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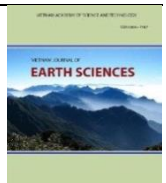

Modeling effects of abiotic and anthropogenic factors to rice production - A case study in Sapa district, Lao Cai province, Vietnam

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ABSTRACT

The famous terraced rice ecosystem in the mountainous areas as Sapa of northern Vietnam has expanded with unstable productivity over generations. However, the question arises of how natural and human conditions on terraces can boost the quality of rice provisioning ecosystem service supply with rice yields as an indicator. The study used a semi-structured interview method, the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool and general linear models to investigate the influence of natural and human-derived components on the rice provisioning service at six villages. The results showed that along with the importance of applying a fertilizer-based system in the terraced rice ecosystem, topology- and hydrology-based systems have been influencing significantly on water and nutrient supply for irrigation on terraced rice fields. Moreover, analyzing the natural components has been considered more efficient than human-derived components for a sustainable rice ecosystem. The results indicated that the high potential of rice provisioning service supply had found at the downstream of Ta Van sub-catchment and the Vu Lung Sung village where the distance from paddy fields to sinks or outlet of streams is lower than five kilometers. The last result of the synthetic model proving 74.28 percent of deviance of terraced rice production did not avoid many noises in collecting and standardizing data that also discuss in this study.

Keywords: Rice production; topology; hydrology; human; semi-structured interview; multiple linear regression; InVEST; Sapa.

1. Introduction

Nowadays, rice provides 90 percent food in Asia and for more than half of the world's population (Abdullah et al., 2006; FAO, 2000; Lewandowski, 2013; MEA, 2003). The unbalance in nutrient and water supplies and the degradation of biodiversity have led to the reduction of rice yield (Power, 2010). Rice production needs to be sustainably improved if stakeholders want to serve enough for nine billion people by 2050, and it has required a better collaboration of water, nutrient and land

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management to stabilize rice productivity (Glavan et al., 2014). In order to improve rice yield, the selection of crop suitability areas and the suitable use of biotechnology play important roles to enhance water and nutrient supply in the soil.

According to the classification based on different dominant farming systems of the International Rice Research Institute (IRRI), upland rice is more common in mountainous regions, following by flood-prone rice and irrigated rice (IRRI, 2006). The productivity of rice on the upland region where are developing mostly terraced rice fields was lower than other regions by one to two-ton/ha due to regular water deficiency and the traditional culture based on shifting cultivation (IRRI, 2006). Over time, four farming systems, which include animal-, tree-, water- and fertilizer-based systems, are developing (IRRI, 2006). IRRI (1985) estimated the application of fertilizer- and pest- controls for upland rice has raised the terraced rice yields into more than 5 ton ha-1. The sustainable farming systems have been applied for maintaining soil quality by providing nutrients, containing water and mitigating soil degradation. However, under the pressure of population and food demand, farmers on the mountainous area must increase cultivating frequency but it accidentally reduced the amount of soil nutrients after the harvesting season. This activity has not only destroyed environmental sustainability but also wasted much money of farmers. Therefore, along with growing up rice productivity, the sustainability of terraced rice farming within the interaction between humans and the environment plays an important role in agricultural development (Frimawaty et al., 2013).

As other rice producers, the exporting value of rice production in Vietnam has grown annually since the 1980s and became the second exporter in the world after Thailand (Dawe, 2010). After the "green revolution", the fertilizer-based system has been used successfully in agriculture, especially in the south of Vietnam (Khush and Virk, 2005). The quality of rice provisioning service in northern regions is lower than southern of Vietnam because of the differences in geographical characteristics of rice ecosystems. However, according to the semi-structured interview, the high potential rice provisioning service in many upland rice fields in northern Vietnam was recorded more than five-ton ha-1. Therefore, a synthetic system of natural and human-derived components will help farmers in choosing suitable places where can support water and nutrient efficiently for terraced rice fields.

In addition to the quality of nutrient and land management, in this study, the impacts of rice cultivation on the environment will also be attended. Since semi-structured interviews and spatial indicators, the study developed a data mining method in predicting rice yields, choosing suitable places for rice cultivation and assess negative impacts on environments.

2. Materials and methods

2.1. Study area

The mountainous region in the Sapa district located in the northwest of Vietnam has well known with terraced rice fields and varieties of ethnic groups. The elevation in the research area fluctuates from 1200 to 1800m and the slope fluctuates mainly from 15 to 35 degrees. Narrow valleys have made local people more difficult to exploited alluvial plains for agriculture. Therefore, terraced rice cultivation on slope lands has been their solution. Because of a plentiful bank of fog and snow in winter, rice is transplanted once per year with low productivity compared with other agricultural regions in Lao Cai province (Lo Dieu Phu, pers. comm.2012). The tourism activities and food demand of local people have put pressure on farmers in improving rice quality and expanding the area of cultivation. However, the area for rice farming in upland regions has been narrowed. Local people from different minority ethnic were forced to reduce the time of the shifting cultivation (from 3-5 years) and cultivated in any bare-soil regions. The increasing of fertilizers and pesticide input in common with the decreasing of environmental quality at paddy fields are leading to unsustainability in local agriculture.

From the classification of IRRI, upland crops became more common than rain-fed and irrigated crops in Sapa (Fig. 1). The terraced rice ecosystem has expanded on the colluvium and alluvial regions in San Sa Ho, Hang Lao Chai, and Ly Lao Chai villages. It has distributed less on the upland areas of Chu Lin, Mong Sen and Vu Lung Sung villages (in Trung Chai community) where flood phenomena occurrence has been reduced. Although the rice ecosystem in Trung Chai was drier than the rest of Sapa, the area of upland rice has expanded nearly two times since the year of 1993 (Hoang, 2014). According to hydrological classification, these paddy fields located along the two large sub-catchments that are Ngoi Dum and Ta Van. The forest region of Hoang Lien Son national park in the south of Ta Van sub-catchment makes more advantage for supplying water into paddy fields, especially along with San Sa Ho and Lao Chai communities.

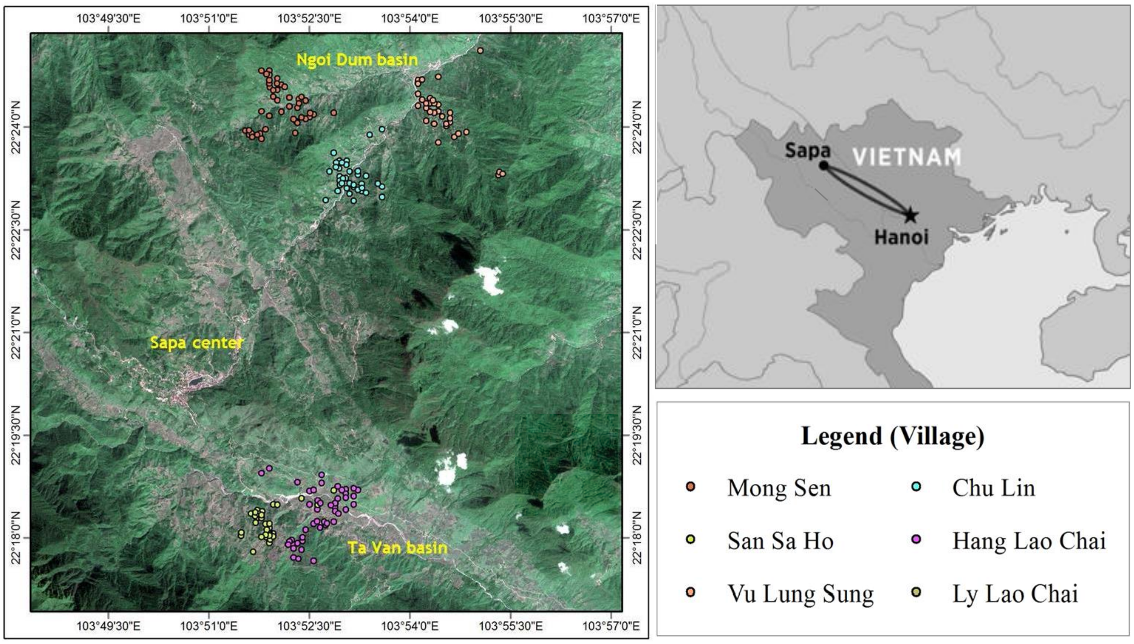

Figure 1. Location of taken samples in six villages in Sa Pa District, Lao Cai Province, Vietnam (Background image: Landsat 7/2018)

2.2. Assessment approach for rice provisioning service on terraces

In the assessment of provisioning service, yields have known as the best indicators (Burkhard et al., 2014). They are not only easy to evaluate the market prices of production but also help to understand the provisioning service flow-through system approach. In particular, rice yield, which provides the information of harvested rice for food, is as a result of the interaction between potential supply and user demand; or between environment and land management (Raffaelli and White, 2013). Therefore, this study used the term "rice provisioning ecosystem service" mentioned as the yield of terraced rice per year.

Jones et al., (2016) emphasized the necessity of analyzing natural and human-derived components in quantifying ecosystem services at different levels. Their combination in the social-ecological system generates rice potential provisioning service supply (Fig. 2) which interacts with the user demand to realize the harvested rice for human consumption as a provisioning service flow. In rice production, the main natural components include water supply (e.g. precipitation and runoff) and nutrient supply in the soil. Besides, radiation intensity and temperature determine the limitation of photosynthesis and evapotranspiration efficiency rates in rice (Gupta and Toole, 1986; IRRI, 1982). In terraced rice fields, some natural components affect indirectly to natural and human-derived components, such as slope, length of flow, weathering crust and bedrock nutrient. These components play crucial roles in distributing water and nutrient for paddy fields (Meylan et al., 2013). However, most terraced rice fields require the supplementation of soil nutrients from fertilizer input (e.g. inorganic fertilizers) and water from irrigation. Such regulation of water and nutrient formulated human-derived components that have known as land management, knowledge, developed seed types, or pesticide inputs.

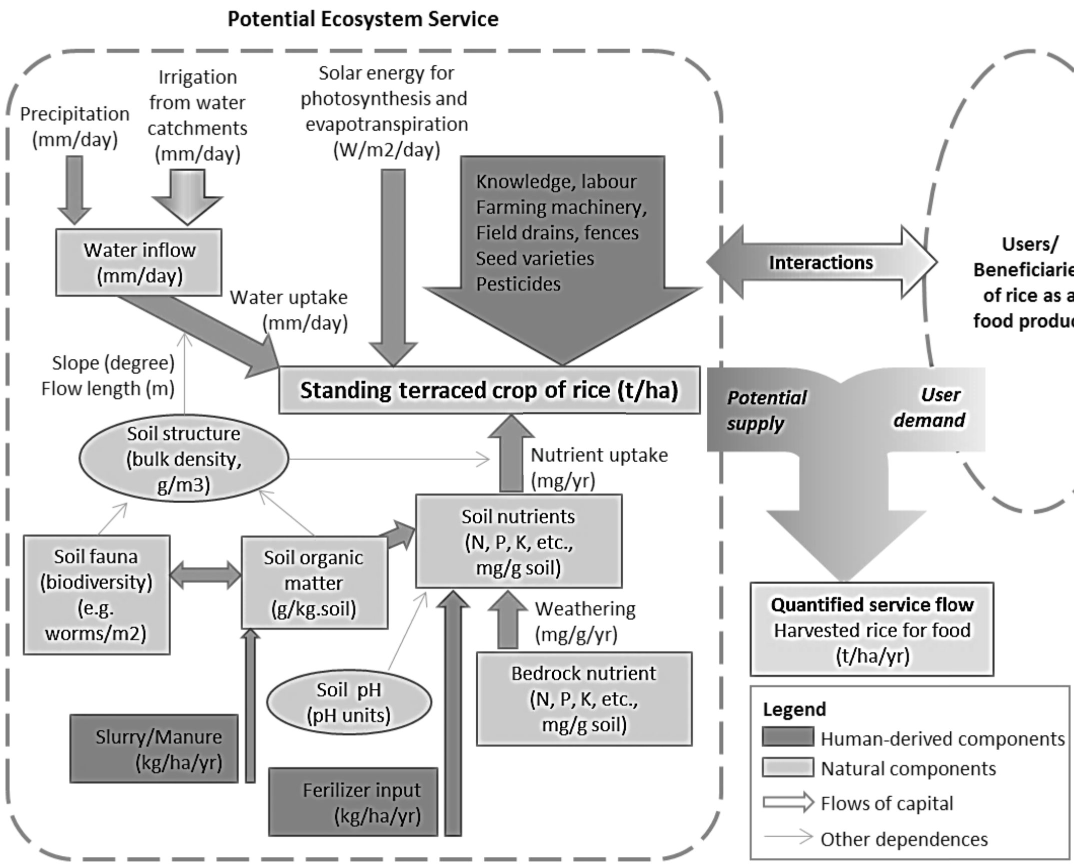

Figure 2. Simplified chart presenting natural and human components inputs to terraced rice provisioning service

Due to the lack of a database, it is very difficult for scientists to isolate natural and human effects in rice ecosystems (Remme et al., 2014). Recently, the LEGATO project has investigated the interaction between rice ecosystems and social-cultural activities in Vietnam and the Philippines since 2011 (Burkhard et al., 2015). In this project, ecosystem function and services were optimized in different rice ecosystems based on the analysis of nutrient cycling, pollination, land use, and cultural landscapes to increase rice productivity which was used as an indicator of providing ecosystem services. However, the interaction between humans and the environment in rice provisioning service is a complicated debate, especially about the human's role in this system. To solve these issues, the study tried to collect databases from various resources including human-derived components from the semi-structured interviews and relevant natural components from models of the geographical information system to find the best predicting system for rice provisioning service that will be presented in next parts.

2.3. Selecting and processing observation and explanatory variables

2.3.1. Collection of databases about rice and human variables

The used method for collecting databases about rice and human activities was semi-structured interviews in 200 farming households to reveal the productivity and location of their terraced rice fields. It was quite hard for farmers to understand the thematic maps and satellite images at first looking, but they became more confident in identifying their paddy fields after explanation by the interviewers although some spatial noise needs to be checked. With such noise on location, this research assigned the points toward the nearest paddy fields within 30m in land use and land cover map that was interpreted by the LEGATO project, and removed points outside 30 m. Along with the distribution of paddy fields, the farmers estimated the year of development, size, seed, yields, fertilizer use, etc. The field surveys in 6 villages were taken about an hour per household by Vietnamese interviewers with the help of translators to Hmong and Dao languages. This dataset was verified by another data source from the General Statistics Office (GSO) of Vietnam and the LEGATO project, in which rice production was determined for the rice grains measured after removing hulls and oven-drying the samples.

Thank to the interview process, the dependent and independent variables were identified and standardize (Table 1). The human variables were realized the influences of land management including fertilizers and seeds input, investment of households, pollution, and policy. According to farmer's answers, they could not estimate the area of their own paddy fields but they know how much seeds input to one hectare. Thus, the realized rice supply from one hectare was calculated by the ratio of the total rice product harvested from paddy fields of each household and the sum of used seeds for one hectare. Because farmers used the different types and amounts of fertilizers and seeds, the invest variable was estimated by a total investment of households for paddy fields, such as fertilizers and seeds. Besides, road and resident density as the additional variables from human activities have illustrated the impact of environmental quality on the rice ecosystem.

Table 1. Description about dependent and independent variables in this study

Name	Description	Source
Dependent variable		
rice	Rice yield per hectare (ton/ha)	1
Topology (Independent variables)		
elevation	Average elevation (m)	2
slope	Average slope (degree)	2
height	Maximum height of terraced rice field (m)	2; 4
sediment	Sediment retention (ton/ha)	5
bedrock	Stabilizing of bed-rock from high ("1") to low ("5")	3
wcrust	Weathered crusts ("bp", " ys", "ps")	3
Hydrology (Independent variables)		
flowlength	Length of flow distance from fields to the sink or outlet of stream (km)	2
waterYield	Water yield (mm/ha)	5
fractp	Evapotranspiration/Precipitation	5
fstream	Accessibility of paddy fields to water resources in forest (m)	2; 4
forestArea	Area of forest region in watershed containing paddy field (ha)	2; 4
Human (Independent variables)		
NPK	NPK input (kg/ha)	1
urea	Urea input (kg/ha)	1
P	Phosphate input - use (1); not use (0)	1
invest	Investment for each paddy field (kVND/ha/year)	1
road	Road density (m ha-1)	2
residence	Residential density (household/ha)	2
village	Include "Hang Lao Chai", "Ly Lao Chai", "San Sa Ho", "Chu Lin", "Vu Lung Sung" and "Mong Sen"	1; 2
(1) Interview in 2011; (2) Topographic map in 1:25.000 scale; (3) Geology map; (4) LULC map 2010 in LEGATO project; (5) InVEST model		

2.3.2. Potential environmental variables

A set of 11 environmental variables, which was selected (Table 1), was divided into two groups (topology and hydrology). These variables presented the different aspects between the terraced rice ecosystem, including local climate, soil characteristics, and water supply. The local climate was illustrated by the changing of elevation, slope and paddy field's height, along with the ratio of evapotranspiration and precipitation (fractp variable) which represented the effect of solar energy, into terraced rice ecosystem. Sediment, bedrock and crust variables, which mentioned the differences in soil formation, decided the content of nutrients in different regions. The last four variables in the hydrology group reappeared the accessibility of paddy fields to different natural water resources such as run-off from the forest, precipitation, and underground water.

In such variables, sediment retention also plays a crucial role in soil erosion which has simulated by the Universal Soil Loss Equation (USLE) factors (Kandziora et al., 2013). The sediment retention model in InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) tool, which has been popular in 102 countries (Posner et al., 2016), has used the USLE foundation:

$$USLE = R * K * LS * C * P \quad (1)$$

Where R is the rainfall factor, K is the soil factor, LS is the slope length factor, C is the management factor and P is the supporting factor (Wischmeier and Smith, 1958). Sediment movement was considered from upstream landscapes to downstream rivers through river channels. Upstream land cover maintained a part of sediment while the rest continued to flow to downstream land cover. This process was influenced by characteristics of topology and land cover; therefore, the model calculated the movement in two cases (without and with the cover of paddy fields) to find out how much sediment was trapped by each paddy. The gap between the two cases is the amount of sediment retention. As an outcome of InVEST, the total sediment arriving each paddy field as downstream points of interest was calculated by separating the terraced rice ecosystem into pixel level (Vigerstol and Aukema, 2011).

2.4. Generally linear model (GLM) for terraced rice provisioning service

After choosing which variables have had a correlation with rice provisioning service, general linear models analyzed the predictabilities of each independent variable with the dependent variable and their interactive effects in variables. This process combined the analysis of multiple linear regression between rice provisioning service variable with continuous predictors (such as elevation, slope, flow length), one-way and two-way ANOVA for categorical predictors (such as wcrusts, sub-catchments, and villages). The covariance matrix and Akaike Information Criterion (AIC) also used for filtering outliers and useless variables (such as height, stream, and road). The AIC values, which present the relative quality of statistical models, used for selecting models and variables (Aho et al., 2014). It was calculated by the following function: $AIC = 2k–2\ln(L)$, where K is the number of estimated variables in the model (e.g. the number of variables and the intercept); and L is the maximum value of likelihood function of such model. Selecting a model with the AIC criteria is better than looking at p-values and the best model with the lowest AIC score. This number can be negative or positive. However, the AIC does not test the null hypothesis of such models, so it is necessary to check the null hypothesis of researching models before and after the filtering process. Lastly, this filter method eliminated interactive effects and chose the independent variables for predicting the quality of terraced rice provisioning service.

3. Results

3.1. The effect of natural and human components to terraced rice provisioning service

In the topology group, although each variable had statistical significance with rice provisioning service in observation, four components including elevation, slope, bedrock and wcrust contributed most predictability of the topology-based for rice provisioning service supply. The combination of these components proved 20.9 percent of the variability of rice PES with AIC equal 125.39. Moreover, table 2 described the evident differences in rice supply in three types of weathering crusts. The acid aluminous soil, which was transformed from ys-wcrust, reduced respectively 0.72 and 1.11 ton ha-1 rice-yield compared with the soils dominated by clay (ps-wcrust) and limestone (bp-wcrust). Especially, all continuous variables in the topology group had a negative correlation with rice provisioning service. On the other hand, the farmer’s choice for a terraced rice field with more steep terrain or unstable sediment of bedrock caused the reduction of rice supply. Related to the spatial effect of topological components, some suitable locations for crop agriculture can be recognized easily, such as flood plains in Ta Van sub-catchment and Vu Lung Sung village while the worst prediction located in the mountainous areas of Ta Van sub-catchment. These topological components realized more specifically the irregular distribution of the rice provisioning service in Mong Sen and Chu Lin villages.

Table 2. The effect of topological components for predicting the deviance of terraced rice provisioning service

Component	Estimate	SD	t value	Pr(>|t|)	Sig.
(Intercept)	5.43	0.80	6.75	0.00	***
Elevation	-0.01	0.00	-1.68	0.09	*
Slope	-0.05	0.01	-3.68	0.00	***
Bedrock	-0.11	0.06	-1.75	0.08	*
Wcrust.ys	0.00	0.00	0.00	0.00	***
Wcrust.bp	0.72	0.33	2.13	0.03	**
Wcrust.ps	1.11	0.24	4.54	0.00	***

Table 3 presents the quality of predicting rice quality based on six hydrological components that include flow length, stream, water yield, fractp, forest area, and sub-catchment. The combination of these components can predict 31.1 percent of the deviance of rice provisioning service with AIC = 102.35. The water yield and evapotranspiration had a close relationship. Their interaction, which had significant meaning with the rice variable, was not necessary for the considering combination. The correlations between water yield and flow length with rice provisioning service are negative values that proved that a paddy field would reduce one ton per hectare, in case of three cubic meters water losing or the distance from that such paddy field to the outlet of the stream by one kilometer further. The increase of ratio between evapotranspiration and precipitation, which interacted strongly with flow length variable, reduced the amount of water supply for paddy fields and their productivities as well. Although the stream and forest area variables were considered as the water supply of up-stream forest for each paddy field, higher water supply lead to higher productivity, the predictability rice provisioning service of forest area variable was more confident. A paddy field, where was supported by a larger up-stream forest by 0.45 square meters, can produce one ton per hectare more. Besides, the paddy fields in Ta Van sub-catchment could be harvested higher 0.81 tons per hectare on average than in the Ngoi Dum sub-catchment.

Table 3. The effect of hydrological components for predicting the deviance of terraced rice provisioning service

Component	Estimate	SD	t value	Pr(>|t|)	Sig.
(Intercept)	9.331	1.79	5.12	0.00	***
Flowlength	-0.001	0.00	-5.21	0.00	***
FStream	0.155	0.09	1.59	0.11	-
WaterYield	-0.003	0.00	-3.34	0.00	***
Fractp	-0.451	0.17	-2.61	0.01	**
ForestArea	0.005	0.00	2.61	0.01	**
Ngoi Dum Sub-catchment	0.000	0.00	0.00	0.00	***
Ta Van Sub-catchment	0.819	0.38	2.15	0.03	**

Table 4 illustrates the better combination of human components, including NPK, urea, and P. These effective variables explained 56.8 percent for the changing of rice supply with AIC = 2.34. In contrast with two previous groups, these predictors had strong correlations with the dependent variable and overpowered other weaker components. Although the road, residential and village variables had statistical significance with rice variables, they just took smaller accounts than the fertilizer variables, so these components were excluded from the human combination by higher AIC values. It seems that if farmers inputted much fertilizer or invest more for each paddy field, they can harvest more rice productivity. Paddy fields using phosphate could be harvested 0.35 tons per hectare higher than fields non-using phosphate. With these predictors, rice provisioning service, which can be calculated more heterogeneous in spatial than two previous groups, was not separated clearly by sub-catchments, weathering crusts or villages.

Table 4. The effect of human components for predicting the deviance of terraced rice provisioning service

Component	Estimate	SD	t value	Pr(>|t|)	Sig.
(Intercept)	1.76	0.14	12.25	0.00	***
NPK	0.34	0.03	10.22	0.00	***
Urea	0.45	0.06	7.22	0.00	***
P (used)	0.35	0.17	2.09	0.03	**

3.3. The best synthetic model for predicting the deviance of terraced rice provisioning service

Table 5 presents the result of the best GLM combination with the nine controlling variables of terraced rice provisioning service. This synthetic group explained 74.28 percent of deviance, with an AIC coefficient of -94.49. Besides this combination, the R-squared can be received the highest point by 0.77 with the contribution of 19 variables in clustering three groups but the statistical meanings of related variables were ineffective with AIC equal-6.69. The best one used three variables in the topology group (elevation, slope, and sediment), three in hydrology group (flow length, water yield, and fractp) and three human groups (NPK, urea and invest). Although there are two interactive effects including flow length-elevation and flow length-fractp, they were eliminated in this result due to the raising in AIC values.

Table 5. The effect of most beneficial components for explaining deviance of terraced rice provisioning service

Variable	Estimate	SD	t value	Pr > |t|	Sig.
(Intercept)	6.991	1.06	6.56	0.00	***
Elevation	0.003	0.00	5.74	0.00	***
Slope	-0.054	0.00	-6.05	0.00	***
Sediment	0.214	0.06	3.30	0.00	***
Flowlength	-0.001	0.00	-8.31	0.00	***
WaterYield	-0.003	0.00	-5.14	0.00	***
Fractp	-0.510	1.08	-4.71	0.00	***
NPK	0.462	0.04	9.84	0.00	***
Urea	0.490	0.06	7.73	0.00	***
Invest	0.161	0.04	3.83	0.00	***

It can be seen the predictability of different models and the regular distribution of rice provisioning service which could be identified by the different sub-catchments or villages (Fig. 3, 4). Although the worst in four combinations is the topology-based, the following is the hydrology-based, human-based and synthetic systems, they had many similarities with the result of the synthetic system. In Ta Van sub-catchment, its distribution was predicted as in two natural-based systems with higher productivity at floodplains along the Ta Van river and lower productivity at upstream regions. However, it was more complicated in Ngoi Dum sub-catchment because of the diversity of topology. The paddy points in Vu Lung Sung village, which were analyzed more particularly than the two natural-based methods, contained the highest amount of rice productivity compared to other villages. The irregular distribution of rice provisioning service in Chu Lin and Mong Sen villages were explained by land management and fertilizer inputs.

Nine predictors can be divided into two important groups based on their contributions in the synthetic system (Fig. 5). The first group contributing more than ten percent includes NPK, invest, urea and flow length. Compared with the human-derived system, the contributions of NPK and urea components reduced about three percent, instead of the growth by 14.6 percent of the household's investment. The second group, which includes the last five components, contributes about fourteen percent of the deviance in rice provisioning service supply. Since their contribution to the topology- and hydrology-based systems, their influences raised a few percent. Especially, the sedimentary characteristics were used instead of two variables about the quality of the weathering crusts in the topology-based system.

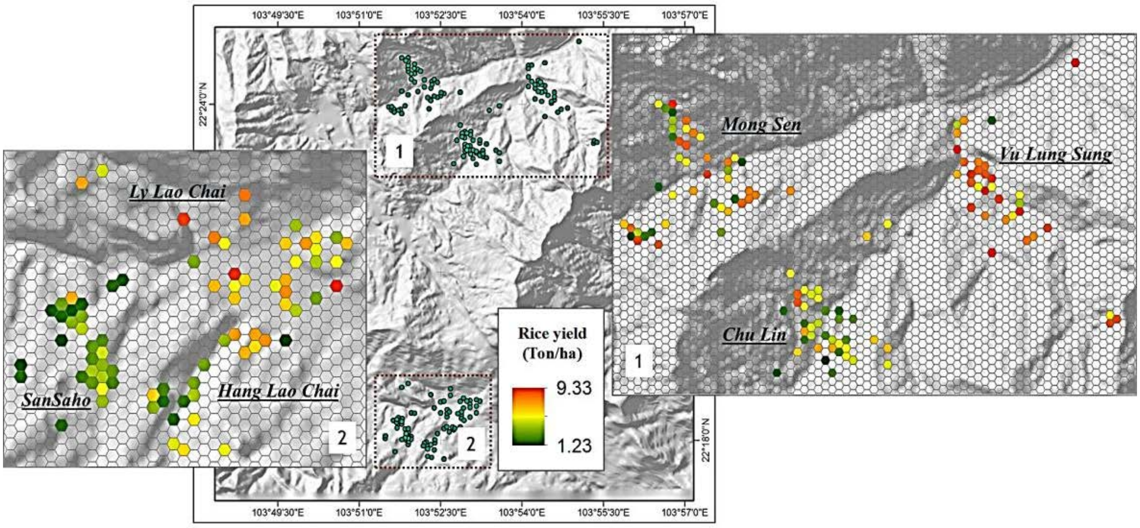

Figure 3. Prediction for terraced rice provisioning service based on the synthetic-based system in Ngoi Dum sub-catchment (1) and Ta Van sub-catchment (2)

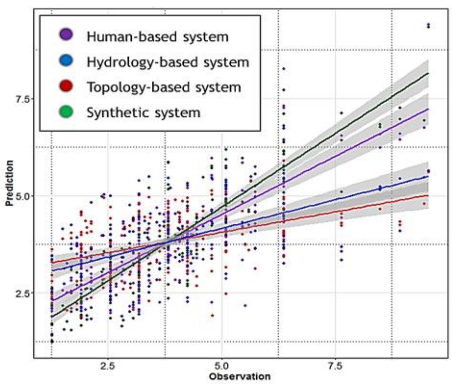

Figure 4. Observed and predicted data in different farming sys

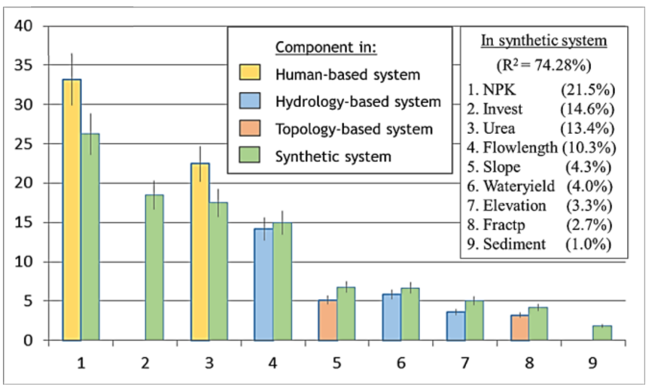

Figure 5. The relative contributions of variables for rice provisioning service supply with 95% confidence intervals

4. Discussions

The analysis of potential ecosystem services for rice required the different components in the topology-, hydrology- and human-based systems. The components in the topology-based system characterized the distribution of soil nutrients based on slope, altitude and sediment retention. Besides slope and altitude was discussed in many studies (Hoang, 2014; Li et al., 2015), rice provisioning service supply is influenced by type and volume of material deposited in sediment retention through the process of soil degradation (Schmitter et al., 2010). The amount of infertile sand in deposition regulates the amount of soil organic carbon and total nitrogen in silt loam and then affect indirectly to rice production (Albizua et al., 2015). An experiment on terraced rice fields of Slaets et al., (2015) claimed half of the total sediment including silt- and clay-sized material was sunk lastly by paddy fields and only one-third of such sediment is a sandy fraction. This material is a suitable condition for the growth of paddy. About water supply in the hydrology-based system, the water availability for irrigation process has not only been affected by the length of flow, precipitation, evapotranspiration, and inflow but also alters the volume of water available for hydropower production (Wu and Chen, 2013). Although the provision of fresh water is an important type of ecosystem services and contributes to human well-being in many ways, the losing water in each paddy field in this process erodes nutrient and water infiltration in soil. Calculating water yield used for each paddy field helps to deal with the unbalancing of water availability for the watershed and paddy field in particular. The study also indicated the flow length of five kilometers is a limitation of water supply by inflow, evapotranspiration and water yield. On the other hand, the irrigation could not supply enough water for paddy fields at the upstream instead of the downstream.

Although Herdt and Capule (1983) found similar contributions of plant characteristics, irrigation and fertilizer input to rice productivity in the 1960s to 70s, the fertilizer-based system seems to be remarkably influenced for rice productivity in Vietnam since the “green revolution”. The significant contribution of fertilizer components induced the misunderstanding of farmers about rice provisioning service supply. An argument about the correlation between the age of terraced rice fields and rice provisioning service was introduced in farmer’s knowledge. In their consideration, the paddy fields with longer age can supply higher rice productivity than the young paddy fields. The variable of paddy field’s age was compared with the variable of rice provisioning service in this study but this correlation was not relevant. The increasing of cultivating frequency and scarcity of cultivated area, which shortened the shifting period of each paddy fields, reduced seriously amount of potential soil nutrient in paddy fields. However, at some old paddy fields with favorable conditions, a high amount of fertilizer inputted by farmers was absorbed and supplied enough nutrients for rice. The improvement of rice quality in such paddy fields based on fertilizer was the reason for the misunderstanding.

5. Conclusions

Under the pressure of population and tourism in the mountainous area as Sapa, the choosing potential regions for cultivating terraced rice fields helps farmers to cut down agricultural expenditures. The semi-structured interviews illustrated the potential of rice provisioning ES supply in terraced fields. About 50% of collected samples supplied more than 3.9 ton/ha in the years of 2010s and many suitable areas provided more than 8 tons/ha. The location of paddy fields, which was pinned on thematic maps by farmers with accuracy by 30 meters, was a sufficient database for analyzing the potential of terraced rice provisioning service.

The study examined natural and human-derived components in the natural-based systems (topology- and hydrology-based systems) and human-based systems to identify their influences on the potential of rice provisioning service supply. Four components in the topology-based system, six components in the hydrology-based system and three components in the human-based systems are able to explain respectively about 20.9, 31.1 and 56.8 percent of the fluctuation of rice provisioning service supply. As a result, the last synthetic model did not only explain about 74.28 percent of deviance of terraced rice provisioning service but also proved the importance of the natural capital in the growing up of rice, especially with the length of flow, slope and water yield, besides human-derived components.

The results help decision-makers to choose different ways in the rice provisioning service flow based on the efficient use of the potential service or demand of beneficiaries in society. The management of the natural components has been considered more powerful and more desirable than human-derived components in improving provisioning service supply. To enhance the quality of terraced rice provisioning service in mountainous areas and minimize investment and fertilizer input, the study recommends that paddy fields should locate in downstream where has the length of flow lower than five kilometers, stable slope and high sediment retention.

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