Assessment of Soil Fertility and Water Quality for Afforestation on Semi-submerged Land: New Insights to Inform Forestry Policy in Thac Mo Hydropower Reservoir

QUANG, Do Van
Thuyloi University

NGOC, Trieu Anh
Thuyloi University

AN, Tran Dang
Thuyloi University

HAI, Nguyen Van
Thuyloi University

他

https://doi.org/10.5109/4772342

出版情報：九州大学大学院農学研究院紀要. 67 (1), pp.53-64, 2022. Faculty of Agriculture, Kyushu University

J. Fac. Agr., Kyushu Univ., **67** (1), 53–64 (2022)

Assessment of Soil Fertility and Water Quality for Afforestation on Semi–submerged Land: New Insights to Inform Forestry Policy in Thac Mo Hydropower Reservoir

Do Van QUANG[1], Trieu Anh NGOC[1]*, Tran Dang AN[1], Nguyen Van HAI[1], Vu Thi Hoai THU[2], Le Cong CHINH[1] and Kazuaki HIRAMATSU

Laboratory of Water Environment Engineering, Division of Bioproduction Environmental Sciences,
Department of Agro–environmental Sciences, Faculty of Agriculture,
Kyushu University, Fukuoka 819–0395, Japan
(*Received October 18, 2021 and accepted November 5, 2021*)

The Binh Phuoc Province is located in the highlands of Vietnam with many cascades of reservoirs, including Thac Mo, Can Don, Srok Phu Mieng, and Phuoc Hoa. These reservoirs have brought significant economic benefits to the province, providing huge amounts of hydropower and water resources for agriculture and industry. However, the construction of reservoirs has taken up a lot of land, especially the semi–submerged lands, thereby changing water quality and leading to soil erosion. Afforestation in semi–submerged regions is vital for recovering the soil, preventing erosion, and effectively exploiting the full potential of the land. This study was conducted by performing field investigations, water and soil sampling, and analysis of the adaptive hierarchy for afforestation in the Thac Mo Hydropower Reservoir. The results revealed that the area of semi–submerged land increased significantly from 1585 ha, calculated based on the data of the afforestation project in 2018, to 1835 ha evaluated under the Circular 03/2012/TT–BTNMT, which is a regulation on the management and exploitation of semi–submerged lands in hydropower and irrigation reservoirs implemented by the Vietnamese Ministry of Natural Resources and Environment. This study not only analyzed factors like topography, slope, inundation time, and soil types but also the soil and water quality. The results emphasized that the area of suitable land for afforestation on the Thac Mo Hydropower Watershed is 1806 ha, of which the very adaptive area is 206 ha, the moderately adaptive area is 724 ha, the less adaptive area is 876 ha, and the non–adaptive area is 302 ha. These results can help formulate an efficient afforestation plan in the Binh Phuoc Province.

Key words: multi–criteria decision–making, adaptive hierarchy, water quality index, soil quality index

INTRODUCTION

The semi–submerged land of hydropower and irrigation reservoirs is an irregular wetland area bounded by the lowest water level in the dry season and the highest water level in the rainy season due to changing seasonal water levels or reservoir operating modes. The duration of flooding in the wetlands of Vietnam is not more than six months in a year (MONRE, 2012). The semi–submerged region is influenced by the soil, water level variation, water quality, and other external factors such as geomorphology, hydrodynamic processes, hydrometeorology, inundation fluctuation, which interact with each other to influence the distribution, abundance, and development of flora and fauna populations in these areas. Previous studies (Saaty, 1984; Duarte, 1986, 1988; Do, 2005; Hilt *et al.*, 2006; Hoan, 2016; Li, 2017; Sub–Fipi, 2018) have shown that soil characteristics and water quality are two of the most essential factors in site zoning.

The influence of site factors on the formation and development of flora has been studied extensively worldwide (Ferreira *et al.*, 2009; Keshavarzi *et al.*, 2020). These studies have shown that the slope of the semi–submerged zone in wetlands is negatively correlated with the maximum plant biomass. In a study (Murphy *et al.*, 2018) conducted at Lake Memphramagog located between Newport, Vermont, USA, and Magog area, Quebec, Canada, it was found that approximately 87% of the variation in maximum biomass in the area was caused by the slope and amount of alluvial deposits due to the difference in the stability of gentle and vertical slopes. Generally, areas of gentle slopes allow the deposition of fine sediments and promote plant growth. In contrast, areas of steep (vertical) slopes result in a high rate of erosion and fine sediment transport, which are not suitable for the growth of crops and plants, which require nutrient–rich soil. The surface area and the shape of the basin significantly influence the size and strength of the waves hitting the shore. Large lake areas are often capable of generating waves of greater size and intensity than small lakes because of the effect of wind on the lake surface. Waves of different sizes and intensities also have other impacts on shoreline erosion and damage to coastal vegetation. In addition, the synergistic effects of factors such as wind direction and strength, slope, and shape of the lake determine the movement of sediments in the semi–submerged area. Topographic altitude has a significant influence on the distribution and diversity of flora (Khanh *et al.*, 1996; Maria *et al.*, 2006; Kumar and Jhariya, 2015; Sub–Fipi, 2018). Water quality also plays an essential role in the growth, development, and distribution of plant species in semi–submerged lands. Li *et al.* (2017) showed that seasonal

[1] Thuyloi University, 175 Tay Son, Dong Da, Ha Noi City, Vietnam
[2] Ho Chi Minh City University of Transport, 02 Vo Oanh, Ward 25, Binh Thanh, Ho Chi Minh City, Vietnam
* Corresponding author (E–mail: ngocta@tlu.edu.vn)

changes in total nitrogen (TN), total phosphorus (TP), ammoniacal nitrogen, and chemical oxygen demand concentrations greatly influenced the distribution of plant populations and aquatic animals in the Honghu Lake of China. Similar research has been conducted by other scientists worldwide (Zhang *et al.*, 2015; Xu *et al.*, 2017).

The adaptive characteristics of the plant species are also decisive factors in their growth, development, and distribution in semi–submerged lands (Silva–Folores *et al.*, 2014; Tamnang and Fukao, 2015). In particular, partial or total inundation has a massive impact on crops in flood–prone ecosystems. Some plants can tolerate these conditions by implementing different survival strategies, including morphological adaptations and physiological adjustments. Waterlogging and submersion are often associated with hypoxic development, triggering various morphological features and adaptive cellular responses. Ethylene, abscisic acid, gibberellic acid, and other hormones play essential roles in genetically controlled survival (Parolin and Wittmann, 2010; Aguirre–Salado *et al.*, 2015; Phukan *et al.*, 2016).

Thus, site conditions and biological characteristics of plants determine the formation, development, and distribution of plant species in flooded and semi–submerged areas (Silva–Folores *et al.*, 2014 ; Tamnang and Fukao, 2015). It is important to select sites that satisfy the requirements of one or more types of plants to form plantation areas. However, site selection is a challenging process because various site factors affect the growth and development of plant species (Verhofstad, 2017). Therefore, with area specificities, one must consider the site factors in the resonant and systematic interactions that determine the growth and development of plants. Special attention should be paid to the significant changes in these factors as one moves from a dry to a flooded environment in semi–submerged areas.

The site conditions for crop cultivation and the development of planted forest areas have been studied by many scientists in Vietnam (Do, 2005). In this study, the author built a system of factors and hierarchical criteria for each factor to divide and evaluate the site for different soil types, including hilly soil, coastal sandy soil, sea, mangroves, and acidic soils. Them (2002) proposed five types of forests and two types of non–forests. The classification of elements must be based on the actual conditions of each area to be divided. Thus, the factors chosen for each site are very diverse, depending on natural conditions, the scope of land use planning and orientation, business objectives, and the ability to collect data from each specific area to determine and classify the site factors accordingly. It is simple and easy to apply. In recent years, research on on–site conditions of planted forests has also been of interest to many researchers. Dien (2014) studied the Luong forest in Quang Hoa District, Thanh Hoa Province and reported the following: (i) site conditions such as topography, soil, and cover of the Luong forest are differentiated; (ii) soil conditions and topography are closely related to the growth of the forest, while forest structure is relatively loosely related.

The research on semi–submerged lands around the world and in Vietnam do not reflect the overall types of semi–submerged lands. It was either too simple or too specific, making it difficult to effectively manage, use, and exploit semi–submerged lands in Vietnam, generally, and in the Binh Phuoc Province in particular.

A case study of on–site conditions for semi–submerged lands in the Binh Phuoc Province was carried out by Hoan (2016). This study initially assessed and classified the topographical factors on semi–submerged lands in the Binh Phuoc Province in four large reservoirs: Thac Mo, Can Don, Sork Phu Mieng, and Dau Tieng. These results are limited to general research on the site factors of semi–submerged areas due to the limitation of survey and collected data.

The above study analyzed the diverse site factors and the impact of each factor and their synergistic effects on the growth and development of plants. However, it did not consider factors such as water quality, groundwater level, and distribution characteristics within the semi–submerged area.

The Thac Mo Hydropower Reservoir in the Binh Phuoc Province has not yet been studied in detail on semi–submerged lands downscaling to classification units. Previous studies have not developed any criteria, assessment, planning, or proposed any effective management and use systems for semi–submerged lands. This study conducted a more detailed survey and evaluation to build a site database and a set of site indicators in the semi–submerged land of the Thac Mo Hydropower Reservoir, which could be applied to the whole Binh Phuoc Province in the future.

MATERIALS AND METHODS

Study area

As shown in **Fig. 1**, the Thac Mo Hydropower Reservoir is located on the upper reaches of the Be River in the territory of two districts of Bu Dang and Bu Gia Map, and two district–level towns of Phuoc Long and Phu Rieng in the Binh Phuoc Province. The Thac Mo hydropower plant is situated 170 km northwest of Ho Chi Minh City, and at the top step of the entire energy exploitation scheme of the Be River Basin.

The Be River originates from the Xi Xa No Plateau and is one of the three major tributaries of the Dong Nai River. The length of the Be River from upstream to the estuary, where the Dong Nai River joins is about 300 km. The river's distance to the Thac Mo Hydropower dam is 153 km. The distance of the Be River to the Thac Mo Hydropower dam is 2.5 km, and the remaining distance is covered by two tributaries—the Dak Lung and Dak Lap Rivers. The catchment area is approximately 2200 km^2, with an average river slope of 0.00024.

The Thac Mo Hydropower Plant has an installed capacity of 150 MWh. It is connected to Vietnam's national electricity grid with an average annual output of about 600 million kWh. In addition, the Thac Mo Hydropower Reservoir is responsible for creating water

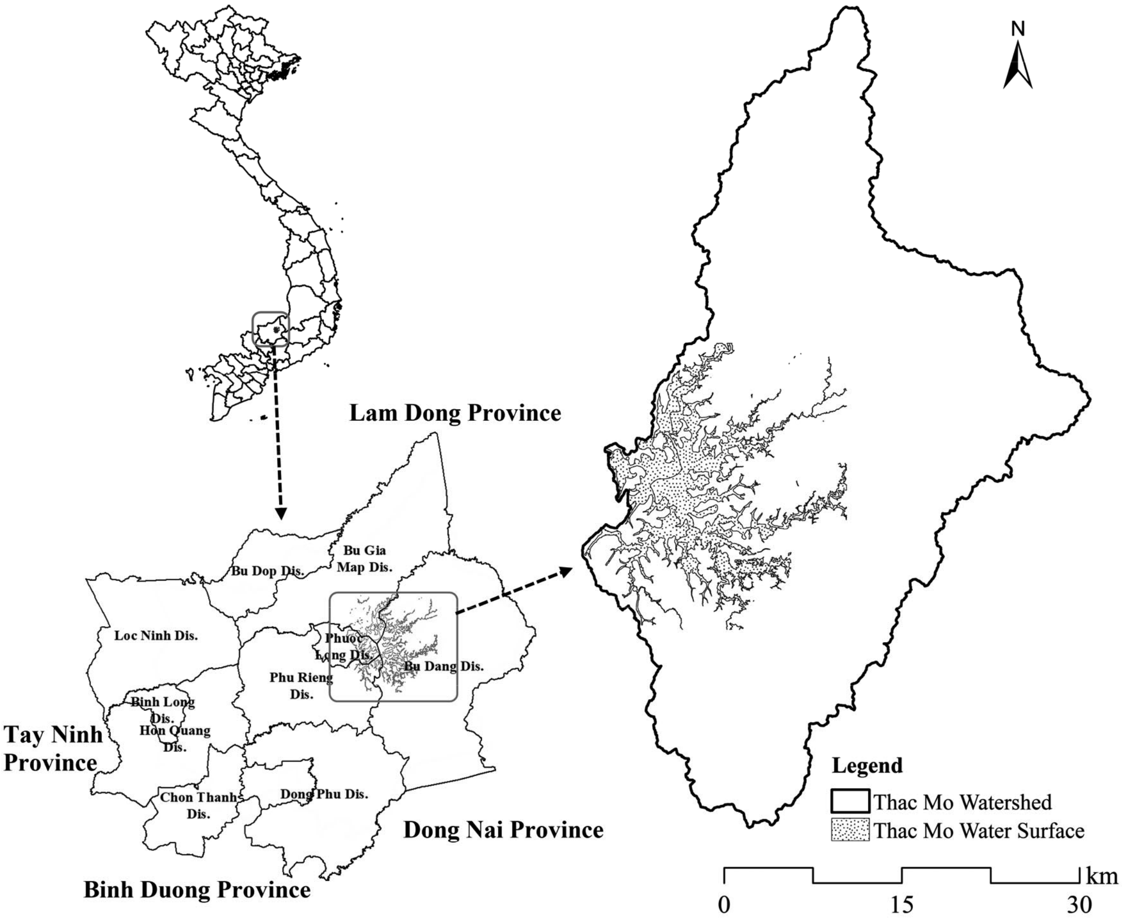

Fig. 1. Location of the Thac Mo Hydropower Reservoir in the Binh Phuoc Province, Vietnam.

resources for irrigation and daily life in the downstream area of the Be River, Phuoc Hoa, and Ho Chi Minh City, with a flow rate of 56 m^3/s in the dry season.

According to the definition of semi–submerged area by the Ministry of Natural Resources and Environment (MONRE, 2012), the Thac Mo Hydropower Reservoir is estimated to have about 1585 ha (55.8% of the total) of semi–submerged area located in two districts of Bu Dang, Bu Gia Map, and two district–level towns of Phuoc Long and Phu Rieng in the Binh Phuoc Province. Currently, this semi–submerged land is managed by the Thac Mo Hydropower Joint Stock Company.

The field survey showed that a majority of the semi–submerged land was mainly unused land with dense vegetation of primarily apricot trees. Only a small part of it was planted with short–term crops by local farmers.

Obtained data and analytical procedure

To assess the adaptation of the semi–submerged area for afforestation, we defined a set of criteria, which included the following groups: (1) topography, (2) hydrometeorology, (3) soil type, (4) soil characteristics, and (5) water quality.

Topography

Topography plays a critical role in the growth, development, and distribution of plants. Altitude and slope are two topographic factors that significantly affect planted forests. The altitude of the area affects the stratification of the climate and other meteorological conditions. The slope affects the ability to drain or retain water in the soil, thereby affecting the moisture content of the soil layer in the planted forest area. The influence of terrain altitude and slope on the growth and development of planted forests in the semi–submerged area of the Thac Mo Hydropower Reservoir were analyzed, and categorized as shown in **Table 1**. In this table, "Adaptive Hierarchy" and "Symbol" will be explained later.

Topographic altitude in the Thac Mo Hydropower Watershed as shown in **Fig. 2**, was obtained from the measurement data of the afforestation project in Binh Phuoc Province in 2019 (Sub–Fipi, 2018). With this topographic data, the ArcGIS was used as a tool to convert to a digital elevation model (DEM) raster format with a grid of 5 m × 5 m. Then, the Slope Spatial Tool in ArcGIS was applied to calculate the slope of the cells accordingly.

Table 1. Definition of adaptive hierarchy and the classification of factors related to topography, hydrometeorology, soil type, soil characteristics, and water quality

No.	Adaptive Hierarchy	Symbol	Altitude (m)	Slope (degree)	Inundated day (d)	Inundated depth (m)	Soil type	Thickness of soil layer (cm)	*SQI* (%)	*WQI* (%)
1	Very adaptive	S1	< 100	0 – 8	< 30	< 0.5	D, Fk, Fp	> 120	75 – 100	75 – 100
2	Moderate adaptive	S2	100 –300	8 – 15	30 – 90	0.5 – 2.0	Fu,Xg, X	70 – 120	50 – 75	50 – 75
3	Less adaptive	S3	300 – 500	15 – 20	90 – 180	2.0 – 5.0	Fs	50 – 70	25 – 50	25 – 50
4	Non–adaptive	N	> 500	> 20	> 180	> 5.0	Others	< 50	< 25	< 25

D: Umbric Gleysols (Cumulic), Fk: Acric Ferralsols (Rhodic), Fp: Haplic Acrisols (Chromic), Fu: Acric Ferralsols (Xanthic), Xg: Gleyic Acrisols (Umbric), X: Haplic Acrisols, Fs: Haplic Acrisols (Endo–Hyperskeletic, Chromic)

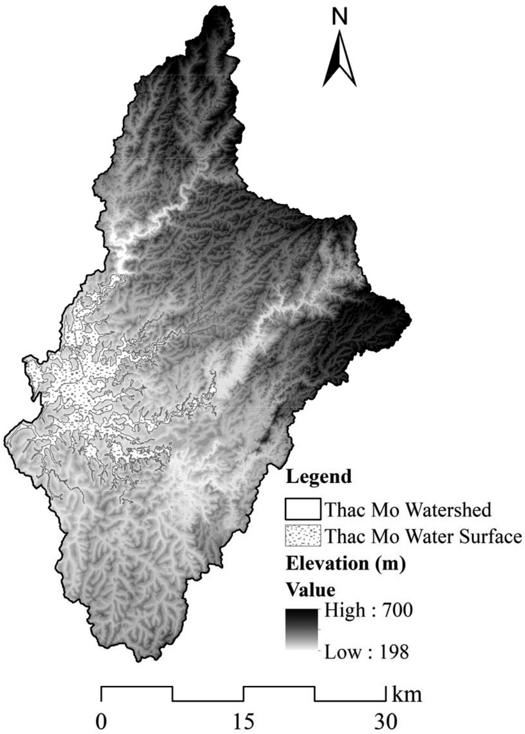

Fig. 2. Digital elevation model (DEM) of Thac Mo Hydropower Watershed.

Hydrometeorology

Hydrological characteristics such as inundation time and depth within the reservoir area are two crucial factors affecting the growth and development of planted forests. According to the Circular 03/2012/TT–BTNMT of MONRE (MONRE, 2012), semi–submerged land was defined as the land area belonging to the hydropower and irrigation reservoir but not regularly flooded for a period of less than six months. Accordingly, this study divided the flooding time into four levels of inundated days, as shown in **Table 1**. The depth of flooding is also a factor that significantly affects the development of planted forests. By analyzing the extent of influence and existing forest conditions in the semi–inundated area of the Thac Mo Hydropower Reservoir, the flooded level was divided into four levels of inundated depth, as shown in **Table 1**.

Based on the design parameters of the Thac Mo Hydropower Reservoir and data of historical reservoir operation documents from 1995–2018, the monthly averages of reservoir water levels that overlapped the DEM raster, flooded area, flooded depth, and duration were determined.

Soi Types

The map of soil characteristics in the Thac Mo Hydropower Watershed shown in **Fig. 3** was collected from the Binh Phuoc Provincial Forest Protection Department.

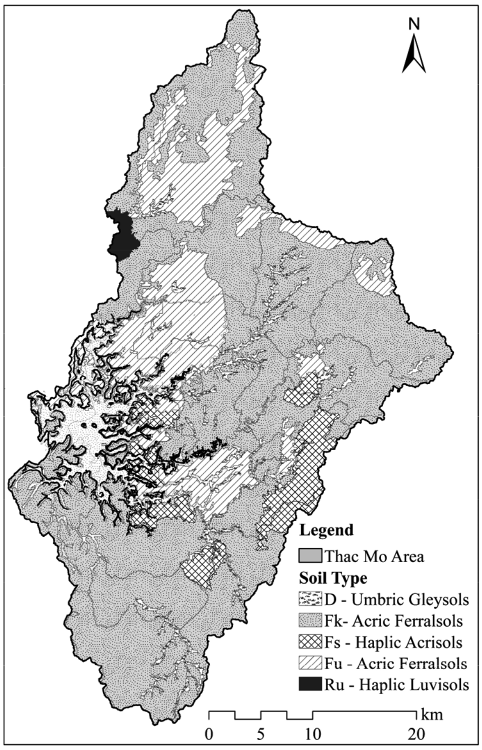

Fig. 3. Soil types of the Thac Mo Hydropower Watershed.

Soil characteristics

Field surveys, interviews with farmers, and consultation with experts revealed that planted forests grow and develop best on basalt soil. Other soils are also suitable for planted forests. Gray soil, ancient alluvial soil, peat soil, and the soil developed on limestone can be planted if there is topsoil from 0 to 50 cm with a clay content of 20%, the soil layer is 0 to 50 cm deep, and the soil layer of 50 to 100 cm has a clay content of 30%. Moreover, the mechanical composition of the soil also greatly affects the adaptability of planted forests in semi–submerged areas. Based on a comprehensive assessment of the influence of soil conditions, including soil type, thickness, and mechanical composition, the soil characteristics in the Thac Mo Hydropower Watershed have been classified into four categories of soil adaptation, as shown in **Table 1**.

In addition, the chemical components of the soil also greatly affect the adaptability of planted forests in semi–submerged lands. Eleven physicochemical components of soil were collected through field investigation and sampling for the following analyses: pH, bulk density, porosity, total organic content, total phosphorus (TP), total nitrogen (TN), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), ferric (Fe^{3+}), and sodium (Na^{+}) ions. The data collection was carried out from May 17 to May 20, 2020, with 30 sites of soil samples along the water surface shore of the Thac Mo Hydropower Reservoir, as shown in **Fig. 4** and **Table 2**.

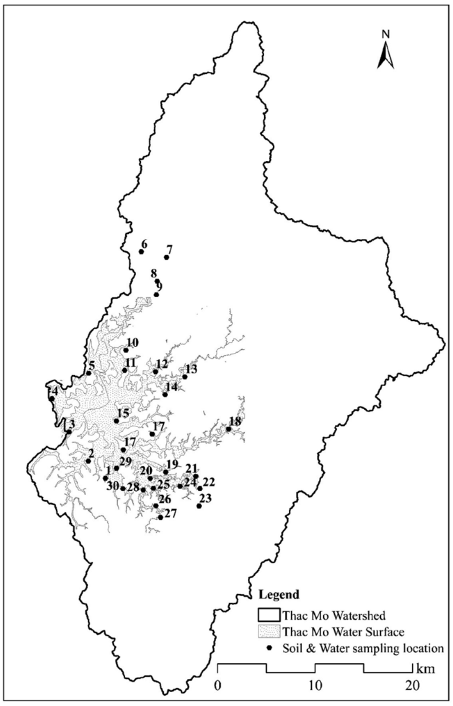

Fig. 4. The water surface of Thac Mo Hydropower Reservoir and soil, water sampling locations.

Table 2. Chemical soil components in semi–submerged land

ID	pH	Bulk Density	Weight	Porosity	Total organic	Total P	Total N	Total K	Ca^{2+}	Mg^{2+}	K^{+}	Fe^{3+}	Na^{+}
		(g/cm^3)		(%)		(mg/kg)			(cmol/kg)				
TM–1	5.8	1.8	1.1	40.6	4.1	1225	1582	163	1.4	0.3	0.1	0.0	0.1
TM–2	6.2	2.0	1.1	42.4	2.2	363	966	90	1.8	0.7	0.1	0.0	0.1
TM–3	6.4	1.4	1.3	10.2	0.4	314	200	88	0.7	0.2	0.0	0.0	0.1
TM–4	5.6	2.3	1.1	52.8	2.8	1048	391	34	2.2	0.5	0.1	0.0	0.1
TM–5	5.4	1.9	1.2	37.6	3.1	459	823	68	0.9	0.3	0.1	0.0	0.1
TM–6	6.0	1.6	1.1	27.7	4.1	586	1866	232	2.8	1.8	0.2	0.0	0.0
TM–7	5.6	1.6	1.3	20.4	2.1	576	1105	69	0.8	1.0	1.6	1.0	1.0
TM–8	6.6	1.5	1.2	27.9	2.4	353	753	50	1.6	1.2	1.3	1.1	1.4
TM–9	6.3	1.7	1.6	39.9	3.4	1130	580	151	2.5	1.5	1.3	1.2	1.2
TM–10	5.9	1.6	1.5	30.7	4.9	793	478	66	0.8	0.9	0.6	0.9	0.7
TM–11	6.7	1.9	1.7	50.7	3.0	542	810	147	0.7	0.8	1.0	0.2	0.7
TM–12	6.4	1.6	1.4	46.0	0.1	886	1332	96	1.0	0.3	0.8	1.2	1.0
TM–13	6.1	1.6	1.4	26.8	3.2	517	458	110	2.3	1.2	0.6	1.3	0.7
TM–14	6.4	2.0	1.7	23.3	4.1	668	472	110	2.4	1.1	0.7	0.5	1.1
TM–15	6.6	2.0	1.7	52.0	2.6	1114	1243	62	2.5	2.0	1.1	0.9	1.4
TM–16	6.8	1.9	1.5	18.9	2.2	1069	1165	157	1.7	1.0	1.2	1.8	0.3
TM–17	6.3	2.0	1.6	19.7	1.9	470	1334	44	2.3	0.8	0.4	1.9	1.4
TM–18	6.8	2.1	1.7	12.9	1.8	1012	1180	89	0.8	1.4	0.1	0.7	1.3
TM–19	5.7	1.8	1.6	14.3	2.6	542	526	112	0.3	0.5	0.9	0.9	1.0
TM–20	5.9	1.8	1.5	42.3	1.6	1026	1231	131	2.4	1.0	1.2	1.1	0.8
TM–21	6.4	1.5	1.3	28.5	1.5	501	913	40	0.8	0.2	1.0	1.4	0.1
TM–22	6.7	1.5	1.3	19.1	4.3	1055	1494	99	0.8	1.4	1.3	1.0	1.7
TM–23	5.7	1.6	1.5	51.8	1.3	644	624	104	1.3	0.7	1.4	0.4	1.2
TM–24	5.9	2.1	1.9	16.7	1.1	837	1076	122	0.8	0.7	1.6	1.4	0.7
TM–25	6.3	1.5	1.3	44.3	0.8	943	1004	153	2.1	1.4	0.4	1.0	0.8
TM–26	6.1	2.0	1.7	23.4	0.8	1094	331	75	1.5	1.3	1.7	0.3	1.1
TM–27	6.6	1.7	1.5	21.5	0.6	659	782	110	2.9	0.9	0.8	0.8	1.2
TM–28	5.6	1.7	1.5	51.7	3.5	465	439	68	1.6	0.3	0.7	1.1	1.4
TM–29	5.4	1.8	1.4	48.7	0.2	1002	453	77	1.2	0.2	0.9	0.6	1.4
TM–30	6.2	1.6	1.5	33.9	1.4	651	840	70	1.9	0.6	0.9	1.8	1.6

To reduce the interference due to a large number of input variables in the analysis process, the chemical components of the soil were integrated into a formula of soil quality index (*SQI*) (Armenise *et al.*, 2013) which is similar to the water quality index (*WQI*; Singh *et al.*, 2020) as follows:

$$SQI = \frac{\sum (SR_i \times WD_i)}{\sum WD_i} \quad (1)$$

$$SR_i = \frac{(OB_o - OB_i)}{(SD_i - OB_i)} \times 100 \quad (2)$$

$$WD_i = \frac{CP}{SD_i} \quad (3)$$

$$CP = \frac{1}{\sum 1/SD_i} \quad (4)$$

where SR_i (%) is the soil quality rating for the i^{th} parameter in Eq.(2), WD_i is the unit weight of the i^{th} parameter in Eq.(3), SD_i is the standard value of the i^{th} parameter, which is the threshold value that plants (trees) can survive, based on Amacher *et al.* (2007), OB_o is an observed value of the o^{th} parameter, OB_i is an ideal value of *the* i^{th} parameter, and *CP* is a constant for proportionality in Eq.(4). The main parameters used for *the SQI* (%) calculations are provided in **Table 3**. The *SQI* was classified into four categories of adaptive hierarchy, as shown in **Table 1**.

Water quality

In addition to the criteria groups of topography, hydrometeorology, and soil characteristics, the water quality criteria group had a significant influence on the growth of plants. To serve as a criteria for water quality, 30 water samples were collected along the Thac Mo Hydropower Reservoir, as shown in **Fig. 4**, with 9 analyzed components: temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), suspended solids (SS), turbidity (NTU), calcium carbonate ($CaCO_3$), TN, and TP, as shown in **Table 4**.

Nine water quality indicators were synthesized using the WQI formula for calculation (Zhai *et al.*, 2017; Ghouili *et al.*, 2018; Adimalla and Qian, 2019; Barakat *et al.*, 2019; Singh *et al.*, 2020; Zhao *et al.*, 2021). The calculation formula of WQI and the hierarchy of adaptation by water quality index are shown below:

$$WQI = \frac{\sum (Q_i \times W_i)}{\sum W_i} \quad (5)$$

$$Q_i = \frac{(C_o - C_i)}{(S_i - C_i)} \times 100 \quad (6)$$

$$W_i = \frac{K}{S_i} \quad (7)$$

$$K = \frac{1}{\sum 1/S_i} \quad (8)$$

where Q_i is the water quality rating for the i^{th} parameter in Eq.(6), W_i is the unit weight of the i^{th} parameter in Eq.(7), S_i is the standard value of the i^{th} parameter, C_o is the observed value of the i^{th} parameter, C_i is the ideal value of *the* i^{th} parameter, and *K* is a constant for proportionality in Eq.(8). The main parameters used for the *WQI* calculations are provided in **Table 5**.

Methods of adaptive hierarchy for reforestation

Multi–criteria decision–making (MCDM) is a technique that combines different standards to produce a final result. MCDM provides decision–makers with varying levels of important criteria or weights of related criteria. The method of consulting experts and personal experience is often used to determine the weights. In multi–criteria decision–making, it is important to first define the alternatives and the criteria by which they need to be evaluated. Next, the criteria are quantified, and the relative importance of each criterion is determined. One approach to determine the relative importance of alternatives is based on the pairwise comparison matrix proposed by Saaty (1984), as shown in **Table 6**. The weight (W_i) of each factor affecting the levels of reforestation adaptation was estimated using a pairwise comparison matrix based on the importance of one criterion over another, according to the Analytic Hierarchy Process (AHP) preference scale (Saaty 1984; Armenise *et al.*, 2013). For example, scale 1 indicates equal importance, while 9 indicates that one is more important

Table 3. Selected parameters for estimating *SQI* in the study area

Parameter	Unit	SD_i	$1/SD_i$	*CP*	WD_i	OB_i	References
pH		3.0	0.33		0.08	7.0	Amacher *et al.* (2007)
Bulk Density	g/cm^3	1.5	0.67		0.16	1.5	Amacher *et al.* (2007)
Prosity	%	50.0	0.02		0.00	50.0	Amacher *et al.* (2007)
Total organic	g/kg	1.0	1.00		0.24	1.0	Amacher *et al.* (2007)
T–P	g/kg	0.8	1.25		0.30	0.5	This study
T–N	g/kg	1.3	0.77	0.24	0.19	1.0	This study
Ca^{2+}	mg/L	1000.0	0.00		0.00	0.0	Amacher *et al.* (2007)
Mg^{2+}	mg/L	500.0	0.00		0.00	0.0	Amacher *et al.* (2007)
K^+	mg/L	500.0	0.00		0.00	0.0	Amacher *et al.* (2007)
Fe^{3+}	mg/L	10.0	0.10		0.02	0.0	Amacher *et al.* (2007)
Na^+	mg/L	500.0	0.00		0.00	0.0	Amacher *et al.* (2007)

Table 4. Chemical water components in semi–submerged land

ID	T	pH	DO	EC	Turbidity	SS	$CaCO_3$	TN	TP
	˚C		mgO_2/L	μs/cm	NTU	mg/L	mg/L	mg/L	mg/L
TM–1	31.0	9.1	5.6	38	156	33	18	1.4	0.4
TM–2	30.8	8.4	5.6	32	48	12	17	1.1	0.3
TM–3	31.0	8.5	5.5	43	173	77	128	1.7	0.4
TM–4	29.5	8.2	5.6	42	192	49	125	1.1	0.4
TM–5	29.2	7.8	5.6	48	246	40	145	1.4	0.4
TM–6	27.7	8.1	5.5	45	121	72	148	1.1	0.3
TM–7	28.6	7.7	5.5	40	147	45	81	1.6	0.4
TM–8	29.7	8.0	5.6	40	147	45	81	1.2	0.4
TM–9	30.1	8.6	5.9	40	147	45	81	1.3	0.3
TM–10	29.9	8.0	5.3	40	147	45	81	1.1	0.4
TM–11	27.9	8.8	5.5	40	147	45	81	1.2	0.5
TM–12	28.8	8.7	5.5	40	147	45	81	1.1	0.4
TM–13	30.1	8.6	5.5	40	147	44	81	1.7	0.4
TM–14	30.2	7.8	5.4	40	147	44	81	1.5	0.3
TM–15	29.8	7.7	5.6	40	147	45	81	1.1	0.3
TM–16	28.9	8.0	5.6	40	147	45	81	1.7	0.4
TM–17	28.8	7.9	5.8	40	147	44	81	1.6	0.5
TM–18	29.1	8.3	5.7	40	147	45	81	1.2	0.3
TM–19	29.6	7.9	5.5	40	147	45	81	1.3	0.2
TM–20	30.6	8.3	5.3	40	147	44	81	1.6	0.4
TM–21	30.2	8.3	5.8	40	147	45	81	1.1	0.5
TM–22	30.2	8.2	5.6	40	147	44	81	1.3	0.1
TM–23	29.7	8.9	5.6	40	147	45	81	1.6	0.2
TM–24	29.5	8.5	5.6	40	147	45	81	1.1	0.6
TM–25	30.1	8.8	5.4	40	147	44	81	1.1	0.5
TM–26	28.6	8.6	5.6	40	147	45	81	1.7	0.5
TM–27	28.8	8.1	5.8	40	147	45	81	1.3	0.6
TM–28	29.3	8.2	5.7	40	147	45	81	1.1	0.3
TM–29	28.6	7.8	5.3	40	147	44	81	1.6	0.6
TM–30	27.6	7.8	5.3	40	147	44	81	1.4	0.7

Table 5. Selected parameters for estimating *WQI* in the study area

Chemical parameters	Unit	S_i	$1/S_i$	K	W_i	C_i	References
Temperature	˚C	25	0.04		0.03	25	MOH (2018)
pH	–	8.5	0.12		0.08	7	MONRE (2015)
DO	mg/L	4	0.25		0.17	6	MONRE (2015)
EC	μS/cm	2250	0.00		0.00	0	Müller and Cornel (2016)
SS	mg/L	15	0.07	0.68	0.05	0	MONRE (2015)
Turbidity	NTU	2	0.50		0.34	0	Jeong *et al.* (2016)
$CaCO_3$	mg/L	300	0.00		0.00	0	MOH (2018)
T–N	mg/L	5	0.20		0.14	0	Müller and Cornel (2016)
T–P	mg/L	3.5	0.29		0.20	0	Müller and Cornel (2016)

than the other. Meanwhile, the reciprocals of 1 to 9 (1/1 to 1/9) show that one is less important than the others (Saaty 1984; Armenise *et al.*, 2013). The relative importance of factors in the pairwise comparison matrix was determined by considering the opinions of a team of experts. Once the matrix is created, the weights are obtained by identifying the normalized principal eigenvector of the matrix (Saaty 1984; Armenise *et al.*, 2013). To ensure the reliability of the identified weights, the consistency ratio index (CR) was calculated using Eq.(9) (Saaty 1984).

$$CR = \frac{CI}{RI} \tag{9}$$

where *RI* is the average result of the consistency index, depending on the order of the matrix given by

Table 6. Pairwise comparison matrix and weights of the main factors to afforestation

Factor	Elevation	Slope	Inundated Depth	Inundated Time	*WQI*	*SQI*	Soil Depth	w_i
Elevation	0.04	0.02	0.04	0.04	0.04	0.04	0.02	0.03
Slope	0.20	0.16	0.15	0.14	0.21	0.26	0.11	0.18
Inundated Depth	0.24	0.31	0.31	0.29	0.25	0.22	0.46	0.30
Inundated Time	0.20	0.31	0.31	0.29	0.21	0.26	0.23	0.26
WQI	0.04	0.02	0.05	0.06	0.04	0.04	0.02	0.04
SQI	0.04	0.03	0.06	0.05	0.04	0.04	0.04	0.04
Soil Depth	0.24	0.16	0.08	0.14	0.21	0.13	0.11	0.15
Reliability Analysis: CI = 0; RI =1.32; CR =0 < 0.1								

Saaty (1984). CI is the consistency index, which can be expressed by Eq.(10), as follows:

$$CI = \frac{(\lambda_{max} - n)}{n-1} \quad (10)$$

where λ_{max} is the largest or principal eigenvalue of the matrix, which was estimated from the matrix described by Saaty and Ramamurthy (Saaty, 1984; Ramamurthy *et al.*, 2020), and n is the number of criteria groups to be considered for evaluation. CI ≤ 0.1 indicates the pairwise comparison matrix has reasonable consistency and robustness, and the estimated weights are accepted.

The overall hierarchy of the adaptation coefficient is evaluated according to the following formula (Amacher *et al.*, 2007):

$$SI = \sum_{i=1}^{n} (w_i \times s_i) \quad (11)$$

where n is the number of criteria groups to be considered for evaluation (in this study n=7), as shown in **Table 6**; s_i is the adaptive hierarchy of adaptation of each criteria group calculated in **Table 1**, *and* w_i is the weight of factor i on adaptation to afforestation in **Table 6**. The SI is encoded as follows: S1=100 (very adaptive), S2=75 (moderately adaptive), S3=50 (less adaptive), and N=25 (non–adaptive), as shown in **Table 1**.

RESULTS AND DISCUSSIONS

Determination of semi–submerged land

According to the definition of the MONRE in the Circular 03/2012/TT–BTNMT (MONRE, 2012), "semi–submerged lands are lands belonging to areas of hydropower reservoirs and irrigation reservoirs that are not regularly flooded, with the duration of flooding depending on reservoir operation process but is generally not more than 6 months".

The rule curves of the Thac Mo Hydropower Reservoir Operation (RCTMO) consist of five water levels:

(1) Retarding water level (RWL): When the water level of the reservoir in the rainy season reaches the retarding water level, the spillway is immediately opened in an attempt to rapidly reduce the upper water level. The RWL is 220.8 m, issued by MOIT (2010).

(2) Upper water level (UWL): When the water level in the reservoir exceeds the upper water level, the spillway should be opened in an attempt to decrease the water level to the upper water level to prevent flooding.

(3) Lower water level (LWL): When the water level in the reservoir is below the lower water levels, water release is restricted in an attempt to maintain the amount of water so that it can be operated in the following months.

(4) Critical water level (CWL): When the water level in the reservoir is below the critical water level, water release for generating electricity must be critically reduced in an attempt to maintain the water level above the dead water level, but the water supply remains for domestic demands.

(5) Dead water level (DWL): When the water level in the reservoir is below the dead level of the reservoir, the water release is stopped for electricity generation except for human demand.

In addition to the five water levels, when the water level in the reservoir is the normal water level (NWL) at the end of the rainy season, the reservoir is defined as having sufficient water for electricity generation for the entire year according to the design capacity (15 MWh). The NWL is 218 m, as defined by MOIT (2010). In this study, the UWL, LWL and CWL were redetermined from the collected reservoir operation data series including the water level and the flow discharge in the period of 1995–2019, in which the UWL was redetermined by the monthly maximum average of water level, the LWL was calculated by the monthly minimum average of water level, and CWL was redefined as the minimum value of the months in the series of historical data. The results of RCTMO are shown in **Fig. 5**. Overlaying the RCTMO with the DEM, the time and depth flood results were obtained in compliance with the Circular 03/2012/TT–BTNMT (MONRE, 2012), as shown in the third column of **Table 7**. However, according to the results of the afforestation project in 2018 (AP2018) investigated by the Subdivision of Forest Inventory, Planning and Yield (Sub–Fipi, 2018), the areas of semi–submerged lands were also determined by the Circular 03/2012/TT–

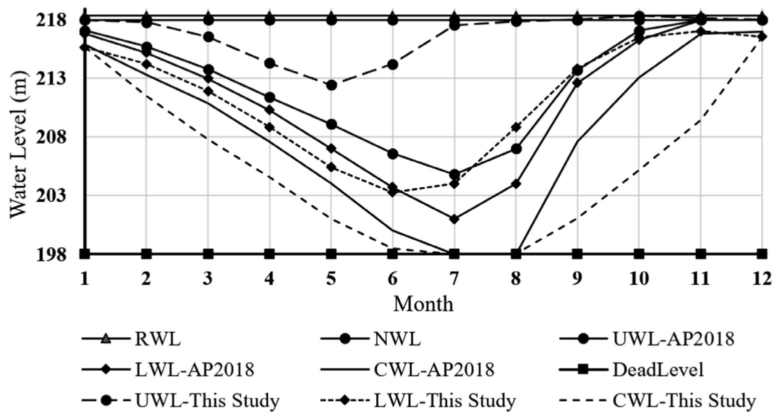

Fig. 5. The rule curves of Thac Mo Hydropower Reservoir operation for AP2018 and this study.

Table 7. Inundated time in the Thac Mo Hydropower Reservoir defined by the Circular 03/2012/TT–BTNMT of MONRE (MONRE, 2012) and this study

No.	Inundated time	This study (ha)	AP2018 (ha)	Difference (ha)
1	1 – 2 months	428	272	156
2	2 – 4 months	786	811	–25
3	5 – 6 months	621	502	119
	Total (ha)	1835	1585	250

Table 8. Adaptive hierarchy for reforestation by *SQI* and *WQI*

Hierarchy	S1 (75–100) (ha)	S2 (50–75) (ha)	S3 (25–50) (ha)	N (0–25) (ha)	Total (ha)
SQI	–	394	1709	6	2108
WQI	60	2048	–	–	2108

BTNMT, as shown in the fourth column of **Table 7**, which shows a remarkable difference compared with the results of this study.

These differences occurred because of the manner of comprehension and application of the definition of semi–submerged areas. In AP2018, the Sub–Fipi determined semi–submerged lands based on the NWL and the existing RCTMO issued by the MOIT (2010). In this study, semi–submerged lands were determined by the RWL, and the RCTMO was recalculated from a series of data collected from 1995 to 2019. Regarding the approach concept of this research, the land with altitude under RWL still belongs to areas of hydropower reservoir because historical data pointed out that over 15years of operation, there were three years when the water level of the reservoir was higher than RWL. The RCTMO reconstructed from historical data to determine the flooding time was achieved more accurately, while AP2018 used the existing RCTMO issued in 2010, and data were not updated from 2011 to 2019.

Fig. 5 shows that the amplitudes of the water level changes for UWL, LWL, and CWL in this study were larger than those in AP2018. This means that the semi–submerged area in this study was larger than the semi–submerged area in AP2018. The results in **Table 7** show that the total semi–submerged area is 1835 ha, with 428 ha flooded for 1–2 months, 786 ha flooded for 2–4 months, and 621 ha flooded for 5–6 months in this study, compared with the results of AP2018 where the total semi–submerged area was 1585 ha, with 272 ha flooded for 1–2 months, 811 ha flooded for 2–4 months, and 502 ha flooded for 5–6 months.

Soil quality index and Water quality index

The total water surface area of the Thac Mo Hydropower Reservoir up to the RWL was 14907 ha. The total area corresponding to the dead water level was 5848 ha, the usual submerged area (>6 months) was 6951 ha, and the semi–submerged area determined for calculating *SQI* and *WQI* index was 2108 ha.

The results in **Table 8** indicate that most of the *SQI* and *WQI* indexes are moderately adapted to the ability of reforestation in the semi–submerged areas of the Thac Mo Hydropower Reservoir. Only 6 ha are non–adaptive (N) according to the *SQI* index. However, the results also revealed that most soil quality components were less adaptive (S3) with 1709 ha, and only 394 ha were moderate adaptive (S2). On the other hand, the *WQI* index shows good results. Almost all of the semi–submerged areas were moderately adaptive (S2), with 2048 ha and 60 ha being very adaptive (S3). **Figs. 6** and **7** show the detailed distribution of the *SQI* and *WQI* in the Thac Mo Hydropower Reservoir.

Adaptive hierarchy for reforestation

Synthetic assessment of influencing factors including (1) topography, (2) hydrometeorology, (3) soil type, (4) soil characteristics, and (5) water quality was performed. The MCDM method is based on the theory of Saaty's weight, as mentioned above, to determine the adaptive hierarchy for reforestation. The calculation results are shown in **Fig. 8** and **Table 9**.

The results of the adaptive hierarchy for reforestation are shown in detail in **Fig. 8**. The results indicated that the total adaptative area for afforestation in the Thac Mo Hydropower Reservoir was 1806 ha, mainly in the Bu Dang District with 1208 ha. The remaining districts were the less adaptive semi–submerged areas for afforestation, with 236 ha in Bu Gia Map District, 165 ha in Phu Rieng Town, and 197 ha in Phuoc Long Town.

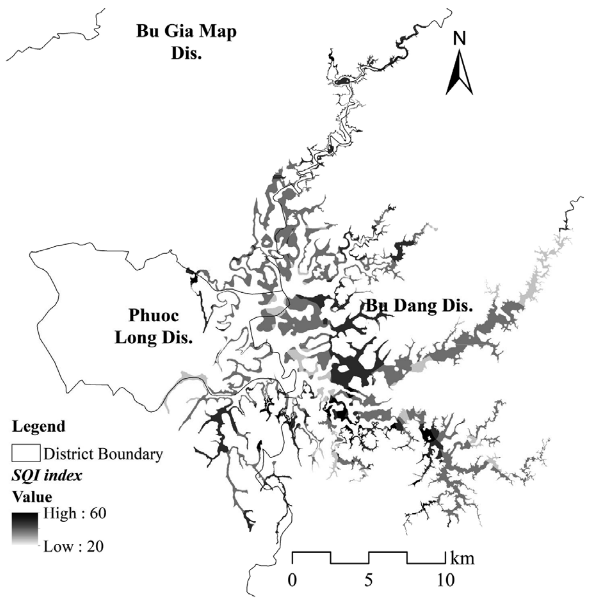

Fig. 6. *SQI* index of Thac Mo Hydropower Reservoir.

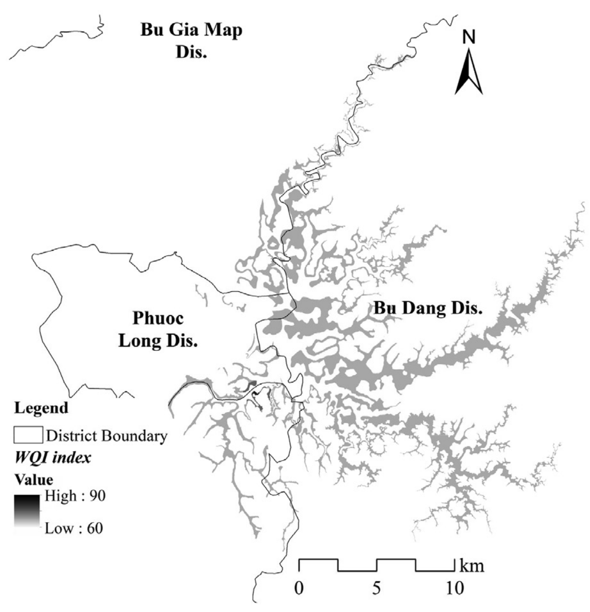

Fig. 7. *WQI* index of Thac Mo Hydropower Reservoir.

Most of the semi–submerged lands adapted for afforestation were moderately adaptive (S2) with 724 ha (40%), and less adaptive (S3) with 876 ha (49%), with only 206 ha (11%) being very adaptive (S1). However, 302 ha (200 ha in Bu Dang District and 2 ha in Bu Gia Map District) were identified as unsuitable for afforestation (N–None–adaptive). This is because this area had relatively low *SQI* and *WQI* indexes (only reached S3), and the slope was quite high, combined with unsuitable soil type for afforestation. Hence, the SI index was lower than 25. These areas are located upstream of the Thac Mo Hydropower.

Table 9 shows a comparison of the adaptive hierarchy for reforestation between the afforestation project in 2018 and the results of this study. The adaptive area for afforestation has increased by 570 ha (32%) from 1236 ha (AP2018) to 1806 ha (this study). This difference was attributed to the following reasons: (1) the approach concept of this research for determination of semi–submerged land as analyzed above, increased by 250 ha from 1585 ha (AP2018) to about 1835 ha (this study); (2) the other increased area of 320 ha is excluded in AP2018 due to not managing the reservoir owners.

Moreover, the proportion of semi–submerged areas adapted for afforestation was different from that of AP2018. In this study, the percentages of adaptation hierarchy for afforestation were 11%, 40%, and 49% for S1, S2, and S3, respectively, while those of AP2018 were 8%, 57%, and 35%, respectively.

CONCLUSION

The determination of semi–submerged lands in the basin of reservoirs plays a significant role in improving the efficiency of reservoirs, land resources, and forest

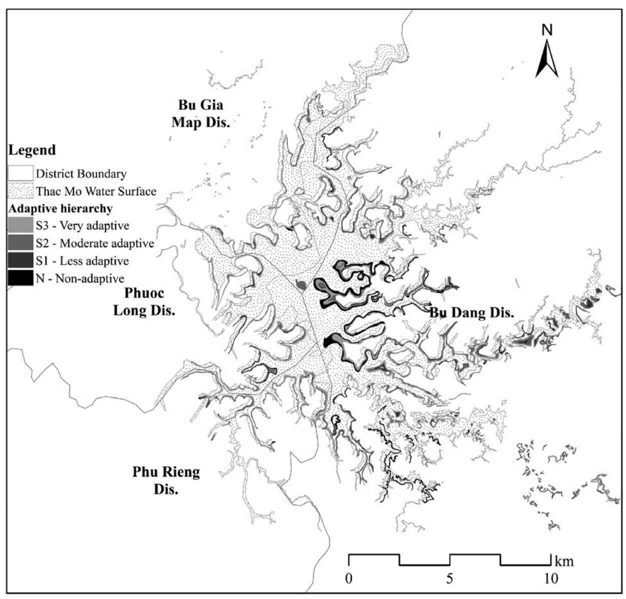

Fig. 8. Adaptive hierarchy map for reforestation in Thac Mo Hydropower Reservoir.

Table 9. Adaptive hierarchy for reforestation in Thac Mo Hydropower Watershed

Case	AP2018					This study					Difference (2)–(1)
Adaptive hierarchy	S1	S2	S3	N	Total (1): S1+S2+S3	S1	S2	S3	N	Total (2): S1+S2+S3	
Bu Dang Dis. (ha)	52	463	309	–	824	148	514	546	300	1208	384
Bu Gia Map Dis. (ha)	6	127	51	–	184	21	86	129	2	236	52
Phu Rieng Town (ha)	6	44	26	–	76	15	63	87	0	165	89
Phuoc Long Town (ha)	32	76	44	–	152	22	61	114	0	197	45
Total (ha)	96	710	430	–	1236	206	724	876	302	1806	570
Proportion	8%	57%	35%	–	100%	11%	40%	49%		100%	32%

management. This study has redefined the semi–submerged area of the Thac Mo Hydropower Reservoir based on a comprehensive approach that includes all influencing factors: (1) topography, (2) hydrometeorology, (3) soil type, (4) soil characteristics, and (5) water quality.

For the determination of semi–submerged areas, the Circular 03/2012/TT–BTNMT of MONRE (MONRE, 2012) stated that: the definition of semi–submerged area is not clear, causing conflict in understanding the application while the reservoir parameters are clearly defined; The results of the study indicated that the semi–submerged area was determined based on statistics from the historical data of reservoir operation, showing an increase in semi–submerged area by about 250 ha, compared with the results of AP2018. This is obvious because AP2018 identified a semi–submerged area based on the existing RCTMO (using NWL and CWL design data instead of updating the data). This study used the RWL and recalculated CWL curve with a much larger amplitude, in which the RWL had a greater value, and the recalculated CWL had a smaller value.

The results of this study showed that the total semi–submerged area was 1,835 ha, which is higher than that of AP2018's semi–submerged area in the order of 155 ha flooded for 1–2 months, 65 ha flooded for 2–4 months, and 119 ha flooded for 5–6 months.

The assessment of afforestation adaptation with *SQI* and *WQI* is new in this study. The *SQI* index was assessed based on 13 chemical indicators of soil components, and the *WQI* index was evaluated based on 9 chemical indicators of water by field investigation, sampling, and laboratory analysis. The results of adaptive hierarchy by *SQI* indicated that the semi–submerged land in the Thac Mo Hydropower Reservoir mostly included less adaptive land (about 1708 ha), accounting for about 81% of the total semi–submerged area. Only about 394 ha (19%) was moderately adaptive, and 6 ha was not suitable for afforestation. The *WQI* showed that the adaptive hierarchy was better than the *SQI*, with 2047 ha (97%) being moderately adaptive (S2), and about 60 ha (3%) being very adaptive (S1).

Factors affecting afforestation, such as topography, hydrometeorology, soil type, soil quality factors, and water quality have been incorporated into the *SI* index of adaptive hierarchy through Saaty's weighted method. This study indicates that the adaptive hierarchy for afforestation has shifted from being partially moderately adaptive (S2) to less adaptive (S3). In the AP2018 results, 57% areas were moderately adaptive (S2), 35% were less adaptive (S3), 40% were S2, and 49% gained S3 in this study. Only a small percentage showed the opposite trend, with 11% being very adaptive (S1) in this study compared to the 8% in AP2018.

This study concluded that the total semi–submerged area was 1806 ha compared to 1236 ha in AP2018. This finding emphasizes that the increased 570 ha in the semi–submerged area for afforestation needs to be considered in afforestation management in an effort to improve the efficiency of operation, exploit land resources to their full potential, and minimize the negative impacts of reservoir operation.

AUTHOR CONTRIBUTIONS

D. V. QUANG evaluated the dataset and drafted the manuscript. T. A. NGOC and V. T. H. THU designed the study, conducted field observations, and reviewed the draft paper. T. D. AN proposed adaptive hierarchy and calculated the SQI and WQI indexes for this research. N. V. HAI built charts and maps for this study. L. C. CHINH performed the analysis and synthesis of water and soil quality data. K. HIRAMATSU revised the manuscript and assisted in its preparation. All authors approved the final version of the manuscript and agreed to be accountable for all aspects, ensuring that issues related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

ACKNOWLEDGMENTS

This paper is one of the results of the project "Building a set of criteria, a database system for managing semi–submerged lands for afforestation in Binh Phuoc province" supported by the Department of Science and Technology in Binh Phuoc province. The authors also appreciate the funding support from JSPS KAKENHI Grant Number JP21K05833.

REFERENCES

Adimalla, N. and H. Qian 2019 Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. *Ecotoxicol. Environ. Saf.*, **176**: 153–161

Aguirre–Salado, C. A., J. R. Valdéz–Lazalde, G. Sánchez–Díaz, L. Miranda–Aragón and A. I. Aguirre–Salado 2015 Modelling Site Selection For Tree Plantation Establishment Under Different Decision Scenarios. *J. Trop. For. Sci.*, **27**: 298–313

Amacher, M. C., K. P. O'Neill and C. H. Perry 2007 Soil vital signs: A new soil quality index (SQI) for assessing forest soil health. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, *Rocky Mountain Research Station*: pp. 1–12

Armenise, E., M. A. Redmile–Gordon, A. M. Stellacci, A. Ciccarese and P. Rubino 2013 Developing a soil quality index to compare soil fitness for agricultural use under different managements in the Mediterranean environment. *Soil Tillage Res.*, **130**: 91–98

Barakat, A., A. Hilali, M. E. Baghdadi and F. Touhami 2019 Assessment of shallow groundwater quality and its suitability for drinking purpose near the Béni–Mellal wastewater treatment lagoon (Morocco). *Hum. Ecol. Risk. Assess.: An Intl. J.*, **26**(6): 1476–1495

Dien, B. T. H. 2014 Classification of site conditions of Luong forest in Quang Hoa District, Thanh Hoa Province. *J. For. Sci. Tech.*, **4**: 1–8 (in Vietnames)

Do, D. S. 2005 *Forest land assessment system in Vietnam*. Science and Technology Publishing House in Hanoi. pp. 1–116 (in Vietnamese)

Duarte, C. M and J. Kalff 1986 Littoral slope as a predictor of the maximum biomass of submerged macrophyte communities, *Limnol. Oceanogr.*, **31**: 1072–1080

Duarte, M. C. and J. Kalff 1988 Influence of lake morphometry on the response of submerged macrophytes to sediment fertilization. *Can. J. Fish. Aquat. Sci.*, **45**: 216–221

Ferreira, C. D. S., M. T. F. Piedade, M. A. S. Tiné, D. R. Rossatto, P. Parolinand and M. S. Buckeridge 2009 The role of carbohydrates in seed germination and seedling establishment of Himatanthus sucuuba, an Amazonian tree with populations adapted to flooded and non–flooded conditions. *Ann. Bot.*, **104**: 1111–1119

Ghouili, N., F. Hamzaoui–Azaza, M. Zammouri, M. F. Zaghrarni, F. J. Horriche, and M. T. C. de Melo 2018 Groundwater quality assessment of the Takelsa phreatic aquifer (Northeastern Tunisia) using geochemical and statistical methods: implications for aquifer management and end–users. *Environ. Sci. Pollut. Res.*, **25**: 36306–36327

Hilt, S., E. M. Gross, M. Hupfer, H. Morscheid, J. Mählmann, A. Melzer, J. Poltz, S. Sandrock, E. M. Scharf, S. Schneider and K. van de Weyer 2006 Restoration of submerged vegetation in shallow eutrophic lakes – A guideline and state of the art in Germany. *Limnologica.*, **36**: 155–171

Hoan, T. Q. 2016 Division and application development in analysis and management of semi–submerged lands in Binh Phuoc province. *J. For. Sci.*, 4513–4523 (in Vietnamese)

Jeong, H., H. Kim, T. Jang 2016 Irrigation Water Quality Standards for Indirect Wastewater Reuse in Agriculture: A Contribution toward Sustainable Wastewater Reuse in South Korea. *Water*, **8**(4): 169

Keshavarzi, A., H. O. Tuffour, A. Bagherzadeh, L. P. Tattrah, V. Kumar, A. Gholizadeh and J. Rodrigo–Comino 2020 Using fuzzy–AHP and parametric technique to assess soil fertility status in Northeast of Iran. *J. Mt. Sci.*, **17**: 931–948

Khanh, N. V. 1996 Report on study on forest site zoning in Vietnam. *Hanoi For. Univ.*, 1–150 (in Vietnamese)

Kumar, T. and D. C. Jhariya 2015 Land quality index assessment for agricultural purpose using multi–criteria decision analysis (MCDA). *Geocarto Int.*, **30**: 822–841

Li, K., L. Wang, Z. Li, Y. Xie, X. Wang and Q. Fang 2017 Exploring the Spatial–Seasonal Dynamics of Water Quality, Submerged Aquatic Plants and Their Influencing Factors in Different Areas of a Lake. *Water*, **9**: 707

Maria Teresa, F. P., P. Parolinand W. J. Junk 2006 Phenology, fruit production and seed dispersal of Astrocaryum jauari (Arecaceae) in Amazonian black water floodplains. *Rev. Biol. Trop.*, **54**: 1171–1178

Ministry of Health (MOH) 2018 *QCVN 01–1: 2018/BYT: National Technical Regulation on Domestic Water Quality*, pp. 1–21. (in Vietnamese)

Ministry of Industry and Trade (MOIT) 2010 *Decission 6964/QD–BCT: the rule curves of Thac Mo Hydropower Reservoir operating modes*, pp. 22–23. (in Vietnamese)

Ministry of Natural Resources and Environment (MONRE) 2012 *Circular 03/2012/TT–BTNMT: Regulation on management and exploitation of semi–submerged land in hydropower and irrigation reservoirs*, pp. 1–3. (in Vietnamese)

Ministry of Natural Resources and Environment (MONRE) 2015 *QCVN 08–MT:2015/BTNMT: National technical regulation on surface water quality*, pp. 1–13. (in Vietnamese)

Müller, K. and P. Cornel 2016 Setting water quality criteria for agricultural water reuse purposes. *Journal of Water Reuse and Desalination.* **7**: 121–135

Murphy, F., K. Schmieder, L. Baastrup–Spohr, O. Pedersen and K. Sand – Jensen 2018 Five decades of dramatic changes in submerged vegetation in Lake Constance. *Aquat. Bot.*, **144**: 31–37

Parolin, P. and F. Wittmann 2010 Struggle in the flood: tree responses to flooding stress in four tropical floodplain systems. *AoB PLANTS*, **2010**: 1–19

Phukan, U. J., S. Mishra and R. K. Shukla 2016 Waterlogging and submergence stress: affects and acclimation. *Crit. Rev. Biotechnol.*, **36**: 956–966

Ramamurthy V., G. P. O. Reddy and N. Kumar 2020 Assessment of land suitability for maize (*Zea mays L*) in semi–arid ecosystem of southern India using integrated AHP and GIS approach. *Computers and Electronics in Agriculture*, **179**: 105806

Saaty, T. L. 1984 *The Analytic Hierarchy Process: Decision Making in Complex Environments. In "Avenhaus R", Huber RK (Editors), Quantitative Assessment in Arms Control: Mathematical Modeling and Simulation in the Analysis of Arms Control Problems*. Springer US, Boston, MA, pp. 285–308

Silva–Flores, R., G. Pérez–Verdín and C. Wehenkel 2014 Patterns of tree species diversity in relation to climatic factors on the Sierra Madre Occidental, Mexico. *PloS one*, **9**(8): e105034

Singh, K. K., G. Tewari, and S. Kumar 2020 Evaluation of Groundwater Quality for Suitability of Irrigation Purposes: A Case Study in the Udham Singh Nagar, Uttarakhand. *J. Chem.*, **2020**: 1–15

Subdivision of Forest Inventory, Planning and Yield (Sub–Fipi) 2018 *Report on Afforestation Project in Binh Phuoc Province*, 18–42 (in Vietnamese)

Tamang, B. G. and T. Fukao 2015 Plant Adaptation to Multiple Stresses during Submergence and Following Desubmergence. *Int. J. Mol. Sci.*, **16**: 30164–30180

Them, H. V. T. 2002 Land and semi–submerged site. *Ho Chi Minh City Univ. Agr. For.*, 1–100 (In Vietnamese)

Verhofstad, M. J. J. M., M. M. Alirangues Núñez, E. P. Reichman, E. van Donk, L. P. M. Lamers and E. S. Bakker 2017 Mass development of monospecific submerged macrophyte vegetation after the restoration of shallow lakes: Roles of light, sediment nutrient levels, and propagule density. *Aquat. Bot.*, **141**: 29–38

Xu, M., L. Ma, Y. Jia and M. Liu 2017 Integrating the effects of latitude and altitude on the spatial differentiation of plant community diversity in a mountainous ecosystem in China. *PloS one*, **12**(4): e0176866

Zhai, Y., X. Zhao, Y. Teng, X. Li, J. Zhang, J. Wu, and R. Zuo 2017 Groundwater nitrate pollution and human health risk assessment by using HHRA model in an agricultural area, NE China. *Ecotoxicol. Environ. Saf.*, **137**: 130–142

Zhang, C., X. Gao , L. Wang, and X. Chen 2015 Modelling the role of epiphyton and water level for submerged macrophyte development with a modified submerged aquatic vegetation model in a shallow reservoir in China. *Ecol. Eng.*, **81**: 123–132