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Research Article

Indicator-based assessment of environmental sustainability of a metalware handicraft village in Hanoi, Vietnam

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Abstract: This research was conducted to assess the environmental sustainability of a metalware handicraft village in Hanoi, Vietnam using 17 indicators of 4 components (Environmental systems - S1, reducing environmental stresses - S2, reducing human vulnerability - S3, and social institutional capacity - S4). All indicators were quantified on a scale of 0-1, reflecting a range from low to high sustainability. A combination of soil and water analysis, and a social survey of 67 local households were conducted. The results show that the number of water samples exceeding the allowable limits for wastewater (QCVN 40:2011/BTNMT, Column B), domestic water (QCVN 01-1:2018/BYT), groundwater (QCVN 09:2023/BTNMT), and surface water (QCVN 08:2023/BTNMT, Column B) was 13/14 (NH_4^+), 9/14 (COD), 8/14 (BOD_5), 4/14 (PO_4^{3-}), 5/14 (Fe), and 6/14 (Mn). The concentrations of heavy metals in soil were within acceptable limits for agricultural soil (QCVN 03:2023/BTNMT). The social survey results present high percentages of households dissatisfaction with the quality of air (43%) and water (74.5%), which were also perceived to negatively impact on human health by 67% and 81% of respondents, respectively. The environmental sustainability of the study area is 0.38 (low sustainability) with the following order: S3 (0.25) < S2 (0.26) < S4 (0.44) < S1 (0.57). Solutions on management, policy, and technology are proposed for ensuring environmental sustainability of the metalware handicraft village.

Keywords: Environmental Sustainability; Handicraft village; Indicator; Metalware; Vietnam.

1. Introduction

Handicraft villages play an important role in socio-economic development, livelihood creation, traditionally cultural value maintenance, and tourism promotion in rural areas. Hanoi is home to 1,350 craft villages, of which 305 have been recognized as traditional villages with their own unique identity, producing sophisticated products that reflect the nation's cultural heritage [1]. The products from these craft villages are diverse, have beautiful designs and high quality, and hold competitive advantages in both domestic and international markets. These products span various sectors, including textiles, ceramics, weaving, embroidery, wooden furniture, mechanics, agriculture, and food processing. However, outdated technology, scattered production, and improper pollutant treatments have posed serious impacts on the environment, ecosystems, and human health [2]. Ensuring environmental sustainability is of great importance which can significantly contribute to food security, human security, and sustainable development [3].

Sustainability refers to the maintenance of core ecosystems and supporting long-term ecological balance while developing the global economy [4]. Several tools and methodologies were developed to evaluate their sustainability performance such as indicators and indices, life cycle sustainability assessment, monetary approach, and integrated assessment [5, 6]. Environmental sustainability was introduced as meeting the resources and services needs of current and future generations without compromising the health of the ecosystems that provide them [7]. Numerous studies have evaluated environmental sustainability in diverse fields, including the digitalization of production [8], the circular economy [9], energy [10, 11], construction [12], and agricultural systems [13]. In which, indicator-based assessment - the most common method for sustainability assessment - is considered as a measure of overall progress toward environmental sustainability, serving as an important tool for evaluating system sustainability, and providing essential information for stakeholders [14]. Some indexes have been widely used for environmental sustainability assessment such as Environmental Sustainability Index (ESI) [15], Environmental Performance Index (EPI) [16]. Driver-Pressure-State-Impact-Response (DPSIR) framework provides an especially effective approach for designing assessments, identifying indicators, communicating results, and supporting environmental monitoring [17–19]. In Vietnam, indicators for environmental sustainability were also mentioned in Decision No. 2157/QĐ-TTg in 2013 [20], Decision No. 2782/QĐ-BTNMT in 2019 [21], and Vietnam Agenda 21 [22]. These indicators were designed for large-scale applications (e.g., regions, countries, provinces, cities, and districts). For smaller scales, especially in craft villages, the sustainability of specific trades and craft villages has also been studied, such as in Minh Hong traditional vermicelli production village [23], Phu Lang pottery village [24], and Dong Ky carpentry village [25]. However, in these studies, environmental sustainability was only mentioned as a sub-criterion within the environmental component, alongside economic, social, cultural, and administrative aspects. In addition, issue-based frameworks were used in which driver and response information for enhancing sustainability may be limited in comparison to the DPSIR framework [26].

This study aimed to assess environmental sustainability of a metalware handicraft village in Hanoi, Vietnam using indicator-based approach. The findings from this research are expected to provide valuable solutions to ensure environmental sustainability in the study area.

2. Materials and methods

2.1. Study area

The metalware handicraft village in this research has started since the 15^{th} century with a total area of 4.65 km^2, of which the percentage of agricultural, specialized-use, residential, and unused land is 63.4%, 19.2%, 16%, and 1.4%, respectively [27]. Up to now, the number of employees in the study area is over 3,000 people and is divided into 2 producing areas, including concentrated production industrial clusters and scattered production households in the village with 428 production facilities and 310 metalworking businesses [27]. The entire production process was firstly handmade with some crude machines and supporting devices. However, at present, high-tech machinery is used to create a wide variety of products with high productivity.

2.2. Methodology

2.2.1. Indicator-based assessment of environmental sustainability

Indicators for environmental sustainability assessment of the metalware handicraft village were proposed mainly based on the Environmental Sustainability Index (ESI) [15] and the Environmental Performance Index (EPI) [16], referring the indicators evaluating the sustainability of specific trades and craft villages [23-25] (Table 1). Selection, adjustment, and addition of indicators were performed following the Bellagio principles for sustainability assessment [26]. A set of 17 indicators belonging to 4 components were introduced including Environmental systems (S1), Reducing environmental stresses (S2), Reducing human vulnerability (S3), and Social institutional capacity (S4) (Table 1).

2.2.2. Sampling and analysis

Field surveys were conducted from May to August in 2024 in the metalware handicraft village for assessing the current status of production activities, society, and environment. Surface soil samples were collected at 0-20 cm depth at 14 points of the gardens and agricultural fields in the study area. Soil samples were then dried in the drying oven at 40°C, sieved through a 2-mm mesh and ground using a HERZOG grinder for further analysis.

A total of 14 water samples were collected including wastewater, surface water, domestic water, and groundwater. The pH value of the water was measured onsite by using the multi-parameter meter HACH HQ30D. The analyses of wastewater, surface water, domestic water, and groundwater were conducted in accordance with guidelines TCVN 5999:1995 [28], TCVN 5994:1995 [29], TCVN 6663-5:2009 [30], and TCVN 6663-11:2011 [31], respectively, and reserved following guidelines TCVN 6663-3:2016 [32]. Concentrations of heavy metals in soil and water were performed by the Plasma Emission Spectrometer (ICP-OES, iCAP PRO X). Nutritional parameters including NH_4^+, PO_4^{3-}, and NO_3^- were measured by the spectrophotometric by UV-VIS Hach Dr6000 (λ = 640 nm), UV-VIS Dynamica Halo RB-10 (λ = 880 nm), and (λ = 415 nm), respectively. Distillation and titration methods SMEWW 5220 C:2017 and SMEWW 5210 D:2017 were used to determine COD and BOD_5 in water, respectively.

Soil and water samples were pre-treated and then analyzed at the Key Laboratory of Geo-environment and Climate Change Response and the Laboratory of Environmental Analysis, University of Science, Vietnam National University, Hanoi and the Institute of New Technology, Academy of Military Science and Technology.

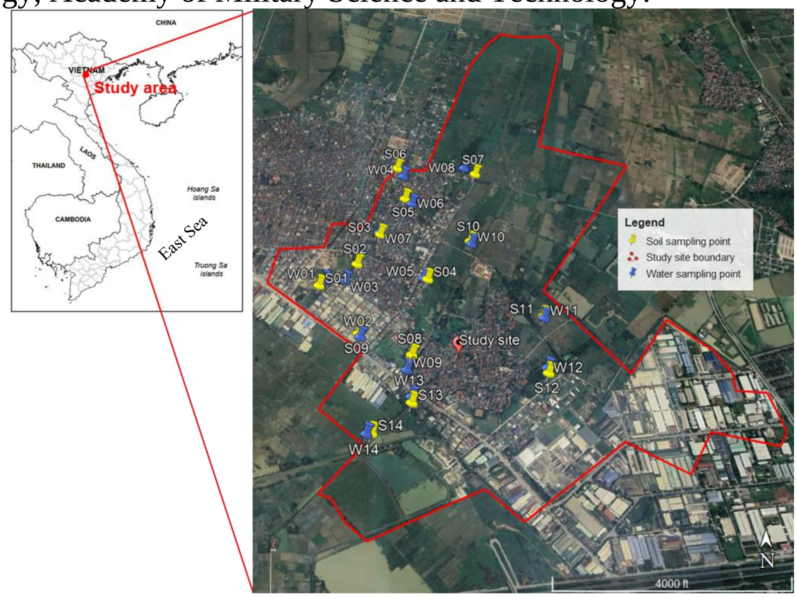

Figure 1. Soil and sampling points in the study area (https://www.google.com/maps/).

2.2.3. Social survey

A semi-structured interview was conducted based on the questionnaire developed from the proposed indicators in Table 1. A total of 67 households in the study area were randomly interviewed to ensure the spatial distribution, production and non-production households, and diversity of livelihoods with the confidence level 90% and margin of error 10% [33].

Table 1. Indicators for environmental sustainability assessment of the metalware handicraft village.

Component	Indicator	Code	Reference	Description	Calculation equation
Environmental systems (S1)	Air quality	S1-1	[15, 16]	The level of people's satisfaction with air quality	1
	Soil quality	S1-2	[15]	Soil quality	3
				The level of people's satisfaction with soil quality	1
	Water quality	S1-3	[15, 16]	Water quality	3
				Water quality index (WQI)	1
				The level of people's satisfaction with water quality	1
	Land resources	S1-4	[15]	The degree of impact of human activities on land resources	2
	Water quantity	S1-5	[15]	The degree of impact of human activities on water resources	2
Reducing environmental stresses (S2)	Reducing air pollution	S2-1	[15, 16]	Increased level of air pollution	2
	Reducing soil stress	S2-2		Increased level of soil pollution	2
	Reducing water stress	S2-3	[15, 16]	Increased level of wastewater	2
				The level of chemical fertilizer use in agriculture	2
				The level of pesticide use in agriculture	2
	Reducing waste discharge pressure	S2-4	[15]	The level of solid waste generation	2
				The level of hazardous waste generation	2
				The level of fossil fuel use for human activities	2
Reducing human vulnerability (S3)	Air quality's impact on health	S3-1	[15, 16]	Assessment of local people about the impact of air quality on health	2
	Soil quality's impact on health	S3-2	[15, 16]	Assessment of local people about the impact of soil quality on health	2
	Water quality's impact on health	S3-3	[15, 16]	Assessment of local people about the impact of water quality on health	2
Social institutional capacity (S4)	Environmental management efficiency	S4-1	[15]	Assessment of local people about environmental management efficiency of local authorities	1
	Wealth	S4-2		Proportion of poor and near-poor households	
	Awareness	S4-3		Awareness about environment protection responsibility	1
	Knowledge	S4-4		The degree of participation in training courses on environmental protection	1
	Environmental protection efforts	S4-5	[15]	The level of environmental protection efforts of local authorities	1

2.2.4. Data analysis

The water quality index (WQI) was calculated following the Decision No.1460/QD-TCMT on Technical Guideline for Calculation and Publication of Vietnam's Water Quality Index [34]. In this study, 3 parameter groups were used for WQI calculation including pH, nutrients (COD, BOD_5, NH_4^+, PO_4^{3-}, and NO_3^-), and heavy metals (As, Cd, Pb, Cr, Cu, and Zn). The data corresponding to the indicators of social survey were coded, normalized by the Min-Max method (on a scale of 0-1) using Eq. (1) and Eq. (2) [23] for positive and negative correlation with environmental sustainability, respectively, and Eq. (3) for analytical indicators.

$$X_{ij} = \frac{X_{ij} - \text{Min}X_{ij}}{\text{Max}X_{ij} - \text{Min}X_{ij}} \quad (1)$$

$$X_{ij} = \frac{MaxX_{ij} - X_{ij}}{MaxX_{ij} - MinX_{ij}} \quad (2)$$

where x_{ij} represents the normalized value of indicator i of the household j; X_{ij} refers to the value of the indicator i for household j; Max and Min indicate the maximum and minimum scaled values of indicator i, respectively.

$$A = \frac{\text{Number of samples} - \text{Number of polluted samples}}{\text{Number of samples}} \quad (3)$$

Component sustainability and environmental sustainability were calculated by average values of corresponding indicators and components. The scale for environmental sustainability assessment of the metalware handicraft village (on a scale of 0-1) is proposed as follows: unsustainability (0.00-0.20), low sustainability (0.21-0.40), medium sustainability (0.41-0.60), relatively high sustainability (0.61-0.80), and high sustainability (0.81-1.00) [23]. The Analytic Hierarchy Process (AHP) method was used to calculate and analyze the weights, make the pairwise comparison for setting priorities of indicators and categories [35]. The input data for AHP was collected from the structure questionnaire of 9 experts including experts in the field of environment and sustainability (3), local authorities (3), and households in the study area (3).

3. Results and discussions

3.1. Assessment of environmental sustainability of the metalware handicraft village

3.1.1. Environmental systems (S1)

Air quality (S1-1): The interview results show that 43% of households were dissatisfied with the air quality in the study area (Figure 2a). Several reasons were mentioned, including the geographical proximity between the study area and a carpentry village where the production process emits a lot of smoke and dust. In addition, the impact of the local industrial park and a nearby tobacco factory on the air quality in the area was also highlighted.

Soil quality (S1-2): The analytical results of soil in the metalware handicraft village are shown in Table 2. Compared to QCVN 03:2023/BTNMT for agriculture soil [36], soil quality in the study area was within acceptable limits.

Table 2. Concentrations of heavy metals in soils in the metalware handicraft village (mg/kg).

Sampling point	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn
S1	3.59	ND	21.2	13.8	480	10.8	15.4	67.6
S2	0.46	ND	125	22.4	276	20.7	26.5	120
S3	3.95	ND	15.4	11.2	237	10.5	19.4	62.7
S4	4.21	ND	21.2	17.5	192	18.5	30.2	73.5
S5	4.89	ND	18.8	12.4	388	17.4	23.5	88.6
S6	10.4	ND	17.7	29.6	530	21.3	17.7	104
S7	6.76	ND	26.2	14.6	490	24.8	22.8	59.0
S8	4.51	ND	18.4	17.4	226	15.6	24.7	89.3
S9	7.35	ND	18.4	8.0	536	12.0	18.2	47.3
S10	5.01	ND	20.9	20.7	98.2	18.2	20.1	71.4
S11	7.24	ND	24.5	22.8	355	27.4	20.7	59.3
S12	3.13	ND	17.7	19.5	171	15.1	24.0	84.5
S13	3.99	ND	20.1	16.8	322	15.8	20.2	62.9
S14	7.33	ND	20.6	13.7	421	15.5	19.9	119
Average	*5.20*	*ND*	*27.6*	*17.2*	*337*	*17.4*	*21.7*	*79.2*
QCVN 03:2023/BTNMT [36]	25	4	150	150	–	100	200	300

Note: ND: Not detectable

The research area is a low-lying area with 63.4% of its land dedicated to agriculture, primarily for rice and seasonal vegetables, is decreasing in farmland area due to industrial development. According to the interview result, the levels of satisfaction with soil quality among households were as follows: very satisfied (2%), satisfied (28%), neutral (54%), dissatisfied (12%), and very dissatisfied (4%) (Figure 2b).

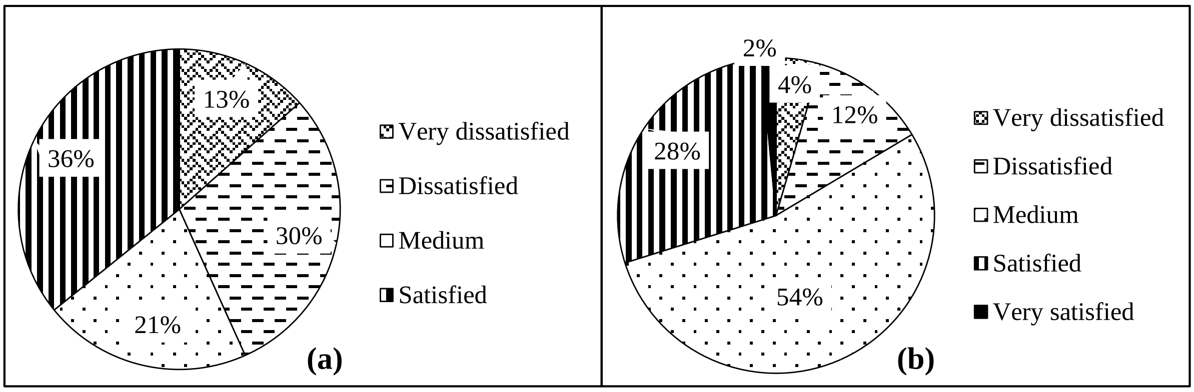

Figure 2. (a) The level of people's satisfaction with air quality; (b) The level of people's satisfaction with soil quality.

Water quality (S1-3): Water quality of the metalware handicraft village including wastewater, domestic water, groundwater, and surface water is shown in Table 3. The analytical results show that COD values in wastewater and surface water ranged within 53-171 mg/L and 26-95 mg/L, respectively. The COD values in surface water were 1.7-6.3 times higher than the QCVN 08:2023/BTNMT (Column B). High BOD_5 values (10-77 mg/L) were also found in all 8 sampling points. High concentrations of NH_4^+ were recorded in 13/14 water sampling points. This result can be explained by NH_4^+ sources such as using chemical NH_4Cl in the plating process (particularly highest in the W1 sample with 33 mg NH_4^+/L), domestic, and agricultural activities. Groundwater and domestic water (tap water) which are pre-treated and supplied by a water supply are also contaminated with NH_4^+, possibly due to the fact that groundwater with high NH_4^+ concentrations is the input water source for the local water supply plant. Some surface water samples collected in the river and lake near paddy field and vegetable gardens (W8, W9, W12, and W14) show that the concentrations of both PO_4^{3-} and NH_4^+ exceeded regulation limitations, implying the possibility of residues of chemical fertilizers. Regarding heavy metals, the concentrations of Fe and Mn found in domestic water (W3), groundwater (W6) and surface water (W9-W14) exceeded the allowable values [38–40]. The concentrations of heavy metals agreed with the village's current status of restricting and removing the plating in the production process, decreasing the discharge of the heavy metal polluted wastewater after plating into the environment.

The water quality index (WQI) was calculated for surface water based on the analytical results of 3 parameter groups: pH, heavy metals, and organic and nutritional parameters [34]. The WQI of the metalware handicraft village is presented in Table 4, ranging within 31-61, indicating the water quality status as moderate (W7, W10, and W11), and poor (W8, W9, W12, W13, and W14). In which, WQI in W8, W9, and W12 were lower than other points because surface water at these points received wastewater from both domestic, production,

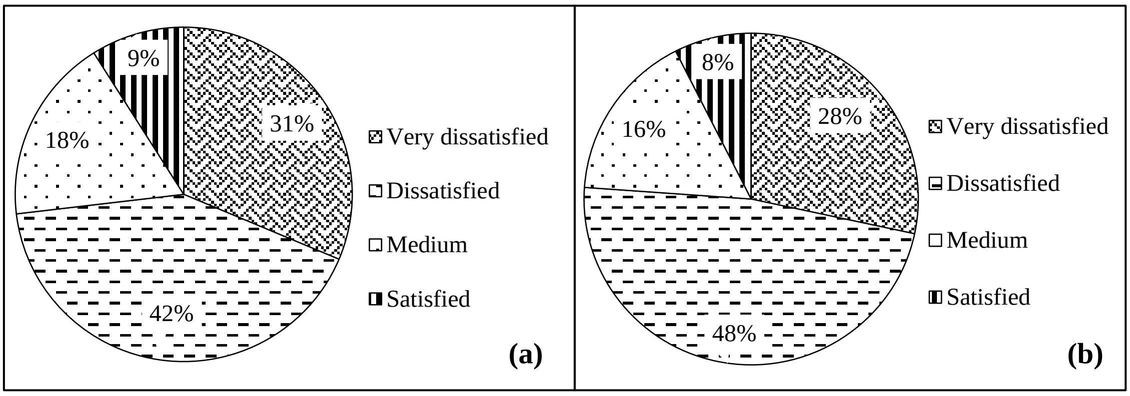

Figure 3. (a) The level of people's satisfaction with drinking water quality; (b) The level of people's satisfaction domestic water quality.

and agricultural activities. According to the report of local authorities in 2023, 83% of households in the metalware handicraft village used tap water supplied by a local water supply plant, while the remaining households still primarily relied on groundwater for their daily needs [27]. However, both groundwater and surface water in the commune have been possibly affected by metalware production activities, livestock farming, and agriculture. As a result, only 9% of residents were satisfied with the drinking water quality (Figure 3a), and 8% were satisfied with the water quality for domestic use (Figure 3b). Most households have installed water filtration systems at home to ensure the water quality before use.

Table 3. Water quality in the metalware handicraft village (mg/L).

	Sampling point	pH	PO_4^{3-}	NO_3^-	COD	BOD_5	NH_4^+	As	Cd	Pb	Zn	Cu	Ni	Fe	Mn	Cr
Wastewater	W1	6.7	0.54	0.18	**171**	10	**32.8**	0.002	0	0.005	0.98	0.004	0.012	2.288	0.125	0.11
	W2	6.7	0.32	0.21	53	14	5.55	0.006	0.001	0.003	0.15	0.005	0.006	0.806	0.388	0.03
	Average	6.7	0.43	0.19	112	12	**19.2**	0.004	0.001	0.004	0.57	0.004	0.009	1.547	0.256	0.07
	QCVN 40:2011[1]	5.5–9.0	6	40	150	50	10.0	0.1	0.1	0.5	3	2	0.5	5	1	1.1
Domestic water	W3	6.5	0.05	1.01	–	–	**1.24**	0.006	0	**0.011**	0.08	0.004	0.004	**0.568**	0.082	0.001
	W4	6.8	0.02	1.21	–	–	**1.04**	0.005	0.002	0.004	0.049	0.005	0.009	0.084	0.017	0.001
	Average	6.6	0.04	1.11	–	–	**1.14**	0.01	0.001	0.01	0.06	0.004	0.007	0.326	0.05	0.001
	QCVN 01-1:2018[2]	6.0–8.5	–	2	–	–	0.30	0.01	0.003	0.01	2	1	0.07	0.3	0.1	0.05
Groundwater	W5	8.3	0.07	2.20	–	–	**4.25**	0.005	0	0.006	0.126	0.002	0.005	0.606	0.055	0.002
	W6	5.7	0.46	2.36	–	–	**5.51**	0.004	**0.01**	0.002	0.047	ND	0.002	**14.2**	0.376	0.008
	Average	7.0	0.27	2.28	–	–	**4.88**	0.005	0.005	0.004	0.087	0.002	0.003	7.42	0.216	0.005
	QCVN 09:2023[3]	5.5–8.5	-	15	–	–	1.00	0.05	0.005	0.01	3	1	0.02	5	0.5	0.05
Surface water	W7	7.9	0.09	0.28	**60**	**24**	**4.19**	0.005	0	0.001	0.023	0.002	0.003	0.576	0.067	0.001
	W8	7.1	**1.97**	0.54	**95**	**77**	**10.01**	0.002	0.001	0.003	0.109	0.004	0.004	0.126	0.053	0.001
	W9	6.8	**0.47**	0.39	**55**	**29**	**6.88**	0.016	0	0.005	0.034	0.003	0.006	0.945	**0.604**	0.001
	W10	6.9	0.14	0.54	**26**	**17**	**3.80**	0.008	0	0.005	0.033	0.003	0.013	**6.157**	**0.562**	0.004
	W11	5.9	0.12	0.70	**28**	**10**	**4.75**	0.006	0	0.003	0.026	0.002	0.005	**3.342**	**0.338**	0.002
	W12	6.0	**0.88**	0.26	**48**	**35**	**8.26**	0.002	0.003	0.004	0.193	0.001	0.011	0.48	**0.379**	0.002
	W13	6.6	0.15	0.68	**67**	**48**	**5.89**	0.004	0	0.002	0.03	0.002	0.002	0.386	**0.138**	0.001
	W14	6.6	**0.92**	0.57	**35**	**14**	**4.87**	0.004	0	0.004	0.022	0.002	0.005	**0.957**	**0.333**	0.002
	Average	6.7	**0.59**	0.49	**52**	**32**	**6.08**	0.006	0.001	0.003	0.059	0.002	0.006	**1.621**	**0.309**	0.002
	QCVN 08:2023[4]	6.0–8.5	≤0.3	≤1.5	≤15	≤6	0.30	0.01	0.01	0.02	0.5	0.1	0.1	0.5	0.1	0.05

Note: Bold values represent concentrations exceeding the allowable standards; QCVN 40:2011[1]: QCVN 40:2011/BTNMT (Column B) [37]; QCVN 01-1:2018[2]: QCVN 01-1:2018/BYT [38]; QCVN 09:2023[3]: QCVN 09:2023/BTNMT [39]; QCVN 08:2023[4]: QCVN 08:2023/BTNMT (Column B) [40].

Table 4. Water quality index (WQI) in the metalware handicraft village.

Sampling point	WQI	Water quality status	Sampling point	WQI	Water quality status
W7	53	Moderate	W11	56	Moderate
W8	31	Poor	W12	36	Poor
W9	36	Poor	W13	46	Poor
W10	61	Moderate	W14	46	Poor

Land resources (S1-4): In the past, most plating wastewater was directly discharged into the environment, with only a small portion collected and treated at the industrial cluster's treatment plant. This wastewater contaminated the soil, impacting agricultural production and reducing crop yields. Over the past decade, increased awareness of the toxicity and pollution from metal plating has led most households in the study area to discontinue this process, resulting in gradual improvements in soil quality. The result of the social survey shows that the impact of the craft village's production on soil quality was rated as very influential (16.4%), moderately influential (20.9%), slightly influential (50.7%), and not at all influential (16.4%). In addition, according to social surveys, the impact of farming on soils was assessed as very high by 1.5%, high by 41.8%, moderate and low by 23.9% each, and no impact by 9%.

Water quantity (S1-5): Similar to their impact on soil resources, both metalworking and agricultural activities directly affected local water resources. Residents have gradually reduced pollution by using organic chemicals and fertilizers or implementing nature-based agricultural solutions. However, 41.8% of residents thought that metalworking had a significant impact on water resources, while 17.9% believed agriculture had a major effect.

3.1.2. Reducing environmental stresses (S2)

The results of the social survey demonstrate that environmental quality gradually decreased in both air, soil, and water (S2-1, S2-2, and S2-3) because of population growth and expansion of production area. However, 100% surveyed households used chemical fertilizers and pesticides with different frequencies of use, from little to completely. Metalware handicraft village generates solid waste from both domestic activities and production processes. Waste is collected regularly, four times a week, and transported to the landfill, which covers an area of 800m². This system ensures that 100% of residential waste is collected promptly. With the increasing population and expansion of production areas, the social survey shows that solid waste from domestic sources increased by 83.6%, and from production by 53.7% (S2-4). However, some residents reported a decrease in domestic waste (14.9%), and production waste (25.4%), attributing this to improved waste management practices such as sorting, collection, recycling, and reuse at the source. Hazardous waste from production in the study area includes tools, chemical-contaminated rags from plating, welding, and painting processes. However, this waste is not separated, collected, and treated regularly. According to interviews with residents, hazardous waste decreased slightly by 53.7%, significantly by

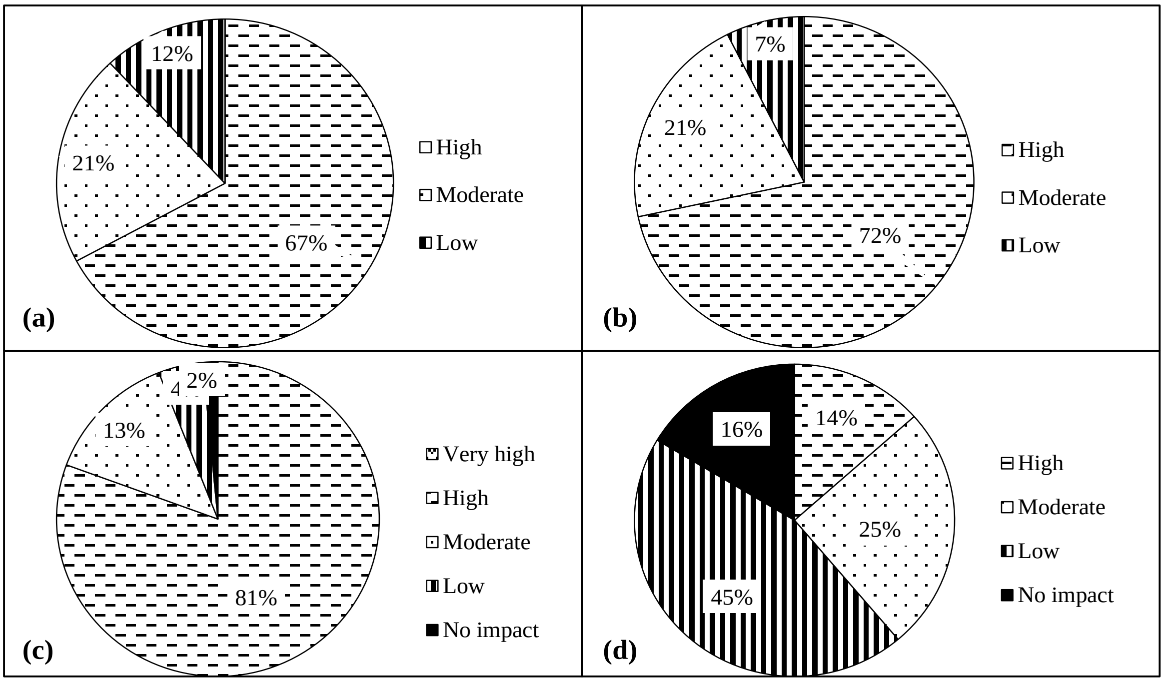

Figure 4. (a) Assessment of local people about the impact of air quality on health; (b) Assessment of local people about the impact of noise on health; (c) Assessment of local people about the impact of water quality on health; (d) Assessment of local people about the impact of soil quality on health.

11.9%, and increased slightly by 28.4% (S2-4). Moreover, along with the advancements in science and technology, production equipment and machinery become more modernized.

High-capacity and electrically-powered devices are replaced by those running on fossil fuels, contributing to a reduction in the local consumption of non-renewable energy.

3.1.3. Reducing human vulnerability (S3)

The result of the social survey shows that the environmental quality affected directly to human health, especially air, noise (S3-1), and water (S3-3) with 67%, 72%, and 81% (Figures 4a-c), respectively, whereas the impact of soil on human health (S3-2) was evaluated as high (14%), moderate (25%), low (45%), and has no impact (16%) (Figure 4d). Noise pollution is a concerning issue in the study area, disrupting the daily lives of non-craft households, and leading to deep environmental conflicts between production and non-production households.

3.1.4. Social institutional capacity (S4)

Environmental management efficiency (S4-1): The social survey results show that persistent conflicts and complaints about the environment and clean water remain unresolved. Community meetings and dialogues are lacking, requiring better coordination among local authorities. According to residents, 6% rated management as very poor, 23.9% as poor, 49.3% as average, and 20.9% as good.

Wealth (S4-2): According to a report of Commune People's Committee, the study site had no household classified as poor, with 134 near-poor households, accounting for 3.78%, a decrease of 1.02% from 2022 [27]. Compared to the national multidimensional poverty rate of 5.71% in 2023, which included 2.93% poor and 2.78% near-poor households [41], the rate in the village is 1.93% lower than the national average.

Awareness (S4-3): The metalware handicraft village lacks an effective centralized wastewater treatment system. Most household wastewater is only pre-treated through basic methods such as septic tanks before being discharged into the environment. The metalware industrial cluster in the study area had a 500 m^2 wastewater treatment plant, operated from 2006 with a capacity of 200 m^3/day. However, the operation of the treatment plant has stopped since 2020. In contrast, all domestic waste is collected and transformed to treat regularly, 4 times per week to ensure the clean environment of residents. For agricultural residues, particularly rice straw, 56.7% of surveyed households have utilized it for organic fertilizer, creating a natural and sustainable source for the next crop, improving soil quality, increasing crop yields, and reducing costs.

Knowledge (S4-4): Interview results show that people have not actively participated in the training courses on environmental protection. Approximately 67.2% of households did not attend any training courses, while 33.8% attended 1-2 times per year.

Environmental protection efforts (S4-5): According to residents, local authorities have gradually paid more attention to environmental protection and have addressed emerging environmental issues. However, there are still delays and obstacles in enforcing environmental regulations, especially concerning craft village production sites. The survey results demonstrate that 26.9% of residents rated the local government's concern for environmental protection as good, 41.8% as average, 20.9% as poor, and 10.4% as very poor.

3.1.5. Environmental sustainability assessment of the metalware handicraft village

AHP results show that the weight of components S1, S2, S3, and S4 was 0.27, 0.26, 0.25, and 0.22, respectively. In detail, indicators of S1-3, S2-3, S3-3, and S4-1 had the highest weight in the components S1, S2, S3, and S4, respectively, indicating the priority for indicators regarding water source and environmental management efficiency of local authorities.

The results of quantitative environmental sustainability assessment of the metalware handicraft village demonstrate that 1/17 indicators are at high sustainability (0.81-1.00) (S4-2), 1/17 indicators are at relatively high sustainability (0.61-0.80) (S1-2), 7/17 indicators are at medium sustainability (0.41-0.60) (S1-1, S1-4, S1-5, S2-4, S3-2, S4-1, and S4-3), 3/17 indicators are at low sustainability (0.21-0.40) (S1-3, S2-3, and S4-5), and 5/17 indicators are classified as at unsustainable (0-0.20) (S2-1, S2-2, S3-1, S3-3, and S4-4) (Table 5). The sustainability of S1, S2, S3, and S4 categories is 0.57, 0.26, 0.25, and 0.44, respectively (Figure 5). The total environmental sustainability of the metalware handicraft village is 0.38, indicating the low sustainability.

Table 5. Environmental sustainability assessment of the metalware handicraft village.

Categories	Indicator	Weighted assessment (Scale 0–1)	Categories	Indicator	Weighted assessment (Scale 0–1)
Environmental systems (S1)	S1-1	0.47	Reducing human vulnerability (S3)	S3-1	0.13
	S1-2	0.80		S3-2	0.54
	S1-3	0.30		S3-3	0.09
	S1-4	0.59	Social institutional capacity (S4)	S4-1	0.54
	S1-5	0.48		S4-2	1.00
Reducing environmental stresses (S2)	S2-1	0.19		S4-3	0.48
	S2-2	0.06		S4-4	0.10
	S2-3	0.32		S4-5	0.36
	S2-4	0.43	**Overall assessment**		**0.38**

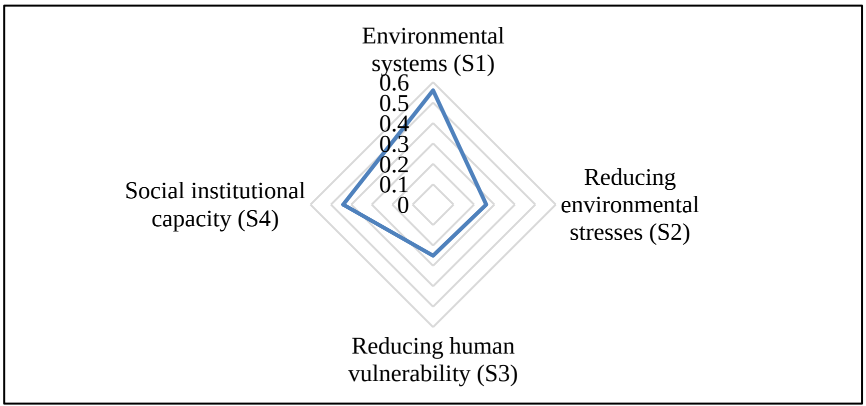

Figure 5. The environmental sustainability of the metalware handicraft village.

3.2. Solutions for enhancing the environmental sustainability of the metalware handicraft village

The study results point out that the environmental sustainability of the metalware handicraft village has faced the high stresses from air, and water pollution, the increasing health risk and the challenges in environmental management and protection of local authorities and residents. Therefore, the following solutions are needed to ensure environmental sustainability in the study area.

3.2.1. Policy

Hanoi has issued various policies not only to develop rural crafts and craft villages [42–45] but also to protect the environment in these areas [46–49]. However, the implementation of these policies in the study area faces many challenges, primarily due to a lack of financial support from local authorities and insufficient community participation. The technical infrastructure in the craft village such as water supply and drainage systems, waste and wastewater treatment remain incomplete, significantly affecting water quality (S1-3) and increasing environmental pressure (S2-2, S2-3, and S2-4). Therefore, investment is needed to improve clean water infrastructure to ensure the quality of domestic water, to construct effective wastewater drainage systems, and to establish waste treatment facilities, along with other specific infrastructure plans for the village. In addition, monitoring activities for environmental compliance should be strengthened, with strict actions taken against non-compliant production facilities.

3.2.2. Technology

According to analysis results, water quality in the metalware craft village was polluted with PO_4^{3-}, NH_4^+, COD, BOD_5, and heavy metals (i.e., Cd, Pb, Fe, and Mn). Water quality (S1-3) is assessed as low sustainability, the other criteria regarding tresses on air (S2-1) and soil (S2-2) and the impacts of air and water quality on human health (S3-1 and S3-3) are at unsustainability level (Table 5). Therefore, to ensure environmental sustainability in the study area, appropriate technological solutions are proposed as follows: (1) Innovating production equipment from manual to automated systems, using environmentally friendly technology and cleaner production methods to increase productivity, to maximize resource efficiency, to minimize waste generation, and to reduce environmental pollution; (2) Upgrading outdated waste and wastewater treatment systems; (3) Applying more cost-effective and environmental friendly for remediation of contaminated water.

3.2.2. Others

Interview results and environmental sustainability assessment of the metalware craft village indicate that 67% of surveyed households were affected by air quality issues, particularly noise from production, with the indicator S3-1 being evaluated as unsustainable (0.13). Therefore, regulations on production hours are needed to ensure workers' rest, to minimize impacts on neighboring households, and to reduce environmental conflicts. Additionally, air quality is also affected by nearby production activities (carpentry village and industrial park). Therefore, air quality issues require coordinated attention and action from various levels of government and local authorities.

The low percentage of households participating in environmental protection training and unsustainability level of the related indicator (S4-4 = 0.1) imply the necessity to enhance communication, to share information, and to organize environmental protection training sessions effectively to encourage active participation from residents.

Other administrative solutions are recommended such as (1) Control and treat pollution at the source; (2) Develop long-term, medium-term, and short-term environmental protection plans, ensure alignment of goals and available resources; and (3) Strengthen effective collaboration among stakeholders in environmental protection and sustainability maintenance.

4. Conclusions

A set of 17 indicators belonging to 4 components (environmental systems, reducing environmental stresses, reducing human vulnerability, and social institutional capacity) is proposed and applied for quantitatively environmental sustainability assessment of a metalware handicraft village in Hanoi, Vietnam. The results demonstrate that the environmental sustainability of the study area is 0.38, indicating low sustainability. It is crucial to implement measures to promote sustainability in both the metalware village and other craft villages. This result may provide scientific data and solutions for ensuring sustainability not only in the study area but also in other craft villages in Vietnam. This is an initial study that provides a preliminary assessment of environmental sustainability. Further research is needed to quantify air quality parameters, pollution levels, health impacts, and to propose additional indicators for a more comprehensive evaluation of environmental sustainability in the study area.

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T.T.H.N., N.T.T.T.; Data analysis, N.T.T.H., N.T.H.H., T.T.H.N., P.T.H., N.T.K.H.; Writing draft manuscript, N.T.T.H.; Editing manuscript, N.T.H.H., T.T.H.N., B.T.H.; All authors have read and agreed to the published version of the manuscript.

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