



Agroforestry Dynamics Among Different Landholding Farmers in Vrishabhavathi Basin, Karnataka

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Received: April 22, 2024 Accepted: July 26, 2024

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Citation

Poornima, M. and Nagaraja, B.C. 2024.

Agroforestry dynamics among different landholding farmers in Vrishabhavathi basin, Karnataka. *Annals of Arid Zone*

63(4): 131-140

<https://doi.org/10.56093/aaz.v63i4.150816>

<https://epubs.icar.org.in/index.php/AAZ/article/view/150816>

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Abstract: The agroforestry emerges as effective adaptation strategy to combat climate change and restrict urban expansion in semi-arid regions of India. The present study aims at understanding the spatial distribution of trees and agroforestry characteristics among small, medium and large landholding farmers around Vrishabhavathi river stretch in peri-urban region of Bangalore. A total of 34379 trees and 41 tree species was recorded in 679.2 ha area belonging to 100 farmers. The major proportion of trees (85 %), belonged to commercial plantation crops such as Areca nut and Coconut. The data indicated significant linear correlation between landholding category and tree density, suggesting that increase in number of trees with increase in land size. Analysis on girth class distribution across landholding indicated that concentration of smaller-sized trees in small and medium landholders, suggesting subsistence-oriented agroforestry practices. An intermediate agroforestry is largely practiced in all three landholding categories, where perennial commercial plantation is done along with food and fodder crops. The study provides insight on agroforestry for farmers, urban planners, agriculture and horticulture functionaries to foster sustainable practices in polluted urban fringe.

Key words: Agroforestry, peri-urban, semi-arid, reservoir pollution, different landholding farmers.

Urbanization significantly impacts peri-urban agriculture, presenting a complex interplay of challenges heightened by climate change and water pollution. Limited water resources are a defining characteristic of semi-arid region's agriculture, changes in land use, due to urbanization and water pollution, potentially diminishing the availability of arable land for agriculture at the urban fringes (Seth, 2003; Kisiangani, 2015). Water pollution poses a significant threat to agriculture, leading to detrimental impacts on soil health, crop yields, groundwater quality, and human health (Lu *et al.*, 2015; Mishra *et al.*, 2019). Key contributors to this issue include industrial discharges, agricultural runoff, and improper waste disposal, which introduce harmful pollutants such as heavy metals, pesticides, and fertilizers into water bodies (Akhtar *et al.*, 2021). When these contaminants infiltrate agricultural fields, they can alter soil texture, disrupt nutrient availability, and reduce microbial

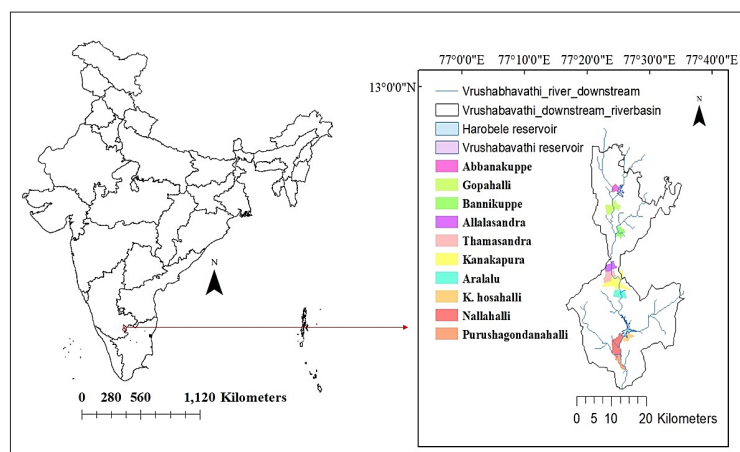


Fig. 1. Study area.

activity. As a result, crops may absorb these pollutants, adversely affecting both their yield and nutritional quality (Lehman *et al.*, 2015; Saha *et al.*, 2017). In particular, the discharge of inadequately treated effluent and sewage into the Vrishabhavathi River poses a serious threat to the traditional agricultural practices in the surrounding peri-urban areas. Amidst these challenges, agroforestry emerges as a resilient adaptation strategy, offering a comprehensive approach to enhance the sustainability and adaptability of peri-urban agriculture practices (Veenhuizen and Halliday, 2019). It is characterized by an intensive integration of forest trees, agricultural and horticultural crop, and shrubs. Agroforestry becomes instrumental in fostering the coexistence of urban development and resilient peri-urban agriculture (FAO, 2012). Agroforestry not only addresses environmental challenges, but also ensures sustained availability of multiple products as direct benefits such as food, vegetables, fruits, fodder, fuel, foliage, medicine and agriculture implement (Dagar and Tewari, 2017).

To gain a deeper understanding of the dynamics of peri-urban agroforestry in semi-arid regions, this study aims to evaluate the tree species present and their spatial distribution in the farm fields along the downstream stretch of the Vrishabhavathi River in the peri-urban area of Bangalore.

Materials and Methods

Study area: In the urban landscape of Bangalore, Vrishabhavathi river serve as one of the major catchment systems as it takes a central route, coursing from city's ridge to peri-

urban lake system. The Byramangala reservoir (Latitude: $12^{\circ}46'3''N$, Longitude: $77^{\circ}25'39''E$), is infamous for accumulating partially treated effluents and sewage from the Vrishabhavathi river's course. This reservoir's water, positioned as a recipient of urban runoff, laden with pollutants, flows through irrigation canals and into downstream Harobele reservoir (Latitude: $12^{\circ}25'23''N$, Longitude: $77^{\circ}26'28''E$) amidst Ramanagara district further contaminating it. These reservoir waters were historically utilized for irrigation through canal network (Ramachandra and Mujumdar, 2009). The canal network in the region was built to sustain the cultivation of major crops such as ragi, maize, pulses, mulberry, coconut, groundnut, fruits, vegetables and flowers often alongside agroforestry practices. Hence, till date farmers are using the canal network laden with polluted water for irrigation purpose because of water scarcity, making the associated agriculture lands highly vulnerable as it accumulates pollutants. The cluster of villages situated around the Byramangala and Harobele reservoir's canal network was selected for the study (Fig. 1). The villages include Abbanaguppe, Gopahalli, Bannikuppe, Allalsandra, Thamasandra, Kanakapura, Aralalu, K. hosahalli, Nallahalli, and Purushagondanahalli village.

A qualitative and quantitative research approach was employed to assess the agroforestry practice in ten-villages coming in command areas of Byramangala and Harobele reservoirs. The focal group discussion was conducted to understand the agrarian crisis and the socio-economic profile of the community. This serves as the foundation to employ a

cluster random sampling for agroforestry survey (Mukhopadhyay, 2008).

The village selection criterion is defined by close proximity to the stream network. Within each village, 10 farmers were selected, resulting in a total of 100 samples drawn from the 10-villages. Farmers were grouped into three classes based on land holding criteria: small <3 ha, medium 3 to 6 ha and large >6.

A total of 100 selected farmers' fields were visited and boundary of each farm were identified. Species identification was accomplished using monographs and field guides (Saldanha, 1984; Kavitha *et al.*, 2012). Then each tree was measured at breast height (GBH) of ≥ 15 cm using measuring tape (Krishnakanth and Nagaraja, 2020; Bekele, 2007; Endale *et al.*, 2016). Simultaneously, a socio-demographic survey was also carried out to gather background information of the farmer and details on tree species introduction, their utilization and end uses.

Total biomass was calculated by adding aboveground biomass (AGB) and belowground biomass (BGB) (MacDicken., 1997; Suryavanshi *et al.*, 2014; Sharma *et al.*, 2021) using the equation given below:

$$AGB = (34.4703 - 8.0671) \times DBH + (0.6589 \times DBH^2)$$

$$BGB = AGB \times (15/100)$$

$$\text{Diameter at breast height (DBH)} = GBH/3.14$$

Generally, for any plant species, 50% of its biomass is its carbon content (IPCC, 2006; Sharma *et al.*, 2021), and carbon dioxide equivalent is calculated using the following equation,

$$\text{Carbon content} = 0.5 \times \text{biomass}$$

$$CO_2 \text{ (eq.)} = (\text{Carbon content} \times 44)/12$$

To quantify and analyze the species diversity, dominance, evenness, similarity index and indicator species, PAST statistical tools (Shannon, 1948; Simpson, 1949; Bray and Curtis, 1957; Pielou, 1966; Hill, 1973; Hammer, 2001) was used. These findings collectively offer insights into biodiversity of agro-ecosystem.

Results and Discussion

A variety of tree species were found in the study area of 10 villages. They could be grouped as (i) Medicinal and multipurpose

trees- *Azadirachta indica* A. Juss. *Ficus religiosa* L., *Phyllanthus emblica* L., *Thespesia populnea* (L.) Sol., *Wrightia tinctoria* R.Br., *Tectona grandis* L.f., (ii) Timber and furniture wood - *Dalbergia sissoo* DC., *Ficus bengalensis* L., *Swietenia macrophylla* King. (iii) Fruit-bearing trees- *Artocarpus heterophyllus* Lam., *Mangifera indica* L., *Psidium guajava* L., *Citrus medica* L., *Citrus maxima* (Burm.) Merr. (iv) Ornamental and shade trees- *Albizia saman* (Jacq.) Merr., *Spathodea campanulata* P. Beauv., *Eucalyptus globulus* Labill., *Albizia lebbbeck* (L.) Benth., *Ficus bengalensis* L. (v) Economic crops- *Areca catechu* L., *Cocos nucifera* L., *Theobroma cacao* L., *Moringa oleifera* Lam. and (vi) Miscellaneous- *Acacia auriculiformis* Benth., *Acacia leucophloea* (Roxb.) Willd., *Acacia nilotica* (L.) Delile., *Albizia odoratissima* (L.f) Benth., *Areca catechu* L., *Cassia fistula* L., *Casuarina equisetifolia* L., *Ficus racemosa* L., *Gliricidia sepium* (Jacq.) Walp., *Grevillea robusta* A. Cunn. ex R.Br., *Limonia acidissima* L., *Madhuca longifolia* var. *longifolia*, *Manilkara zapota* (L.) P. Royen., *Melia dubia* Cav., *Phyllanthus acidus* (L.) Skeels, *Pongamia pinnata* (L.) Pierre. *Prosopis juliflora* (Sw.) DC., *Syzygium cumini* (L.) Skeels, *Tamarindus indica* L.

Socio-demographic overview in selected villages of Vrishabhavathi river basin:

Participants of different age groups were selected for the study, with a notable presence farmers (30%) of 60 years and above. Educational qualifications of the selected farmers were also different with a significant proportion (55%) having completed secondary school while 15% had achieved higher education. About 30% were illiterate. The majority of 62% had medium family size (3 to 6 members), about 28% were nuclear family (<3) and 9% had big family household of >6 members. Agriculture was the predominant occupation contributing to household income. 60% farmers showed a notable participation in intermediate agroforestry followed by commercial agroforestry practice (31%) and subsistence agroforestry practice (9%).

Biomass and carbon stock in selected villages of Vrishabhavathi river basin:

A comprehensive overview of species-specific ecological parameters, offering insights into the basal area, biomass, carbon content and carbon dioxide equivalent per hectare for various tree species are given in Table.1.

Table 1. Density, biomass and carbon content of dominant tree species in selected villages of Vrishabhavathi river basin in Karnataka.

Species	No. of individual	Basal area (m ²)	Total Biomass (t ha ⁻¹)	CO ₂ Eq (t ha ⁻¹)
<i>Melia dubia</i>	1379	2185.7	48.8	89.5
<i>Mangifera indica</i>	994	649.8	14.4	26.4
<i>Tectona grandis</i>	896	1295.2	28.9	53.0
<i>Manilkara zapota</i>	354	368.5	8.2	15.1
<i>Theobroma cacao</i>	300	644.9	14.5	26.5
<i>Swietenia macrophyll</i>	296	512.8	11.5	21.0
<i>Azadirachta indica</i>	184	21.2	0.4	0.8
<i>Grevillea robusta</i>	77	10.6	0.2	0.4
<i>Eucalyptus globulus</i>	63	1.7	0	0.1
<i>Pongamia pinnata</i>	54	3.3	0.1	0.1
Other*	256	96.8	2.1	3.8
Total	4853	5790	129	237

Note: * Other includes 30 tree species. Commercial palm trees such as Arecanut and Coconut are excluded for carbon estimation.

The tree species such as *Melia dubia*, *Mangifera indica*, followed by *Tectona grandis* are dominant tree species in the region, contributing for biomass and carbon storage, with high basal areas. These species, known for their large sizes, not only enhance the structure of agroforestry but also play a crucial role in mitigating climate change through substantial carbon sequestration (Jose and Bardhan, 2012). The high carbon content and biomass of these species underscore their ecological relevance and potential for climate change mitigation (Rodrigues *et al.*, 2023).

Tree species diversity, dominance, evenness and similarity in selected villages of Vrishabhavathi river basin: Among the ten villages surveyed, Abbanaguppe village

exhibited the lowest diversity ($H = 0.073$) and high dominance index ($D = 0.981$), suggesting a limited variety of tree species and implying concentration of a few dominant species respectively (Table. 2). Conversely, Kokkarehosahalli has the highest diversity ($H = 1.092$) and the lowest dominance index ($D = 0.417$), indicating a rich and diverse ecosystem and indicating a more even distribution among species. Other villages fell between these two extremes, highlighting differing degrees of diversity and dominance. Villages with low diversity and high dominance may benefit from initiatives promoting biodiversity, such as afforestation programs and the introduction of native species. (McElwee and Nghi, 2021). Ecosystems with high diversity and low

Table 2. Overall tree diversity, dominance and evenness in selected villages' agro-ecosystem of Vrishabhavathi river basin of Karnataka

Villages	No. of individuals	No. of species	Shannon Diversity index (H)	Simpson Dominance index (D)	Pielou Evenness (E)
Abbanaguppe	1783	9	0.073	0.981	0.120
Allalasandra	2645	15	0.170	0.952	0.079
Gopahalli	3059	15	0.403	0.834	0.100
Aralalu	7678	17	0.419	0.831	0.089
Bannikuppe	2825	12	0.641	0.696	0.158
Thamsandra	504	19	0.764	0.740	0.113
Kanakapura	1574	14	0.911	0.474	0.178
Nallahalli	4027	10	0.999	0.504	0.272
Purushagondanahalli	3657	9	1.013	0.493	0.306
Kokkarehosahalli	6627	13	1.092	0.417	0.229
Total	34379				

dominance, maintain ecological integrity of agroforestry system.

Evenness (E) values provide insights into species distribution within each village. Notably, Nallahalli exhibits the highest evenness ($E = 0.272$), suggesting a relatively balanced distribution among species. Abbanaguppe, with its low evenness ($E = 0.120$), indicates an uneven distribution, likely dominated by a few species. Thamsandra and Kanakapura village show intermediate evenness values, showcasing a moderate balance in species distribution (Table 2). Managing evenness is essential for stability; villages with lower evenness may need interventions to prevent the dominance of specific species (Kindt *et al.*, 2006).

Bray-Curtis similarity index is commonly used in ecological studies to measure the compositional similarity between different sites based on species abundances. The Bray-Curtis index ranges from 0 to 1, where 0 indicates complete similarity, and 1 indicates complete dissimilarity (Clarke *et al.*, 2003). Allalasandra and Abbanaguppe villages exhibited a substantial similarity of 0.80, indicating a strong resemblance in their species compositions. Bannikuppe village demonstrated moderate to high similarities with villages Abbanaguppe (0.77) and Allalasandra (0.86), while Gopahalli village exhibiting comparable values with

Allalasandra (0.91) and Bannikuppe villages (0.80). Purushagondanahalli village, in turn, demonstrated moderate to high similarities with several sites, including Allalasandra (0.78), Bannikuppe (0.82), and Gopahalli (0.73) villages. Contrastingly, Thamsandra village displayed consistently low similarity values with other sites, indicating a distinct ecological composition (Fig. 2).

Land holding and Agroforestry type in selected villages of Vrishabhavathi river basin:

According to socio-economic characteristics, agroforestry is grouped into subsistence, intermediate and commercial. The relationship between small, medium and large land holding with these groups indicates that, the intermediate agroforestry shows broader participation (Fig. 3) with small farmers contributing 57.5%, medium farmers at 69.7% and the large farmers, showing 53.8% participation rate. A noteworthy trend was noticed in commercial agroforestry, where large farmers contributed 46.2% suggesting a strong proclivity for economically motivated agroforestry practices followed by medium and small and marginal farmers.

Land holding and girth class distribution in selected villages of Vrishabhavathi river basin:

Small and medium landholding farmers have 30% and 34% of trees in the girth class of '< 30 cm', respectively. It suggests that small and medium landholders often engage

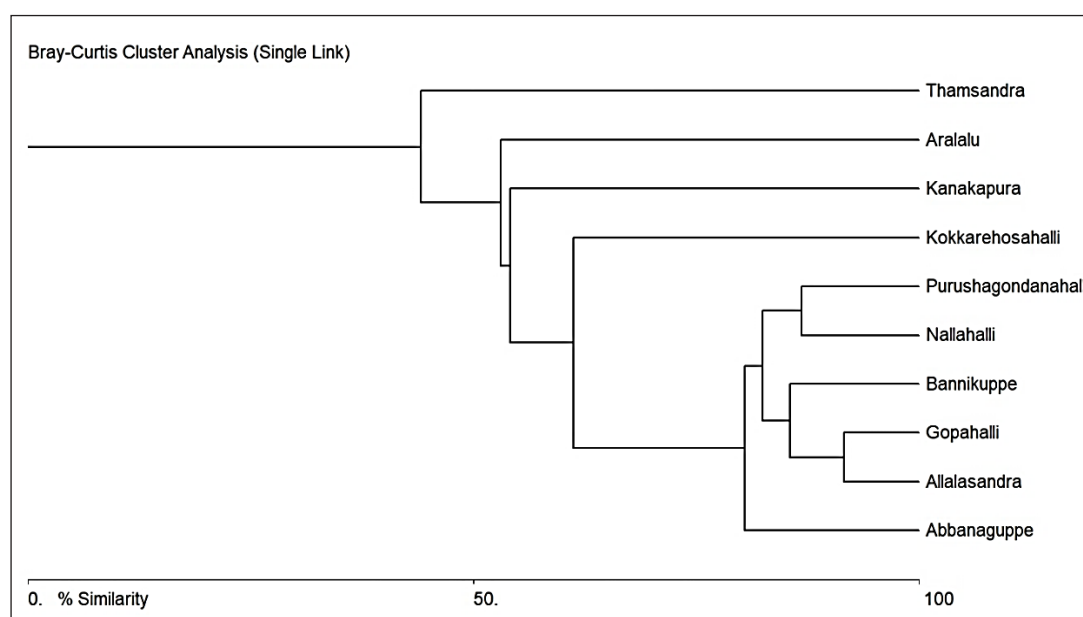


Fig. 2. Bray Curtis's similarity and distance index of tree species among villages selected around irrigation channel network in Vrishabhavathi river basin of Karnataka.

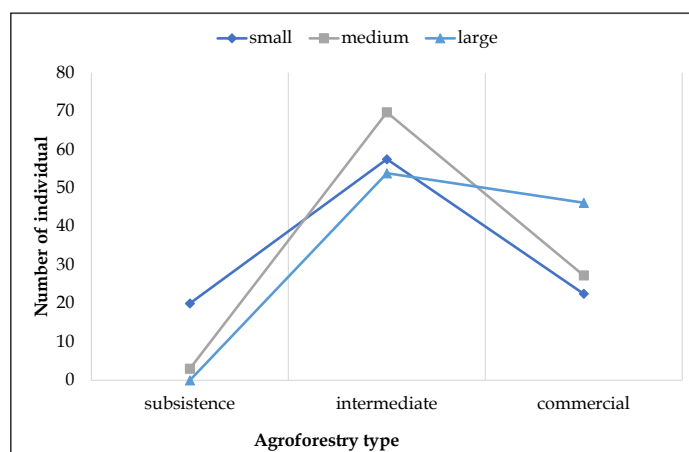


Fig. 3. Correlation between land holding and socio-economic classification of agroforestry in selected villages of Vrishabhavathi river basin of Karnataka.

in agroforestry for subsistence purposes, cultivating a diverse array of smaller-sized tree species to meet local needs and enhance farm resilience (Pande, 2021).

The larger-sized tree species (30-60 cm girth) are predominantly observed in medium and large landholdings, indicating a possible emphasis on commercial or timber-oriented agroforestry practices (Mercer *et al.*, 2014). The declining trend in tree numbers as girth classes exceed 60 cm is anticipated, reflecting the natural growth and maturation of tree species. The maintenance of trees in larger girth classes suggests intentional cultivation aimed at maximizing both economic and ecological benefits.

Spatial distribution of trees among landholding categories in selected villages of Vrishabhavathi river basin: The spatial distribution of trees across different landholding

categories reveals a decreasing trend in species diversity from small to large landholdings. Conversely, the total number of individual trees increases with land size (Fig. 4). This pattern suggests a potential correlation between land size and biodiversity, highlighting the importance of larger landholdings in supporting a greater number of tree individuals while potentially accommodating a broader range of species in the region.

Spatial distribution and indicator species among land use categories in selected villages of Vrishabhavathi river basin: Five land use categories such as bund, boundary, line, block and homestead plantation, within agroforestry systems was identified, each serving specific purposes and providing unique benefits to farmers. Homestead agroforestry, observed in all landholding categories, highlights the integration of trees around living spaces, offering a range of benefits including shade,

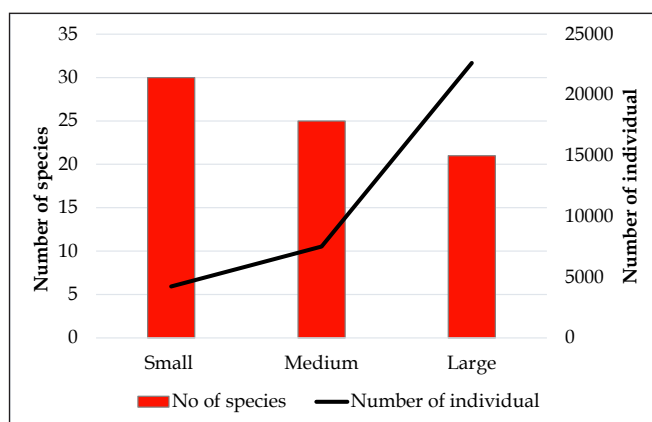


Fig. 4. Spatial distribution of trees among landholding categories in selected villages of Vrishabhavathi river basin in Karnataka.

Table 3. End use of trees in selected villages of Vrishabhavathi river basin in Karnataka.

End usage	No. of individuals	Individuals (%)	Example
Fruit + byproduct	29526	85.88	<i>A. catechu</i> , <i>C. nucifera</i>
Fodder + leaf manure + timber	2587	7.52	<i>M. dubia</i> , <i>T. grandis</i> , <i>S. macrophylla</i>
Fruit + windbreak	994	2.89	<i>M. indica</i>
Fruit	709	2.06	<i>M. zapota</i> , <i>T. coaco</i>
Timber + foliage	308	0.90	<i>A. indica</i> , <i>E. globulus</i> , <i>P. pinnata</i>
Timber + windbreak	118	0.34	<i>A. auriculiformis</i> , <i>G. robusta</i>
Fruit + timber	67	0.19	<i>A. heterophyllus</i> , <i>S. cumini</i>
Timber + fodder + fuelwood	50	0.15	<i>A. lebbeck</i> , <i>A. catechu</i>
Keystone species (worshiping)	20	0.06	<i>F. benghalensis</i> , <i>F. religiosa</i>
Total	34379	100	

food, and aesthetic value (Umrani, 2010; Kumar, 2015). Medium and large landholders are observed to frequently engage in block plantations, often associated with commercial crops such as arecanut and coconut, which offer significant economic benefits (Nair, 2012)

To identify species indicative of specific groups within each agroforestry system,

a correlation analysis for tree species was conducted following the method of Dufrene and Legendre (1997). Among the five land-use types considered in the study, only block and boundary plantations exhibited an Indicator Value Percentage (IndVal%) greater than 30. This highlights the presence of indicator species in both boundary and block plantations (Fig. 6).

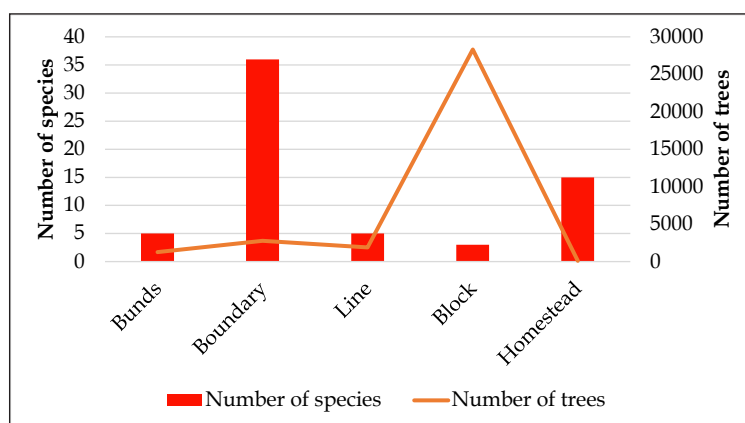
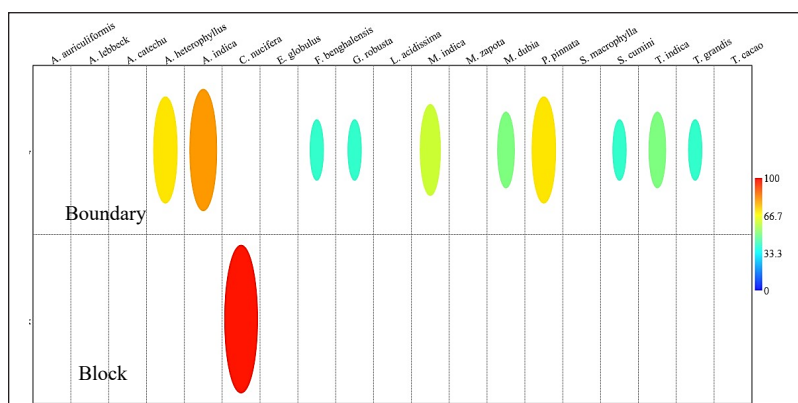


Fig. 5. Spatial distribution of trees across five land use categories in selected villages of Vrishabhavathi river basin in Karnataka.

Fig. 6. Indicator species in boundary and block plantation in selected villages of Vrishabhavathi river basin in Karnataka. (Significant at p -value >0.05)

In block plantation, *Cocos nucifera* emerged as a highly significant indicator species with 97.31 (p-value >0.05). The following species exhibit significant indicator values in boundary plantation: *Azadirachta indica* (80%), *Artocarpus heterophyllus* (70%), *Pongamia pinnata* (70%), *Mangifera indica* (60%) and others with indicator value of 40.

End uses of tree species in selected villages of Vrishabhavathi river basin: The data on tree species offers valuable insights into the potential adoptability of agroforestry practices (Table 3). The diversity of tree species and their varied end uses, such as fodder, fruit production, timber, and cultural significance, aligns with the principles of agroforestry, which integrates trees into agricultural systems for multiple benefits.

The presence of species such as *Cassia fistula*, *Gliricidia sepium*, and *Moringa oleifera* suggested that they provide not only agricultural benefits but also supplementary resources. Furthermore, the dominance of horticultural cash crops such as *A. catechu* and *C. nucifera* underscores the economic potential of integrating fruit-bearing trees into agroforestry, where by-products contribute to the overall agricultural economy.

Tamarindus indica is the predominant tree crop in the region, with its byproducts, such as coir, shells, and seeds, being utilized in agro-based industries (Krishnakanth and Nagaraja, 2020). Additionally, the presence of species like *Acacia nilotica*, *Albizia lebbek*, and *Acacia auriculiformis* highlights their potential to provide timber as well as other benefits, such as fodder and windbreaks.

Moreover, the inclusion of keystone species such as *Ficus benghalensis*, *Ficus racemosa*, and *Ficus religiosa* reflects the cultural and religious dimensions of agroforestry. The acknowledgment of these species in worship practices suggests a harmonious integration of trees into the cultural fabric, further supporting the idea that agroforestry aligns not only with ecological sustainability but also with cultural values.

Agroforestry as adaptation in selected villages of Vrishabhavathi river basin: Considering the socio-demographic characteristics and ecological dynamics in the region, agroforestry emerges as a promising adaptation strategy. The reliance on

agriculture as the primary income source for 98% of households is evident from the study. Among the 10 villages studied, Gopahalli and Kokkarehosahalli exhibit high species richness, whereas Abbanaguppe and Allalasandra show lower diversity. This underscores the need for targeted interventions to enhance biodiversity in specific areas. Tree species such as *Swietenia macrophylla*, *Tectona grandis*, and *Melia dubia*, contribute significantly to biomass and also play a crucial role in carbon sequestration, aligning with global efforts to combat climate change. While all categories participate in subsistence agroforestry, large landholders dominate in commercial agroforestry, showcasing a clear economic motivation. In small landholder's data reveals a highest subsistence agroforestry practice with comparatively high species diversity and low girth class distribution. This indicates that small farmers are more resilient among the three landholding classes.

Conclusion

In the face of escalating urbanization, dwindling water resources, and climatic uncertainties, agroforestry practices in the Arkavati River Basin elucidates the pivotal role of agroforestry in bolstering peri-urban agriculture. The semi-arid, urban fringe of Bangalore city, with its delicate ecological balance, exemplifies the intricate challenges faced by peri-urban agricultural communities. The spatial distribution of tree species within the agroforestry systems emphasizes the significance of diverse land use categories, species diversity and their end use. Carbon sequestration potential of certain tree species, coupled with their diverse end uses, highlights multiple benefits of agroforestry systems, ranging from food security to climate change mitigation. The findings of this study provide valuable insights for policy makers, urban planners, and local communities to foster sustainable agricultural practices in peri-urban region. Agroforestry, when integrated into urban planning, emerges not only as a strategy to combat environmental challenges but also as a means to enhance community resilience and biodiversity conservation. Moving forward, a collaborative effort is essential to promote agroforestry as an integral component of peri-urban ecosystem, ensuring a harmonious coexistence between urban expansion and sustainable agriculture in the region.

References

- Akhtar, N., Syakir Ishak, M.I., Bhawani, S.A. and Umar, K. 2021. Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water* 13(19): 2660. <https://doi.org/10.3390/w13192660>
- Bekele-Tesemma, A. and Tengnäs, B. 2007. Useful trees and shrubs of Ethiopia: identification, propagation, and management for 17 agroclimatic zones (p. 552). Nairobi: RELMA in ICRAF Project, World Agroforestry Centre, Eastern Africa Region. https://blog.trytreats.com/useful-trees-and-shrubs-of-ethiopia-identification-propagation-and_YjozMD02.pdf
- Bray, J.R. and Curtis, J.T. 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* 27(4): 326-349. <https://www.jstor.org/stable/1942268>
- Clarke, K.R., Somerfield, P.J. and Chapman, M.G. 2006. On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray-Curtis coefficient for denuded assemblages. *Journal of Experimental Marine Biology and Ecology* 330(1): 55-80. <https://www.sciencedirect.com/science/article/pii/S002209810500599X>
- Dagar, J.C. and Tewari, V.P. 2017. Agroforestry. Singapore: Springer Singapore. doi, 10, 978-981. <https://link.springer.com/content/pdf/10.1007/978-981-10-7650-3.pdf>
- Dufrene, M. and Legendre, P. 1997. Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecological Monographs* 67:345-366. [https://doi.org/10.1890/0012-9615\(1997\)067\[0345:SAAI\]2.0.CO;2](https://doi.org/10.1890/0012-9615(1997)067[0345:SAAI]2.0.CO;2)
- Endale, Y., Derero, A., Argaw, M., and Muthuri, C. (2017). Farmland tree species diversity and spatial distribution pattern in semi-arid East Shewa, Ethiopia. *Forests, trees and LiveLihoods*, 26(3), 199-214. <https://doi.org/10.1080/14728028.2016.1266971>
- Food and Agriculture Organization of the United Nations (FAO) 2012. Coping with water scarcity: An action framework for agriculture and food security. FAO Water Reports, No. 38. Rome. <https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1395516/>
- Hammer, O. 2001. PAST: paleontological statistics software package for education and data analysis palaeontologia electronica. http://palaeo-electronica.org/2001_1/past/issue1_01.htm Accessed, 1.
- Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecology* 54(2): 427-432. <https://doi.org/10.2307/1934352>
- IPCC 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T.; Tanabe, K., Eds.; Prepared by the National Greenhouse Gas Inventories Programme; IGES: Hayama, Japan, 2006 <https://www.osti.gov/etdeweb/biblio/20880391>
- Jose, S. and Bardhan, S. 2012. Agroforestry for biomass production and carbon sequestration: an overview. *Agroforestry Systems* 86: 105-111. <https://doi.org/10.1007/s10457-012-9573-x>
- Kavitha, A., Deepthi, N., Ganesan, R. and Joseph, G.J. 2012. Common dryland trees of Karnataka: bilingual field guide. *Ashoka Trust for Research in Ecology and the Environment, Bangalore*. <https://archived.atree.org/content/common-dryland-trees-karnataka-bilingual-field-guide>
- Kindt, R., Van Damme, P. and Simons, A.J. 2006. Tree diversity in western Kenya: using profiles to characterise richness and evenness. *Forest Diversity and Management*, 193-210. https://doi.org/10.1007/978-1-4020-5208-8_11
- Krishnakanth, B.N. and Nagaraja, B.C. 2020. Agroforestry as an adaptation to climate variability in semi-arid regions of Karnataka, India. *Annals of Arid Zone* 59(1&2): 29-36. <https://epubs.icar.org.in/index.php/AAZ/article/view/103049>
- Kisiangani, R. 2015. An analysis of land use potential in arid and semi-arid areas: Central location, isiolo county (Doctoral dissertation). <http://hdl.handle.net/11295/95038>
- Kumar, V. 2015. Importance of homegardens agroforestry system in tropics region. *Biodiversity, Conservation and Sustainable Development* (Issues and Approaches), 2: 978-8186772751. https://www.researchgate.net/publication/287996797_Importance_of_Homegardens_Agroforestry_System_in_Tropics_Region
- Lehman, R.M., Cambardella, C.A., Stott, D.E., Acosta-Martinez, V., Manter, D.K., Buyer, J.S. and Karlen, D.L. 2015. Understanding and enhancing soil biological health: the solution for reversing soil degradation. *Sustainability* 7(1): 988-1027. <https://doi.org/10.3390/su7010988>
- Lu, Y., Song, S., Wang, R., Liu, Z., Meng, J., Sweetman, A. J. and Wang, T. 2015. Impacts of soil and water pollution on food safety and health risks in China. *Environment International* 77: 5-15. <https://www.sciencedirect.com/science/article/pii/S0160412015000021>
- MacDicken, K.G. 1997. A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects; Winrock International Institute for Agricultural Development: Washington, DC, USA, 1997. https://www.researchgate.net/profile/Cp-Rahangdale/post/What-are-the-different-methods-for-estimating-biomass-density-of-forest-ecosystem/attachment/5a9b73784cde266d588f09b6/AS%3A600312578584576%401520137080386/download/Winrock+International+%E7%A2%

- B3%E7%9B%91%E6%B5%8B%E6%8C%87%E5%8D%97.pdf
- McElwee, P. and Nghi, T.H. 2021. Assessing the social benefits of tree planting by smallholders in Vietnam: lessons for large-scale reforestation programs. *Ecological Restoration* 39(1-2): 52-63. <http://er.uwpress.org/>
- Mercer, D.E., Frey, G.E. and Cubbage, F.W. 2014. Economics of agroforestry. *Handbook of Forest Resource economics*, 188-209. <https://www.fs.usda.gov/research/treesearch/download/48058.pdf>
- Mishra, S. *et al.* 2019. Heavy metal contamination: An alarming threat to environment and human health. In: *Environmental Biotechnology: For Sustainable Future* (Eds. R. Sobti, N. Arora and R. Kothari), 103-125. Springer, Singapore. https://link.springer.com/chapter/10.1007/978-981-10-7284-0_5 (Full editors name pl.)
- Mukhopadhyay, P. 2008. Theory and methods of survey sampling. India: PHI Learning. <https://www.phindia.com/Books/BookDetail/9788120336766/theory-and-methods-of-survey-sampling-mukhopadhyay>
- Nair, P.K.R. 2012. Climate change mitigation: A low-hanging fruit of agroforestry. *Sustainable Science* 7(1): 109-111. https://doi.org/10.1007/978-94-007-4676-3_7
- Pande, V.C. 2021. Farm-forestry, smallholder farms and policy support-the way ahead. In *Agroforestry-Small Landholder's Tool for Climate Change Resiliency and Mitigation*. London, UK: IntechOpen. <https://www.intechopen.com/chapters/75916>
- Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of theoretical biology*, 13 (1), 131-144. [https://doi.org/10.1016/0022-5193\(66\)90013-0](https://doi.org/10.1016/0022-5193(66)90013-0)
- Ramachandra, T.V. and Mujumdar, P.P. 2009. Urban floods: Case study of Bangalore. *Disaster and Development, Journal of the National Institute of Disaster Management* 3(2):1-98 https://www.researchgate.net/publication/285321898_Urban_floods_case_study_of_Bangalore_disaster_development
- Rodrigues, C.I.D., Brito, L.M. and Nunes, L.J. 2023. Soil carbon sequestration in the context of climate change mitigation: A review. *Soil Systems* 7(3): 64. <https://doi.org/10.3390/soilsystems7030064>
- Saha, J.K., Selladurai, R., Coumar, M.V., Dotaniya, M.L., Kundu, S., Patra, A. K. and Patra, A. K. 2017. Major inorganic pollutants affecting soil and crop quality. *Soil Pollution-an Emerging Threat to Agriculture* 75-104. https://link.springer.com/chapter/10.1007/978-981-10-4274-4_4
- Seth, S.M. 2003. Human impacts and management issues in arid and semi-arid regions. *International Contributions to Hydrogeology* 23(1): 289-341. <https://www.taylorfrancis.com/chapters/edit/10.1201/9780203971307-13/human-impacts-management-issues-arid-semi-arid-regions-arid-semi-arid-regions-%E2%80%94seth>
- Shannon, C.E. 1948. A Mathematical Theory of Communication. *The Bell System Technical Journal*, 27: 379-423. <https://doi.org/10.1002/j.1538-7305.1948.tb01338.x>
- Sharma, R.; Pradhan, L.; Kumari, M.; Bhattacharya, P. 2021. Assessment of Carbon Sequestration Potential of Tree Species in Amity University Campus Noida. *Environmental Sciences Proceedings* 3(1): 52. doi:10.3390/IECF2020-08075
- Simpson, E.H. 1949. Measurement of diversity. *Nature*, 163, 688. doi:10.1038/163688a0
- Saldanha, C.J. 1984. *Flora of Karnataka*. Oxford and IBH Publishing Co., New Delhi, Vol. 1, 316 pp. https://wgbis.ces.iisc.ac.in/biodiversity/sahyadri_enews/newsletter/issue41/article1/herbarium.pdf
- Suryavanshi, M.N., Patel, A.R., Kale, T.S. and Patil, P.R. 2014. Carbon Sequestration Potential of tree Species in the Environment of North Maharashtra University Campus, Jalgaon (MS) India. *Bioscience Discovery* 5: 175-179. <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=c93d36ae24728140c6976662dfd453590b1eac07>
- Umrani, R. 2010. Agroforestry systems and practices. https://library.uniteddiversity.coop/Permaculture/Agroforestry/Agroforestry_systems_and_practices.pdf