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Evaluation of Appropriate Locations and Capacities of On-farm Ponds in Northeast Thailand

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Abstract

For planning to construct a small-scale on-farm pond in rainfed agricultural areas, the selection of an appropriate location and capacity is extremely important in order to maximize the availability and hydrologic benefits of the pond. To identify both features, we used hydrologic functions related to water harvesting and distribution at existing on-farm ponds in Nong Saeng village, Khon Kaen Province, northeast Thailand. We used two indices, the water harvesting index (I_{HW}) and the water distribution index (I_{DW}), to evaluate the appropriateness of locations and capacities. The Soil Conservation Service (SCS) method and water balance method were used to calculate I_{HW}, and GIS analysis was performed to identify the potential area for I_{DW}. The evaluation showed that no on-farm pond in the study area had a good combination of both. This result indicates that it is necessary to select appropriate location and capacity by applying the indices before constructing a new on-farm pond.

Discipline: Watershed and regional resources management

Additional key words: GIS, index of water distribution (I_{DW}), index of water harvesting (I_{HW}), rainfed agriculture

Introduction

Northeastern Thailand is characterized by a monsoon climate that consists of a rainy season from mid-May to mid-October and a dry season for the rest of the year. However, differences among years are significant, and the fluctuation of rainfall renders agriculture in the region unstable[6]. In addition to the pattern of fluctuating rainfall, the region's soils are typically sandy, with a low water-holding capacity, making the development of large-scale water resources difficult. Consequently, these conditions make new irrigation facilities difficult and expensive to construct. Under such circumstances, small-scale on-farm ponds, which are considered to offer a cost-effective way to harvest water and supply it during dry periods, have been extensively constructed in northeast Thailand. However, many on-farm ponds are not effectively utilized owing to an inappropriate choice of pond location or capacity[4]. Selecting an appropriate location and capacity for these ponds is necessary in order to harvest and distribute water properly, thereby permitting sustainable rainfed agriculture in the region.

The objective of this study is to evaluate the appropriateness of locations and capacities of on-farm ponds under different conditions in two subwatersheds around Nong Saeng village, Khon Kaen Province, northeast Thailand. It is expected that the results can contribute toward providing useful information for planning and constructing new on-farm ponds.

Materials and methods

1. Site description

We selected two subwatersheds near Nong Saeng village, approximately 30 km south of Khon Kaen city, northeast Thailand (Fig. 1), to evaluate the appropriateness of locations and capacities of on-farm ponds. Subwatershed 1 (SW1) and subwatershed 2 (SW2) cover an area of 158 and 77.8 ha, respectively. Both are located within the Huai Muang watershed, which supplies water to the Chi River. The topography of this region is gently undulating, and the annual rainfall is around 1,200 mm. Lowland areas are dominated by paddy fields, and upland areas grow

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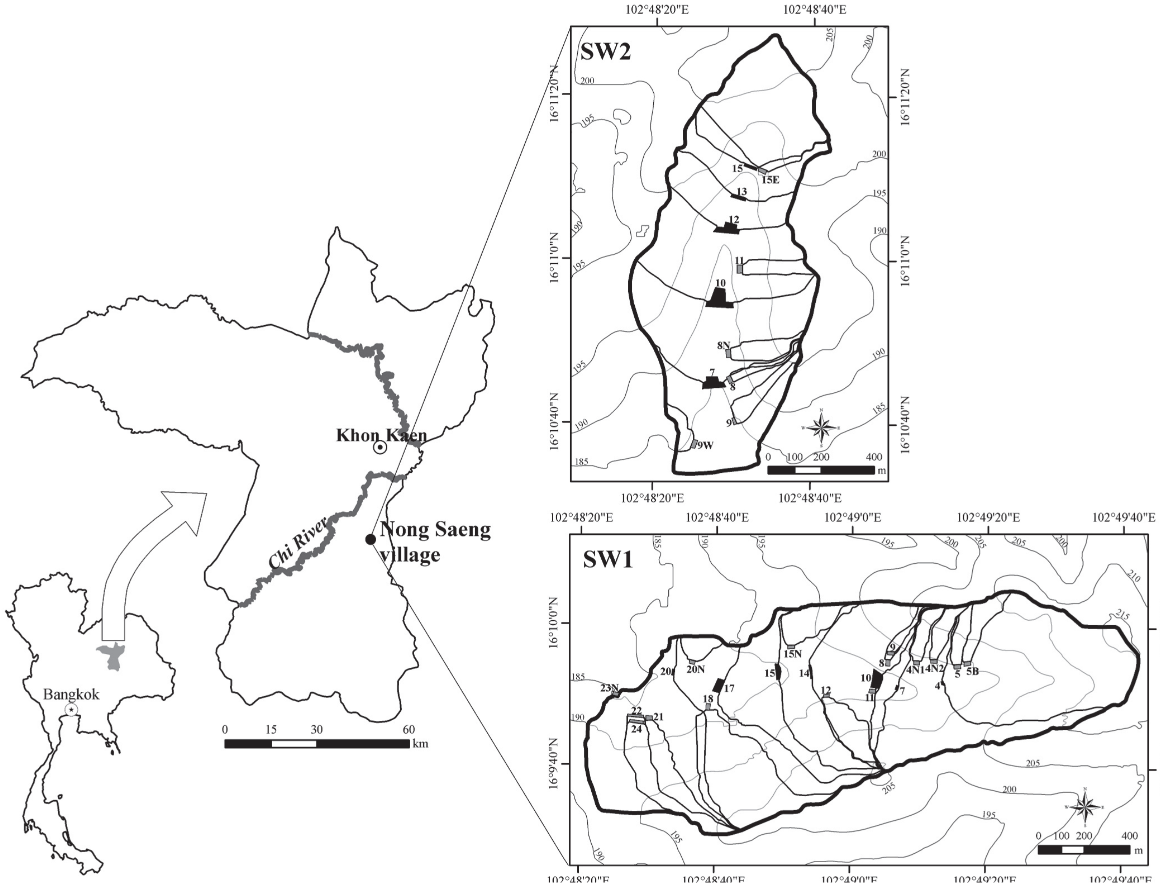

Fig. 1. Location of the study site and of the on-farm ponds in two subwatersheds (SW1 and SW2)

: Upper pond, : Lower pond, : Subwatershed boundary,
: Pond catchment boundary, : Counterline.

cassava and sugarcane. We analyzed 33 on-farm ponds, 22 in SW1 and 11 in SW2.

The following are given conditions in this paper based on the actual situations.

-Water in the on-farm ponds can be used in rainy season only.

-The on-farm ponds belong to each individual farmers; the water irrigates only the paddy fields of the farmer.

2. Data collection

Daily rainfall data were recorded from 2002 to 2004. GIS datasets that included land tenure, pond capacity and land use were produced by interpreting a QuickBird panchromatic image acquired on 13 April 2002. All on-farm ponds were classified as lower or upper ponds based on their geographical location, as interpreted from the satellite image. Lower ponds were located close to the valley, whereas upper ponds were located farther from the valley. We obtained a digital elevation model (DEM) with 5-m resolution from Thailand's Land Development Department. All analyses were performed using ArcView v. 9.2 in combination with the Spatial Analyst extension and ENVI v. 4.3. The flowchart that we followed in this analysis is shown in Fig. 2.

3. Index of water harvesting (I_{HW})

The water-harvesting ability of an on-farm pond depends on the characteristics of its catchment area. We estimated the runoff from each pond's catchment using the Soil Conservation Service (SCS) method and the pond's water balance. The SCS method is widely used to estimate runoff volumes (excess rainfall), and the equation[1] is expressed as follows:

$$P_e = (P - 0.2S)^2 / (P + 0.8S) \quad (1)$$

where P_e is the depth of excess rainfall (mm), P is the depth of total rainfall (mm), and S is the potential maximum water retention after runoff begins (mm). S depends on the soil types and land uses in the catchment, and is related to the curve number (CN: CN(I), CN(II) and CN(III), $0 \le CN \le 100$) as follows:

$$S = (25400 / CN) - 254 \quad (2)$$

The curve numbers under normal antecedent moisture con-

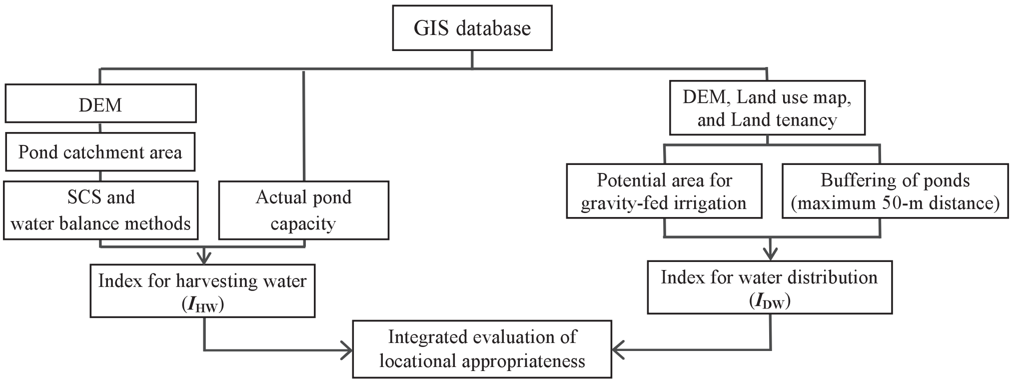

Fig. 2. Flowchart used to evaluate the appropriateness of locations of on-farm ponds. SCS, Soil Conservation Service

ditions (*AMC II*) are based on Chow et al.[1] (1988). Under dry conditions (*AMC I*) or wet conditions (*AMC III*), equivalent curve numbers can be computed as follows:

$$CN(\mathrm{I}) = 4.2CN(\mathrm{II}) / [10 - 0.058CN(\mathrm{II})] \quad (3)$$

$$CN(\mathrm{III}) = 23CN(\mathrm{II}) / [10 + 0.13CN(\mathrm{II})] \quad (4)$$

The range of antecedent moisture conditions for each class is based on total 5-day antecedent rainfall (Chow et al.[1], 1988).

To compute the excess rainfall using the SCS method, the first step is to delineate each pond's catchment area using a contour map at 1-m intervals, which was produced from a DEM by the Spatial Analyst Extension. The second step is to determine the curve number (*CN*) for each pond catchment area based on its land uses by using the runoff curve numbers for selected agricultural, suburban and urban land uses (Chow et al.[1]) and equations 3 and 4. Because a pond's catchment contains more than one type of land use, a composite weighted-average *CN* (II) was computed. Since the dominant soil type from the surface to a depth of 1 m in Nong Saeng village is loamy sand[2], we classified the hydrologic soil group of the pond catchments, which is the most important factor in determining the *CN*, as the soil group of *Shallow loess, sandy loam*[1]. After computing the *CN*, we used daily rainfall data from 2002 to 2004, observed by automatic rainfall gauges at the two subwatersheds, to determine the *AMC* and the amount of excess rainfall in each pond catchment area using Equation 1. Although we used the excess rainfall to estimate runoff volume in each pond, this approach tends to overestimate pond capacity. Therefore, we used the water balance of each pond to estimate an appropriate net storage capacity. This analysis used the following relationship:

$$V_{\mathrm{NSCS}} = P_{\mathrm{e}} - E_{\mathrm{pond}} - L_{\mathrm{S}} - W_{\mathrm{U}} \quad (5)$$

where V_{NSCS} is the net appropriate storage capacity of the pond (m^3) calculated using the SCS method and the pond's water balance, E_{pond} is the evaporation loss from the pond's surface (m^3), L_S is the seepage loss (m^3), and W_U is the water use during the rainy season (m^3). The height of seepage loss was assumed to be 1.4 mm/d, as suggested by Kumar[3]. Water use during the rainy season was assumed to account for 10% to 20% of the pond's total water storage. The height of evaporation loss (mm/d) can be calculated as:

$$E_{\mathrm{pond\ (height)}} = K_{\mathrm{p}} E_{\mathrm{pan}} \quad (6)$$

where K_{p} is the pan coefficient ($K_{\mathrm{p}} \approx 0.8$) when the temperature of water in a pan with standardized dimensions is higher than that of the pond water[5], and E_{pan} is the pan evaporation (mm/d) based on the available data (the mean pan evaporation data from May through October from 1961 to 1990 at Khon Kaen city).

We then calculated an index of water harvesting (I_{HW}):

$$I_{\mathrm{HW}} = V_{\mathrm{AP}} / V_{\mathrm{NSCS}} \quad (7)$$

where V_{AP} is the actual pond capacity (m^3). The amount of rainfall and the catchment area dictate the amount of inflow into a pond. If the inflow is much smaller than the pond's capacity, the pond is oversized and uneconomical due to decreasing arable land. If the inflow amount is much larger than the pond's capacity, the pond is undersized and the overflow can damage the pond's banks and intensify erosion problems. We calculated the interval for I_{HW} for an appropriate pond capacity based on the data for maximum excess rainfall recorded between 2002 and 2004. On this basis, we assumed that the optimum capacity of a pond would be within ±20% of the inflow volume. Therefore, a suitable I_{HW} should be $0.8 \leq I_{\mathrm{HW}} \leq 1.2$. An undersized pond has $I_{\mathrm{HW}} < 0.8$ and an oversized pond has $I_{\mathrm{HW}} > 1.2$.

4. Index of water distribution (I_{DW})

The index of water distribution (I_{DW}) measures the potential, which a pond distributes water to a farm household's holding area. At the study site, water is distributed by pumps or gravity-fed irrigation systems. To determine the I_{DW}, we used two methods. The first method is to identify the area in which water can be distributed by a pump on the basis of buffer analysis. The second method is to estimate the potential area for gravity-fed irrigation of the land holdings of each farm household.

The ArcView buffer distance was defined as 50 m from the edge of each on-farm pond, as Suzuki et al.[4] suggested that this was the critical distance for water distribution from a pond; most farmers in Nong Saeng village use a 30-m-long hose, and the length of a paddy plot is about 15 to 20 m. Therefore, we assumed that the area located within 50 m of an on-farm pond was the potential area for distribution of water from that pond. We therefore created 50-m buffers around all ponds using the Buffer tool in ArcView. Since only the buffer areas inside the land holdings of each farm household were needed for this analysis, we ignored the land outside these buffers in our analysis. The buffered area inside the landholding area of each farm household was divided by the total holding of each farm household, as follows:

$$A_{PB} = A_{IB} / A_{TH} \tag{8}$$

where A_{PB} is the potential area ratio for pump irrigation estimated using the 50-m buffer, A_{IB} is the land holding of each farm household inside the buffer (ha), and A_{TH} is the total land holding of each farm household (ha).

Areas lower than the mean elevation of on-farm ponds were identified as the potential area for gravity-fed irrigation. The mean elevation of each pond was computed using the Zonal Statistics tool provided by the Spatial Analyst extension. Using the ENVI software, we automatically divided the DEM layer into two segments by using the mean elevation of each on-farm pond as the threshold value. Areas lower than the mean elevation of the on-farm ponds inside the land holding of each farm household were then calculated using ArcView. The potential area for gravity-fed irrigation of each on-farm pond per unit of land holding area was estimated as:

$$A_{GI} = A_{IG} / A_{TH} \tag{9}$$

where A_{GI} is the potential area ratio for gravity-fed irrigation, and A_{IG} is the land holding area of each farm household inside the potential area for gravity-fed irrigation (ha).

We calculated I_{DW} as:

$$I_{DW} = A_{PB} + A_{GI} - \text{overlap} \tag{10}$$

A value of I_{DW} close to 1 indicates that the potential area that can be irrigated by the pond covers the whole holding area, and that the pond location is nearly optimal for water distribution.

Results and discussion

1. Evaluation results based on I_{HW}

The I_{HW} values for each pond catchment in SW1 and SW2 are shown in Tables 1 and 2, respectively. The values range from 0.005 to 17.42 in SW1 and from 0.07 to 50.48 in SW2. Based on the characteristics of the two subwatersheds (Table 3), the average curve number (*CN*) values were nearly identical owing to the similarity of the hydrologic conditions of catchment. We examined the range of suitable I_{HW} values by estimating the net appropriate storage capacity (V_{NSCS}) of each pond from the maximum excess rainfall. Our statistical analysis revealed that the mode of I_{HW} in the two subwatersheds approached 1.0, with a standard deviation of 0.2. Therefore, we assumed that a range of I_{HW} from 0.8 to 1.2 was suitable by taking the lower and upper limits as ±0.2 from the mode.

As a result, the numbers of ponds classified as undersized ($I_{HW} < 0.8$), suitable-sized ($0.8 \leq I_{HW} \leq 1.2$), and oversized ($I_{HW} > 1.2$) were 12, 2 and 8 in SW1, and 6, 1 and 4 in SW2, respectively (Table 4). Most of the undersized ponds, which are too small to store the estimated inflow amount, were located in lowland areas. Lower ponds have a large catchment area as a result of their location and thus receive a larger amount of the estimated runoff volume than upper ponds. Consequently, all lower ponds in both SW1 and SW2 were classified as undersized. Available water can be increased by expanding or deepening these ponds. In contrast, all ponds classified as oversized, which are too large for the estimated inflow amount, were located in upland areas. If farmers construct a pond with a capacity greater than that required by the amount of inflowing water, the pond rarely fills with water, and is thus uneconomical. Ponds 15N and 20N in SW1 and 9 in SW2 were classified as suitable-sized, and these ponds were located in upland areas. The actual capacities of these ponds were close to the appropriate capacities (estimated from excess rainfall).

2. Evaluation results based on I_{DW}

As shown in Tables 5 and 6, I_{DW} ranged from 0.19 to 0.95 in SW1 and from 0.15 to 0.55 in SW2. A value of I_{DW} close to 1 indicates that the pond can potentially distribute water to a large proportion of the farm household's holding area. In SW1, the I_{DW} of four ponds was 0.8 or more, indicating that these ponds can distribute water to 80% or more of the farmer's land holdings. The ponds

Table 1. Characteristics of the on-farm pond catchments in subwatershed 1 (SW1)

Pond type	Pond No.	Catchment area (ha)	Actual pond capacity (V_{AP}) (m^3)	Average catchment slope (%)	Curve numbers (*CN*) under antecedent moisture conditions I-III *CN*(I)	*CN*(II)	*CN*(III)	Net appropriate storage capacity (V_{NSCS}) (m^3)	I_{HW}
Upper ponds	4N1	1.5	1,800	2.77	61	79	90	662.6	2.71
	4N2	1.6	2,400	3.22	61	79	90	650.0	3.69
	5	1.4	9,600	3.27	60	78	89	550.1	17.42
	5B	2.2	1,500	3.06	58	77	88	915.4	1.64
	8	0.8	1,800	3.65	45	66	82	232.4	7.71
	9	0.7	1,800	3.85	55	75	87	211.2	8.47
	11	59.7	1,800	3.94	56	75	87	25,971.3	0.07
	12	3.2	1,800	3.82	40	62	79	883.7	2.03
	15N	3.2	1,800	2.90	68	83	92	1,655.0	1.09
	18	14.7	500	2.50	42	63	80	4,387.7	0.11
	20N	1.4	605	2.20	59	77	89	526.7	1.15
	21	3.7	750	3.21	65	82	91	1,810.8	0.41
	22	5.2	3,000	2.64	57	76	88	2,202.7	1.36
	23N	158.1	600	3.25	53	73	86	65,406.8	0.01
	24	5.0	450	2.48	61	79	90	2,334.3	0.19
Lower ponds	4	36.6	200	2.96	57	76	88	16,608.5	0.01
	7	57.1	270	3.94	56	75	88	25,099.6	0.01
	10	59.6	1,600	3.94	56	75	87	25,920.7	0.06
	14	78.6	200	3.73	54	74	87	33,306.0	0.01
	15	91.5	9,600	3.64	54	73	86	38,272.2	0.25
	17	103.7	4,500	3.49	54	73	86	43,077.5	0.10
	20	128.8	240	3.28	52	72	85	51,220.1	0.005

Table 2. Characteristics of the on-farm pond catchments in subwatershed 2 (SW2)

Pond type	Pond No.	Catchment area (ha)	Actual pond capacity (V_{AP}) (m^3)	Average catchment slope (%)	Curve numbers (*CN*) under antecedent moisture conditions I-III *CN*(I)	*CN*(II)	*CN*(III)	Net appropriate storage capacity (V_{NSCS}) (m^3)	I_{HW}
Upper ponds	8	0.74	1,620	3.88	59	78	89	173.4	9.28
	8N	1.58	1,800	3.82	50	70	85	356.7	5.03
	9	1.45	600	3.93	62	79	90	510.8	1.17
	9W	0.92	1,350	2.12	28	48	68	25.8	50.48
	11	1.30	1,500	3.28	59	77	89	376.4	3.98
	15E	13.94	1,800	3.33	59	77	89	4,933.8	0.36
	7	61.86	2,400	3.29	56	75	87	20,855.1	0.12
Lower ponds	10	43.92	4,500	3.36	58	77	89	15,103.2	0.30
	12	27.53	720	3.45	59	78	89	9,789.4	0.07
	13	21.11	600	3.36	59	78	89	7,641.7	0.08
	15	15.11	600	3.27	59	78	89	5,405.1	0.11

Table 3. Characteristics of the two subwatersheds

	SW1	SW2
Catchment area (ha)	158	77.8
Number of on-farm ponds	22	11
Average catchment area of an on-farm pond (ha)	37.2	17.22
Catchment slope (%)	2.20-3.94	2.12-3.93
Average capacity of an on-farm pond (m^3)	2195	1600
Average curve number (*CN*) under antecedent moisture conditions I to III		
CN (I)	56	55
CN (II)	75	74
CN (III)	87	86
Average maximum excess rainfall (mm)	43.4	33.1
Dominant land use type	upland cropping	upland cropping

Table 4. Number of ponds classified by size in the two subwatersheds

Pond size	SW1			SW2		
	Total	Upper ponds	Lower ponds	Total	Upper ponds	Lower ponds
Undersized	12	5	7	6	1	5
Suitable-sized	2	2	0	1	1	0
Oversized	8	8	0	4	4	0

classified as being appropriately located for water distribution on this basis were 5B, 21, 22, and 24 in SW1. These ponds are all located in upland areas. These ponds had high values of I_{DW} because they were constructed close to fields (within 50 m from the edge of the ponds) and were located in higher parts of the farmer's land holdings, making them suitable for gravity-fed irrigation. The I_{DW} values for the lower ponds were less than 0.5, with one exception (9W), indicating that these ponds can distribute water to less than 50% of the farmer's land holdings.

3. Evaluation based on integrated indices

We also integrated the two indices to identify ponds that were appropriately located and sized for water harvesting and distribution. The combinations of the I_{HW} and I_{DW} values are presented in Figs. 3 and 4. No pond had suitable values for both indices. However ponds 5B and 22 in SW1 had an I_{DW} value greater than 0.8 and an I_{HW} value slightly above the suitable range; that is, both ponds were classified as being closest to the suitable ranges for both indices.

Conclusions

To evaluate the appropriateness of locations and capacities of existing on-farm ponds, we evaluated the hydrological functions of water harvesting and distribution at on-farm ponds in two small subwatersheds in northeast Thailand using original evaluation indices. Although some upland ponds had suitable values of one index, no pond had suitable values of both indices. These results indicate that the existing on-farm ponds in the study area are not optimal. One of the reasons is that the locational conditions of most existing on-farm ponds had not been taken into accounted so far.

To utilize on-farm ponds more efficiently, it is necessary to plan their location and capacity on the basis of their catchment area and the potential area that can be irrigated by each pond before they are built. The approach proposed in this study can be useful in selecting appropriate locations and capacities for on-farm ponds construction in the near future.

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Table 5. I_{DW} values for SW1

Pond type	Pond No.	Total holding area (ha)	Farm household	Mean elev. of pond (m)	(1) Area lower than mean elev. of pond (ha)	(2) Buffered area (ha)	(3) Overlapped area (ha)	(4) Net irrigable area (1 + 2 - 3) (ha)	I_{DW} (4 /Total holding area)
Upper ponds	4N1	5.39	A	198.2	2.47	0.71	0.38	2.80	0.52
	4N2	5.39	A	199.6	2.97	0.89	0.51	3.35	0.62
	5	5.46	B	198.8	1.22	1.09	0.40	1.91	0.35
	5B	0.95	C	199.6	0.79	0.29	0.18	0.90	0.95
	8	6.54	D	196.1	2.06	0.78	0.34	2.50	0.38
	9	6.54	D	197.4	2.92	0.67	0.28	3.31	0.51
	11	8.08	E	193.5	2.27	0.93	0.50	2.70	0.33
	12	7.44	F	193.3	4.66	0.87	0.32	5.21	0.70
	15N	7.44	F	191.2	1.55	0.75	0.21	2.09	0.28
	18	9.32	G	188.5	3.90	1.28	0.67	4.51	0.48
	20N	2.75	H	186.6	1.02	0.60	0.41	1.21	0.44
	21	5.26	I	187.6	3.70	1.10	0.66	4.14	0.79
	22	5.01	J	187.6	3.97	0.83	0.71	4.09	0.82
	23N	5.01	J	184.5	1.45	0.92	0.35	2.02	0.40
	24	5.01	J	187.3	3.73	0.50	0.25	3.98	0.79
Lower ponds	4	5.39	A	196.6	1.39	0.61	0.00	2.00	0.37
	7	6.54	D	194.0	0.54	1.11	0.43	1.22	0.19
	10	8.08	E	193.5	2.27	1.46	0.70	3.03	0.37
	14	7.44	F	191.2	1.55	1.52	0.52	2.55	0.34
	15	3.27	K	189.0	0.75	1.22	0.20	1.77	0.54
	17	9.32	G	186.9	0.79	1.88	0.47	2.20	0.24
	20	5.26	I	185.5	0.91	0.75	0.36	1.30	0.25

Table 6. I_{DW} values for SW2

Pond type	Pond No.	Total holding area (ha)	Farm household	Mean elev. of pond (m)	(1) Area lower than mean elev. of pond (ha)	(2) Buffered area (ha)	(3) Overlapped area (ha)	(4) Net irrigable area (1 + 2 - 3) (ha)	I_{DW} (4 /Total holding area)
Upper ponds	8	2.78	L	186.7	1.03	0.61	0.43	1.21	0.43
	8N	25.74	M	187.7	3.52	0.93	0.47	3.98	0.15
	9	4.17	N	184.1	1.77	0.79	0.50	2.06	0.49
	9W	4.17	N	184.3	2.04	0.95	0.71	2.28	0.55
	11	7.55	O	190.8	1.35	1.00	0.40	1.95	0.26
	15E	3.35	P	195.1	0.52	0.86	0.21	1.17	0.35
Lower ponds	7	2.78	L	185.1	0.20	1.35	0.20	1.35	0.48
	10	25.74	M	188.6	4.87	2.79	0.46	7.20	0.28
	12	2.26	Q	190.2	0.31	1.09	0.31	1.09	0.48
	13	8.76	R	193.3	0.75	1.43	0.42	1.76	0.20
	15	3.35	P	195.5	0.88	1.12	0.57	1.43	0.43

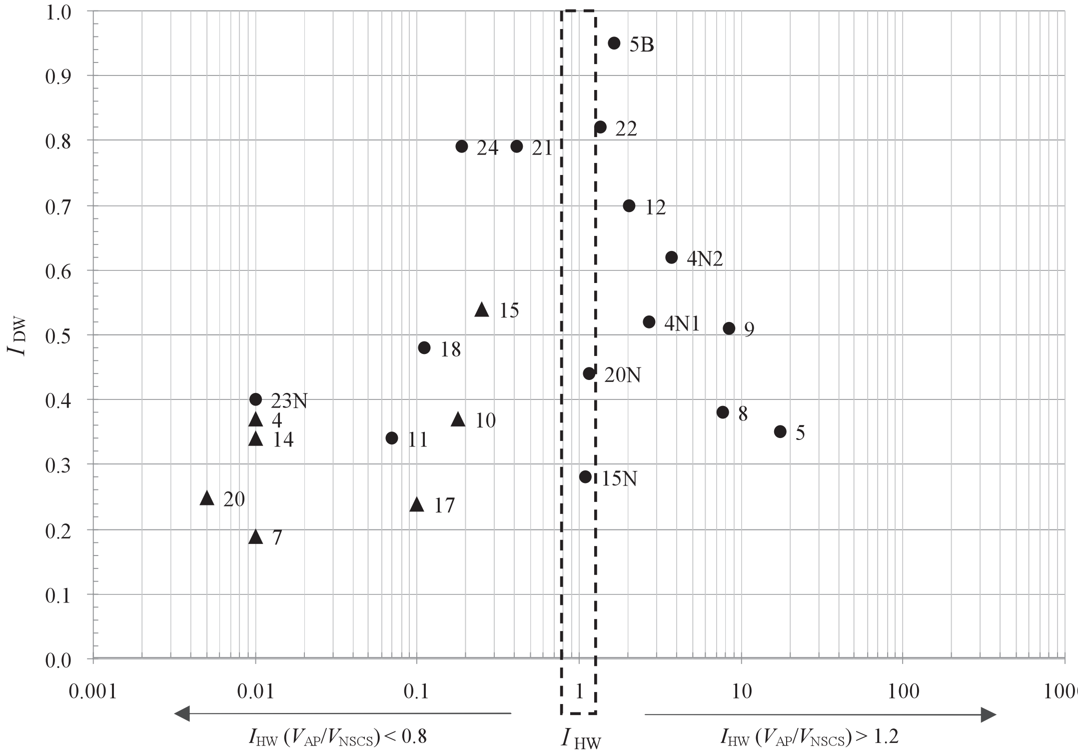

Fig. 3. Results of the evaluation of SW1 based on the combination of I_{HW} and I_{DW}
● : Upper pond, ▲ : Lower pond.
Suitable range for harvesting water: $0.8 \leq I_{HW} \leq 1.2$.

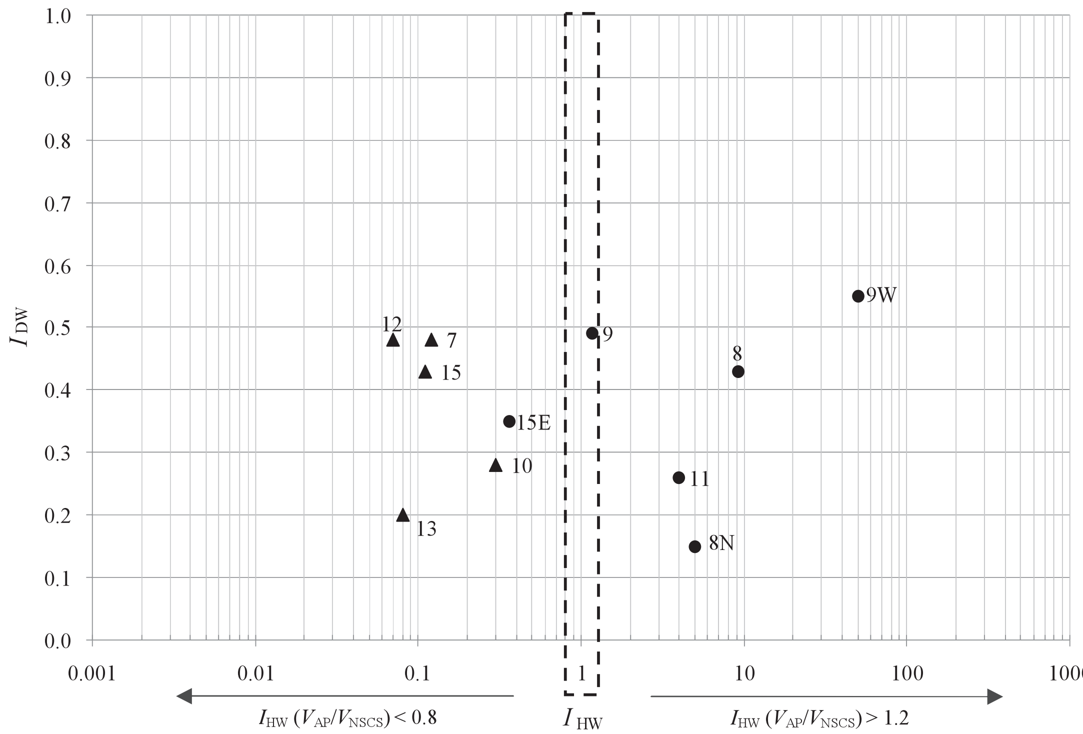

Fig. 4. Results of the evaluation of SW2 based on the combination of I_{HW} and I_{DW}
● : Upper pond, ▲ : Lower pond.
Suitable range for harvesting water: $0.8 \leq I_{HW} \leq 1.2$.

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