inflammatory (202; 203); Typhoid (204)
Kigelia africana	Decoction	Oral	Stomach ache		
Lannea welwitschii	Decoction	Bathing/Steam bathing, Oral, Body massage	Aseram, Child fever, Piles	Haemorrhoids (205; 206); Back-ache (205); Fever (207; 208)	Anti-inflammatory (209; 205); Antimalarial (210; 211)
Macaranga barteri	Decoction	Oral	Foot rot	Foot rot [39]	Antimicrobial and antifungal (212; 213)

(*continued on next page*)

Table 4 (*continued*)

Botanical name	MOP	MOA	Therapeutic properties	Ethnopharmacological use reported in literature	Pharmacology
Mallotus oppositifolius	Decoction, Grinding	Oral, Body massage	Waist pain	Paralysis and spasms (214)	Anti-inflammatory and antioxidant (214)
Mangifera indica	Grinding, Decoction	Oral, Eaten	Ulcer, Low sperm count, Bedwetting, Measles, Fever	Infertility (192); Excessive urination (215); Measles (216; 217); Cough (215; 218); Stroke (219); Diarrhoea (215; 218); Fever (70; 74)	Antioxidant (220; 221); Anti-diarrhoea (222; 223); Antiplasmodial and antipyretic (224)
Mansonia altissima	Eaten raw	Eaten	Body pain	Body pains (89)	
Margaritaria discoidea	Decoction	Oral	Stomach pain		
Milicia excelsa	Decoction	Oral	Stomach ache		
Morinda lucida	Decoction	Oral	Candidiasis, Stomach pain, Malaria	Malaria (225; 226); Candidiasis (89); Stomach-ache (227); Typhoid fever (86; 226; 227)	Antimalarial (227, 228); Antidermatophytic (229); antifungal (230); antimicrobial (231)
Moringa oleifera	Decoction, Grinding, Eaten raw, Crushing	Oral, Eaten	Arthritis, Heart disease, Anaemia, Erectile dysfunction,	Reproduction function (232); Malaria (233); Hypertension (204; 233; 234); Anaemia (39; 233); Heart disease (235); Blood impurities; Erectile dysfunction (136); Dementia (236); Mental disorder (80); Jaundice (39; 233; 237); Fever (233; 237); Cardiometabolic disorders (238)	Antimalarial (239); Antihypertensive (240); Blood booster (241); Cardioprotective (242); Hypocholesterolemic effect (243); High epididymal maturity (244); Neuroprotective (245; 246); Antimicrobial (247; 248); Antipyretic (249)
Newbouldia laevis	Decoction, Eaten raw, Grinding	Oral, Eaten	Cough, Infertility, High blood pressure, Pregnancy care	Infertility (192); Cough ([2]; 250; 251); Inflammation (252)	Antihypertensive [54]; Infertility (46; 62; 253); Antimicrobial (254); Anti-inflammatory (255; 256)
Okoubaka aubrevillei	Decoction, Grinding, Crushing	Bathing/Steam bathing	Fertility, Pregnancy care		
Persea americana	Decoction	Oral	Skin disease, Ulcer, Fever	Fever (257)	Antimalarial (64); Antioxidant (258)
Petersianthus macrocarpus	Decoction, Grinding	Oral, Body massage	Fibroid, Constipation, Menstrual pain		
Pouteria altissima	Decoction	Oral	Stops bleeding	Constipation (259)	
Psidium guajava	Decoction, Crushing, Grinding, Infusion	Oral, Eaten, Body massage	Haemorrhoid, Heart disease, Constipation	Heart disease (260; 261); Candidiasis (262), Chickenpox (266; 267); Measles (268; 269; 270)	Anti-inflammatory (263); Antimicrobial (264; 265)
Psydrax subcordata	Crushing, Infusion, Grinding	Oral, Body massage	Fertility, Boils, Body pains, Skin disease	Boils (271); Skin rashes (272); Body pains (271)	Antibacterial (273); Anti-inflammatory (274)
Pycnanthus angolensis	Crushing, Decoction	Oral	Fertility, Blood tonic, Piles, Pregnancy care	Infertility (275; 276); Inflammation (275)	Anti-inflammatory (276)
Rauvolfia vomitoria	Grinding, Decoction	Oral, Body massage	Hernia, Chicken pox, Piles, Body pains	Pain (278); Fever (135); Chickenpox (279); Skin disorder (279; 280; 281); Haemorrhoid (282; 283); Hernia (279; 284; 285)	Anti-inflammatory (278); Antimalarial (286); Antimicrobial (287); Antisickling (288; 289)
Ricinodendron heudelotii	Decoction, Grinding	Oral, Body massage	Malaria, Waist pain, Piles	Inflammation (290); Malaria (290; 291); Wound (292)	Anti-inflammatory (290)
Spathodea campanulata	Decoction, Grinding	Oral, Body massage	Typhoid, Stroke, Malaria, Wound	Malaria (293); Wound (293); Stroke (130); Typhoid ([2]; 83)	Antimalarial (294; 295); Wound healing (296); Antioxidant (297); Antimicrobial (298)
Spondias mombin	Decoction	Oral	Gonorrhoea		

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Table 4 (*continued*)

Botanical name	MOP	MOA	Therapeutic properties	Ethnopharmacological use reported in literature	Pharmacology
Sterculia rhinopetala	Decoction	Oral	Piles, Waist pain		
Tectona grandis	Decoction	Oral	Malaria		Anti-plasmodial (83)
Terminalia ivorensis	Grinding	Eaten	Piles	Haemorrhoids (299)	
Terminalia superba	Decoction	Oral	Convulsion	Convulsion [39]	Antioxidant 300)
Tetrapleura tetraptera	Decoction	Oral	Asthma, Blood pressure, Typhoid, Arthritis, Blood tonic	Cough ([49]; 135; 301); Hypertension (234; 302; 303); Heart disease; Infertility (192; 304), Asthma (305; 306); Brain disorder (307); Typhoid ([49]; 308); Inflammatory arthritis (309)	Haematopoetic (310); Antihypertensive [54]; Estrogenic properties (311); Neuroprotective (307; 312); Antimicrobial (313); Anti-inflammatory (306); Testicular integrity (314); Reproductive toxicity (315)
Theobroma cacao	Eaten raw, Crushing, Decoction, Grinding	Oral, Eaten	Chest pain, Malaria, Cough, Blood tonic, Fever	Increases air flow to lungs (89); Inner pains (89); Fever (316)	Antimalarial (83); Cough suppressant (317); Anti-inflammatory (318); Anti-biofilm (319)
Trichilia monadelpha	Decoction, Grinding, Crushing	Oral	Piles, Heart burns	Analgesic (320)	
Xylopia aethiopica	Decoction, Eaten raw	Oral, Eaten	Anaemia, Cough	Anaemia (321); Cough (322)	Tonic (323; 324); Anti-infective (325)
Xylopia villosa	Grinding	Oral	Amenorrhoea		
Zanthoxylum leprieurii	Decoction, Grinding, Crushing	Ear/Eye drop, Oral, Body massage	Sickle cell anaemia, Rheumatism, Stomach ulcer	Sickle cell anaemia (326; 327; 328; 329); Tumours (330); Stroke ([39]; 130); Epilepsy and mental disorder (80); Rheumatism (331)	Antioxidant (329)

NB: references cited in Table 3 are listed in Supplementary Information 2 (SI 2) file.

was obtained from either parents or shared-common knowledge in the local communities. It may also be related to the fact that experience in relation to medicinal plant use was similar across most socio-demographic characteristics (Table 1).

Interestingly, ethnobotanical knowledge was similar across the different age groups, suggesting no erosion of information on medicinal plants between the elderly and the young. The greater proportion of men being involved in medicinal plants than women (male:female ratio of 2.38) in this study may be largely because medicinal plants are generally sourced from the natural forest at long distances and hilly areas which are usually difficult for women to access [18]. The predominance of males may also be explained by men generally taking care of non-domestic affairs, the attachment of men to all that is traditional or the men's vigilance for the balance of diseases. Our findings corroborate several ethnobotanical studies conducted in Ghana and elsewhere ([17,18,32]). Our finding that marital status and number of dependants influenced the level of ethnobotanical knowledge may be because a large number of dependants and the loss of a spouse are associated with limited income or access to resources and this may lead them to explore medicinal plants as an additional source of income. For example, we found that most respondents were farmers who practice herbal medicine as an alternative source of livelihood while a few were engaged in the practice and trade of herbal medicinal products on a fulltime basis (Table 1). The age of respondents ranged between 21 and 80 with an average age of 43, which implies that younger members of the study communities dominate the profession. This is consistent with other studies that have noted a shift in demographics in the herbal medicine industry in Ghana, with an increasing trend of the youthful population being involved in the herbal medicine industry or health care [17]. In general, the hypothesis that local knowledge about medicinal plants varies across socio-demographic characteristics was rejected.

4.2. Medicinal tree species and tree parts used

Relative citation frequency is a quantitative measure of the ethnobotanical significance of various plant species [14]. Therefore, the study estimated the relative citation frequency of the tree species reported by respondents used as medicinal plants in the study communities (SI 1). *Azadirachta indica* was the most frequently cited tree species. This was followed by *Alstonia boonei Cocos nucifera*, *Khaya senegalensis*, *Moringa oleifera*, *Ceiba pentandra* and *Citrus aurantiifolia*, *Tetrapleura tetraptera* and *Ficus exasperate*, *Carica papaya*, *Morinda lucida*. This result indicates the diversity of medicinal plants and the rich knowledge of medicinal plants in the study communities. These species are also widely established to possess high pharmacological and ethnobotanical potential ([12,14]). In a study conducted to assess the phytochemical potential of some medicinal plant species Nguta et al. [19] reported that many of these species have active ingredients with medicinal properties which make them effective in the treatment of different kinds of diseases. The authors further argued that these species contain diverse phytochemicals, making them a reliable source for pharmacological activities. Specifically, the authors indicated that *A. indica* contains some methanolic and ethanolic extracts which are effective for treating many bacterial and fungal diseases. The relative citation frequencies recorded in our study are higher than other previous studies in Sudan [12]. The difference in the results may be due to the differences in the traditional medicinal knowledge of our respondents and their exposure to a diverse array of medicinal plants due to the sourcing of medicinal plant materials from protected forest reserves [8].

To assess the sustainability of medicinal plants and the sustainable management of forest products in the study communities, we assessed respondents' knowledge on the plant parts used to treat diseases. The study revealed that the parts used vary from species to species and from disease to disease as different plant parts have different levels of potency of active ingredients. Plant parts reported to be harvested for the herbal remedies include stem bark, leaves, roots, seeds, flowers, and stems (Fig. 2). However, the stem bark was the most used tree part, followed by leaves, roots, seeds, flowers, and stems. Other studies have reported that leaves, roots, and bark are the commonly used tree parts for the preparation of herbal remedies for the treatment of different kinds of diseases ([1,2,7,8,13,23, 316,332]). This may be because these plant parts are readily available, easy to collect, and prepared during the rainy and dry seasons compared to other plant parts ([2,10,18]). According to Appiah et al. [2], the prevalence of photosynthetic activities in leaves makes it the part of the tree with the most bioactive substances and hence its high medicinal properties compared to other parts of the tree. The harvesting of leaves poses minimal, or no threat to the tree as many tree species can recover even with the removal of up to 50 % of the tree leaves ([7,15]). However, harvesting roots, barks and stems for such herbal remedies can be destructive and poses a great threat to the survival of the medicinal tree species and sustainable forest management in general (316,332).

4.3. Family distribution and species use values of medicinal trees

The plant species reported by respondents for treating different diseases were distributed across a diverse range of plant families. The ten most represented families in terms of species numbers were Fabaceae and Anacardiaceae, Sterculiaceae, Rutaceae, Moraceae, Meliaceae and Euphorbiaceae, and Sapindaceae, Rubiaceae, Bignoniaceae, Apocynaceae, and Annonaceae with Fabaceae and Anacardiaceae being the most dominant families (Fig. 4). The dominance of species belonging to the Fabaceae family may be due to their availability in a diverse range of ecosystems due to their speedy regeneration potential, resilient and ability to thrive in extreme weather conditions ([20,333,334]). Other studies have also revealed that species belonging to the family Fabaceae have biosynthetic phytochemicals with potent antioxidant, free radical scavenging, and antilipoperoxidant properties effective for treating bacterial diseases ([4,335]). Other medicinal plant surveys in Ghana, Africa and other parts of the world have reported the dominance of species belonging to the family Fabaceae among plant species used for medicinal purposes ([1,2,7,8,17,23,335]).

Use value measures the relative importance of plant species based on their uses [10]. It also indicates the relative value of medicinal plant species to their users [2]. In recent years of the rapid depletion of traditional medicinal knowledge, information on the use value of species will be critical for the preservation of knowledge on underutilized species as well as increase pharmacological studies on highly used species [12]. Therefore, the study estimated the family and species values of the various medicinal tree species reported in

the study. The most cited families were Meliaceae, Arecaceae, Rubiaceae and Malvaceae while *Azadirachta indica*, *Alstonia boonei*, *Khaya senegalensis*, *Moringa oleifera* and *Cocos nucifera* five top plant species in terms of species use values (Fig. 3). The high use values of these families and species in our study area indicates they are readily available and accessible or it indicates the rich knowledge of the local people on medicinal plants in their communities [10]. Though Appiah et al. [2] reported high use values for the species such as *Alstonia boonei* and *Azadirachta indica* in a similar study in Ghana, the use values recorded in our study were relatively higher. The difference in the use values between our study and theirs may be due to the difference in knowledge, utilization and value placed on these species by the study respondents. Our results support our hypotheses that highly known plant families are the most useful plant families, and that the most useful plants are those with the most useful plant parts (Fig. 5). Taken together, our results support the plant use value hypothesis, which states that the usefulness of a plant for medicinal purposes is a function of its traits ([336,337]). Furthermore, we found that medicinal plants that were collected from more than one source had higher mean RCF and SUV than those collected from a single source (Table 3). Thus, our findings also support the availability hypothesis which proposes that plants are used for medicinal purposes because they are locally more accessible or abundant ([337–339]). Therefore, we propose that an integration of the availability and the plant use value hypotheses may best explain our results. That notwithstanding, further studies should explore the synergy between selection of medicinal plants for their ecological traits and the socio-demographic traits of the local users.

4.4. Mode of preparation and administration of plant medicine

The study revealed variations in the mode of preparations of plant-based remedies used in the treatment of diseases in the study communities with decoction being the most popular mode of preparation (Fig. 6). This is followed by grinding, crushing, infusion, and eating raw (ingestion). However, the choice of preparation mode depends on the plant parts used, the route of administration, and the type and position of the disease it is intended to cure [7]. According to Wodah and Asase [8], these preparation modes are common in traditional communities in most parts of Africa, where traditional medicine is widely utilized. In rationalizing the modes of preparation for the medicinal plants, Muluye and Ayicheh [335] reported that the preparation modes are sometime combined to extract a greater percentage of the active ingredients in the medicinal plants. According to the authors, grinding is preferred for preparation of herbal remedies when the plant parts are in their fresh form. This is followed by decoction i.e., heating of the grinded material in water in a pot to extract phytochemicals from the plant material. However, powdering is the preferred mode of preparation for plant materials that are not readily available or available in dry forms, as it helps to preserve the plant material for a long period of time. Other studies have reported similar modes of preparation as the most preferred in different parts of the world and Africa in particular ([1,2,6,8,10,12,15,18,332]).

Regarding the administration routes, the study revealed that the routes of administration of the remedies also appear to be dependent on the type of disease, part of the body affected by the disease and medicinal plant species used. However, oral administration was predominantly used, followed by body massage, eating, bathing/steam bathing and nasal/ear/eye drop, and inhalation (Fig. 7). Both external and internal routes of administration of traditional remedies are common in traditional medicine practices [8]. According to Demie et al. [18], medicinal remedies are administered orally to treat internal problems while other routes such as body massage, and bathing/steam bathing are largely prescribed for skin and other trauma-related problems that require an external application. However, some skin and related trauma-related issues require remedies that are administered orally. The authors further argued that many of the treatments are administered using solvents such as water and food as they are believed to transport remedies to target organs in the body. This may have contributed to the predominance of oral administration among the administration routes reported in this study. Our results are consistent with other studies which reported on oral and dermal administration as the most frequently used method for herbal remedies in different parts of the world ([1,2,6,7,10,335]). Particularly, Abebe and Chane [15] and Getachew et al. [4] reported oral administration as the most frequently cited mode of administration followed by body massage, smearing, or tying onto the wound and bath.

4.5. Condiments and side effects of medicinal plant medicine

According to Wodah and Asase [8], the preparation of traditional medicines requires the use of different components, including preservatives, flavouring and colouring agents. Therefore, the study sought to identify the condiments used in the preparation of herbal remedies in the study communities. The study revealed that condiments are widely used in the herbal remedies preparations in the study area, with some being plant-based (Ginger) while others are finished products (Alcohol). Muluye and Ayicheh [335] argued that these additives apart from their capacity to extract different phytochemicals from plant materials, also contribute to the improvement of the taste and smell of the herbal mixture for easy consumption and reduce adverse effects such as vomiting and diarrhoea [15]. They have also been an effective antidote against the poisoning effects of some medicinal plants. Other studies have also reported the extensive usage of adjuvants such as water, honey, shea butter, and alcohol in the preparation of herbal medicines ([2,335]). Data on the side effects of the plant medicine also indicated that a greater percentage of the medicinal plants posed no side effects while a few exhibited side effects such as headache, running stomach, dizziness, bitter mouth, frequent urination, sweating, and more complicated forms like kidney failure, low sperm count and liver poisoning. Other studies on medicinal plants have revealed that most herbal remedies have no side effects ([8,27]). The few studies that have reported some side effects have largely linked herbal remedies to adverse effects such as vomiting and diarrhoea [15]. Our results also appear to be consistent with other studies that reported some toxic effects of medicinal plants on some internal organs [340].

4.6. Alternative uses of medicinal tree species

Though medicinal plants are widely used in managing and treating diseases, the study revealed that most medicinal trees are multipurpose and therefore have alternative uses other than medicine. The tree species were largely used for fuel wood, followed by craftwork, food, construction, and fodder (Fig. 8). Having established that these tree species are already under threat due to the harvest of parts such as roots, bark, and even stems for medicinal purposes, these alternative uses will impose significant pressure on those tree species leading to a decline in their population dynamics. Also, the fact that most of the medicinal plants are sourced from forest reserves regardless of the level of restriction, distance and other threats in the forest ecosystem may be motivated by the decline or rarity of these species from off reserves areas within the communities [15]. These in addition to other anthropogenic activities, agricultural expansion, timber exploitation, bushfires and urbanization, pose severe threats to the sustainability of medicinal plant and forest resources management in general ([8,15,316]). Our results are consistent with other studies that have reported alternative uses such as charcoal making, construction, farm tools, household utensils, firewood, fencing, forage, and furniture ([13,15]).

4.7. Sources of medicinal tree materials used in treating diseases

The study revealed that the medicinal tree materials were sourced from different places. Majority of the species were collected from the forest while the remaining were collected from the bush (fallow lands) and farmlands (Fig. 9). The high dependence on the forest for medicinal plants may be because forest reserves due to the strict protection contain the most diverse assemblages of indigenous species which are largely used in the treatment of diseases [20]. It is also believed that plants growing in their natural habitat over a long period have a high concentration of phytochemicals needed treating different kinds of diseases compared to similar species from other sources [18]. This, in addition to the ease of locating the suitable species for the different species, makes it the most reliable source for medicinal plants. Also, farmers who are aware of the medicinal value of some tree species on their farms maintain some of them during farming activities for use in the treatment of family and other community diseases [20]. However, the sustainable supply of medicinal plants from these sources is threatened by the increase in anthropogenic activities due to the rapid growth in the human population and demand for natural resources. According to Giday et al. [316], agricultural practices such as continuous cultivation and limited fallow lands within communities are potential threats to medicinal plants sourced from this location. Furthermore, other anthropogenic activities and alternative uses of medicinal plants such as agricultural expansion, logging, urbanization, firewood production and charcoal making put pressure on medicinal trees with many becoming endangered, threatened, at risk, and even extinct ([7,332]). Many other studies on medicinal plants have corroborated the findings of this study that medicinal plants are primarily sourced from the wild ([2,10,15,17,18,316]).

4.8. Comparison of ethnobotanical and published pharmacological uses of identified medicinal trees

Plants remain the ultimate and most widely used source of medicinal drugs. As such, ethnopharmacological data regarding their therapeutic relevance has become very essential. As indicated in Table 4, the pharmacological use of majority of the identified tree species have been extensively studied. The literature search results revealed that 78 % of the plants have been used in other parts of the world for similar therapeutic purposes ([36,37,45,79–81,252,258,260–262,266,268,269]). This observation supports the finding that people from different places share similar knowledge about the effectiveness of medicinal plants in curing diseases [31]. However, sixteen species (22 %) from comparison with published data are documented for the first time for the treatment of diseases indicated by respondents in the study area. This could be due to the preference of the species by the people in the study area as well as the cultural background of the study communities, as culture is a major indicator to the choice of particular medicinal plants for treating specific ailments ([18,31,114]). It is also important to note that most of the species (30 %) were used to treat multiple range of diseases compared to other parts of the world. This is buttressed by the findings of Rahmatullah et al. [114] that a single plant could be employed in the treatment of multiple diseases. Similarly, there was rich pharmacological data on *C. papaya*, *C. aurantiifolia*, *C. nucifera*, *K. senegalensis*, *M. oleifera*, *M. lucida*, *P. guajava*, *R. vomitoria* and *T. tetraptera*. This finding could be highly attributed to the presence of pharmacologically active compounds like phytochemicals which influence the efficacy and use of these species in other parts of the world ([17,27,41,44,76,96,108,128,136]). *A. indica, C. nucifera, A. boonei, M. oleifera*, and *K. senegalensis* are reported to contain phytochemicals with antimicrobial and antioxidant activities like alkaloids, flavonoids, and tannins ([163,334,335,340,341]). These active ingredients are reported to possess therapeutic effects against human and plant diseases [342] including cancer. The wide range of pharmacological characteristics such as anti-inflammatory, anti-malarial, anti-microbial, anti-bacterial and reproductive boosting potential of the tree species validates their potency in combating a broad spectrum of diseases as well as their high preference by the people in the study area as well as around the globe [343–354].

4.9. Sources of knowledge about medicinal plants

The survey revealed that the respondents acquired knowledge about medicinal plants from different sources. Parental training was the most common source of knowledge for the majority of the respondents (Fig. 9). This was followed by common knowledge in the area, formal training, herbalists, and media, and very few obtained their knowledge through apprenticeship. Many studies have reported that knowledge about medicinal plants is kept in strict secrecy by elderly members of communities and transferred to their trustworthy elderly sons [15]. The dominance of oral transmission among the modes of knowledge transfer is a matter of concern as such means of knowledge transfer have been reported to be characterized by misrepresentation, distortion, incompleteness, or

omission of the original information [332]. That notwithstanding, our results demonstrated a similarity in ethnobotanical knowledge across different ages, gender, religion and educational level, thus, suggesting an effective transfer of indigenous knowledge among individuals of the local communities. Also, many studies in recent years have established that the young generation of these communities who are supposed to be recipients of this knowledge are largely disinterested in this traditional practice due to the influence of modernization, globalization, environmental change, and cultural transmission barriers ([7,12]). Our results showed that assertion may be site specific as the youth in our study area demonstrated similar knowledge, interest, and experience in the use of medicinal plants as the elderly did. However, the cited factors have the potential to contribute significantly to the depletion of indigenous knowledge of medicinal plants in many communities. It is therefore necessary to document this important knowledge especially in Africa where access to medical facilities is limited [20]. These systems of indigenous knowledge transfer have been widely reported in similar studies elsewhere ([1,15,316]). Other studies in Ghana particularly in the northern and southern parts of the country, have revealed that knowledge of medicinal plants is largely transferred orally from one generation to the other ([2,8]).

5. Conclusion

The local communities use diverse tree species (70 species belonging to 34 plant families) to meet their healthcare needs. Thus, species diversity is central to ensuring good health and the general well-being of local communities of all ages. Discussions on providing nature-based solutions to contemporary issues, including diseases, must critically consider preserving of species diversity and indigenous knowledge systems. Respondents who had lost their spouses or had a large number of dependants irrespective of their gender, religion, education and age were more knowledgeable in concerning medicinal tree species, possibly because they relied on medicinal trees for their health care needs and/or sustenance. Thus, innovative policies seeking to enhance traditional knowledge about medicinal plants in the study area could target and involve these groups. The transmission of information about medicinal trees via parents in the communities has been effective, with no erosion of knowledge among the different generations. Despite the fact that males dominated the practice of herbal medicine, both genders possessed similar ethnobotanical knowledge. The most well-represented plant families were Fabaceae, Anacardiaceae, Sterculiaceae, Rutaceae, Moraceae, Meliaceae, and Euphorbiaceae (with 4–5 species each) while the families with the highest use values were Meliaceae, Arecaceae, Rubiaceae and Malvaceae. *Azadirachta indica*, *Alstonia boonei*, *Khaya senegalensis*, *Moringa oleifera* and *Cocos nucifera* were the top five tree species in terms of species use values. Together these taxa are the most valuable for healthcare needs in the communities; thus, they may be targeted for further evaluation of their bioactive constituents and potential development of semisynthetic drugs. From the perspective of indigenous knowledge in the local communities, decoction and oral modes were the best way to prepare and administer herbal remedies. Tree species used for medicinal purposes had alternative uses such as food, fuelwood, fodder, construction and craftwork. In conclusion, our results reveal that the selection of medicinal plants for use are related to the usefulness of their plant parts, botanical family and availability, which supports the plant use value and availability hypotheses. In addition, medicinal tree species serve multiple purposes in the local communities; hence, strategies such as integrating of medicinal trees on farms or backyard gardens may enhance their sustainability and conservation.

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Data availability statement

Data has not been uploaded to publicly available repository because the dataset(s) supporting the conclusions of this article is(are) included within the article (and its supplementary file(s)) referenced in the article. Further information about data will be made available on request.

CRediT authorship contribution statement

Michael Asigbaase: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing, Data curation. **Daniel Adusu:** Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Adisa Ayeley Musah:** Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Linda Anaba:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Collins Ayine Nsor:** Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Simon Abugre:** Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. **Mercy Derkyi:** Formal analysis, Methodology, Supervision, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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