Environmental Role Assessment of a Recovering Fragmented Dry Dipterocarp Forest on Surrounding Villages through Investigations of Soil Water Storage and Plant Communities in Northern Thailand

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ABSTRACT

Fragmented forests are dispersed across the uplands of northern Thailand. The forests are primarily the result of human activities, including establishing villages and roads. In the past, the forests were utilized for various purposes, both wood and non-wood products. At present, the utilization of only non-wood products is allowed. About 50 years of forest conservation have resulted in recovering forests. This research aims to assess the environmental significance of a fragmented dry dipterocarp forest as a water catchment area for surrounding villages through studying water retention and storage within soil and plant communities, including two sites of hilly (HA) and flat (FA) areas. Ten sampling plots, 40 x 40 meters in size, were used for plant community analysis in each area by a stratified random sampling. In each plot, all trees with at least 1.5-meter heights were measured for stem girth at 1.3 meters above ground and tree heights. The data were calculated for biomass using allometric equations. As a result, HA and FA forests were composed of 55 and 78 species, respectively. Twenty-seven species, each with five stems, were selected for collecting fresh samples of bark, stem, branch, and leaf, and subsequent measurements of water content for estimating amounts in plant biomass. The HA and FA forests had the amounts of 35.95 and 41.55 m^3/ha, respectively.

In each area, three plots were used for studying soil and water storage. Soil samples were collected along the depths to investigate gravel, bulk density, texture, organic matter, and water content. A soil corer, 5-cm diameter and height, was employed to estimate field capacity and soil moisture. The maximum water storage in HA three soil pits were estimated at 785.17, 909.54, and 800.83 m^3/ha (averaging 831.85 m^3/ha) whereas FA soil pits contained 1,486.88, 2,515.94, and 4,417.94 m^3/ha (2,806.92 m^3/ha). The water storage in plant biomass and soils of HA and FA areas was 867.80 and 2,848.50 m^3/ha, respectively. HA soil could store the maximum water of 95.85%, and only 4.15% in plant biomass while the FA soil had 98.54% for soil and 1.46% for plant biomass. HA forest could store maximum rainfall of 86.78 mm, while FA forest was 284.85 mm. Water storage can fluctuate daily and monthly throughout the year. In dry season (January 9, 2026), average water amount in HA soil was 105.42 m^3/ha, while that of FA soil was 745.56 m^3/ha, that is, HA soil contained only 12.67% of the maximum storage while FA soil was higher, 26.56%. The fragmented forests in HA and FA had differences of water storage due to different soil properties and depths. The total forest area was estimated to be 550 ha; 300 ha HA and 250 ha FA. In 2025, annual rainfall was recorded to be 1,630 mm, thus the total rainfall amount in this year was 8,965,000 m^3. The maximum water storage in HA and FA was in the following order: 260,340 m^3 and 712,125 m^3, a total of 972,465 m^3. The rainfall during the day of this year varied 5 to 70 mm (50 to 700 m^3/ha). If rainfall was 70 mm a day, the maximum rainfall amount of total area was 385,000 m^3.

Keywords: Fragmented forest/ Water storage/ Plant community/ Soil characteristics

1. INTRODUCTION

The fragmented forests provide both direct and indirect benefits to local people. The direct benefits include wood and non-wood forest products. However, tree cutting in the forest through forest concessions and use by local people is now prohibited, but the people can use dead trees as fuel wood as well as bamboo stems for household use. The main non-wood products in the dry dipterocarp forest (DDF) are edible mushrooms, insects and young sprouting leaves which give food and income to the

villagers for supporting sufficient economy. The indirect benefits of the forests are their environmental roles including carbon storage for reducing global warming and climate change, releasing oxygen into the air, water catchment area, wind break, protection of soil erosion, etc. The forest ecosystem has the functional role of hydrologic cycle which plays important influence in maintaining all organisms including plants, animals and microbes [4], [7], [16]. It can storage rainwater in various components particularly plant biomass and soil. A part of rainwater is intercepted by forest canopy and later lost into the atmosphere through evaporation. The remains pass the canopy as throughfall and stem flow to the ground. The organic layer on soil can absorb some water, and a part infiltrates into mineral soil while the remains lost to streams through surface and sub-surface runoff. Plants usually uptake water from soil and store in plant tissues of different organs such as stem, branch, leaf and root. This water is used for metabolism and their growth while some amount is lost into atmosphere through transpiration and makes cooling of forest site. The pioneer work on water storage in forest ecosystem was reported by Khamyong *et. al.* [2]. It was the research on water storages in plants and soils of two lower montane community forest of Karen tribe in northern Thailand and found that the conservation (watershed) forest had the higher amount of storage than the utilization forest. Tree cutting was permitted only in the utilization forest and became the main cause of decreasing hydrologic cycle function. The concept of water storage in forest ecosystem was applied to plantation forests in highland watershed [3], [14]. The objective of this research is to assess environmental role of a recovering fragmented DDF in northern Thailand on surrounding villages as the catchment area of rainwater through investigations of water storage potentiality in soil and plant community.

2. METHODOLOGY

2.1 Study area

The research area was DDF nearby Phra Phutthabat Tak Pha temple, Pa Sang district, Lumphun province in northern Thailand. It is located at a fragmented forest in the Mae Aow national reserve forest, covering about 5.5 square kilometers. The forest consists of three small mountains with altitudes of 342 to 515 meters. The level area is the wavey area with gentle slopes. In 2025, the average annual temperature was 27.9 ^{o}C and annual rainfall recorded by researchers was 1,630 millimeters and varied between 5 and 70 millimeters a day. The parent material is mainly sandstone. The rocks are weathered to be red-yellow lateritic soil. Deep into the soil, plinthite (hydrous oxides of iron and aluminum with clay) is formed and becomes hard as blocks when it is exposed to air [12]. The laterite blocks were extracted for sell to make building walls and houses by local people about 50 years ago and the old pits were observed. The forest had been used by local villagers since long time ago, and it was in very poor condition before the conservation. The large trees were cut down for house construction, while medium-sized trees were used to produce charcoal as a source of income for local people in nearby villages. The small trees were used as fuelwood. Nowadays, the forest is protected by the village head in cooperation with forestry officers. The condition of this secondary forest is gradually improving and is expected to develop into a healthy forest in the future.

2.2 Plant community study

The plant communities on hilly (HA) and flat (FA) areas were studied for their structures by using 10 sampling plots for each area, 40 x 40 meters in size. Each plot was divided into 16, 10 x 10 meters, and stem girths at breast height (1.3 meters) and tree heights of all trees with heights of 1.5 meters or more. The collected data were calculated for quantitative characteristics of tree species using functions described by Krebs [6]. Each tree species was identified for frequency, density, dominant and ecological important value index (IVI). Species diversity index was based on Shannon-Wiener Index (SWI). Similarity of plant communities between two areas was calculated form (2Sab/Sa+Sb) x 100 whereas Sa = number of species in communities A, Sb = number of species in communities B and Sab = number of species in both communities. These parameters were used for comparison of plant

community structures between the two areas. The plant species were identified for common, intermediate and rare species.

2.3 Plant community study

Calculation of standing plant biomass of all plant species used allometric equations studied by Ogino *et al*. [9] and Ogawa et al. [8]. Twenty-seven common species were selected as samples (5 individual per species) for collecting data of water content in bark, stem, branch and leaf by extraction of their fresh tissues (10-20 g). To determine the water content, tissue samples were oven dry at 80 ^{o}C for a few days. The content in root was the average of values in stem and branch. The means of these species were used for other species.

(1) stem biomass in kg/tree (W_S)

$$W_S = 189\ (D^2H)^{0.902}$$

(2) branch biomass in kg/tree (W_B)

$$W_B = 0.125\ (WS)^{1.204}$$

(3) leaf biomass in kg/tree (W_L)

$$1/W_L = (11.4/W_S^{0.90}) + 0.172$$

where D = diameters at breast height in meter
H = tree heights in meter

(4) root biomass in kg/tree (W_R)

$$W_R = 0.026\ (D^2H)^{0.775}$$

where D = diameters at breast height in centimeter
H = tree heights in meter

The amount of water stored in the biomass of each species was calculated, multiplying its biomass by the water content on a dry-weight basis. Water storage per hectare was estimated using the conversion factor of 1.0 Mg of water equivalent to 1.0 m^3.

2.4 Soil study and water storage

In each site of HA and FA, three sampling plots were selected for soil study. The three plots at mountain summit, middle and lower slopes were used whereas those of FA were located at nearby foot hill extending to the flat area with distance of about 500-700 meters apart. In each plot, three soil pits were made; one pit at the center area and two pits were in obliques about 15 meters apart. A total of 9 pits were made for each area. The pit was 1.5 m width and 2.0 m long. In the HA, three soil pits were very shallow (25 cm depth). The soil in FA varied from shallow to moderate deep and deep (40 to 130 cm). In each pit, soil samples were collected from the depth of 0-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100 and 100-130 cm. or depending on soil depth. The collection based on composite sampling, soil samples of the same layer from three pits within the same plot were mixed before laboratory analysis. Soil taxonomy used the American system [13]. Physicochemical properties of soil samples including bulk density, gravel content, texture, field capacity (FC), moisture content and organic matter were based on the methods of soil analysis [5], [10].

The maximum water storage of soil was determined from the field capacity (FC) [1], [2]. Water was added into the soil sample with the corers until the soil sample was completely saturated with water, and the water was allowed to drain out of the macro pores. Then, the soil samples were oven dried at 105°C within a few days or until they achieved constant weights, and later, their moisture content values by volume were determined. Finally, the amount of water storage per unit area (hectare) in each soil layer was determined and the total amount within the soil depth per unit area was calculated.

3. RESULTS AND DISCUSSION

In Table 1, topographic features of 10 sampling plots each of HA and FA were given: altitude ranges, 346-511 and 309-359 meters; slope gradients, 2-28% and 1-8%, respectively. The summit had a very gentle slope (2%) while other areas of middle and lower slopes varied between 10-28%. As for FA, it had almost gentle slopes. The aspects of HA were mainly northwest and southwest sites while those of FA were in the southeastern direction. This implies that HA had greater variation of solar radiation, temperature and site moisture than FA. Differences in topographic features might influence plant community structure and soil characteristics, which could further affect rainwater storage.

Table 1 Topographic features of 10 sampling plots, each of HA and FA in DDF

Plot	Altitude (m)	Position		Slope (%)	Slope aspect	Slope position	Most dominant species
		X	Y				
Hilly area							
S1	346	491357	2039722	18	S 35° W	Lower slope	*S. obtusa*
S2	347	491411	2039888	10	N 65° W	Lower slope	*G. usitata*
S3	362	491296	2039452	21	N 80° W	Middle slope	*S. obtusa*
S4	360	491621	2039962	28	N 70° W	Middle slope	*S obtusa*
S5	360	491584	2039777	26	N 32° W	Lower slope	*S. obtusa*
S6	368	491360	2039340	24	N 66° W	Middle slope	*P. siamensis*
S7	400	491340	2039181	24	S 80° W	Middle slope	*S. obtusa*
S8	374	491208	2039168	18	S 80° W	Lower slope	*S. obtusa*
S9	511	491622	2039486	2	S 24° E	Mount summit	*P. siamensis*
S10	487	491564	2039085	18	N 60° W	Mount summit	*P. siamensis*
Flat area							
F1	350	491101	2039382	3	N 85° W	Foot hill	*D. obtusifolius*
F2	343	490437	2039047	1	S 80° E	Gentle slope	*D. obtusifolius*
F3	336	490064	2038925	2	S 15° E	Flat	*D. obtusifolius*
F4	335	490178	2038980	1	S 3° E	Flat	*S. obtusa*
F5	344	490277	2038730	2	S 17° E	Flat	*D. obtusifolius*
F6	320	490132	2038699	2	S 8° E	Flat	*D. obtusifolius*
F7	331	490409	2038902	2	S 25° E	Flat	*S. obtusa*
F8	309	490036	2038699	7	S 2° W	Flat	*S. obtusa*
F9	326	490969	2039405	4	S 80° W	Flat	*S. obtusa*
F10	359	491101	2039258	10	N 65° W	Foot hill	*D. obtusifolius*

3.1 Plant community structure

In Table 2 and 3, plant community structures include dominant tree species, species composition, richness and populations were described. In both areas, *S. obtusa* was the most dominant tree species. The HA consisted of 55 species and had a density of 414 trees per plot. Species with the highest frequency (100%) include six, *Shorea obtusa*, *P. siamensis*, *Gluta usitata*, *Lannea coromandelica*, *Xylia xylocarpa* and *Dalbergia oliveri*. *S. obtusa* had the highest density (124 tree/plot) and dominance value, followed by *P. siamensis*, *G. usitata*, *Dipterocarpus obtusifolius* and *D. tuberculatus*. *S. obtusa* had also the highest important value index (IVI, 22.12%), followed by *P. siamensis*, *G. usitata*, *D. obtusifolius*, *L. coromandelica* and *D. tuberculatus*. As for FA, it consisted of 78 species and density of 433 tree/plot. Species with the highest frequency (100%) include five, *S. obtusa*, *L. coromandelica*, *Sindora siamensis*, *D. tuberculatus* and *Canarium subulatum*. *S. obtusa* had the highest density (119 tree/plot), followed by *D. obtusifolius*, *Memecylon scutetellatum*, *L. coromandelica* and *S. siamensis*. *S. obtusa* and *D. obtusifolius* had the highest dominance, followed by *C. subulatum*, *D. tuberculatus* and *X. xylocarpa*. *S. obtusa* had also the highest IVI (22.12%), followed by *D. obtusifolius*, *M. scutellatum*,

L. coromandelica and *P. siamensis*. The two communities had similarity of 70.67%. The Shannon-Wiener indexes of species diversity in communities of HA and FA were 3.20 and 4.05, respectively. It was implied to the lower species diversity in HA and higher in FA. Some species had different populations between two areas affecting their structures. *P. siamensis* in HA and FA were 793.2 and 130.7 tree/plot whereas *G. usitata* had 291.9 and 97.6 tree/plot. These two species were more abundant in HA. In contrast, *S. obtusa* in HA and FA had 543.9 and 889.7 tree/plot whereas *D. obtusifolius* were 156.7 and 409 tree/plot. *L. coromandelica* in HA and FA were 108.1 and 133.4 tree/plot. *M. scutellatum* had values of 8.8 and 303 tree/plot. These four species were more abundant in FA. *D. tuberculatus* in HA and FA had 53.9 and 44.3 tree/plot with a small difference. The other species had some small differences. These indicate some differences of plant community structure.

Table 2. A species list of plants in DDF in hilly and flat areas

Family	Scientific name	Growth form
1. Anacardiaceae	*1. Buchanania lanzan* Spreng.	big tree
	2. Gluta usitata (Wall.) Ding Hou	big tree
	3. Semecarpus anacardium Linn.f.	medium tree
	4. Lannea coromandelica (Houtt.) Merr.	big tree
2. Annonaceae	*5. Uvaria rufa* Blume	climber
	6. Uvaria dulcis Dunal	climber
	7. Goniothalamus laoticus C. E. C. Fisch.	small tree
	8. Monoon viride (Craib) B. Xue & R. M. K. Saunders	big tree
3. Apocynaceae	*9. Amphineurion marginatum* (Roxb.) D. J. Middleton	climber
	10. Wrightia arborea (Dennst.) Mabb.	medium tree
4. Bignoniaceae	*11. Stereospermum cylindricum* Pierre ex Dop.	medium tree
	12. Heterophragma sulfureum Kurz	small tree
	13. Millingtonia hortensis L. F.	small tree
5. Burseraceae	*14. Canarium subulatum* Guillaumin	big tree
6. Capparaceae	*15. Capparis zeylanica L.*	climber
7. Celastraceae	*16. Celastrus paniculatus* Willd.	climber
	17. Lophopetalum duperreanum Pierre	medium tree
8. Clusiaceae	*18. Garcinia succifolia* Kurz	medium tree
9. Combretaceae	*19. Terminalia chebula* Retz. var. *chebula*	small tree
	20. Terminalia mucronata Craib & Hutch.	big tree
	21. Combretum deciduum Collet & Hemsl.	climber
	22. Combretum latifolium Blume	climber
	23. Combretum wallichii DC.	climber
	24. Combretum quadrangulare Kurz	small tree
10. Chrysobalanaceae	*25. Parinari anamensis* Hance	medium tree
11. Dilleniaceae	*26. Dillenia obovata* (Blume) Hoogland	small tree
12. Dipterocarpaceae	*27. Pentacme siamensis* Miq.	big tree
	28. Shorea obtusa Wall. ex Blume	big tree
	29. Dipterocarpus obtusifolius Teijsm. ex Miq.	big tree
	30. Dipterocarpus tuberculatus Roxb.	big tree
13. Ebenaceae	*31. Diospiros ehretioides* Wall. ex G. Don	small tree
	32. Diospiros castanea (Craib) H. R. Fletcher	medium tree
	33. Diospiros mollis Griff.	small tree
14. Euphorbiaceae	*34.Croton persimilis* Mull. Arg.	small tree
15. Fabaceae	*35. Albizia odoratissima* (L.f.) Benth.	medium tree
	36. Albizia lebbeck (L.) Benth.	medium tree

Table 2. A species list of plants in DDF in hilly and flat areas (continue)

Family	Scientific name	Growth form
	37. Bauhinia variegata L.	small tree
	38. Bauhinia glauca (wall. ex Benth.) Benth.	climber
	39. Millettia extensa (Benth.) Baker	climber
	40. Dalbergia cultrata Graham ex Benth.	big tree
	41. Dalbergia oliveri Gamble	medium tree
	42. Dalbergia lakhonensis Gagnep	medium tree
	43. Sindora siamensis Teijsm. ex Miq.	medium tree
	44. Spatholobus parviflorus (DC.) Kuntze	climber
	45. Pterocarpus macrocarpus Kurz	big tree
	46. Lysiphyllum strychnifolium (Craib) A. Schmitz.	climber
	47.Xylia xylocarpa (Roxb.) W. Theob.	big tree
15. Hypericaceae	*48. Cratoxylum formosum* Byer subsp. *pruniflorum* Gogel	medium tree
16. Irvingiaceae	*49. Irvingia malayana* Oliv. ex A.W. Benn.	big tree
17. Lamiaceae	*50. Vitex peduncularis* Wall. ex Schauer	medium tree
18. Lauraceae	*51. Beilschmiedia gammieana* King ex Hook. f.	big tree
	52. Litsea glutinosa (Lour.) C.B. Rob.	small tree
	53. Litsea sp.	small tree
19. Loganiaceae	*54. Strychnos nux-vomica* L.	small tree
20. Malvaceae	*55. Colona flagrocarpa* (C. B. Clarke) Craib	small tree
	56. Pterospermum semisagittatum Buch.-Ham. ex Roxb.	small tree
21. Melastomataceae	*57. Memecylon plebejum* Kurz var. *plebejum*	shrub
22. Meliaceae	*58. Walsura robusta* Roxb.	small tree
	59. Chukrasia tabularis A. Juss.	medium tree
	60. Azadirachta indica A. Juss.	medium tree
23. Moraceae	*61. Artocarpus gomezianus* Wall. ex Trecul	medium tree
24. Myrtaceae	*62. Tristaniopsis burmanica* (Griff.) Peter G. Wilson & J.T. Waterh	small tree
25. Opiliaceae	*63. Cansjera rheedei* J.F. Gmel.	climber
	64. Melientha suavis Pierre	small tree
26. Ochnaceae	*65. Ochna intergerrima* (Lour.) Merr.	small tree
27. Olacaceae	*66. Schoepfia fragrans* Wall.	small tree
28. Phyllanthaceae	*67. Aporosa villosa* (Wall. ex Lindl.) Baill.	shrub
	68. Phyllanthus columnaris Mull. Arg.	small tree
	69. Phyllanthus emblica L.	small tree
	70. Antidesma ghaesembilla Gaertn.	small tree
	71. Bridelia retusa (L.) A. Juss.	small tree
29. Rhamnaceae	*72. Ziziphus oenoplia* (L.) Mill.	climber
30. Rubiaceae	*73. Catunaregam spathulifolia* Tirveng.	shrub
	74. Wendlandia tinctoria (Roxb.) DC.	small tree
	75. Gardenia obtusifolia Roxb. ex Gordon	shrub
	76. Gardenia sootepensis Hutch.	small tree
	77. Mitragyna rotundifolia (Roxb.) Kuntze	medium tree
	78. Morinda coreia Ham.	small tree
	79. Ixora sp.	shrub
31. Rutaceae	*80. Atalantia monophyla* (L.) DC.	small tree
32. Salicaceae	*81. Casearia gallifera* Tathana	small tree
	82. Flacourtia indica (Burm. F.) Merr.	small tree
33. Sapindaceae	*83. Schleichera oleosa* (Lour.) Merr.	big tree

Table 2. A species list of plants in DDF in hilly and flat areas (continue)

Family	Scientific name	Growth form
34. Sapotaceae	*84. Madhuca esculenta* H.R. Fletcher	small tree
35. Simaroubaceae	*85. Brusea javanica* (L.) Merr.	shrub
36. Symplocaceae	*86. Symplocos recemosa* Roxb.	small tree

Table 3. Quantitative characteristics of plants in DDF on hilly and flat areas

No.	Species	tree/plot	Frequency	Relative value (%)			IVI, 300	IVI, %
			%	Frequency	Density	Dominance		
				Hilly area				
1	*S. obtusa*	123	100	4.26	29.83	32.26	66.35	22.12
2	*P. siamensis*	121	100	4.26	29.32	24.99	58.57	19.52
3	*G. usitata*	41	100	4.26	10.00	12.39	26.64	8.88
4	*D. obtusifolius*	28	90	3.83	6.64	10.55	21.03	7.01
5	*L. coromandelica*	19	100	4.26	4.54	2.57	11.37	3.79
6	*D. tuberculatus*	9	90	3.83	2.27	3.38	9.48	3.16
7	*X. xylocarpa*	8	100	4.26	1.96	2.62	8.83	2.94
8	*G. obtusifolia*	7	70	2.98	1.71	0.71	5.40	1.80
9	*B. lanzan*	6	90	3.83	1.35	0.57	5.75	1.92
10	*M. esculenta*	6	80	3.40	1.33	1.55	6.29	2.10
	Species 11-55	46	1430	60.83	11.05	8.41	80.29	26.76
	Total (tree/rai)	414	2350	100	100	100	300	100
				Flat area				
1	*S. obtusa*	119	100	3.23	27.49	28.20	58.91	19.64
2	*D. obtusifolius*	76	90	2.90	17.48	28.40	48.78	16.26
3	*M. scutellatum*	40	90	2.90	9.29	3.60	15.79	5.26
4	*L. coromandelica*	25	100	3.23	5.83	3.48	12.53	4.18
5	*P. siamensis*	15	90	2.90	3.54	1.64	8.08	2.69
6	*S. siamensis*	12	100	3.23	2.84	2.62	8.69	2.90
7	*G. usitata*	12	60	1.94	2.79	1.96	6.68	2.23
8	*X. xylocarpa*	11	90	2.90	2.63	4.25	9.79	3.26
9	*D. tuberculatus*	11	100	3.23	2.57	4.52	10.31	3.44
10	*C. subulatum*	11	100	3.23	2.50	4.78	10.50	3.50
	Species 11-78	101	2190	70.31	23.04	16.55	109.94	36.64
	Total (tree/rai)	433	3100	100	100	100	300	100

3.2 Role of plant biomass on water storage

As shown in Table 4, 5 and 6, average values of water contents in different organs of 27 common tree species among 86 species varied: bark, 30.16-68.39%; stem, 17.61-50.43%; branch, 36.30-59.22%; leaf, 43.91-69.11% and root, 28.22-59.41%. The mean water content was the highest in leaf, followed by bark, brunch, root and stem. The water contents in bark were relatively higher (61.80-64.28%) for *G. usitata*, *L. coromandelica*, *C. subulatum* and *M. rotundifolia*, and in leaf (63.31-69.11%) for *B. lanzan*, *M. coreia*, *G. sootepensis* and *M. rotundifolia*. In HA, *S. obtusa* had the highest biomass water among 55 species (28.81%), followed by *P. siamensis*, *D. obtusifolius*, *G. usitata*, *L. coromandelica*, *D. tuberculatus*, etc. As for FA, *D. obtusifolius* had the highest water amount among 78 species (31.05%), followed by *S. obtusa*, *C. subulatum*, *L. coromandelica*, *D. tuberculatus*, *X. xylocarpa*, etc.

In Table 7, plant biomass within 10 plots of HA varied between 7,945.724 and 11,984.69 kg/rai (10,118.62 kg/rai on average), and lower than those of FA were 8,680.46 and 12,770.16 kg/rai

(10,691.28 kg/rai). However, the difference in plant biomass between the two areas was not statistically significant. The biomass in this study was lower than that of the DDF at the Huai Hong Khrai Royal Development Study Center (site 1), Chiang Mai Province (99.99 Mg/ha), where forest conservation began in approximately the same year as in the study area, and also lower than a community forest (site 2) which had been well conserved for a long period (125.49.0 Mg/ha) [11].The lower biomass was caused by severe disturbance from tree cutting in the past, which subsequently resulted in lower water storage in plant biomass. The water amounts in plant biomass varied among 10 sampling plots: 29.41-42.20 m^3/ha for HA (averaging 35.95 m^3/ha) and 30.13-59.16 m^3/ha for FA (41.58 m^3/ha) (Table 8). Phongkhamphanh *et al*. [11] reported that the amounts of water storage on sites 1 and 2 were also higher, 100.70 and 124.55 m^3/ha, respectively.

Table 4. Average water contents in plant organs of 27 tree species in the DDF

Plant species	Water content (% by fresh weight)				
	Bark	**Stem**	**Branch**	**Leaf**	**Root**
1. *S. obtusa*	40.01	26.23	40.25	49.34	33.12
2. *P. siamensis*	38.27	33.13	43.13	51.81	35.70
3. *D. obtusifolius*	40.10	30.80	48.94	52.70	35.45
4. *D. tuberculatus*	54.39	30.35	55.41	59.31	42.37
5. *G. usitata*	64.11	34.00	51.91	55.87	49.05
6. *L. coromandelica*	68.39	50.43	59.22	54.72	59.41
7. *X. xylocapa*	57.85	26.36	49.69	53.20	42.11
8. *D. oliveri*	39.47	17.61	36.55	49.44	28.54
9. *G. obtusifolia*	50.66	33.08	46.58	56.67	41.87
10. *B. lanzan*	42.95	39.28	52.44	69.11	41.11
11. *M. esculenta*	55.45	28.81	48.33	46.21	42.13
12. *C. subulatum*	64.27	42.17	56.34	57.19	53.22
13. *P. semisagittatum*	45.13	31.58	44.38	50.12	38.36
14. *C. spathulifolia*	33.10	25.52	36.70	55.36	29.31
15. *S. anacadium*	43.94	43.83	53.81	59.15	43.88
16. *M. coreia*	40.09	43.27	48.33	63.31	41.68
17. *M. plebejum*	30.25	28.51	40.99	57.26	29.38
18. *I. malayana*	48.38	30.93	46.99	55.84	39.66
19. *T. mucronata*	46.57	30.31	43.47	54.97	38.44
20. *S. siamensis*	30.16	26.28	36.30	43.91	28.22
21. *G. sotepensis*	43.77	40.19	54.42	68.31	41.98
22. *A. indica*	53.45	29.57	46.94	53.93	41.51
23. *L. glutinosa*	48.98	36.23	45.53	54.09	42.61
24. *M. rotundifolia*	61.80	33.56	58.41	59.98	47.68
25. *O. intergerrima*	38.91	33.33	42.02	52.87	36.12
26. *D. obovata*	55.84	41.41	56.30	65.89	48.62
27. *P. macrocarpus*	52.03	25.48	45.77	55.29	38.75
mean	**47.72±10.19**	**33.05±7.05**	**47.75±6.54**	**55.77±5.89**	**40.38±7.25**

Table 5. Amounts of water stored in biomass of tree species in DDF on hilly area (HA)

Species	Water amount in plant biomass (m^3/ ha)						
	Bark	**Stem**	**Branch**	**Leaf**	**Root**	**Total**	**%**
1. *S. obtusa*	1.751	4.052	2.264	0.687	1.602	10.356	28.81
2. *P. siamensis*	1.378	3.966	1.420	0.548	1.268	8.580	23.87
3. *D. obtusifolius*	0.561	1.957	1.189	0.238	0.744	4.690	13.05
4. *G. usitata*	0.639	1.838	0.692	0.237	0.567	3.973	11.05
5. *L. coromandelica*	0.036	0.935	0.338	0.063	0.299	1.671	4.65
6. *D. tuberculatus*	0.094	0.569	0.455	0.094	0.265	1.476	4.11
7. *X. xylocapa*	0.074	0.345	0.288	0.060	0.166	0.934	2.60
8. *C. subulatum*	0.028	0.444	0.215	0.042	0.151	0.881	2.45
9. *M. esculenta*	0.052	0.138	0.148	0.040	0.088	0.466	1.30
10. *I. malayana*	0.028	0.137	0.073	0.020	0.051	0.309	0.86
11. *D. oliveri*	0.058	0.093	0.071	0.020	0.041	0.285	0.79
12. *L. duperreanum*	0.037	0.107	0.037	0.015	0.035	0.231	0.64
13. *S. anacadium*	0.017	0.092	0.039	0.011	0.036	0.195	0.54
14. *G. obtusifolia*	0.017	0.080	0.028	0.018	0.037	0.179	0.50
15. *V. peduncularis*	0.012	0.105	0.026	0.008	0.021	0.172	0.48
16. *B. lanzan*	0.022	0.057	0.033	0.018	0.033	0.163	0.45
17. *M. coreia*	0.016	0.074	0.027	0.010	0.023	0.151	0.42
18. *M. rotundifolia*	0.009	0.053	0.035	0.008	0.024	0.129	0.36
19. *A. gomerzianus*	0.008	0.076	0.024	0.004	0.013	0.125	0.35
20. *O. intergerrima*	0.012	0.043	0.013	0.007	0.016	0.090	0.25
21. specie 21 to 55	0.122	0.428	0.155	0.055	0.131	0.891	2.48
Total	**4.97**	**15.59**	**7.57**	**2.20**	**5.61**	**35.95**	**100**

3.3 Role of soils on water storage

3.3.1 Soil physical properties and depths

In Table 9, physical properties have important role in water retention and storage including soil types, bulk density, gravel contents, texture and organic matter. The three soil pits on HA were very shallow, 25 cm depths with a profile of A/AC/C/R classified into order Entisols. It was the soil having very poor horizon development. In contrast, those on FA varied from shallow to moderately deep and deep, order Inceptisols. The soil depths and horizons were varied: FA-1; 40 cm, A/BA/Bw/C, FA-2; 80 cm, A1/A2/B1/B2/BC/C and FA-3; 130 cm, A1/A2/B1/B2/B3/BC/C (Figure 1). The bulk density is soil particles of sand, silt and clay excluding gravel in Mg/m^3. Three soil pits of HA had very low values (VL), 0.49-0.76 Mg/m^3 because of many gravels. As for FA, the variation was appeared among soil pits: FA-1, moderately low (ML) at 0-20 cm depth and low (L) at 20-40 cm; FA-2 moderately low (ML) at 0-10 cm depth, low (L) at 10-20 cm, very low (VL) at 20-80 cm; FA-3, moderately (M) at 0-60 cm depth and moderately high (MH) at 60-130 cm. The soils of both two areas had low densities. The density impacted on water infiltration, soil erosion and movement of matter into subsoils. The three soil pits in HA had relatively high gravel contents in their profiles, varying 49.87-69.81% by weight. Those of FA had the smaller amounts: FA-1, 11.94-23.73%; FA-2, 8.08-54.31% and FA-3, 0.18-1.60%. The high gravel contents in soil of HA imply to slowly rock weathering whereas the lower contents of FA soil indicate progressive soil horizon development with more rock weathering. The soil texture is combination of three percentages of sand, silt and clay particles. In HA, soil textures were coarse: loamy sand and sandy loam. In contrast, those of FA had also a coarse texture, mainly loamy sand. There was a small difference in soil texture between two areas. These soils had relatively low clay content throughout the soil profiles, resulting in low water retention. Soil organic matter influences both physical and chemical properties. Its physical effect includes water retention; the higher content of

organic matter results in greater water holding capacity. These factors are important to water infiltration moving down to subsoils [1].

Table 6. Amounts of water stored in biomass of tree species in DDF on flat area (FA)

Species	Water amount in plant biomass (m^3/ ha)						
	Bark	**Stem**	**Branch**	**Leaf**	**Root**	**Total**	**%**
1. *D. obtusifolius*	1.540	5.374	3.332	0.634	2.018	12.899	31.05
2. *S. obtusa*	1.550	3.587	2.040	0.595	1.412	9.185	22.11
3. *C. subulatum*	0.098	1.538	0.857	0.115	0.479	3.087	7.43
4. *L. coromandelica*	0.049	1.288	0.475	0.085	0.408	2.305	5.55
5. *D. tuberculatus*	0.136	0.823	0.669	0.131	0.378	2.137	5.14
6. *X. xylocapa*	0.125	0.582	0.513	0.092	0.271	1.583	3.81
7. *M. coreia*	0.127	0.580	0.260	0.056	0.152	1.175	2.83
8. *S. siamensis*	0.230	0.365	0.182	0.045	0.126	0.948	2.28
9. *M. plebejum*	0.177	0.354	0.116	0.092	0.155	0.895	2.15
10. *A. villosa*	0.046	0.293	0.125	0.059	0.115	0.639	1.54
11. *G. usitata*	0.092	0.264	0.087	0.040	0.089	0.571	1.37
12. *A. indica*	0.041	0.242	0.149	0.030	0.087	0.550	1.32
13. *I. malayana*	0.049	0.236	0.145	0.028	0.080	0.539	1.30
14. *P. siamensis*	0.080	0.229	0.072	0.036	0.080	0.498	1.20
15. *T. mucronata*	0.051	0.217	0.124	0.028	0.074	0.494	1.19
16. *S. anacadium*	0.035	0.185	0.090	0.019	0.066	0.395	0.95
17. *D. obovata*	0.016	0.179	0.077	0.030	0.068	0.371	0.89
18. *C. spathulifolia*	0.095	0.095	0.070	0.023	0.042	0.325	0.78
19. *M. rotundifolia*	0.022	0.129	0.091	0.018	0.055	0.314	0.76
20. *P. macrocarpus*	0.020	0.085	0.058	0.016	0.036	0.214	0.52
21. species 21 to 78	0.264	1.241	0.422	0.145	0.354	2.426	5.84
Total	**4.84**	**17.89**	**9.96**	**2.32**	**6.55**	**41.55**	**100**

3.3.2 Water storage in soils

In Table 10, field capacity (FC) and maximum water storage were difference between HA and FA soils: FC, 27.76-36.88% for HA and 24.42-47.30% for FA by volume, and maximum water storage in soil profiles, 785.17-909.54 m^3/ha within 25 cm depth HA soil (831.85 m^3/ha in average) and 1,486.88-4,081.15 m^3/ha within 40-130 cm FA soil (2,694.66 m^3/ha). The maximum storage of HA soil was lower than FA soil because of shallow soil, higher gravel content and lower amount of soil mass. Within 25 cm depths, the HA soil had slightly lower water storage (15.01% of FA soil) as compared with the upper layer of FA three soil pits which had water amounts of 929.02-1,021.85 m^3/ha (averaging 978.74 m^3/ha). This implies different soil properties, particularly soil mass. HA soil contained many gravels and thus decreasing soil mass whereas FA soil had a larger amount of soil mass and fewer or less gravel. Thichan *et al*. [15] reported that the DDF soil of order Oxisols with 100 cm depth could store the larger amount of maximum water storage as 5,113.74 m^3/ha, because this soil type had the high clay accumulation in their soil profiles.

Table 7. Amounts of plant biomass within 10 plots in DDF, each of HA and FA

Plot no.	Most dominant species	No. of trees	Biomass (kg/plot)				
			W_S	W_B	W_L	W_R	Total
			Hilly area				
1	*Shorea obtusa*	416	7,671.71	1,873.34	377.06	1,772.14	11,694.24
2	*Gluta usitata*	342	5,208.42	1,236.57	266.65	1,233.59	7,945.24
3	*Shorea obtusa*	449	6,673.02	1,618.84	332.23	1,559.55	10,183.64
4	*Shorea obtusa*	439	6,871.36	1,636.96	350.12	1,619.50	10,477.94
5	*Shorea obtusa*	565	7,858.54	1,877.20	398.78	1,850.17	11,984.69
6	*Pentacme siamensis*	459	6,357.08	1,485.58	332.29	1,518.32	9,693.26
7	*Shorea obtusa*	347	6,508.64	1,595.74	318.22	1,500.11	9,922.72
8	*Shorea obtusa*	349	5,820.08	1,398.03	293.54	1,366.01	8,877.67
9	*Pentacme siamensis*	332	6,538.36	1,595.10	321.81	1,510.85	9,966.11
10	*Pentacme siamensis*	442	6,841.96	1,661.74	339.87	1,597.12	10,440.70
	Mean (kg/rai)	414	6,634.92	1,597.91	333.06	1,552.74	10,118.62
	S.D.	73	779.87	195.24	37.88	178.11	1,188.28
	Mean (kg/ha)	2,587	41,468.23	9,986.94	2,081.61	9,704.61	63,241.38
			Flat area				
1	*Dipterocarpus obtusifolius*	517	7,554.03	1,963.20	339.35	1,691.65	11,548.23
2	*Dipterocarpus obtusifolius*	299	8,359.85	2,245.91	354.02	1,810.37	12,770.16
3	*Dipterocarpus obtusifolius*	175	6,279.66	1,768.31	244.23	1,317.34	9,609.55
4	*Shorea obtusa*	270	5,834.65	1,575.65	245.86	1,267.34	8,923.51
5	*Dipterocarpus obtusifolius*	355	6,302.65	1,614.44	290.29	1,427.67	9,635.05
6	*Dipterocarpus obtusifolius*	369	8,136.14	2,140.21	358.57	1,796.81	12,431.72
7	*Shorea obtusa*	585	7,247.41	1,694.88	380.21	1,740.93	11,063.42
8	*Shorea obtusa*	523	7,600.03	1,865.01	372.82	1,766.26	11,604.12
9	*Shorea obtusa*	600	5,685.21	1,258.77	318.18	1,418.31	8,680.46
10	*Dipterocarpus obtusifolius*	633	6,966.99	1,649.41	360.80	1,669.39	10,646.59
	Mean (kg/rai)	433	6,996.66	1,777.58	326.43	1,590.61	10,691.28
	S.D.	151	892.25	274.38	47.76	199.02	1,360.63
	Mean (kg/ha)	2704	43,729.13	11,109.87	2,040.21	9,941.29	66,820.49

Table 8. Amounts of water stored in plant biomass of 10 plots each of HA and FA in DDF

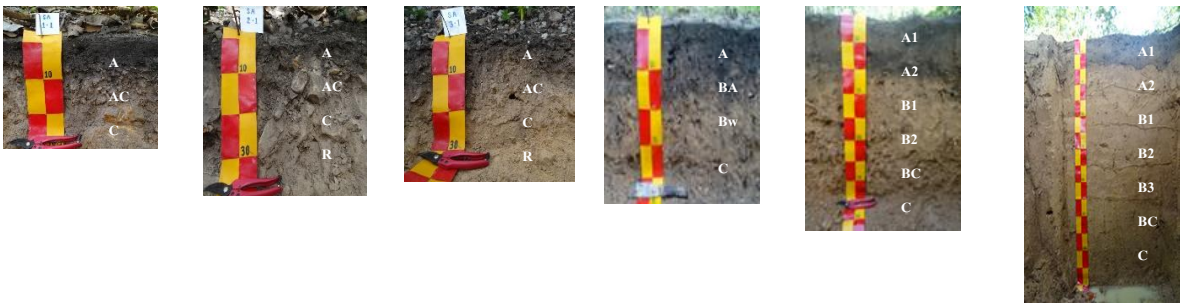
Plot	Bark	Stem	Branch	Leaf	Root	Total	
	(m^3/plot)					m^3/rai	m^3/ha
Hilly area							
1	0.94	2.45	1.29	0.38	0.92	5.98	37.41
2	0.65	2.12	0.91	0.29	0.73	4.71	29.41
3	0.77	2.65	1.30	0.36	0.94	6.02	37.65
4	0.83	2.32	1.22	0.37	0.90	5.64	35.23
5	0.90	2.85	1.49	0.42	1.08	6.75	42.20
6	0.73	2.44	1.16	0.36	0.89	5.58	34.85
7	0.76	2.30	1.22	0.34	0.86	5.48	34.28
8	0.67	2.17	1.16	0.32	0.83	5.14	32.15
9	0.87	2.65	1.03	0.33	0.83	5.71	35.71
10	0.82	2.98	1.33	0.37	0.99	6.49	40.58
mean	0.79±0.10	2.49±0.29	1.21±0.16	0.35±0.04	0.89±0.10	5.75±0.60	35.95±3.76
Flat area							
1	0.84	3.47	1.90	0.41	1.23	7.85	49.04
2	0.90	3.72	2.18	0.40	1.30	8.51	53.16
3	0.60	2.59	1.72	0.30	0.95	6.16	38.51
4	0.56	2.55	1.46	0.30	0.89	5.77	36.06
5	0.73	2.49	1.47	0.34	0.94	5.97	37.32
6	0.92	3.35	1.90	0.41	1.19	7.77	48.54
7	0.86	2.78	1.38	0.42	1.06	6.50	40.60
8	0.84	2.91	1.52	0.40	1.06	6.72	42.01
9	0.66	2.02	0.99	0.33	0.82	4.82	30.13
10	0.84	2.73	1.41	0.39	1.05	6.42	40.12
mean	0.77±0.13	2.86±0.52	1.59±0.34	0.37±0.05	1.05±0.16	6.65±1.11	41.58±6.92

3.4 Water storage in the DDF ecosystem

In this study, the average in plant biomass of two areas was 65.03 Mg/ha and could store water amount of 38.77 m^3/ha. Water storage in plant biomass depends on forest conditions, which can be determined as poor, intermediate, or good. Poor forests generally have lower biomass and, consequently, lower water storage. As for DDF soils, differences in soil types accompanied by increasing soil depth, from Entisols to Inceptisols, Ultisols, and Oxisols, result in an increase in maximum water storage [11], [15]. The maximum water storage of HA and FA were 831.85 and 2,806.92 m^3/ha. The water storage in DDF ecosystem was the combination of water in plant biomass and soil. Their total amounts were 867.8 and 2,736.2 m^3/ha. These values can be stored the maximum rainwater of 86.8 mm in HA and 284.9mm in FA (185.8 mm on average). As shown in Figure 2, most of the water storage in DDF ecosystem occurred in soil, 95.54% in HA and 98.54% in FA, and very small values were found in plant biomass (4.15% in HA, 1.46% in FA).

Table 9. Soil physical properties in HA and FA of DDF

Depth (cm)	Bulk density (Mg/m^3)	Gravel (%)	Organic matter (%)	Sand (%)	Silt (%)	Clay (%)	Texture
Hilly area							
Pedon 1							
0-10	0.66 VL	49.87	3.62	80	16	4	loamy sand
10-25	0.67 VL	61.08	0.49	80	16	4	loamy sand
Pedon 2							
0-10	0.49 VL	68.73	3.54	70	20	10	sandy loam
10-25	0.76 VL	51.48	0.79	70	20	10	sandy loam
Pedon 3							
0-10	0.51 VL	69.81	2.94	70	22	8	sandy loam
10-25	0.66 VL	58.14	0.49	68	24	8	sandy loam
Flat area							
Pedon 4							
0-10	1.34 ML	12.19	0.90	82	12	6	loamy sand
10-20	1.28 ML	11.94	0.47	82	14	4	loamy sand
20-30	1.11 L	23.73	0.21	82	12	6	loamy sand
30-40	1.15 L	18.82	0.17	82	10	8	loamy sand
Pedon 5							
0-10	1.37 ML	8.08	0.67	84	14	2	loamy sand
10-20	1.09 L	25.58	0.43	82	14	4	loamy sand
20-30	0.96 VL	39.51	0.20	82	14	4	loamy sand
30-40	0.92 VL	37.21	0.21	82	16	2	loamy sand
40-60	0.94 VL	36.23	0.19	82	14	4	loamy sand
60-80	0.74 VL	54.31	0.22	82	14	4	loamy sand
Pedon 6							
0-10	1.40 M	0.45	0.47	82	16	2	loamy sand
10-20	1.43 M	0.39	0.27	84	12	4	loamy sand
20-30	1.48 M	0.24	0.24	82	14	4	loamy sand
30-40	1.42 M	0.18	0.16	82	14	4	loamy sand
40-60	1.53 M	0.39	0.19	82	14	4	loamy sand
60-80	1.60 MH	0.42	0.15	82	14	4	loamy sand
80-100	1.63 MH	0.43	0.16	80	14	6	loamy sand
100-130	1.79 MH	1.60	0.20	76	12	12	sandy loam



Summit (HA-1) | Middle slope (HA-2) | Lower slope (HA-3) | Foot hill (FA-1) | Middle area (FA-2) | Flat area (FA-3)

Figure 1. Six soil profiles and horizons in HA and FA of DDF

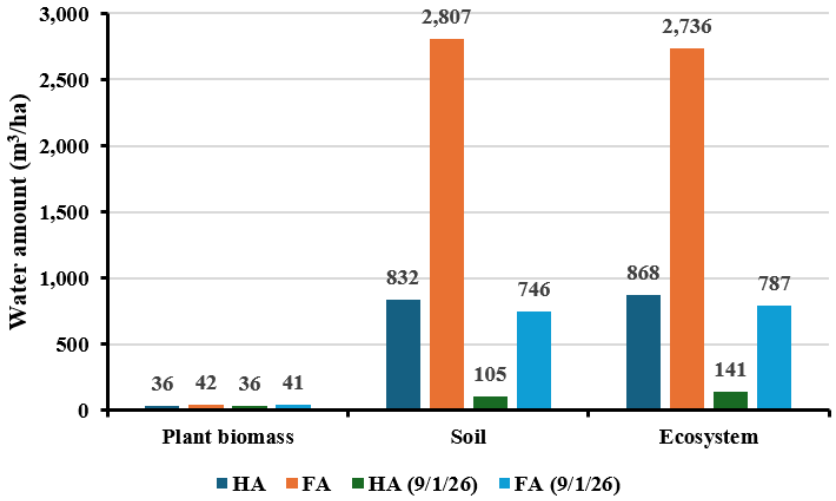


Figure 2. The maximum water storage and water amount (09/01/2026) in plant biomass, soil and ecosystem of the DDF

In winter on 9th January 2026, soil moisture contents were very low in this season (12.67% of FC for HA and 27.67% for FA), and all leaves were fallen to the ground (thus, no water storage in leaf biomass). The amounts of ecosystem water storage were quite very low. Compared with the head watershed forest of lower mountain forest (LMF) with well protection [2], the forest had plant biomass of 252.4 Mg/ha and could store a high amount of water, 222.6 m^3/ha. The maximum water storage within 2 m depth was estimated at 9,584 m^3/ha. Then, the maximum ecosystem storage was calculated to 9,806.6 m^3/ha, equivalent to a rainwater storage capacity of 980.7 mm. This indicated that the DDF ecosystem had a lower water storage capacity, at only 18.95% of that of the LMF ecosystem. In Figure 3, The annual rainfall in 2025 was 1,630 mm (February to November) with variation of rainfall as 5 to 70 mm per day. Therefore, this forest area can support the maximum rainfall (70 mm), and there is no risk of flooding but high risk of drought. There is a trend of decreasing rainfall in this research area in 2026. The conservation of the fragmented forests in Lamphun province is important for maintaining moisture conditions of local areas.

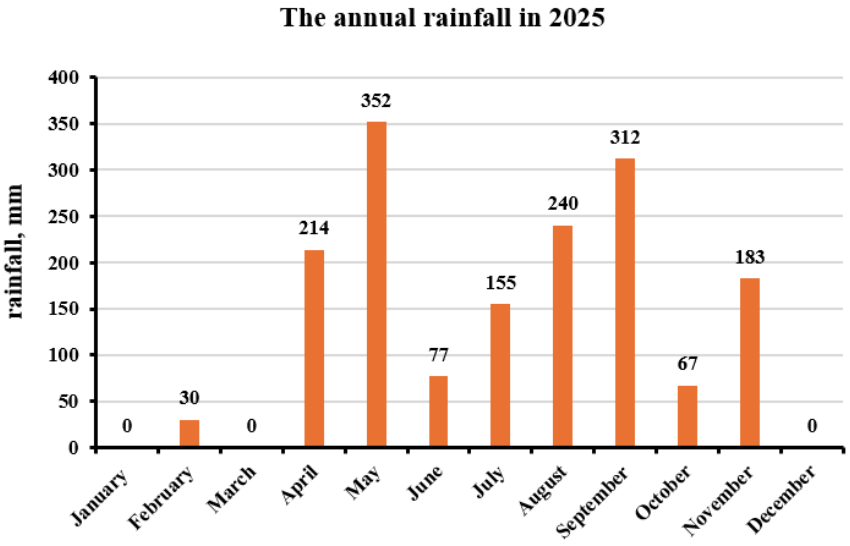


Figure 3. The seasonal rainfall amounts in the study area

Table 10. Maximum amount of water storage and water storage in DDF soil on 9 January 2026

Depth (cm)	Field capacity by volume %	Maximum water storage m^3/ha	Soil water (09/01/2026) by volume %	Soil water (09/01/2026) Amount m^3/ha
		Hilly area		
Pedon 1				
0-10	36.88	368.82	2.29	22.86
10-25	27.76	416.36	4.93	73.94
0-25 (total)		**785.17**		**96.80**
Pedon 2				
0-10	36.62	366.20	4.19	41.89
10-25	36.22	543.34	4.91	73.63
0-25 (total)		**909.54**		**115.52**
Pedon 3				
0-10	34.52	345.24	3.20	32.03
10-25	30.37	455.59	4.79	71.90
0-25 (total)		**800.83**		**103.93**
Mean (3 pedons)		**831.85**		**105.42**
		Flat area		
Pedon 4				
0-10	47.30	472.97	3.56	35.57
10-20	38.10	381.01	3.79	37.91
20-30	33.57	335.73	4.37	43.65
30-40	29.72	297.17	4.64	46.44
0-40 (total)		**1,486.88**		**163.57**
Pedon 5				
0-10	43.68	436.79	1.99	19.87
10-20	33.53	335.25	4.02	40.15
20-30	31.40	313.95	5.57	55.68
30-40	31.20	311.98	6.88	68.76
40-60	31.48	629.61	7.54	150.76
60-80	24.42	488.36	8.43	168.70
0-80 (total)		**2,515.94**		**503.92**
Pedon 6				
0-10	41.74	417.36	5.03	50.34
10-20	38.22	382.20	5.42	54.18
20-30	37.16	371.60	6.88	68.76
30-40	33.12	331.24	6.86	68.59
40-60	33.68	673.56	8.66	173.25
60-80	32.12	642.31	13.14	262.86
80-100	31.64	632.73	15.12	302.47
100-130	32.23	966.93	19.62	588.74
0-130 (total)		**4,417.94**		**1,569.19**
Mean (3 pedons)		**2,806.92**		**745.56**
p-value (0.05 = 2.776)		0.083		0.205
df (1, 4)		ns		ns

4. CONCLUSIONS

The DDF could store rainwater in two components: soil and plant biomass, with some differences between hilly and flat areas. The water amounts in biomass and soil of hilly area were lower than flat area, but they were not statistically significant. Plant community structure had some differences between two areas whereas soil type was different due to depths, bulk densities, gravel contents, textures and organic matter. Fragmented forests play an important role as water catchment areas in reducing the risk of drought in Lamphun province, where rainfall has shown a decreasing trend due to climate change.

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