Project Report

Nature Positive Solutions for Shifting Agrifood Systems to More Resilient and Sustainable Pathways

(Work Package 3: Restore)

ICAR-National Institute of Abiotic Stress Management

Malegaon (kh), Baramati (Maharashtra)-413115

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Abstract

The project "Nature Positive Solutions for Shifting Agrifood Systems to More Resilient and Sustainable Pathways (Work Package 3: Restore)" focuses on the development of agroforestry models designed to restore degraded lands in the Akole cluster of Maharashtra, with an emphasis on enhancing both nutritional and environmental security. The project addresses several challenges, including soil erosion, fodder scarcity, and reduced tree cover. Agroforestry systems such as block plantations, silvipasture, and integrated farming were implemented to restore these degraded lands. The collaboration with BAIF, Pune along with CGIAR partners The Alliance Bioversity International-CIAT and International Water Management Institute, carried out this study with focus on the impact of restoration interventions on biodiversity, soil health, and carbon sequestration.

A micro-watershed of about 63 hectare was identified in Chicondi village to implement technological interventions. The activities carried out under this project include the successful establishment of three agroforestry models—Fodder, Wadi, and Bamboo—on farmers' fields in Chichondi Village. Species like Mango and Bamboo were identified as priority species for plantation, with fodder scarcity being the most critical issue, as indicated by the constraints ranking. The Wadi system, dominated by Mango and Teak, played a key role in addressing both nutritional needs and environmental security. These systems also contributed significantly to biomass, carbon sequestration, and oxygen production.

A comprehensive biodiversity assessment revealed significant variation in species richness and diversity across different land-use systems. The Bamboo system (New) exhibited the highest biodiversity, with a Shannon-Wiener Index of 3.7225 and species richness of 77, while the Agriculture Fallow system had the lowest biodiversity (Shannon-Wiener Index = 2.6469, Species Richness = 19). These findings underscore the importance of habitat-specific conservation strategies to maintain ecosystem health and support biodiversity.

Soil properties showed variations in soil parameters, including pH, electrical conductivity, organic carbon content, nitrogen, phosphorus, and potassium levels across the systems. Soil pH ranged from 5.09 in the Wadi Control system to 6.51 in the Forest system, while organic carbon content varied from 0.55% in the Wadi Control system to 1.90% in the Forest system. These variations highlight the significant role of different agroforestry systems in improving soil health.

Carbon sequestration studies showed that forest systems had the highest carbon stock at 112.9 Mg/ha, followed by agricultural fallow systems at 94.61 Mg/ha and Wadi systems at 75.34 Mg/ha. The Wadi control system, lacking tree cover, had the lowest carbon stock at 46.01 Mg/ha. Wadi agroforestry systems, dominated by Mango and Teak, significantly contributed to carbon sequestration, with 16.60 Mg/ha of carbon stock and 4.32 Mg/ha of CO_2 sequestration. These systems also produced 20.91 Mg/ha of oxygen, with Mango contributing 9.01 Mg/ha and Teak 8.06 Mg/ha.

These findings highlight the key role of Wadi (Old) systems in restoring degraded lands, increasing tree cover, and improving carbon sequestration. Therefore, development of Agroforestry systems is vital in restoring ecosystems, boosting biodiversity, and mitigating climate change, while also providing sustainable income opportunities for local communities, ensuring long-term environmental sustainability and resilience.

1. Project Background

Degradation of land is a very vital question to be addressed in present times and needs immediate attention for restoration. The degradation is largely caused due to both natural and anthropogenic activities making the land to become unproductive, fundamentally affecting crop productivity, biological diversity, hydrological cycles, nutrient transformation, groundwater quality, and overall socioeconomics of the region concerned. In India, 29.3% of the geographical area has undergone land degradation, with maximum contribution from water erosion, acidification, wind erosion, desertification, salinization, and mining (ISRO 2018). At the landscape scale, land degradation can also lead to a loss of biodiversity and cause negative microclimatic changes, thus facilitating desertification. Degradation causes serious consequences by exacerbating climate change, increasing greenhouse gas emissions, affecting local livelihood by reducing water, food & nutritional security. The proper management of natural resources through planting trees helps in maintaining an ecological balance of agroecosystems (Bremer and Farley 2010). Degraded lands in India are becoming a part of the solution to achieve the targets of the Paris Agreement of 2015, 14th CoP of United Nations Conventions to Combat Desertification 2021, and more recently CoP-26 at Glasgow to enhance sequestering of carbon of 1 billion to 2.3 billion carbon dioxide equivalents by 2030. As of today, 26 million hectares of degraded land can be rehabilitated through vegetation means to sequester carbon and enhance ecosystem services. Under such a situation, agroforestry systems (AFS) are becoming an established approach to integrated land management, not only for renewable resource production but also for climate change mitigation and land reclamation.

In view of the above mentioned, the following key points have been identified based on a field visit and scoping study in the Akole cluster of Maharashtra:

- Felling of trees from field boundaries, forests and common lands has drastically reduced tree cover leading to landslide, high erosion of agricultural field and field bunds during heavy rainfall.
- Scarcity of green fodder is primely reported by many of the farmers. After December, the availability of green fodder as well as dry fodder is a big constraint. Farmers have shifted towards, goat farming as income generating enterprise.
- Wild animals like monkeys, peacocks, and wild pigs cause a huge menace to the agricultural field and forced farmers to abandon traditional groundnut and other cash crops cultivation.

- For rice cultivation, forest is cleared to create small fields and many trees are lopped and brunt to make rice nurseries (rabbing). The reduced tree density increases the chances of soil erosion in the fields.
- Local people depend on forests for energy (fuel wood) and nutrition. Except for summer season, fruit availability is poor.

Unavailability of fodder

Absence of tree cover

Fuelwood dependence on forest

Illicit felling

Mono cropping

Soil erosion

Based on these challenges, there was an urgent need to develop a strategy to rehabilitate the landscape to reduce soil erosion, enhance tree cover, round the year green fodder availability, energy and nutritional security of farmers and sustainable livelihoods. Agroforestry models such as block plantations, bund plantations, silvipasture systems, homestead gardens, fruit systems and integrated farming systems seem to be a viable solution to address sustainable income of local communities while also restoring degraded lands, soil and local biodiversity. The research project on “Development of agroforestry models for restoration of degraded lands to address nutritional and environmental security” under Work package 3: Nature+ explores a cost-efficiency model for community land restoration aiming to harnessing the potential of agroforestry to enhance the sustainability and resilience of degraded landscapes

The activities conducted under Nature-Positive Solutions for Shifting Agri-Food Systems to More Resilient & Sustainable Pathways in Work Package 3 were carried out with the support of the BAIF, Pune team. These activities included farmer selection, field biodiversity surveys, Wadi assessments, and soil sampling. Based on the periodical review, following activities were shortlisted to be carried out during the project period on priority basis. Activities included:

i. Development of agroforestry models for livelihood and environmental security
ii. Assessment of biodiversity in the study site
iii. Quantification of impact of various land-use systems on biomass, soil health and carbon sequestration
iv. Carbon sequestration of study pre-established *Wadi*

2. Study Area Description

Chichondi village is located in Akole Tehsil of Ahmednagar District, Maharashtra, at coordinates 19°34'52.92"N and 73°45'13.32"E. The village lies in close proximity to Kalsubai Peak (1,646 meters), the highest point in Maharashtra, and the Bhandardara region, known for its scenic landscapes, waterfalls, and lakes (Fig 1). A total of 63 hectares of micro-watershed in Chichondi village were selected for implementing various nature-positive technological interventions. This geographical setting, being part of the Western Ghats, significantly influences the area's climate, biodiversity, and agricultural practices. The region receives moderate to high rainfall, ranging from 1,200 to 2000 mm annually, with temperatures varying between 8°C in winter and 38°C in summer. The fertile soils and favorable agro-climatic conditions support a mix of agriculture, horticulture, and agroforestry, with *Wadi*[1] systems being a prominent feature. The area's topography is characterized by undulating hills, forest patches, and riparian zones, offering a rich biodiversity that includes both endemic flora and fauna. Water resources are augmented by seasonal streams, natural springs, and reservoirs, making it an ideal location for sustainable development initiatives and ecological research. The proximity to Kalsubai and Bhandardara also creates opportunities for eco-tourism and conservation-focused projects.

[1] *Wadi* programme is an integrated farming systems approach which includes horticulture and forestry tree species and crop diversification in the farming system implemented by BAIF. See https://baif.org.in/what-we-do/Agri-horti-forestry/ for additional details

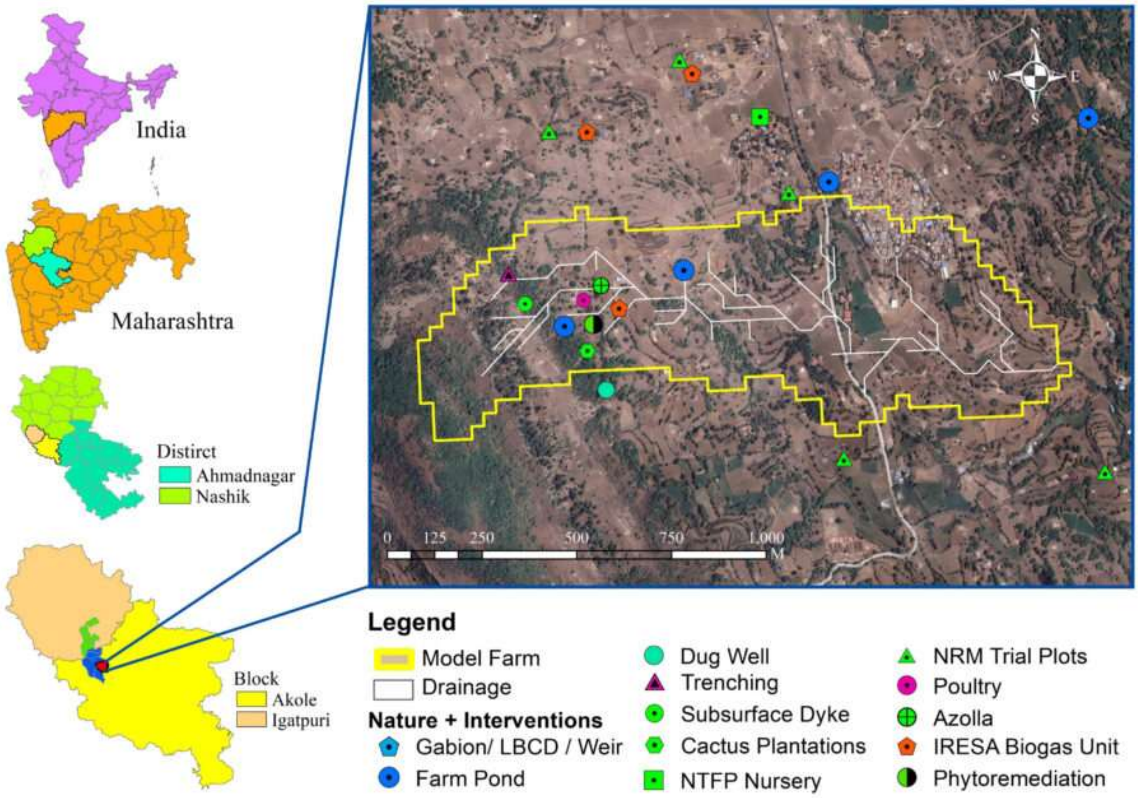

Figure 1: Pilot NPS project site covers a 63-hectare micro-watershed in Chichondi Village of Ahmednagar district, Maharashtra

3. Activity 1: Development of agroforestry models for livelihood and environmental security

In the project, three agroforestry models were selected based on the need and discussion with the project partners. The project area is hilly tract of the western ghat having undulating land topography, valley area and high rainfall and farmers willingness, following which three models were implemented in the project site. A survey was carried out to understand the farmers constraint and preference for adoption of various trees (Plate 1). The constraint ranking and preferential rankling (Matrix) were considered as base for selection of models and species compositions which is explained in detail below.

Plate 1: Survey and interaction with the farmers in study area

3.1. Constraints ranking in study site

The constraints faced by the system were ranked and analyzed based on their impact percentages. The most critical issue was the scarcity of fodder availability, which affected 26.64% of respondents and significantly impacted livestock health and productivity (Fig. 2). The practice of monocropping paddy followed closely, reported by 15.88% of respondents, leading to reduced soil fertility and increased pest problems. The extinction of traditional knowledge and landraces was another significant concern, noted by 13.25% of respondents, as it threatened agricultural diversity. Wildlife conflicts affected 10.6% of respondents, resulting in crop damage and economic losses. Illicit tree felling, reported by 4.99% of respondents, contributed to deforestation and environmental degradation. Landslides and soil erosion, though affecting only 0.21% of respondents, remained important concerns due to their potential for long-term soil damage. Finally, the shift in nutrition and dietary patterns was not perceived as a major issue, with no respondents identifying it as a concern. This prioritization helped focus efforts on addressing the most pressing challenges while monitoring less critical ones.

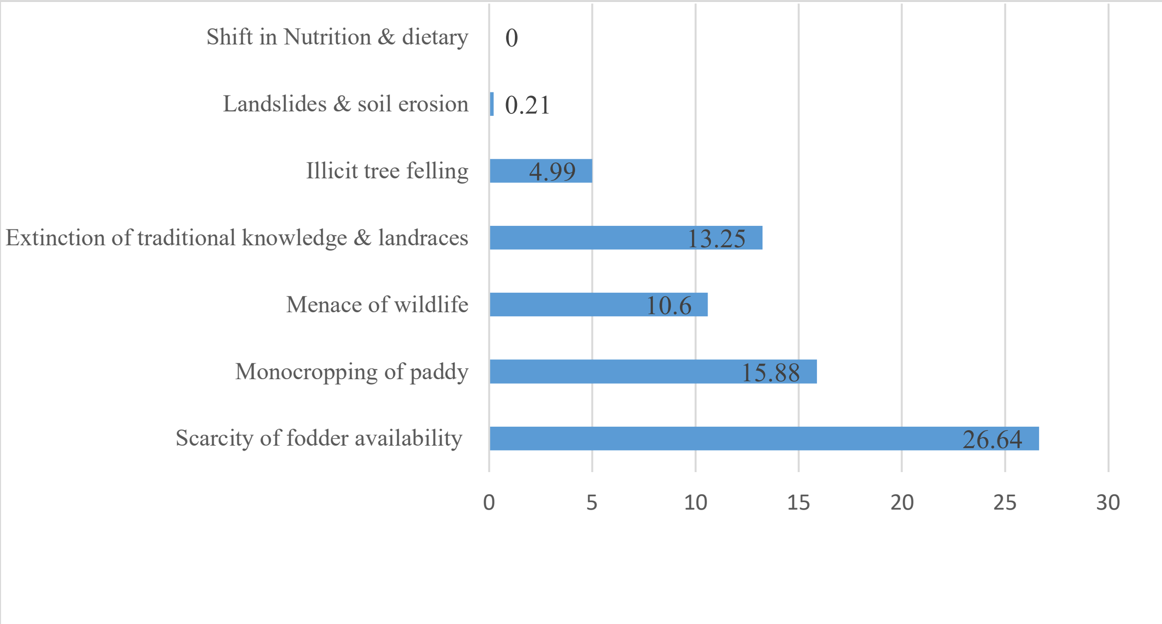

Figure 2: Constraint ranking of problem faced by the farmers in study area

3.2. Matrix ranking

Matrix ranking was used as a participatory tool to evaluate options based on parameters such as market demand, growth rate, maintenance, yield, and resilience. A consistent scoring system (e.g., 1 to 10) ensured uniformity, while stakeholder involvement captured diverse perspectives. Critical parameters were weighted for relevance, and total scores were calculated to compare alternatives and analyze trends effectively. The matrix ranking results presented in Table 1.

Table 1: Ranking of selected tree species for plantation

Parameter	**Kesar Mango**	**Jambhul**	**Teak**	**Jackfruit**	**Bamboo**	**Karavand**
Market Demand	97	77	67	56	75	29
Growth Rate	87	76	47	56	85	35
Maintenance	87	76	42	57	80	36
Yield	97	77	58	58	82	31
Resilience	87	83	57	59	83	35
Total Score	455	389	271	286	405	166

The preference percentages for the evaluated species indicated that Mango (*Mangifera indica*) had the highest preference at 91%, followed by Bamboo (*Dendrocalamus stocksii*) at 81%. Jambhul (*Syzygium cumini*) received a moderate preference of 77.8%, while Jackfruit (*Artocarpus heterophyllus*) and Teak (*Tectona grandis*) had lower preferences at 57.2% and 54.2%, respectively (Fig 3). Karavand (*Carissa carandas*) was the least preferred species, with a preference of only 33.2%. Overall, Kesar Mango and Bamboo were identified as priority species, while diversification efforts could have included Jambhul and Jackfruit. Teak and Karavand appeared to require targeted interventions to enhance their appeal and viability.

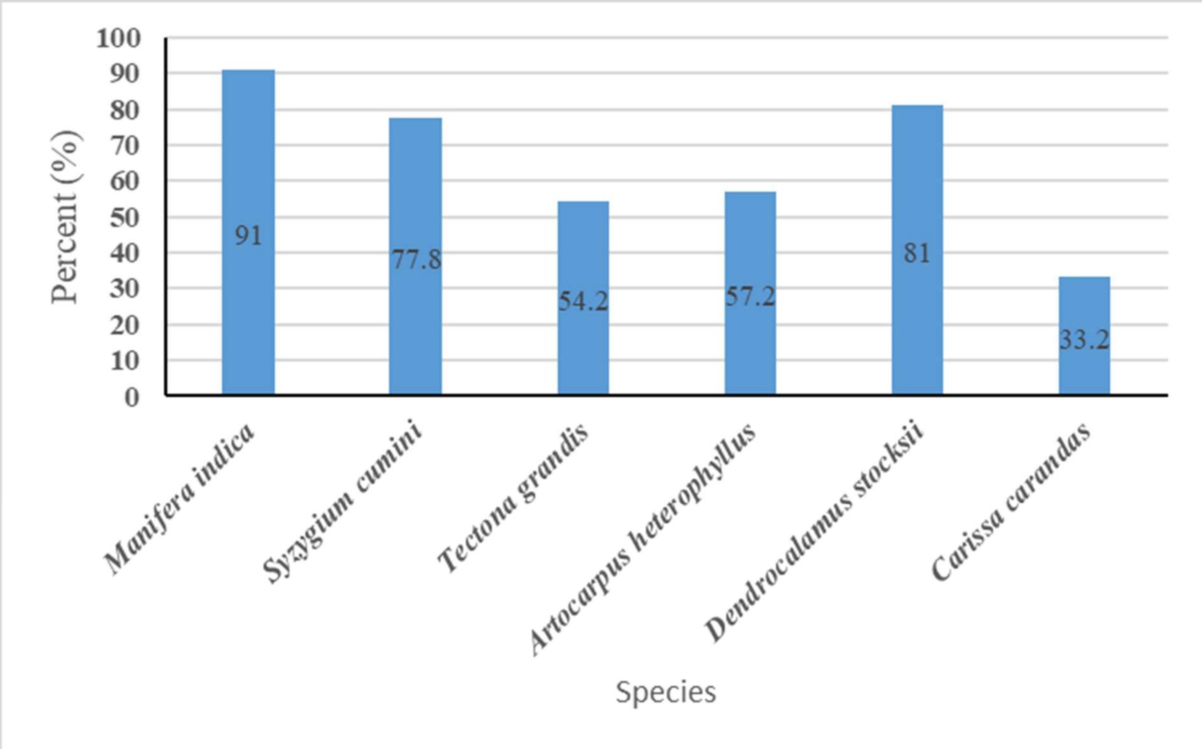

Figure 3: Preferential ranking of woody species in study site

3.3. Agroforestry models

Based on the survey, interactions, scoping study, and expert meetings, three models were optimized: 1) Fodder, 2) *Wadi*, and 3) Bamboo. These models were selected for implementation on pilot farmers' fields. The local staff and NIASM team identified suitable farmers for the implementation in Chindondi Village. The following sections present the selected models and the results of their implementation.

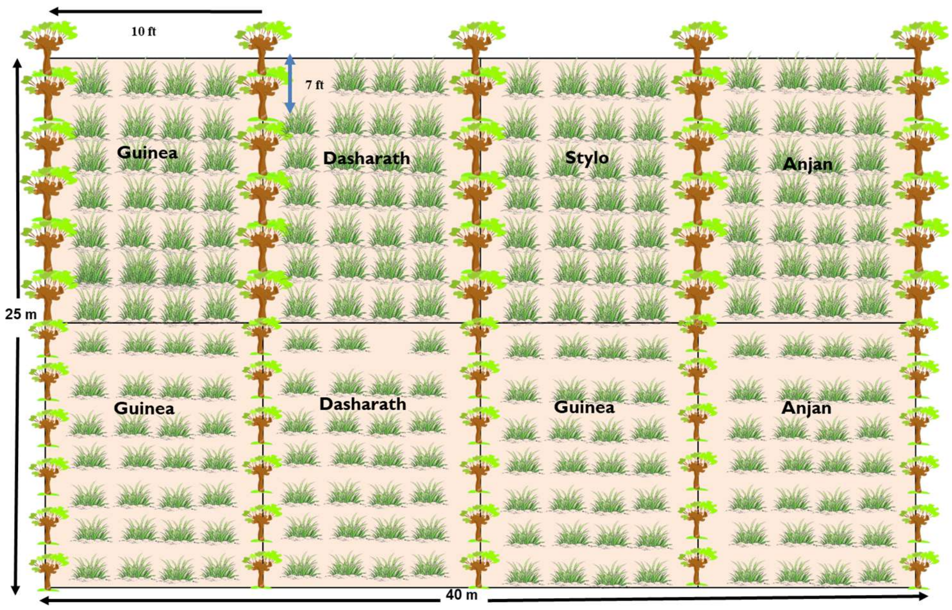

Figure 4: Silvipasture model

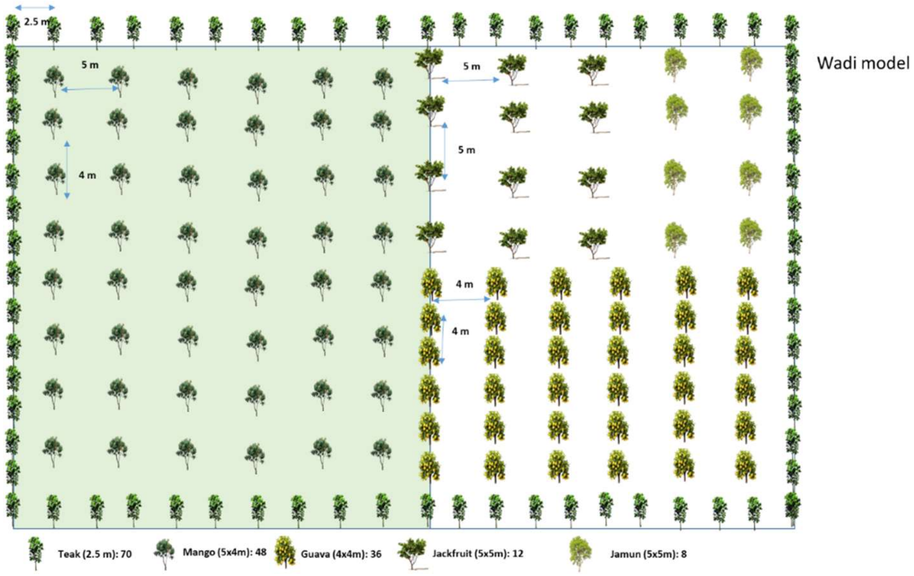

Figure 5: BAIF Wadi Model

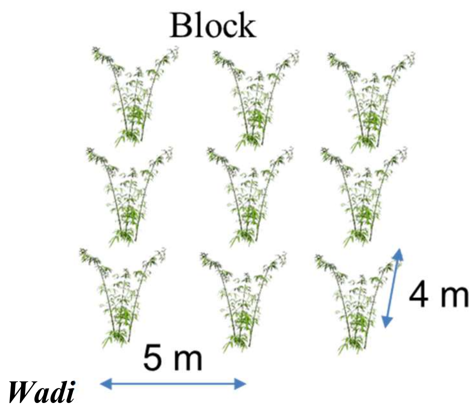

Figure 6: Bamboo in block plantation

In July 2024, preparatory activities were undertaken on the fields of selected farmers in the Chichondi micro-watershed. The site layout was finalized, and pits were carefully dug to accommodate the planned interventions. Planting materials, including seeds of grasses, fodder tree seeds, bamboo seedlings, and clonal plants of fruit and teak, were sourced from reputable suppliers to ensure quality. These materials were then distributed to the farmers for implementation.

Three models were planned for execution: the *Wadi* Model, the Bamboo Model, and the Fodder Model (Plate 2). These models were successfully established on eight, seven, and five farmers' fields, respectively. The work was completed in August 2024. However, due to heavy and persistent rainfall, the Silvipasture Model could not be implemented as planned. Despite this setback, the successful establishment of the other two models marks a significant step forward in promoting sustainable agricultural and agroforestry practices in the region.

Plate 2: View of planting of seedlings under NPS Project

4. Activity 2: Assessment of biodiversity

4.1. Introduction

Biodiversity is a key indicator of ecosystem health, supporting pollination, carbon sequestration, soil fertility, water regulation, and climate resilience. Flora, including herbs, shrubs, and trees, plays a vital role in maintaining ecological balance. Understanding floral biodiversity across land-use systems is essential for evaluating human impacts on ecosystems and species conservation. In India, conserving 70% of genetic diversity in crops and socio-economically important plants is challenging. Integrating community-conserved biodiversity into agricultural landscapes and prioritizing on-farm and in-situ conservation in forests and protected areas is critical. The alarming loss of biodiversity, particularly threatened tree species, calls for urgent action as climate change could result in the disappearance of 10% of India's tree species. The Deccan Plateau, a biodiversity hotspot, faces severe exploitation, leading to a loss of genetic resources and ecological balance.

This study aims to assess floral biodiversity in bamboo planting fields, *Wadi* fields, forests, and fallow lands using quadrat sampling. Biodiversity indices, including the Shannon-Weiner Index, Simpson's Index, and Margalef Index, will quantify species richness, evenness, and diversity, providing insights into ecosystem health and biodiversity status.

4.2. Methodology

Sampling Design:

The quadrat method was employed to assess species biodiversity across different land-use types. The study utilized quadrats of specific dimensions to suit varying vegetation structures:

Herbaceous plants- were sampled using 1x1 m quadrats in newly established field of Bamboo and Wadi systems, as due to absence of shrubs and woody trees. Woody shrubs and trees in Forest areas, wadi and agricultural fallow lands**-** were sampled with 10x10 m quadrats to account for both herbaceous plants and trees. The details of the total number of quadrats and size of quadrats are mentioned below.

The sampling effort included:

- **Bamboo planting fields**: 30 quadrats (1x1m each).
- ***Wadi* fields (Newly)**: 30 quadrats (1x1m each).
- **Forest areas**: 5 quadrats (10 x10 m each).
- **Agricultural fallow areas**: 10 quadrats (10x10 m each).
- **Wadi (Pre**-established 10 quadrats (10 x10 m each), 10 for herbs ((1x1m each).

Data Collection

Within each quadrat, data on herbaceous and tree species were recorded systematically. For herbaceous species, identification was conducted using local names provided by a local resident, Google Lens, and by sharing photos with an expert for species confirmation.. local knowledge, followed by counting the number of individuals per species and recording their abundance. For tree species, identification and counts were performed, along with measurements of height and diameter at Breast Height (DBH). This detailed data collection approach ensured a comprehensive assessment of floral biodiversity within the study area.

Biodiversity Indices:

a. Shannon-Weiner Diversity Index (H')

The Shannon-Weiner Index measures the diversity of a community, accounting for both abundance and evenness of species.

$$H' = \sum_{i=1}^{s} Pi.\ln(pi)^2$$

S: Total number of species.

Pi: Proportion of individuals of one species compared to the total number of individuals.

b. Simpson's Index of Diversity (1-D)

The Simpson's Index measures the probability that two individuals randomly selected from a sample belong to different species.

$$D = \sum_{i=1}^{s} Pi^2$$

The diversity is expressed as:

$$1 - D$$

S: Total number of species.

Pi: Proportion of individuals of one species compared to the total number of individuals.

c. Margalef's Richness Index (Dmg)

Margalef's Index assesses species richness relative to the total number of individuals in the community.

$$Dmg = \frac{S-1}{In(N)}$$

S: Total number of species.

N: Total number of individuals in the sample.

d. Species Evenness (E)

Species Evenness indicates how evenly individuals are distributed across the species in a community.

$$E = \frac{H'}{In(s)}$$

H′: Shannon-Weiner Diversity Index.

S: Total number of species.

e. Species Richness (S)

Species Richness is simply the count of species in a given area or sample.

$$S = Total\ number\ of\ species$$

4.3. Results

The biodiversity assessment across five land-use systems, including *Wadi* (Pre-established), *Wadi* (Newly established), Bamboo (Herb), Agriculture Fallow (Tree, Shrub), and Forest (Tree, Shrub), reveals substantial variations in species diversity, richness, and distribution, reflecting the ecological uniqueness of each system (Table 2). The major herbs, shrub and tree has been documented and presented (Plate 3, 4, 5).

Table 2: Species distribution in different land use systems

Land-uses	Species
***Wadi* Systems (newly established)**	*Cynodon dactylon, Aemella radicans, Ageratum conyzoides, Alternanthera sessilis, Alternanthera ficoidea, Alysicarpus monilifer, Ammannia coccinea, Asystasia gangetica, Axonopus compressus, Basella alba, Bidens tenuisecta, Blumea lacera, Brachiaria umbellata, Brachiaria nana, Brachiaria reptens, Celosia argentea, Cenchrus ciliaris, Commelina diffusa, Cyathula sp., Cynodon dactylon, Desmodium canescens, Desmodium triflorum, Dichanthelium malawan, Digera muricata, Digitaria sanguinalis, Echinochloa colona, Eclipta prostrata, Eleusine indica, Glycine max, Helianthus annuus, Heliotropium indicum, Herbaria logfia, Leersia virginica, Lippia dulcis, Macroptilium lathyroides, Murdannia nudiflora, Murdannia spirata, Panicum brevifolium, Phanthera mollis, Portulaca oleracea, Rhynchosia minima, Rorippa dubia, Saccharum spontaneum, Scopolia japonica, Alternanthera sessilis, Setaria barbata, Solanum stipuloideum, Sphenoclea zeylanica, Synedrella nodiflora, Taraxacum officinale, Thymelaea passerina, Urena lobata, Veronica opaca, and Chenopodium album*
Bamboo System	*Achyranthes japonica, Aerva lanata, Ageratum coayzoides, Alternanthera sessilis, Axonopus compressus, Baccharis anomala, Bidens bipinnata, Boehmeria nivea, Brachiaria reptans, Brillantaisia owariensis, Calopogonium mucunoides, Chromolaena odorata, Commelina africana, Commelina benghalensis, Commelina communis, Commelina diffusa, Commelina ensifolia, Common teasel, Crotalaria trichotoma, Crotalaria triquetra, Cyngoglossum zeylanicum, Desmodium triflorum, Dichanthelium clandentium, Digitalis purpurea, Digitaria ciliaris, Drymaria cordata,*

	Echinochloa colonum, Ehrharta erecta, Eleusine indica, Emilia sonchifolia, Epipactis myelleri, Eragrostis cillanensis, Eragrostis superba, Eragrostis cilianensis, Fuirena umbellata, Hemidesmus indicus, Hippocrepis comosa, Hyssopus officinalis, Imperata cylindrica. Indigofera prostrata, Indigofera trifoliata, Justicia procumbens, Lamarckia aurea, Leersia oryzoides, Leonotis nepetifolia, Leucas aspera, Liatris compacta, Linum hirsutum, Mentha canadensis, Mucuna pruriens, Oplismenus undulatifolius, Panicum capillare, Panicum virgatum, Paspalum conjugatum, Pentanema germanicum, Pentanema germaniam, Phalaris minor, Phaseolus vulgaris, Phyllanthus maderaspatensis.Phyllanthus narayanswamii, Pimpinella saxifraga, Plectranthus amboiniens, Poa annua, Rhynchosia malacophylla, Rhynchosia viscoba, Rotheca myricoides, Rottboellia cochinchinensis, Salvia nemorosa, Salvia uliginosa, Senecio glaucus, Setaria faberi, Setaria italica, Sgeratum conyzoides, Sonchus oleraceus, Stachytarpheta mutabilis, Tragoa involucrata, Triumfetta rhomboidea.
Forest-system	**Herb:** *Agave americana*, *Justica adhatoda*, *Thespesia lampas*, and *Tragia benthamii* ***Shrub****: Woodfordia fruticosa*, *Carissa carandas*, *Lantana camara*, and *Leea indica* ***Trees:*** *Syzygium aqueum*, *Acacia auriculiformis*, *Terminalia elliptica*, *Pterocarpus marsupium*, Bamboo, *Banisteriopsis muricata*, *Cassia fistula*, *Terminalia chebula*, *Syzygium cumini*, *Bauhinia variegata*, *Bombax ceiba*, *Eucalyptus globulus*, *Vitex negundo*, *Butea monosperma*, *Maranthes corymbosa*, and *Terminalia paniculata*
Ag-fallow systems	***Herbs:*** *Agave americana, Musa spp., Persicaria glabra, Melanthera biflora, Calotropis gigantea.* ***Shrubs:*** *Leea macrophylla, Carissa carandas, Lantana camara, Sambucus nigra L., Xylosma hawaiensis.* ***Trees:*** *Terminalia elliptica, Syzygium cumini, Meyna laxiflora, Acacia auriculiformis, Terminalia chebula, Artocarpus heterophyllus, Mangifera indica, Eucalyptus globulus, Moringa oleifera*
Wadi **(Pre-establsihed)**	***Herbs:*** *Agave americana* (Sisal fibre), *Piper nigrum* (Black Pepper), *Hylocereus undatus* (Dragon Fruit Cactus), *Musa spp.* (Banana), *Cinnamomum verum* (Cinnamon), *Curcuma longa* (Turmeric), *Trigonella foenum-graecum* (Fenugreek), *Spinacia oleracea* (Spinach), *Colocasia esculenta* (Taro/Colocasia), *Solanum melongena* (Eggplant/Brinjal), *Cucumis sativus* (Cucumber), *Oryza sativa* (Rice), *Eleusine coracana* (Finger Millet/Ragi), *Triticum aestivum* (Wheat), and *Zea mays* (Maize/Corn). ***Shrubs*** *Psidium guajava* (Guava), *Carica papaya* (Papaya), *Punica granatum* (Pomegranate), *Ziziphus mauriti*ana (Indian Jujube), *Eugenia uniflora* (Surinam Cherry), *Citrus spp.* (Lemons, Oranges, etc.), and *Murraya koenigii* (Curry Leaf), *Dendrocalamus strictus* (Male Bamboo) ***Trees:*** *Tectona grandis* (Teak), *Eucalyptus globulus* (Eucalyptus), *Bombax ceiba* (Silk Cotton Tree), *Madhuca indica* (Mahua), *Embelia ribes* (False Black Pepper), *Aegle marmelos* (Bael), *Syzygium cumini* (Jamun), *Tamarindus indica* (Tamarind), *Emblica officinalis* (Indian Gooseberry/Amla), , *Mangifera indica* (Mango), *Manilkara zapota* (Sapota/Chikoo), *Phoenix dactylifera* (Date Palm), *Cocos nucifera* (Coconut), *Artocarpus heterophyllus* (Jackfruit), and *Moringa oleifera* (Drumstick Tree).

Biodiversity indices were calculated by deploying standard methodology, as described in the above sections. Based on the presence of the species, herb diversity was calculated in Wadi (new) and bamboo, tree diversity alone was calculated in Ag-fallow and forest, however herbs, and tree diversity was calculated in Wadi (established systems). The biodiversity indices reveal significant variations across different systems. The Shannon-Wiener Index (H') shows the highest diversity in the Bamboo (Herb) system (3.7225), indicating a rich variety of herbaceous species. In comparison, Agriculture Fallow has the lowest diversity (2.6469), suggesting a less diverse plant community. Species Richness (S) is highest in the Bamboo (Herb) system with 77 species, and lowest in Agriculture Fallow (19 species), reflecting the number of different species present. The Species Evenness (E) values indicate a relatively even distribution of species in all systems, with *Wadi* (Tree, Shrub) showing the highest evenness (0.8838). The Simpson's Index (1-D) suggests that the Bamboo (Herb) system has the highest dominance (0.9936), implying fewer dominant species, while Agriculture Fallow exhibits a relatively lower dominance (0.9081), suggesting more even species distribution. The Margalef Index reveals the highest richness in the Bamboo (Herb) system (10.3659) and the lowest in the Agriculture Fallow (4.51243), which aligns with the findings of lower species richness in agricultural fallow areas. Overall, the Bamboo (Herb) system stands out for its high species diversity and richness, while Agriculture Fallow has the lowest biodiversity across most indices.

a) Bamboo System

The Bamboo system exhibited the highest herb biodiversity among all the systems analyzed, with a Shannon-Wiener Index (H') of 3.7225 and the greatest species richness (S = 77). These values indicate a highly diverse herbaceous community. Dominant species identified in this system included *Dichanthelium clandestinum*, *Brachiaria reptans*, and *Justicia procumbens*. The high Simpson's Index (1-D = 0.9936) demonstrates that no single species dominates, resulting in a balanced ecosystem where species coexist equitably. The species evenness (E = 0.8570) further supports this observation, suggesting a well-distributed plant community with minimal ecological competition. This maximum diversity can be attributed to the favourable microclimatic conditions provided by the dense bamboo canopy, which regulates soil temperature, retains moisture, and reduces competition from invasive species. Bamboo systems often serve as refuges for various herbaceous plants, fostering a robust and resilient ecosystem.

b) *Wadi* System (Pre-established)

The *Wadi* system was assessed separately for its tree and shrub layer and herbaceous layer, showcasing a clear stratification in biodiversity. The tree and shrub layer recorded a Shannon-Wiener Index (H') of 2.8448 and a species richness (S = 25). Prominent species included *Tectona grandis* (Teak) and *Mangifera indica* (Mango). The high species evenness (E = 0.8838) indicates a uniform distribution of these species, highlighting the managed nature of the *Wadi* agroforestry system. The presence of economically and ecologically important species like teak and mango demonstrates the dual purpose of *Wadi* systems in providing both ecological and economic benefits. The herbaceous layer within the *Wadi* system demonstrated a slightly lower diversity, with a Shannon-Wiener Index (H') of 2.7169 and a species richness (S = 55). Dominant species included *Panicum brevifolium*, *Saccharum spontaneum*, *Portulaca oleracea*, and *Cynodon dactylon*. The species evenness (E = 0.6780) was comparatively lower, suggesting that a few dominant herbaceous species thrive under the conditions typical of agroforestry systems, such as regular irrigation and fertilization. The stratified biodiversity in the *Wadi* system reflects the deliberate planting strategies employed to maximize ecological services and economic returns.

c) Forest System

The Forest system, characterized by natural and relatively undisturbed vegetation, recorded a Shannon-Wiener Index (H') of 2.9500 and a species richness (S = 27). Dominant tree species included *Terminalia elliptica*, *Syzygium cumini*, and *Bambusa spp.* (Bamboo), while the Shrub layer was often dominated by *Lantana camara*. The Simpson's Index (1-D = 0.9248) reflects a well-balanced species composition, and the high species evenness (E = 0.8951) indicates minimal dominance by any single species. The forest system's diversity highlights the ecological significance of preserving natural vegetation, which supports a variety of plant species while maintaining ecosystem functions such as soil stabilization, nutrient cycling, and habitat provision. The dominance of species like *Lantana camara* may, however, point to the encroachment of invasive plants, which could alternative biodiversity in the long term.

d) Agriculture Fallow System

The Agriculture Fallow system recorded the lowest biodiversity among all the systems analyzed, with a Shannon-Wiener Index (H') of 2.6469 and a species richness (S = 19). Dominant species included trees and shrubs like *Terminalia tomentosa*, *Terminalia chebula*, and *Ziziphus mauritiana*. Despite the lower species richness, the species evenness (E = 0.8989) was relatively high, indicating a uniform distribution of the few species present. The limited biodiversity in fallow lands can be attributed to the degraded soil conditions and reduced vegetative cover typical of abandoned agricultural fields. These areas often require significant ecological restoration efforts to recover their biodiversity and productivity.

Table 3: Biodiversity Indices of difference systems

Name of System	Shannon-Wiener Index (H')	Species Richness (S)	Species Evenness (E)	Simposons index(1-D)	Margalef Index ((Dmg)
Bamboo (Herb)	3.7225	77	0.8570	0.9936	10.3659
Wadi (Herbs)	2.7169	55	0.6780	0.8589	7.2919
Wadi (Tree, Shrub)	2.8448	25	0.8838	0.9191	5.6879
Forest (Tree)	2.9500	27	0.8951	0.9248	6.0220
Agriculture Fallow	2.6469	19	0.8989	0.9081	4.51243

Plate 3: Documented herb under various land-uses systems

Plate 4: Documented herb under various land-uses systems

Plate 5 Diversity of plant species in homestead garden in study site

5. Activity 3: Impact of various land-use systems on soil nutrient composition

Preliminary study on soil health was carried out in seven land-use systems for the study: 1) Forest, 2) Agricultural Fallow (Ag-Fallow) systems, 3) Pre-established *Wadi*[2], 4) Newly established Bamboo plantations[3], 5) *Wadi* (New)[4], 6) *Wadi* Control[5], and 7) Multitier systems[6]. Among these, the *Wadi* (New) and Bamboo models were newly established as project interventions (June, 2024), while the remaining systems were selected from the study area to assess their impact on soil nutrients. Other systems such as *Wadi* (pre-established) was established in 1989-90 with support of BAIF, Forest systems was at mature stage where as Agricultural fallow consists of trees on boundary of fields and fallow lands. Farmer with support of BAIF established multi-tier systems in 2020-21 on degraded lands, which was also considered for this study. The aim of the study was to understand the available nutrient in the soil and impact of different land uses on soil nutrient status.

Soil sampling was conducted in July 2024 from two soil depths (0–15 cm and 15–30 cm) across these land-use systems, following standard protocols. The collected samples were transported from the project site to the Soil Laboratory of ICAR-NIASM, Baramati (Pune). The samples were then processed and prepared for analyzing various soil properties, including pH, EC, OC, Nitrogen, Phosphorus, Potassium, Zinc, Calcium, and Magnesium, using standard analytical methods. The results are presented below.

5.1. Soil pH and EC

The analysis of soil properties across the seven land-use systems revealed variations in pH and Electrical Conductivity (EC) between depths and systems. The soil pH ranged from 5.09 to 6.51, indicating slightly acidic to moderately acidic conditions across all systems. Forest and *Wadi* (Old) systems exhibited higher pH values (6.51; 6.43), particularly at the 15–30 cm depth, with the Forest system recording the highest pH (6.51). In contrast, the *Wadi* Control system showed the lowest pH (5.09) at the 15–30 cm depth, and similar acidic conditions were observed in the Multi-tier, Bamboo, and Ag-Fallow systems, which showed minimal variation between depths (Fig 7).

The EC values ranged from 30.06 to 45.05 µS/cm, with notable differences among the systems. The *Wadi* (Old) and Forest systems recorded the highest EC values, indicating

[2] Pre-established Wadi is 34 years old
[3] Newly established Bamboo plantations are 6-month-old
[4] Wadi (New) are 6-month-old
[5] Wadi control is open area where agricultural activities are absent
[6] Multitier systems are 2 years old

relatively higher salinity levels, especially in the deeper soil layers. In contrast, Bamboo and Ag-Fallow systems exhibited the lowest EC values, reflecting less saline soil conditions. The newly established *Wadi* system had moderate EC values, similar to those observed in the Multi-tier system.

Overall, the results highlight significant variations in soil chemical properties across the land-use systems, influenced by vegetation type, land-use practices, and soil management. The comparatively higher pH and EC in forest land use is due to high vegetation in hilly areas

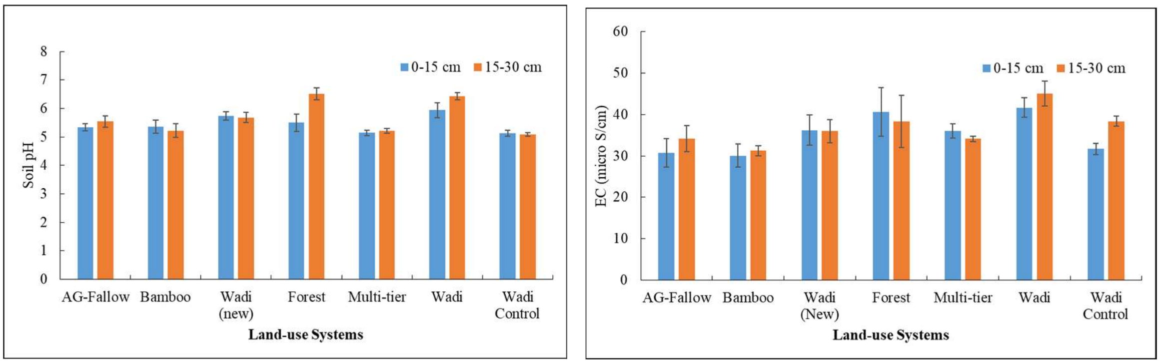

Figure 7: Impact of various land uses systems on soil pH and EC in study site

which generally promotes nutrient accumulation, organic matter decomposition, and reduced erosion, leading to comparatively higher pH and EC values than open areas.

5.2. Soil Organic carbon (%)

The analysis of organic carbon (OC) content across the different land-use systems revealed noticeable variations between depths and systems (Fig. 8). The OC content at 0–15 cm depth ranged from 0.55% in the *Wadi* Control system to 1.9% in the Forest system, with the Forest system having the highest OC content. Other land-use systems such as *Wadi* (New) and *Wadi* (Old) also showed relatively higher OC percentages, with values of 1.42% and 1.57%, respectively. The Multi-tier system recorded the lowest OC content at 0.83%. According to the Wadi Control, the OC content measured 1.06%, whereas the Multi-tier system recorded the lowest OC at 0.64%. These findings highlight significant variation in organic carbon levels across land-use systems, which could be influenced by vegetation types, land management practices, and soil depth.

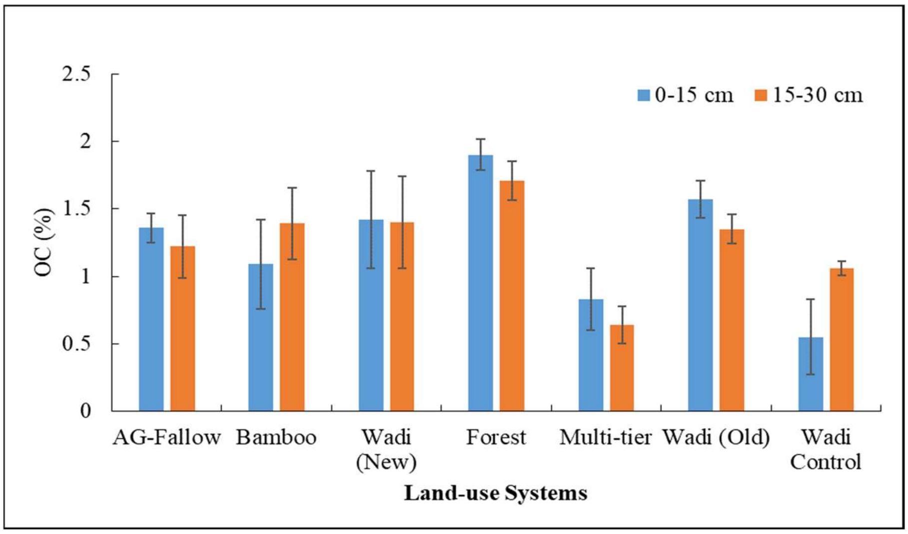

Figure 8: Impact of various land uses systems on soil organic carbon (%) in study site

5.3. Nitrogen, Phosphorus and Potassium

The soil nutrient content (mainly N, P and K) from studied land-use systems significantly varied at both 0–15 cm and 15–30 cm soil depths. For nitrogen, the values ranged from 79.45 kg/ha in the Multi-tier system to 233.32 kg/ha in the *Wadi* (Old) system at the 0–15 cm depth. At 15–30 cm, nitrogen content ranged from 91.99 kg/ha in the Multi-tier and *Wadi* Control systems to 223.28 kg/ha in the *Wadi* (Old) system (Fig 9). The elevated nitrogen levels in Wadi (old) can be attributed to the greater density of trees, particularly deciduous species, which enhance nutrient cycling and contribute more nitrogen to the soil. Additionally, the presence of certain leguminous tree species, combined with reduced disturbance, has helped increase the soil's nitrogen content. Phosphorus levels were highest in the Forest system at both depths, with 7.4 kg/ha at 0–15 cm and 8.42 kg/ha at 15–30 cm. The lowest phosphorus values were observed in the Bamboo system, with 2.57 kg/ha at 0–15 cm and 2.18 kg/ha at 15–30 cm (Fig 10). For potassium, the highest levels were found in the Forest system, with 255.14 kg/ha at 0–15 cm and 276.64 kg/ha at 15–30 cm. The lowest potassium values were observed in the *Wadi* Control system, with 91.84 kg/ha at 0–15 cm and 94.45 kg/ha at 15–30 cm (Fig 11).

These findings demonstrate the variation in nutrient content across different land-use systems, with certain systems like *Wadi* (Old) and Forest showing higher nutrient levels, particularly nitrogen and potassium, compared to others. This variation is influenced by factors such as species composition, tree density, plantation age, and management practices, which significantly impact soil properties. Additionally, processes like nutrient leaching, nutrient pumping from deeper soil layers, and leaf litter decomposition contribute to the higher nutrient availability in these systems compared to others.

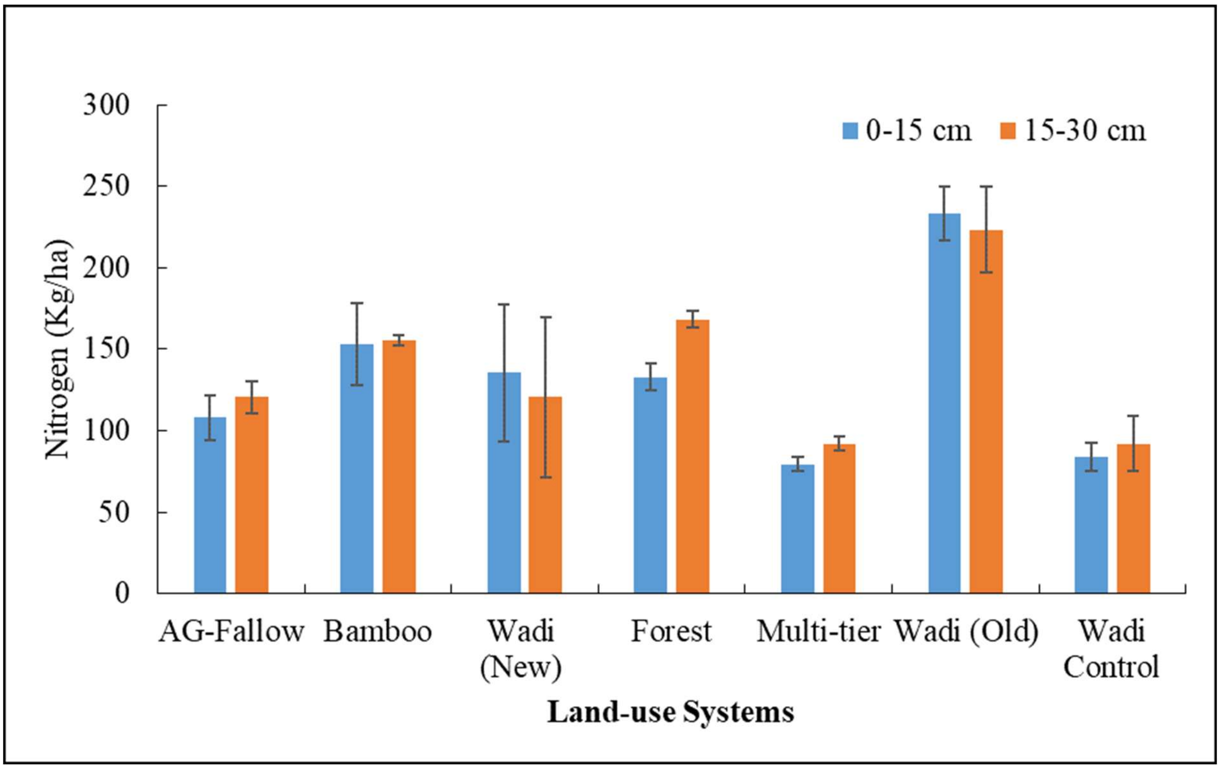

Figure 9: Impact of various land uses systems on Nitrogen (kg/ha) in study site

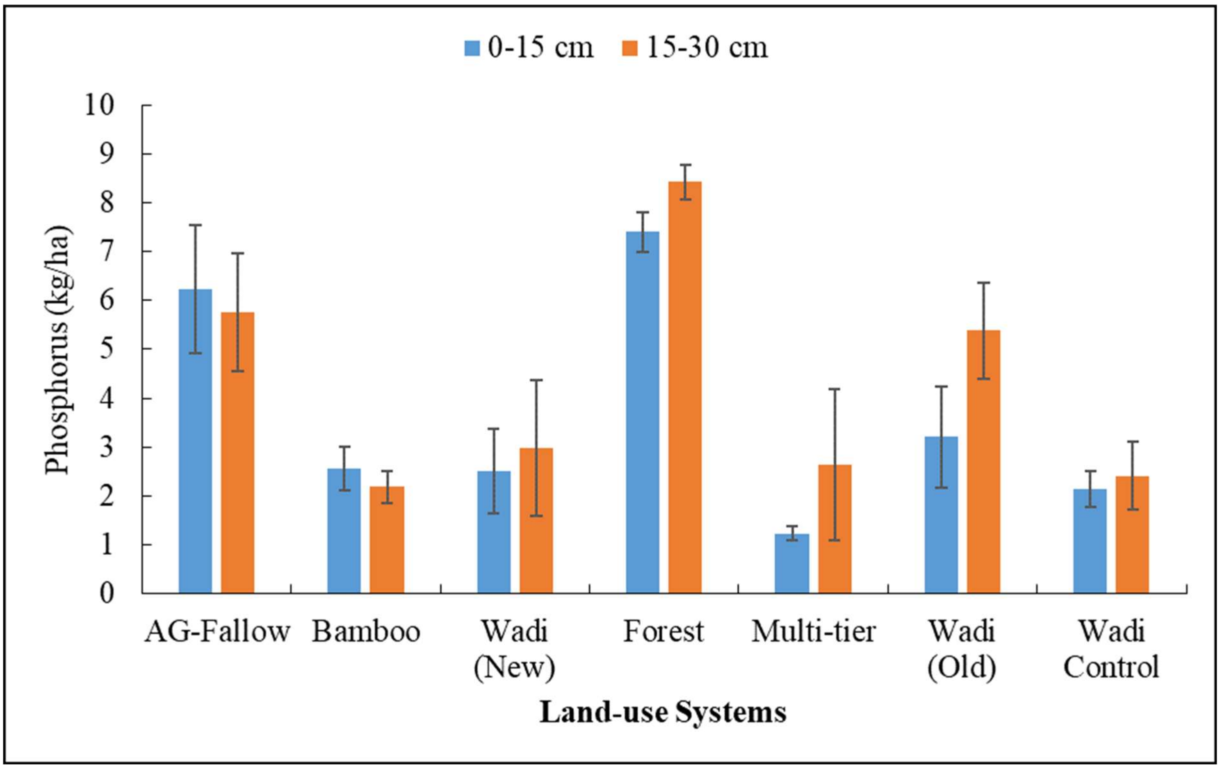

Figure 10: Impact of various land uses systems on Phosphorus (kg/ha) in study site

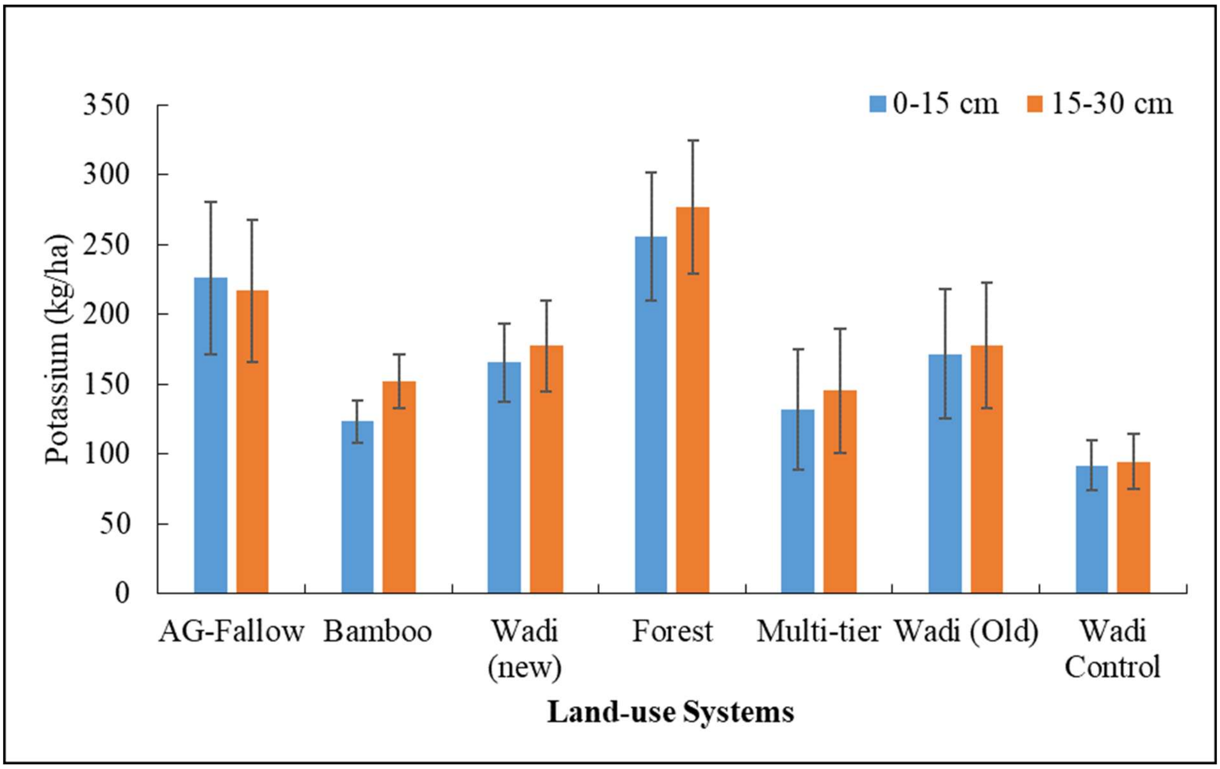

Figure 11: Impact of various land uses systems on Potassium (kg/ha) in study site

5.4. Micronutrients

The levels of Copper (Cu), Zinc (Zn), Manganese (Mn), Iron (Fe), and Boron (Bo) varied significantly across the different land-use systems, with distinct differences observed at the 0–15 cm and 15–30 cm soil depths. Copper content ranged from 0.4 mg/kg in the *Wadi* (Old) system to 0.95 mg/kg in the Bamboo system at 0–15 cm, with slightly higher values in the 15–30 cm depth for most systems (Fig 12). Zinc levels were highest in the Bamboo system, with 0.33 mg/kg at 0–15 cm and 0.37 mg/kg at 15–30 cm, while the lowest values were recorded in the *Wadi* (Old) system at 0.09 mg/kg in both depths (Fig 12).

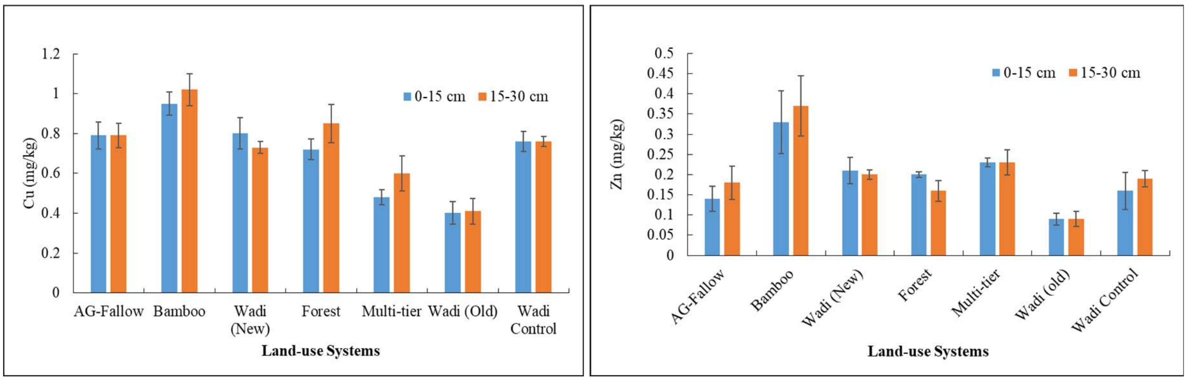

Figure 12: Impact of various land uses systems on copper (left) and zinc (right) in study site

Manganese was most abundant in the *Wadi* (New) and Bamboo systems, with values of 10.14 mg/kg and 9.86 mg/kg, respectively, at 0–15 cm, while the lowest was in the *Wadi* Control system at 2.02 mg/kg. Iron content was highest in the Forest system, with 1.604 mg/kg at 0–15 cm, and lowest in the Multi-tier system, with 0.664 mg/kg at the same depth (Fig 10). Boron levels were most elevated in the Forest system, reaching 1.864 mg/kg at 0–15 cm, while the Multi-tier system recorded the lowest value of 0.924 mg/kg at the same depth (Fig 11). These results highlight the variability in micronutrient availability, influenced by vegetation type, soil management, and depth.

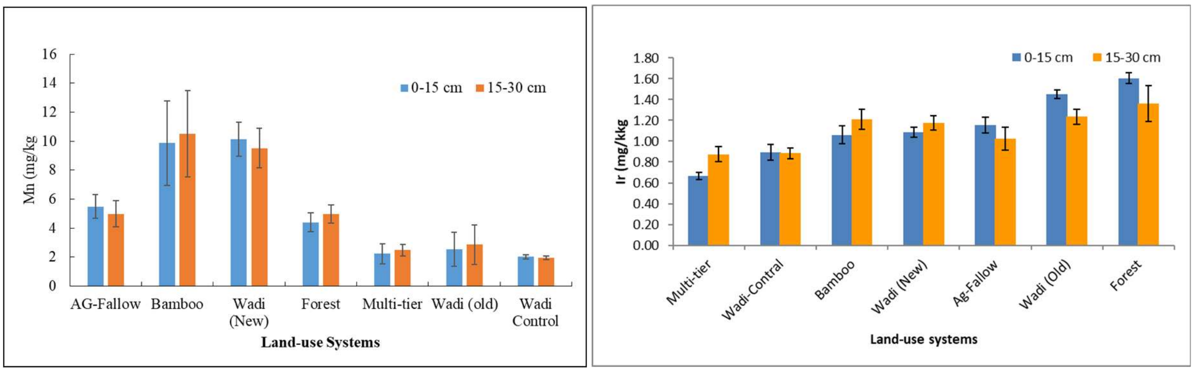

Figure 13: Impact of various land uses systems on Manganese (left) and iron (right) in study site

The $CaCO_3$ content showed notable variations across land-use systems. The highest levels were recorded in the Ag-Fallow system, with 2.488% at 0–15 cm and 2.602% at 15–30 cm, followed closely by the *Wadi* (Old) system and Bamboo system, which also exhibited elevated $CaCO_3$ levels (Fig 11). Moderate levels were observed in the Forest system, with 2.174% at 0–15 cm and 2.008% at 15–30 cm. The *Wadi* (New) and Multi-tier systems had slightly lower values, ranging from 1.876% to 2.05% across both depths. The lowest $CaCO_3$ content was found in the *Wadi* (Control) system, with 1.836% at 0–15 cm and 1.966% at 15–30 cm. These variations reflect differences in vegetation types, soil management, and environmental conditions across the land-use systems. Understanding $CaCO_3$ levels helps farmers optimize soil amendments and choose crops suited to specific conditions. High $CaCO_3$ influences soil pH, nutrient availability, and water retention, impacting irrigation and productivity. Adopting moisture conservation techniques can mitigate these effects and improve soil health.

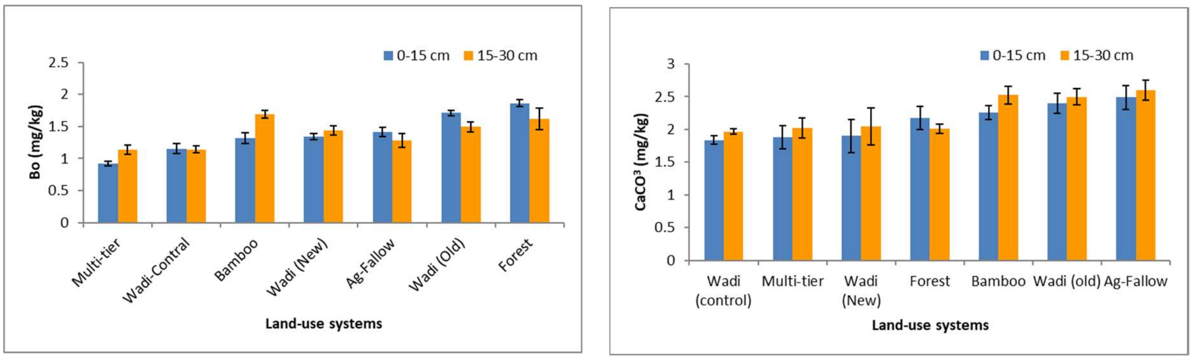

Figure 14: Impact of various land-use systems on boron (left) and calcium carbonate (right) in study site

6. Activity 4: Quantification of carbon sequestration under various land-use systems

Under the current climate change scenarios, carbon sequestration has become a vital strategy to mitigate greenhouse gas emissions. One effective approach to achieve this is the rehabilitation of degraded lands by introducing perennial tree-based systems such as agroforestry, silvipasture, or fruit plantations. These systems not only enhance carbon storage but also provide ecological and economic benefits. As part of the Nature Positive Solutions (NPS) Project, Work Package 3, efforts have been focused on rehabilitating degraded landscapes to improve carbon stocks. To achieve this, a study was conducted to quantify carbon stocks across five different land-use systems, employing two types of sampling: tree-based carbon assessment and soil carbon estimation.

For estimating tree carbon stocks, representative quadrats were laid across the study area, and tree enumeration was carried out. Within each quadrat, trees were identified to the species level, and their height (m) and girth at breast height (cm) were measured. Tree density was then calculated and extrapolated on a per-hectare basis. Using the traditional volume-mass approach, tree volume was estimated. To ensure precision, species-specific form factors, obtained from literature, were applied to account for tapering in tree shape. The calculated tree volumes were then multiplied by species-specific wood densities to estimate the aboveground biomass (kg/tree).

Belowground biomass was estimated by applying a root-to-shoot ratio of 0.26 to the aboveground biomass. The total tree biomass (aboveground and belowground) was then used to estimate carbon stocks. The IPCC default carbon fraction (0.50) was applied to calculate the carbon stock (kg/tree), which was further extrapolated to a per-hectare basis using tree density estimates. In addition to tree-based carbon, soil carbon stocks were also assessed. Soil samples were collected from the five land-use systems up to a depth of 30 cm, with separate analyses conducted for 0–15 cm and 15–30 cm layers. These samples were processed and analyzed for organic carbon content following standard protocols. Soil organic carbon content was then converted into soil organic carbon stock (kg/m^2) using bulk density and sampling depth. Finally, the total carbon stock for each land-use system was calculated by combining the tree carbon stock with the soil organic carbon stock.

6.1. Carbon stock (Tree and soil)

The results of carbon stock estimation across different land-use systems revealed significant variations in tree carbon, soil carbon, and total carbon stocks. The forest land-use system, with a tree density of 680 trees per hectare, recorded the highest total carbon stock of 112.9 Mg/ha, comprising 40.82 Mg/ha of tree carbon and 72.08 Mg/ha of soil carbon. Similarly, the agricultural fallow system, with a tree density of 270 trees per hectare, exhibited a substantial total carbon stock of 94.61 Mg/ha, with 38.68 Mg/ha of tree carbon and 55.93 Mg/ha of soil carbon (Fig 15). The *Wadi* system, having 237 trees per hectare, showed a moderate total carbon stock of 75.34 Mg/ha, with 16.6 Mg/ha of tree carbon and 58.74 Mg/ha of soil carbon. In contrast, the *Wadi* control system, which lacks tree cover, had no tree carbon and relied solely on soil carbon, resulting in a total carbon stock of 46.01 Mg/ha. Lastly, the multi-tier system, with 495 trees per hectare, exhibited a relatively lower total carbon stock of 37.46 Mg/ha, comprising only 1.94 Mg/ha of tree carbon and 35.52 Mg/ha of soil carbon.

Forest systems have the highest carbon stock, followed by Fallow-Agriculture and *Wadi*, with Multitier and Control-*Wadi* showing the lowest carbon storage due to reduced tree density. These results underscore the importance of integrating tree-based systems in land management to enhance carbon sequestration. Forest and agricultural fallow systems demonstrated the highest carbon stocks, highlighting their potential for climate change mitigation and sustainable land-use practices.

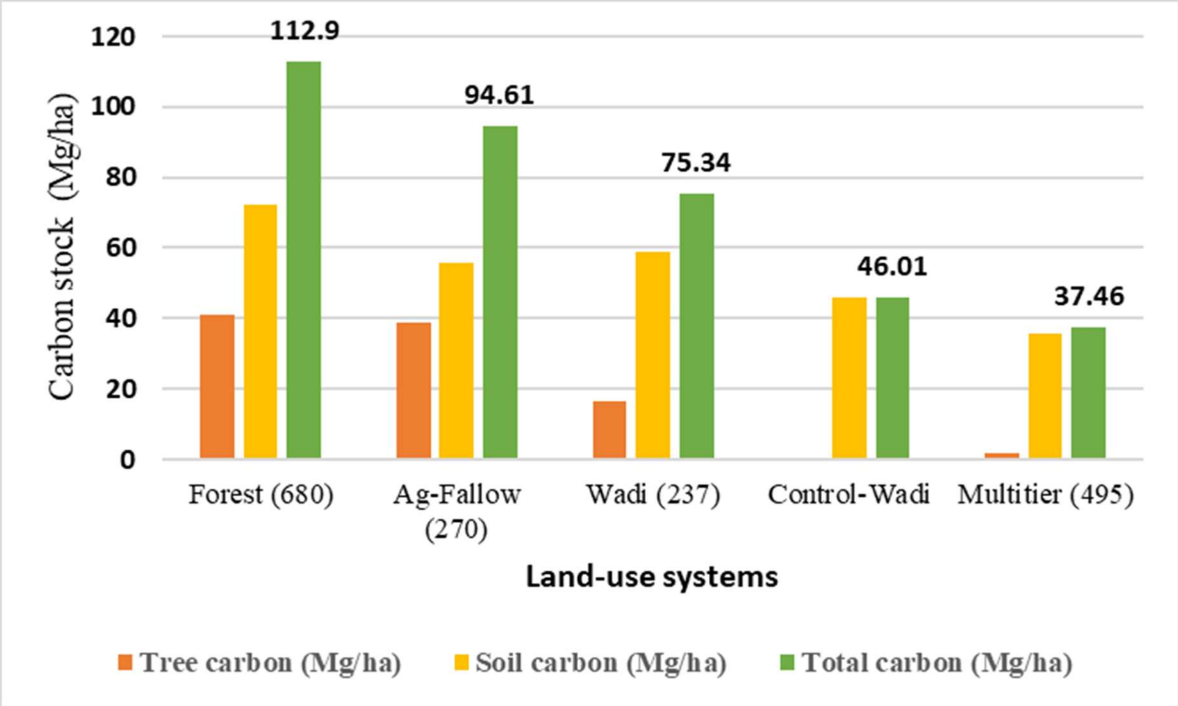

Figure 15: Carbon Stocks in Different Land-Use Systems of study site (Number of trees are in parenthesis)

7. Activity 5: Case Study - Agri-Horti-Forestry (*Wadi*)

7.1. Background

In India, out of the 104 million population of the Scheduled Tribes, nearly 90 percent live in rural areas (Census of India, 2011). Traditionally, tribal people lived in and around the forest, and their lives and livelihoods were based on natural resources. A majority of tribal groups work in the primary sector and are heavily dependent on agriculture, either as cultivators or as agricultural labourers (Government of India, 2014). Tribal households traditionally had a backyard garden that had multipurpose indigenous trees, plants, herbs, and shrubs. The produce from this small garden was sufficient to meet the food and nutritional needs of a family for an entire year.

BAIF's innovative model of "Agri-horti-forestry (*Wadi*)" which integrates horticulture into the farming system for sustainable livelihoods through climate smart practices, productive engagement with under-utilized land and optimal use of local resources. The model with horticulture as the core component ensures multiple income streams round the year especially during lean periods from a combination of medium gestation-high resilience and short gestation-high returns cropping patterns. This has been depicted through a case study of Shri. Tukaram Gabhale guruji, a retired teacher, who hails from Manhere, Tehsil Akole, District Ahmednagar. He is highly passionate and knowledgeable about agrobiodiversity and sustainable living. He is one of the pioneer farmers to implement *Wadi* system in 1989. Manere village situated beautifully amidst the Sahyadri ranges in Bhandardara, Maharashtra.

According to 2011 census, about 47% of Akole tehsil comprises of tribals among which Mahadev koli tribes are the most prominent. Majority of the tribals are small and marginal landholders and practice rain-fed subsistence agriculture. Low returns from agriculture leads to challenges such as fast depleting traditional resources (Forest degradation, loss of land races and traditional knowledge), poor health and lack of access to services resulting in distress migration for survival. There is an urgent need to create alternative cropping systems that can ensure sustainable livelihoods resources.

The *Wadi* program, initiated by BAIF and successfully implemented in South Gujarat, has become a transformative model for rural and tribal livelihoods. By integrating horticulture, forestry, and diversified farming systems, it addresses critical issues like poverty, reliance on rainfed agriculture, natural resource depletion, and seasonal distress migration. This report evaluates the sustainability of the *Wadi* model, its relevance to local needs, and the process for selecting species for its implementation. The *Wadi* program is a sustainable approach to rural development, emphasizing environmental, economic, and social benefits. Environmentally, *Wadi* promotes biodiversity through the inclusion of horticulture and forestry tree species while enhancing soil health and conserving water. These measures not only combat land degradation but also contribute to carbon sequestration, aligning with global goals of carbon neutrality. Economically, *Wadi* provides a steady income for rural families by integrating fruit trees and multipurpose forestry species. This diversified approach reduces the risk of crop failure and ensures a year-round income. Additionally, value-chain development through Farmer Producer Organizations (FPOs) facilitates aggregation, processing, and marketing of farm produce, enabling better returns and long-term financial security. Socially, *Wadi* reduces distress migration by creating local employment opportunities. Improved income and access to nutrition from fruit crops directly enhance the health and education outcomes of rural families, especially children. These holistic benefits make *Wadi* a sustainable intervention for rural development.

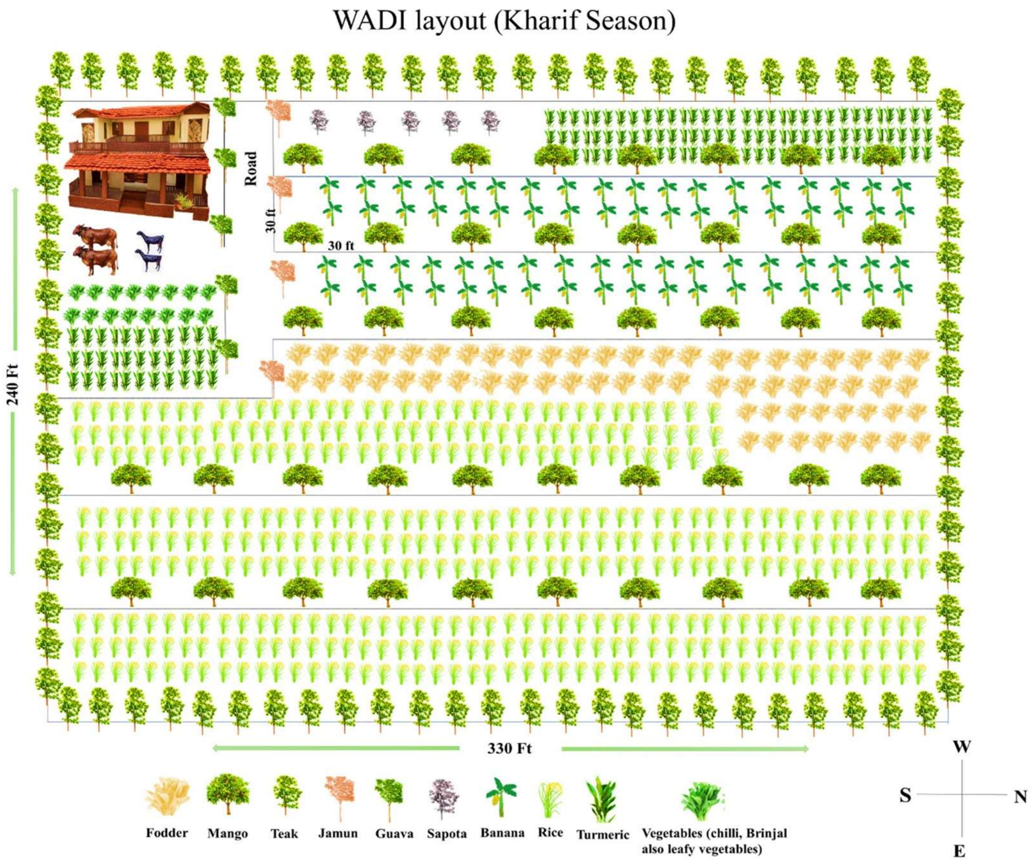

Figure 16: Layout of Tukaram Gabhale Wadi

7.2. Selection of Species for Planting in *Wadi*

The selection of species in the *Wadi* program is guided by the local ecological and socio-economic conditions. Emphasis is placed on indigenous and multipurpose species that address the diverse needs of the community. Fruit trees such as mango, guava, and cashew are commonly planted for their high market value and nutritional benefits. Forestry species are chosen for their ability to provide fuelwood, timber, and fodder, with a focus on varieties that regenerate quickly and improve soil health. Consideration is also given to the compatibility of species with the existing agroclimatic conditions, ensuring long-term sustainability.

The below table highlights the diverse plant species chosen for Ghabhale Guruji's *Wadi*, showcasing a thoughtful approach to meeting both ecological and community needs. Forest trees like Teak and Eucalyptus are included for their timber value and ability to protect the soil. Non-Timber Forest Products (NTFP) such as Amla, Tamarind, and Bamboo offer additional income while supporting nutrition and sustainable resource use. Horticultural crops, including Mango, Guava, and Dragon Fruit, provide a steady income from fruits while improving nutrition. Spices like Black Pepper and Turmeric add variety and market value. Fodder crops like Napier grass and Subabhul ensure there is enough feed for livestock. Vegetables like

Methi, Spinach, and Moringa, along with intercrops like Rice, Wheat, and Finger Millets, improve food security and efficient use of farmland.

This careful selection of species in Ghabhale Guruji's *Wadi* reflects a practical, sustainable, and community-oriented farming model that can be adapted to different regions for better livelihoods and environmental health.

Table 4: Species distribution of Wadi at study site

Types	***Species***
Forest Trees	*Tectona grandis (Teak), Eucalyptus globulus (Eucalyptus), Bombax ceiba (kapok tree)*
NTFP	*Zyziphus regusa (Indian Jujube), Madhuca indica (Mahua), Embeleia ribes (Vavding), Agel marmelos (Bael), Sysigium cumini (Jamun), Tamarindus indica (Tamarind), Emplica officinalis (Indian Gooseberry/Amla), Dendrocalamus strictus (Solid Bamboo), Agave americana (Century Plant).*
Horticulture	*Mangifera indica (Mango), Manilkara zapota (Sapota), Psidium guajava (Guava), Carica papaya (Papaya), Phoenix dactylifera (Date palm), Cocos nucifera (Coconut), Punica granatum (Pomegranate), Ziziphus mauritiana (Ber), Eugenia uniflora (Brazilian cherry), Artocarpus heterophyllus (Jackfruit), Hylocereus undatus (Dragon ruit), Citrus spp (limbu)., Musa spp (banana).*
Spices	*Cinnamomum verum (Cinnamon), Murraya koenigii (curry leaves), Piper nigrum (black pepper) and Curcuma longa (turmeric) ()*
Fodder Crops	*Leucaena leucocpehala (Subabhul), Pennisetum glaucum × Pennisetum purpureum (Bajara Napier), , Zea mays (Maize), Local Grasses*
Vegetables	*Trigonella foenum-graecum (Methi), Spinacia oleracea (Spinach), Colocasia esculenta (Colocasia Leaves), Solanum melongena (Eggplant), Moringa oleifera (Moringa), Coriandrum sativum (Coriander), and Cucumis sativus (Cucumber).*
Intercrops	*Oryza sativa (Rice), Eleusine coracana (Finger millet), Triticum aestivum(Wheat), and Zea mays (Maize)*

7.3. Local Need for *Wadi*

Rural and tribal communities face acute challenges such as marginal landholdings, dependence on rainfed agriculture, and depleting natural resources. These conditions often force families into seasonal migration, disrupting their social and economic stability. *Wadi* addresses these needs by transforming unproductive and degraded lands into thriving assets.

By promoting fruit and forestry trees, *Wadi* meets the local demand for food, fodder, timber, and fuelwood. This not only improves self-sufficiency but also enhances the nutritional status of families. Additionally, supplementary activities like vegetable cultivation, floriculture, and inland fisheries provide short-term income and diversify livelihoods, aligning closely with the local requirements of rural households.

7.3.1. Seasonal analysis

This seasonal calendar highlights the strategic planning behind the diversified *Wadi* model, ensuring a balanced availability of products throughout the year. The integration of annual and perennial crops allows farmers to sustain income, meet household nutritional requirements, and optimize land productivity. The provided cropping calendar illustrates a highly diversified and sustainable farming system that enables year-round harvesting of various crops, including fruits, vegetables, spices, grains, fodder, and medicinal plants. This integrated system ensures economic viability, food security, and ecological balance. The temporal distribution of harvests reflects a well-planned approach to optimize resource use and minimize income variability, with multiple crops maturing at different times of the year.

Perennial crops like coconut (*Cocos nucifera*), moringa (*Moringa oleifera*), and curry leaves (*Murraya koenigii*) provide continuous harvest opportunities, ensuring consistent income and market engagement. Seasonal fruits such as mango (*Mangifera indica*), jamun (*Syzygium cumini*), and guava (*Psidium guajava*) dominate the summer months, while staple grains like rice (*Oryza sativa*) and wheat (*Triticum aestivum*) align with the kharif and rabi cropping cycles, contributing to dietary sustenance. High-value crops like turmeric (*Curcuma longa*), black pepper (*Piper nigrum*), and cinnamon (*Cinnamomum verum*) are cultivated during specific months, boosting farm profitability through market-driven opportunities.

Fodder crops, including Napier grass (*Pennisetum purpureum*) and subabul (*Leucaena leucocephala*), integrate seamlessly into this system, supporting livestock productivity and reducing dependency on external feed inputs. Vegetables such as eggplant (*Solanum melongena*), cucumber (*Cucumis sativus*), and leafy greens like spinach (*Spinacia oleracea*) are cultivated in shorter cycles, ensuring a steady supply of fresh produce for both home consumption and market sales. Additionally, the inclusion of diverse fruits like pomegranate (*Punica granatum*), jackfruit (*Artocarpus heterophyllus*), and tamarind (*Tamarindus indica*) contributes to nutritional security and market diversity.

This diversified cropping system exemplifies ecological resilience by mitigating the risks associated with monoculture, such as pest outbreaks and climate variability. Furthermore, it enhances soil health through varied nutrient demands and contributes to biodiversity conservation. The system also ensures consistent cash flow by balancing long-term investments, such as perennial and timber crops, with short-term returns from vegetables and staples. The integration of food, fodder, and high-value crops creates a robust and adaptable farming model that promotes sustainability, economic stability, and resilience against environmental challenges.

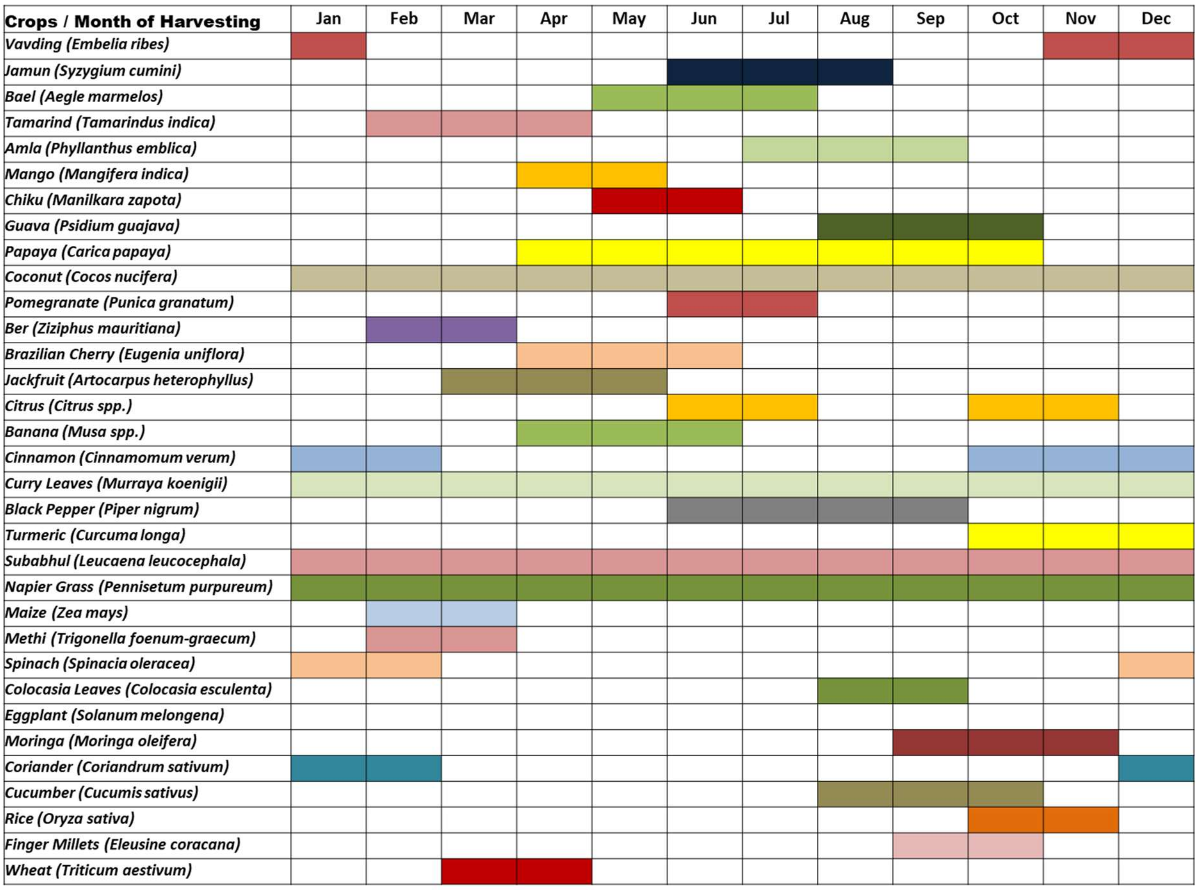

Figure 17: Seasonal analysis (Month-Wise Harvesting Schedule) for Diverse Cropping in Wadi model

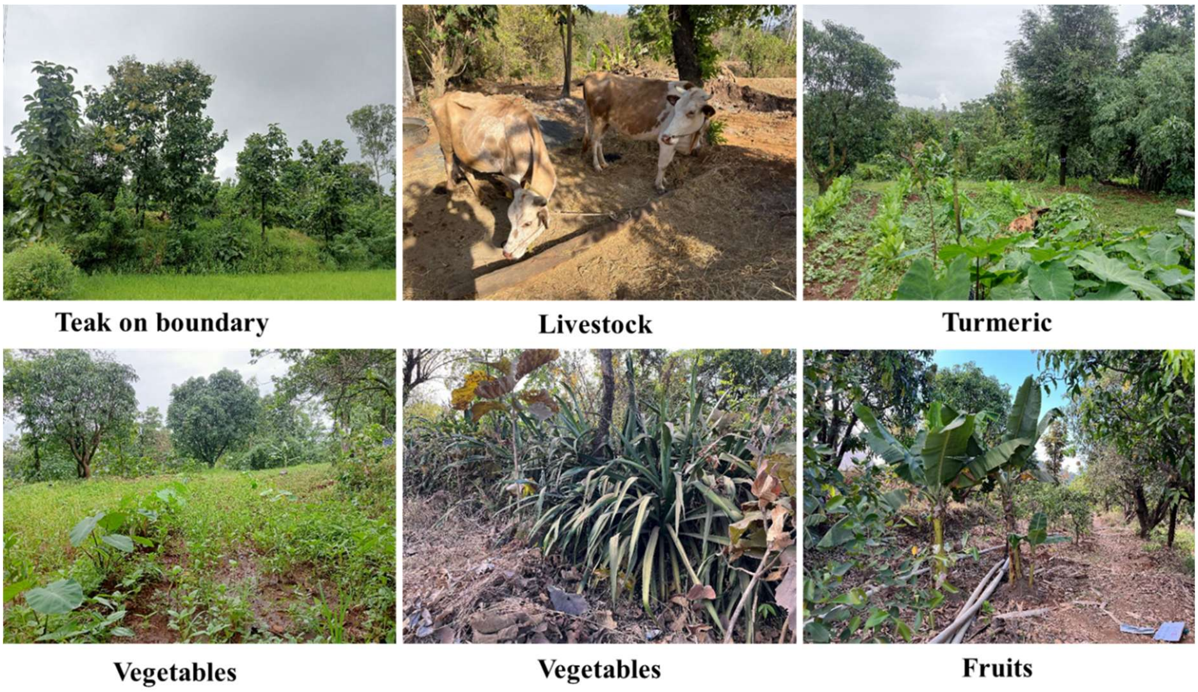

Plate 6: Components of *Wadi* system in Study Site

7.4. Economic Returns of *Wadi*

The *Wadi*-based farming system, established in 1989, showcases a sustainable and diversified approach to agriculture, integrating multiple components that provided both economic and practical benefits over the years. Spread across 1.8 acres, the system included intercrops (rice and wheat), mango orchards, vegetable cultivation, livestock, and timber trees (eucalyptus and teak). Initially, intercrops and livestock were the primary sources of income, with intercrop earnings starting at Rs. 10,000 in 1989 and growing to Rs. 30,600 by 2009, adjusted for inflation. Livestock, consisting of two cows and two goats, consistently contributed an annual income of Rs. 20,000–30,000 throughout the period. Vegetables, cultivated for both home consumption and market sales, added Rs. 5,000–15,000 annually to the household income (Fig 18).

The mango trees began fruiting in 1994, yielding 50 kg and earning Rs. 500. By 2009, mango yields peaked at 500 kg, generating Rs. 5,000 annually. In 2023, market price adjustments increased mango income to Rs. 50,000. Timber provided substantial periodic income, with eucalyptus harvested in 2002 and used for building the family home, saving an estimated Rs. 1,00,000 in construction costs. Teak harvested in 2023 brought in Rs. 3,00,000, demonstrating the high returns of long-term agroforestry investments. Total annual income increased from Rs. 30,000 in 1989 to Rs. 1,68,800 in 2024, with a significant peak of Rs. 4,64,500 in 2023 due to timber sales.

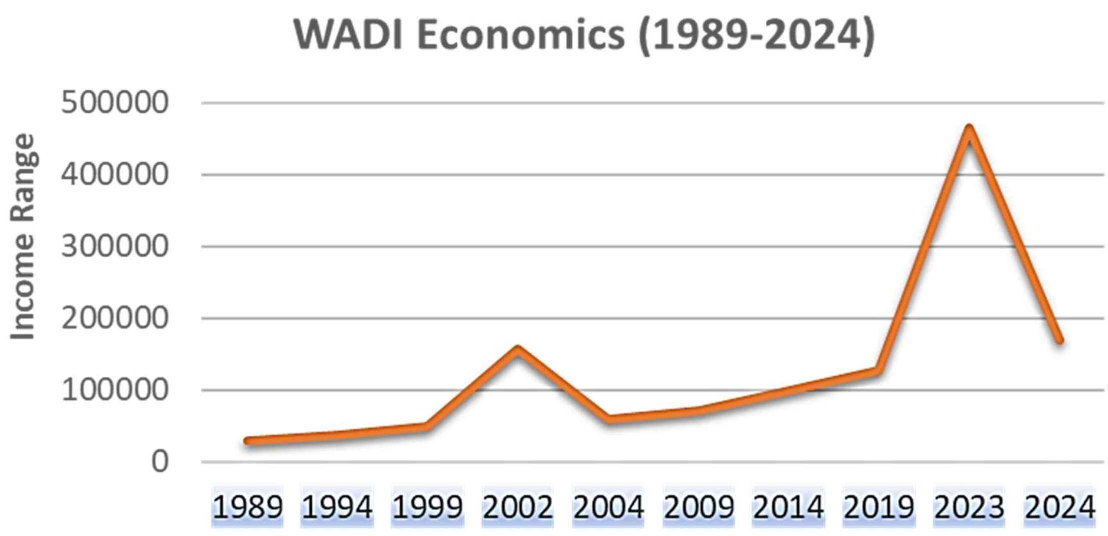

Figure 18: Economics of Wadi system (1989 to 2024)

This *Wadi* system highlights the importance of diversification in agriculture. It ensured consistent annual cash flow through intercrops, livestock, and vegetables while providing substantial periodic income from mangoes and timber. The use of timber for home construction exemplifies the self-sufficiency achieved through this model, reducing reliance on external resources. By integrating diverse components, the system balanced short-term income needs with long-term financial security. This approach serves as a sustainable model for small and marginal farmers, combining economic stability, resource efficiency, and ecological balance.

7.5. Carbon Sequestration Potential of *Wadi* System

Wadi system, play a significant role in carbon sequestration by integrating perennial trees with agricultural crops. This study evaluates the carbon sequestration potential of a *Wadi* system by measuring the biomass and carbon stock of selected tree species within the system. By capturing atmospheric carbon dioxide (CO_2) and storing it in biomass, the *Wadi* system contributes to mitigating climate change while providing ecological and economic benefits.

The carbon sequestration analysis was based on field measurements of tree girth and height, following a systematic methodology:

The volume of a standing tree was calculated as

$$\textbf{Volume of tree (m}^3\textbf{)} = \pi r^2 h$$

Where r is the radius and h is the height of the tree.

Calculation of biomass weight: Aboveground biomass (AGB) of each tree was estimated using the following formula

$$\textbf{AGB (kg tree}^{-1}\textbf{) = Volume (m}^{3}\textbf{)} \times \textbf{wood specific gravity (WSG)}$$

Wood specific gravity (WSG) was estimated by water displacement method.

Belowground biomass (BGB) includes live root biomass, excluding fine roots and is calculated using a root: shoot ratio of 0.26

$$\textbf{BGB (kg tree}^{-1}\textbf{) = AGB} \times \textbf{0.26.}$$

Determination of biomass carbon stock: Total biomass (TB) is the sum of AGB and BGB of trees

$$\sum \textbf{TB (Kg tree-}^{1}\textbf{)} = \sum \textbf{AGB (kg tree}^{-1}\textbf{)} + \sum \textbf{BGB (kg tree}^{-1}\textbf{)}$$

Carbon in Tree

$$\textbf{Carbon fraction (0.5)} \times \textbf{TGB}$$

Co_2 sequestration by tree

$$\textbf{3.67} \times \textbf{carbon in tree}$$

7.6. Tree biomass of *Wadi* model

In the *Wadi* system, the total biomass per tree varied among species. Teak (*Tectona grandis*) exhibited a total biomass of 123.53 kg per tree, with 98.04 kg attributed to aboveground biomass and 25.49 kg to belowground biomass. Eucalyptus (*Eucalyptus globulus*) had a total biomass of 93.90 kg per tree, comprising 74.53 kg aboveground and 19.38 kg belowground. Mango (*Mangifera indica*) demonstrated a total biomass of 341.62 kg per tree, with 271.13 kg aboveground and 70.49 kg belowground. Other species such as *Syzygium cumini, Ziziphus rugosa*, and *Bombax ceiba* also contributed notable biomass, with *Syzygium cumini* reaching 347.67 kg per tree. Species like *Aegle marmelos* and *Artocarpus heterophyllus* had relatively lower values, contributing 146.36 kg and 95.41 kg per tree, respectively. *Citrus limon* and *Psidium guajava* showed the least biomass at 20.11 kg and 34.20 kg per tree.

Table 5: Growth parameter and biomass of various tree species of Wadi model

Tree species	**Number of trees in *Wadi***	**Tree height (m)**	**DBH (cm)**	**Aboveground Biomass (kg/tree)**	**Belowground Biomass (kg/tree)**	**Total biomass (kg/tree)**
Terminalia tomentosa	**1**	10	20	145.22	37.76	182.98
Aegle marmelos	**1**	6.67	21	116.16	30.20	146.36
Ziziphus rugosa	**5**	10.24	20	180.30	46.88	227.18
Bombax ceiba	**2**	10.33	27	185.19	48.15	233.34
Phoenix sylvestris	**4**	11.08	20	128.68	33.46	162.14
Terminalia chebula	**3**	9.78	16	88.95	23.13	112.08
Artocarpus heterophyllus	**3**	7.44	17	75.72	19.69	95.41
Syzygium cumini	**3**	11.11	25	275.93	71.74	347.67
Citrus limon	**1**	6.67	9	15.96	4.15	20.11
Mangifera indica	**38**	9.83	28	271.13	70.49	341.62
Eucalyptus globulus	**10**	14.3	14	74.53	19.38	93.90
Psidium guajava	**4**	5.25	14	27.14	7.06	34.20
Gmelina arborea	**1**	10	16	58.22	15.14	73.36
Ficus racemosa	**1**	8.33	25	83.96	21.83	105.79
Tectona grandis	**94**	9.05	17	98.04	25.49	123.53

Carbon sequestration of *Wadi* The study on the total biomass, carbon stock, CO2 sequestration, and oxygen production in the *Wadi* system revealed important insights. The total biomass per hectare across all tree species amounted to 41.83 Mg/ha, with *Mangifera indica* (mango) contributing the highest biomass at 18.03 Mg/ha, followed by *Tectona grandis* (teak) at 16.13 Mg/ha (Table 6). These two species alone accounted for the majority of the total biomass in the *Wadi* system. In terms of total carbon stock, the *Wadi* system had an estimated carbon stock of 16.60 Mg/ha. *Mangifera indica* contributed significantly to this, with 7.15 Mg/ha of carbon stock, while *Tectona grandis* contributed 6.40 Mg/ha.

In the *Wadi* system, *Mangifera indica* (mango) and *Tectona grandis* (teak) dominate the carbon stock, contributing 43.1% and 38.6%, respectively, accounting for over 80% of the total carbon. Medium contributors like *Syzygium cumini* (3.5%), *Eucalyptus globulus* (3.1%), and *Ziziphus rugosa* (3.8%) play a lesser role. Species such as *Bombax ceiba* and *Phoenix sylvestris* contribute 1-2%, while others like *Terminalia tomentosa* and *Aegle marmelos* have minimal contributions, under 1% (Fig 19).

Table 6: Biomass, carbon and oxygene potential of Wadi systems

Tree species	**Tree per ha**	**Total Biomass (Mg/ha)**	**Total Carbon (Mg/ha)**	**Total CO_2 (Mg/ha)**	**Total Oxygen (Mg/ha)**
Terminalia tomentosa	1	0.25	0.10	0.03	0.13
Aegle marmelos	1	0.20	0.08	0.02	0.10
Ziziphus rugosa	7	1.58	0.63	0.16	0.79
Bombax ceiba	3	0.65	0.26	0.07	0.32
Phoenix sylvestris	6	0.90	0.36	0.09	0.45
Terminalia chebula	4	0.47	0.19	0.05	0.23
Artocarpus heterophyllus	4	0.40	0.16	0.04	0.20
Syzygium cumini	4	1.45	0.57	0.15	0.72
Citrus limon	1	0.03	0.01	0.00	0.01
Mangifera indica	53	18.03	7.15	1.86	9.01
Eucalyptus globulus	14	1.30	0.52	0.13	0.65
Psidium guajava	6	0.19	0.08	0.02	0.09
Gmelina arborea	1	0.10	0.04	0.01	0.05
Ficus racemosa	1	0.15	0.06	0.02	0.07
Tectona grandis	131	16.13	6.40	1.66	8.06
Total	238	**41.83**	**16.60**	**4.32**	**20.91**

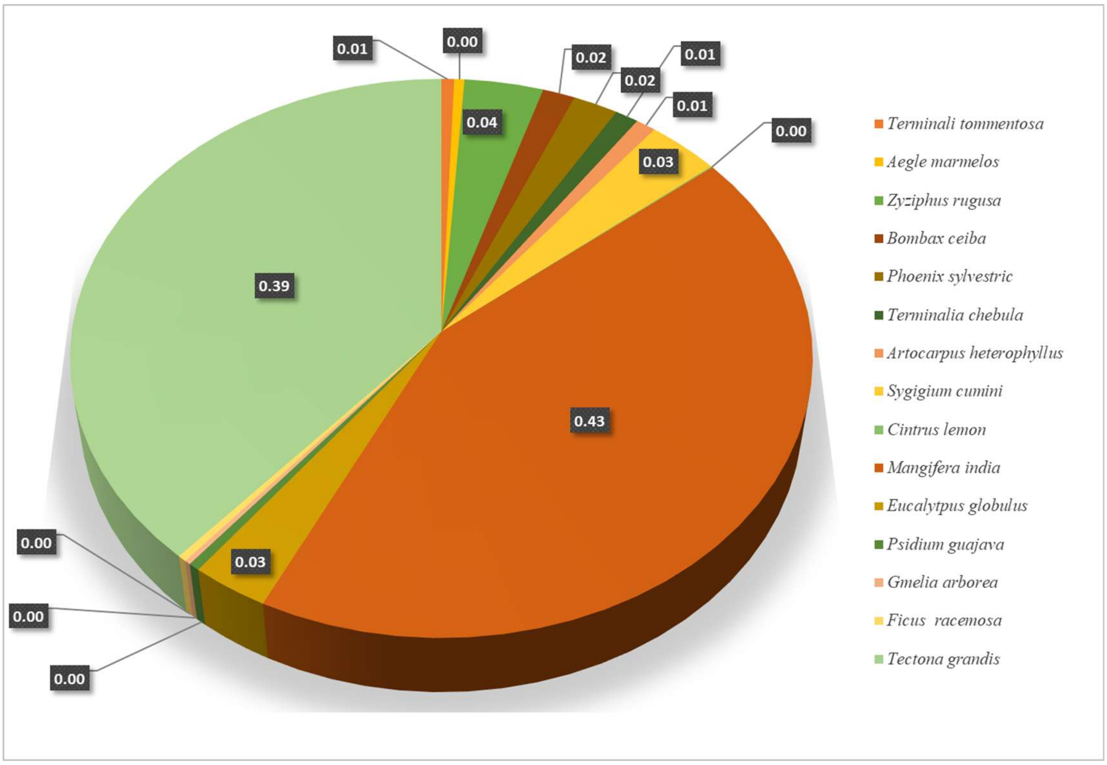

Figure 19: Percent contribution of tree in total carbon sequestration of Wadi model

For CO_2 sequestration, the system captured 4.32 Mg/ha of CO_2, with mango and teak again being the dominant contributors, sequestering 1.86 Mg/ha and 1.66 Mg/ha of CO_2, respectively. Regarding oxygen production, the total oxygen produced per hectare in the *Wadi* system was 20.91 Mg/ha. The key contributors to oxygen production were *Mangifera indica* and *Tectona grandis*, producing 9.01 Mg/ha and 8.06 Mg/ha of oxygen, respectively. Other species, including *Syzygium cumini* and *Ziziphus rugosa*, also played a significant role in oxygen production, contributing 0.72 Mg/ha and 0.79 Mg/ha, respectively.

The *Wadi* system, particularly with species such as *Mangifera indica* and *Tectona grandis*, plays a crucial role in biomass accumulation, carbon sequestration, CO_2 reduction, and oxygen production, thereby contributing positively to environmental sustainability.

The results highlight the significant role of the *Wadi* agroforestry system in carbon sequestration, with *Mangifera indica* (mango) contributing the highest share of sequestered CO_2, at 77.78 tons. Timber species such as *Tectona grandis* (teak) and *Eucalyptus globulus* (eucalyptus) also contributed notably to carbon storage due to their high biomass production. The inclusion of smaller species like *Syzygium cumini* (jamun), *Ficus racemosa* (fig), and *Aegle marmelos* (bael) demonstrates the ecological diversity of the *Wadi* system, which not only supports carbon storage but also provides multiple ecosystem services, including fruit production, soil health improvement, and habitat conservation. Additionally, species such as

Cocos nucifera (coconut) and Bamboo contribute to consistent carbon storage while offering economic returns.

After 25 years of planting, the farmer harvested 45 teak trees, which were used for constructing his house. Teak, is a highly valued timber species. The inclusion of perennial components along the boundaries of *Wadi* systems offers long-term financial benefits for families, as it serves as a savings source for essential expenses like house construction, marriages, medical emergencies, and education. In the case of Guruji's *Wadi*, teak played a vital role in supporting house construction, as depicted in the figure.

Plate 7: View of teak plantation used for house construction and furniture

8. Acknowledgements

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9. Annexure 1

Reported tree, shrubs and herbs species in study site

TREE				
Sr. No	**Scientific Name**	**Common Name**	**Parts Used**	**Medicinal & Other Uses**
1	*Terminalia chebula*	Hirda / Chebulic Myrobalan	Fruits, Bark	Digestive aid, antioxidant, treats constipation, respiratory health, tannin, dye extraction
2	*Acacia auriculiformis*	Australian Acacia	Bark, Leaves, Pods	Used for skin diseases, gum infections, wounds, infections, fever; timber, fuelwood, erosion control
3	*Terminalia tomentosa*	Asan Tree	Bark, Wood	Treats diarrhea, diabetes, urinary problems
4	*Phyllanthus emblica*	Indian Gooseberry	Fruits	Boosts immunity, improves digestion, antioxidant
5	*Bambusa spp.*	Bamboo	Leaves, Shoots	Used for bone health, urinary infections; construction, handicrafts, paper production
6	*Aegle marmelos*	Bael	Fruits, Leaves	Treats diarrhea, digestive health, diabetes
7	*Ziziphus mauritiana*	Indian Jujube	Fruits, Leaves	Used for skin care, digestive aid, insomnia
8	*Bombax ceiba*	Silk Cotton Tree	Bark, Flowers, Roots	Used for wounds, inflammation, diarrhea, fiber, timber, ornamental use
9	*Phoenix dactylifera*	Date Palm	Fruits	Energy booster, treats anemia, respiratory issues
10	*Artocarpus heterophyllus*	Jackfruit	Fruits, Seeds	Used for digestive health, skin issues, and ulcers
11	*Syzygium cumini*	Indian Blackberry	Fruits, Seeds	Treats diabetes, boosts immunity, antioxidant
12	*Mangifera indica*	Mango	Fruits, Leaves	Treats diarrhea, promotes digestion, skin health
13	*Melia azedarach*	Chinaberry Tree	Leaves, Bark	Used for skin diseases, deworming, wounds
14	*Eucalyptus globulus*	Eucalyptus	Leaves, Oil	Treats respiratory issues, antibacterial, antifungal
15	*Psidium guajava*	Guava	Fruits, Leaves	Treats diarrhea, improves digestion, antioxidant
16	*Gmelina arborea*	Beechwood	Leaves, Bark	Used for fever, wounds, inflammation
17	*Tamarindus indica*	Tamarind	Fruits, Seeds, Leaves	Used for digestive issues, fever, wound healing
18	*Tectona grandis*	Teak	Wood, Bark	Used for headaches, wounds, bronchitis

19	*Ziziphus rugosa*	Rugose Jujube	Leaves, Fruits	Used for skin care, digestive issues
20	*Ficus glomerata*	Cluster Fig	Fruits, Leaves, Bark	Treats diabetes, diarrhea, respiratory issues
21	*Terminalia catappa*	Indian Almond	Leaves, Seeds	Antimicrobial, treats diarrhea, improves immunity
22	*Terminalia elliptica*	Indian Laurel	Bark, Wood	Treats diarrhea, urinary issues, diabetes
23	*Pterocarpus marsupium*	Indian Kino	Bark, Wood	Treats diabetes, wounds, inflammation
24	*Cassia fistula*	Golden Shower Tree	Pods, Bark, Leaves	Used as a laxative, treats skin infections, ornamental, timber, dye extraction
25	*Terminalia paniculata*	Kindal Tree	Bark, Wood	Treats diarrhea, wounds, fever
26	*Tragia benthamii*	Stinging Nettle Vine	Leaves, Root	Used for rheumatism and skin disorders
27	*Syzygium aqueum*	Water Apple	Fruits, Bark	Used for diabetes, digestion, and fever; edible fruit, ornamental plant
28	*Musa spp.*	Banana Tree	Fruit, Leaves, Pseudostem	Fruits for energy, leaves for wound healing
29	*Moringa oleifera*	Drumstick / Moringa	Leaves, Pods, Seeds	Known for its nutritional and medicinal benefits
30	*Hibiscus rosa-sinensis*	Hibiscus	Flowers, Leaves	Used for skin care, hair health, and reducing fever
31	*Sambucus nigra L.*	Elderberry	Berries, Flowers, Leaves	Known for treating colds, flu, and as an anti-inflammatory
32	*Xylosma hawaiensis*	Xylosma	Leaves, Twigs	Used in some cultures for skin treatment and as a mild laxative
33	*Lagerstroemia lanceolata*	Crape Myrtle	Leaves, Bark, Flowers	Used for treating skin diseases, diarrhea, and as a diuretic
34	*Butea monosperma*	Flame of the Forest	Flowers, Bark, Gum	Used for ulcers, eye diseases, wound healing, dye extraction, fodder, religious use
35	*Maranthes corymbosa*	Merbatu, Sea Beam	Bark, Leaves	Used for skin infections, anti-inflammatory, timber, traditional medicine
		Shrubs		
1	Justicia adhatoda	Malabar Nut, Adhatoda	Leaves, Roots	Used for respiratory issues, cough, asthma, and as an anti-inflammatory.

2	*Agave americana*	Century Plant, American Aloe	Leaves, Stem, Root	Used in traditional medicine for wounds, digestive problems, and as a laxative.
3	*Banisteriopsis muricata*	None (Banisteriopsis species)	Leaves, Bark	Known for its use in folk medicine for fever and inflammation.
4	*Woodfordia fruticosa*	Fire Flame Bush	Flowers, Bark	Used to treat skin disorders, dysentery, and as an anti-inflammatory.
5	*Leea indica*	Indian Leea	Leaves, Roots	Used for treating fever, inflammation, and as an antimicrobial agent.
6	*Bauhinia variegata*	Orchid Tree	Leaves, Flowers	Used for treating wounds, fever, and as an anti-inflammatory.
7	*Thespesia lampas*	Pacific Rosewood	Bark, Flowers, Leaves	Used in traditional medicine for treating coughs, chest pain, and as an antiseptic.
8	*Carissa carandas*	Karanda, Bengal Currant	Fruit, Leaves, Root	Fruits are used in treating fever, constipation, and as an antimicrobial.
9	*Lantana camara*	Lantana, Red Sage	Leaves, Flowers	Used for treating skin diseases, fevers, and as an anti-inflammatory.
10	*Vitex negundo*	Five-leaved chaste tree	Leaves, Seeds, Flowers	Used for treating arthritis, fever, skin conditions, and menstrual disorders.
11	*Tragia benthamii*	Benthamii	Leaves, Roots	Used in some cultures to treat wounds, fever, and infections.
12	*Citrus limon*	Lemon	Fruits, Leaves	Treats sore throat, improves digestion, immunity booster.
13	*Carica papaya*	Papaya	Fruits, Leaves, Seeds	Digestive health, anti-inflammatory, skin health.
14	*Nyctanthes arbor-tristis*	Night-flowering Jasmine	Leaves, Flowers	Treats fever, arthritis, and skin problems.
15	*Melanthera biflora*	None	Leaves	Used in some folk medicine for treating cuts, wounds, and fevers.
		Herbs		
1	*Achyranthes japonica*	Japanese Chaff Flower	Whole plant	Treats inflammation, pain, and acts as a diuretic.
2	*Aerva lanata*	Mountain Knotgrass	Whole plant, roots	Used for kidney stones, urinary disorders, and respiratory issues.
3	*Ageratum conyzoides*	Goatweed	Leaves, flowers	Antibacterial, wound healing, and used for fever in traditional medicine.

4	*Alternanthera sessilis*	Sessile Joyweed	Leaves	Used as a leafy vegetable; treats digestive disorders and wounds.
5	*Axonopus compressus*	Carpet Grass	Leaves	Ground cover and soil erosion prevention.
6	*Baccharis anomala*	-	Leaves, stems	Limited information available.
7	*Bidens bipinnata*	Spanish Needles	Leaves, flowers	Used for wounds, cuts, and as an anti-inflammatory agent.
8	*Boehmeria nivea*	Ramie/China grass	Fibers	Fibers used in textiles; roots used for detoxification in traditional medicine.
9	*Brachiaria reptans*	Creeping Signal Grass	Leaves, stems	Used as fodder and ground cover for erosion prevention.
10	*Brillantaisia owariensis*	Tropical Brillantaisia	Leaves, stems	Treats fever and respiratory problems in traditional medicine.
11	*Calopogonium mucunoides*	Tropical Kudzu	Leaves, stems	Used as forage and to improve soil fertility.
12	*Chromolaena odorata*	Siam Weed	Leaves, stems	Wound healing, antiseptic, and used for erosion control.
13	*Commelina africana*	African Dayflower	Leaves, stems	Used for wound healing and as fodder.
14	*Commelina benghalensis*	Bengal Dayflower	Leaves, stems	Treats wounds, burns, and is used as fodder.
15	*Commelina communis*	Asiatic Dayflower	Leaves, stems	Used in traditional medicine for skin diseases.
16	*Commelina diffusa*	Spreading Dayflower	Whole plant	Treats wounds, fever, and diarrhea.
17	*Commelina ensifolia*	Swordleaf Dayflower	Leaves, stems	Limited information available.
18	*Common teasel*	Teasel	Roots	Used for joint pain, inflammation, and Lyme disease.
19	*Crotalaria trichotoma*	Hairy Crotalaria	Whole plant	Used as green manure and fodder; some species are toxic.
20	*Crotalaria triquetra*	Three-angled Rattlebox	Whole plant	Used for soil improvement and green manure.
21	*Cynoglossum zeylanicum*	Indian Hound's Tongue	Leaves, roots	Treats skin diseases, fever, and wounds.
22	*Desmodium triflorum*	Tick Clover	Whole plant	Used for respiratory issues, wounds, and digestive disorders.
23	*Dichanthelium clandentium*	Panicgrass	Leaves, stems	Used as fodder.
24	*Digitalis purpurea*	Foxglove	Leaves	Used for heart-related ailments (contains cardiac glycosides).
25	*Digitaria ciliaris*	Southern Crabgrass	Leaves, stems	Fodder and erosion control.
26	*Drymaria cordata*	Tropical Chickweed	Leaves, stems	Treats colds, wounds, and eye infections.

27	*Echinochloa colonum*	Jungle Rice	Seeds, leaves	Used as fodder; seeds are consumed in times of famine.
28	*Ehrharta erecta*	Veldt Grass	Leaves, stems	Used as ornamental grass and for erosion control.
29	*Eleusine indica*	Indian Goosegrass	Seeds, leaves	Used as fodder; seeds used in porridge in some cultures.
30	*Emilia sonchifolia*	Lilac Tasselflower	Leaves, flowers	Treats wounds, fever, and digestive issues.
31	*Epipactis myelleri*	Myeller's Helleborine	Whole plant	Limited medicinal uses recorded.
32	*Eragrostis cillanensis*	Lovegrass	Leaves, stems	Used as fodder and for soil conservation.
33	*Eragrostis superba*	Weeping Lovegrass	Leaves, stems	Used as fodder and for soil stabilization.
34	*Fuirena umbellata*	Umbrella Fuirena	Roots, leaves	Treats skin infections and inflammation.
35	*Hemidesmus indicus*	Indian Sarsaparilla	Roots	Blood purifier, treats skin diseases, and digestive issues.
36	*Hippocrepis comosa*	Horseshoe Vetch	Leaves, flowers	Forage for livestock and used in traditional remedies for respiratory issues.
37	*Hyssopus officinalis*	Hyssop	Leaves, flowers	Used for coughs, digestive problems, and antiseptic purposes.
38	*Imperata cylindrica*	Cogon Grass	Rhizomes, leaves	Soil stabilization, fodder, and treating urinary infections.
39	*Indigofera prostrata*	Trailing Indigo	Leaves, stems	Limited use in traditional medicine for wounds.
40	*Indigofera trifoliata*	Three-Leaf Indigo	Leaves, stems	Used for treating ulcers and skin conditions.
41	*Justicia procumbens*	Water Willow	Leaves, roots	Antipyretic and used for treating fever and snake bites.
42	*Lamarckia aurea*	Golden Top Grass	Leaves, stems	Used as ornamental grass and for erosion prevention.
43	*Leersia oryzoides*	Rice Cutgrass	Leaves, stems	Fodder and soil erosion control.
44	*Leonotis nepetifolia*	Lion's Ear	Leaves, flowers	Antibacterial, wound healing, and used in ornamental gardening.
45	*Leucas aspera*	Thumbai	Leaves, flowers	Treats cough, cold, and snake bites; insect repellent.
46	*Liatris compacta*	Blazing Star	Leaves, flowers	Used in ornamental gardening and as a pollinator attractant.
47	*Linum hirsutum*	Hairy Flax	Seeds	Used for linen fiber; oil extracted for skin care and medicinal purposes.
48	*Mentha canadensis*	Japanese Mint	Leaves	Treats digestive issues, cough, and headaches.
49	*Mucuna pruriens*	Velvet Bean	Seeds, roots	Treats Parkinson's disease, nerve issues, and acts as an aphrodisiac.
50	*Oplismenus undulatifolius*	Basketgrass	Leaves, stems	Ground cover and forage for animals.
51	*Panicum capillare*	Witch Grass	Leaves, stems	Forage and used for erosion control.

52	*Panicum virgatum*	Switchgrass	Leaves, stems	Bioenergy crop and forage.
53	*Paspalum conjugatum*	Sour Paspalum	Leaves, stems	Used as ground cover and fodder.
54	*Pentanema germanicum*	German Elecampane	Leaves, roots	Limited medicinal use; ornamental plant.
55	*Phalaris minor*	Little Canary Grass	Leaves, seeds	Fodder; seeds used in poultry feed.
56	*Phaseolus vulgaris*	Common Bean	Seeds, pods	Edible; rich in protein; used in various cuisines.
57	*Phyllanthus maderaspatensis*	Madras Leaf Flower	Whole plant	Treats liver disorders and urinary infections.
58	*Phyllanthus narayanswamii*	-	Whole plant	Limited information available.
59	*Pimpinella saxifraga*	Burnet Saxifrage	Roots, leaves	Used in treating colic, digestive disorders, and to reduce fever.
60	*Poa annua*	Annual Bluegrass	Whole plant	Commonly considered a weed, but used in some traditional remedies.
61	*Portulaca oleracea*	Purslane	Leaves, stems	Rich in omega-3 fatty acids, used for inflammation and skin issues.
62	*Setaria verticillata*	Prostrate Bristlegrass	Leaves, stems	Fodder and ground cover.
63	*Sida acuta*	Wireweed	Whole plant	Treats wounds, ulcers, and fever.
64	*Sida rhombifolia*	Arrowleaf Sida	Leaves, roots	Used for fever and digestive issues.
65	*Solanum nigrum*	Black Nightshade	Leaves, berries	Treats fever, inflammation, and acts as an anti-inflammatory.
66	*Spilanthes acmella*	Toothache Plant	Leaves, flowers	Used for toothaches, mouth infections, and as a mild anesthetic.
67	*Stachytarpheta jamaicensis*	Blue Porterweed	Leaves, flowers	Treats fever and malaria.
68	*Synedrella nodiflora*	Guinea Grass	Whole plant	Fodder, used for erosion control.
69	*Tridax procumbens*	Coat Buttons	Whole plant	Wound healing, reduces bleeding, and treats fever.
70	*Urochloa mutica*	Para Grass	Leaves, stems	Used for forage and erosion control.
71	*Vetiveria zizanoides*	Vetiver	Roots	Used for soil erosion control, fragrance, and medicinal uses.
72	*Vigna radiata*	Mung Bean	Seeds	Edible; used for detoxification and digestive issues.
73	*Zornia diphylla*	Two-leaved Zornia	Whole plant	Limited medicinal uses.