DETERMINATION OF K-COEFFICIENTS FOR PAYMENT FOR FOREST ENVIRONMENT SERVICES USING GIS-BASED METHODS: A CASE STUDY IN BACKAN PROVINCE, VIETNAM

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ABSTRACT

Payments for forest ecosystem services (PFES) have been widely implemented in developing countries towards improving natural resource management and enhancing local incomes and livelihoods. In Vietnam, PFES programs have been recently demonstrated in several pilot provinces and have achieved some significant outcomes. However, experiences during the piloting phase show the difficulty of determining the K-coefficient, the factor is designed to adjust the distribution of payments. Many provinces are struggling to fully apply K-coefficients in practice and they often use a constant value (K = 1.0) for all forest stands, according to Vietnam Forest Protection and Development Fund. This approach leads to inequity concerns and it does not set an incentive for forest owners who provide the best ecosystem services. In this study, we proposed a GIS-based method for spatially calculating K-coefficients to support PFES implementation in BacKan province that is covered by about 337.0 thousand hectares of forests. K-coefficients were determined for all forest stands by combining its four components including: forest volume status (K1), forest function (K2), origin of forest (K3), and the difficulty of forest protection (K4). K1-coefficient was calculated by reclassifying a forest stand volume map (regrowth and poor forest, medium forest, and rich forest). Forest functions (special-use forest, protection forest, and production forest) were determined based on a provincial forest management map while forest origins were derived by investigating the establishment history of each stand (natural or plantation forests). The level of difficulty in forest protection (very difficult, difficult, or not very difficult) of each forest stand was spatially determined based on multiple factors including the distance to residential areas and road systems, and elevation and slope of the forest stand. Our results indicate that K-coefficients for PFES in BacKan ranged from 0.65 to 1.0. In which, the area associated with a K-coefficient of 1.0 was the lowest (only 33.73 ha, accounting for 0. 01% of the total forested area) while the area associated with a K-coefficient of 0.77 was the largest (greater than 107.2 thousand hectares, accounting for 31.8%). Methods and results from this study provide decision makers with a good solution to improve the quality of PFES implementation.

Keywords: *PFES, forest, GIS, K-coefficient*

1. INTRODUCTION

Payment for forest environmental services (PFES) is an issue that is of concern to many countries around the world. The basic idea of PFES is to create benefits for individuals and communities to protect environmental services by compensating them for the costs incurred in managing and providing those services. this (Alix-Garcia, De Janvry & Sadoulet, 2008; Mayrand & Paquin, 2009). Officially deployed in Vietnam from the beginning of 2011 immediately after Decree 99/2010/ND-CP dated September 24, 2010 of the Government took effect (hereinafter Decree 99) (Government of the Socialist Republic of Vietnam, 2010), PFES has become one of the most prominent and notable forestry policies in Vietnam, achieving many meaningful achievements. Revenue from PFES payments has gradually become a stable financial source, about 1,000-1,300 billion VND per year, dedicated to forest management and protection activities; From there, it helps reduce the pressure on state budget spending for annual forestry investment from 22% to 25%. With an average payment of 250,000 VND/ha, this policy has added an average income of 1.8-2.0 million VND/household/year for nearly 349,000 households and more than 5,700 participating household and community groups. manages and protects nearly 5 million hectares of forests nationwide (General Department of Forestry, 2015) .

Currently, payments for forest environmental services have been implemented in many localities across the country. Although many achievements have been achieved in many localities, payments for forest environmental services still encounter difficulties and obstacles (McElwee, Huber & Nguyen, 2019). Reviewing forests and determining forest boundaries and forest owners is still slow, largely manual, lacking human resources, and the management area is large. More importantly, there is currently no accurate, transparent scientific basis to calculate the value of PFES payments (Nguyen V.D., & Nguyen H.V., 2016). Most provinces implementing PFES are currently in the pilot phase and have difficulty calculating and determining the K coefficient, the coefficient used to adjust the value of PFES. Therefore, localities often apply a single K coefficient (K=1) to all forest plots (Haas, Loft & Pham 2019). This method does not bring fairness to forest owners and does not encourage forest protection (Pham et al., 2013). Finding a scientific and accurate method to determine the K coefficient for each forest block and plot is very necessary for localities that are implementing the PFES program (Nguyen V.H., 2016) .

Starting from the above issues, this study proposes a method to apply GIS technology in accurately determining the K coefficient for each forest plot to improve efficiency in PFES work. The research was conducted in Bac Kan province.

2. RESEARCH METHODS

2.1. Research area

The project's research area is the forested land area in Bac Kan province (about 337 thousand hectares). Forest area accounts for more than 70% of the total natural area of Bac Kan province and plays an important role in maintaining and improving the livelihoods of local people (Hoang M.H.,, 2014). Bac Kan is one of 11 provinces in the Northeast region that has established a PFES steering committee, a forest protection and development fund, and a fund executive board to carry out PFES work. The whole province has nearly 90 thousand hectares of forest that have been paid for PFES using this method, accounting for 26.6% of the total existing forest area. Like many other localities that are implementing PFES payments, Bac Kan uses a coefficient K = 1 for all paid subjects during the pilot period of 2016 - 2020 (Bac Kan Provincial People's Committee, 2016) . The main difficulty today is that there is no accurate and transparent scientific basis for making payments for forest environmental services. Therefore, developing a scientific and accurate method to determine the K coefficient for each forest block and plot is very necessary to improve the effectiveness of PFES payment in the province.

2.2. Research materials

Data used to determine the K factor in this study were collected from many different sources, including existing forest resource mapping systems, digital elevation models (DEMs), and data layers, other socioeconomic data (Table 1). Data on forest resources are mainly provided by the Department of Agriculture and Rural Development of Bac Kan province. After being collected, map data is checked, standardized (data format, coordinate system) and converted to raster format (30m resolution) for use in the steps of calculating the coefficients of K components. In addition to map data, a number of central and local legal documents and instructions were also collected and referenced. The main research tools in this study are the software ArcGIS 10.5 and Microsoft Excel 2016.

Table 1. Data used in the study

Group	Data name	Content
Forest resources	Forest status inventory data	Area, status, and purpose of forest use
	Forest survey data	Structure, reserves, and diversity of forest plants
	Forest planning data	Planning map of 3 types of forests
	Map of land and forest allocation	Digital land and forest allocation map
Remote sensing	Digital elevation model (DEM)	SRTM data provided by USGS, 30m resolution
Socio-economic	Population distribution map	
	Traffic map	
	Administrative maps	

2.3. Method for determining K coefficient

The K coefficient of each forest status plot is an integration of the component K coefficients, including: K_1 , K_2, K_3 , K_4 (Pham et al. 2013). The method to determine the component K coefficients is as follows:

- *Determine the coefficient K1 according to forest reserve*

Coefficient K1 is used to adjust PFES payment levels according to forest reserves, including rich forests, medium forests, poor forests and restoration forests (Government of the Socialist Republic of Vietnam 2010; Pham et al. 2013) . The coefficient K1 has a value of: 1 for rich forests; 0.95 for medium forest; and 0.90 for poor and restored forests. From the existing forest status map, process and filter objects that are forest plots according to the land type and forest type, assign the value K1 corresponding to 3 values K1 = (1.00; 0.95; 0.90) for each forest type.

- *Determine the coefficient K2 according to the purpose of forest use*

Coefficient K2 adjusts the PFES level according to forest use purposes, including special-use forests, protection forests and production forests. The coefficient K2 has a value of: 1 for special-use forests; 0.95 for protection forests; and 0.90 for production forests. In this study, the K2 coefficient is determined corresponding to the use purpose of each forest plot based on the current forest use status map approved by the People's Committee of Bac Kan province in 2016.

- *Determine the coefficient K3 according to the origin of forest formation*

Coefficient K3 adjusts the PFES level according to the origin of forest formation, including natural forests and planted forests (Government of the Socialist Republic of Vietnam, 2010). The coefficient K3 has a value of: 1 for natural forests; and 0.90 for planted forests. The K3 coefficient is determined by combining many different data such as forest status maps, forest inventory survey data, and consulting with experts and forest management households.

- *Determine the coefficient K_4 coefficient according to difficulty level in forest management and protection*

Coefficient K_4 adjusts the level of payment for forest environmental services according to the level of difficulty in forest protection, including social and geographical factors. Criteria for determining the level of difficulty in forest protection in the province are determined using a multi-criteria synthesis method. Criteria used include distance to residential areas, elevation and average slope of the forest plot. These principles are often used for building difficulty level maps for forest protection (Nguyen V.T. & Tran T.M.A., 2016). The steps to build a map to determine PFES payments according to the coefficient K4 are shown in Figure 1.

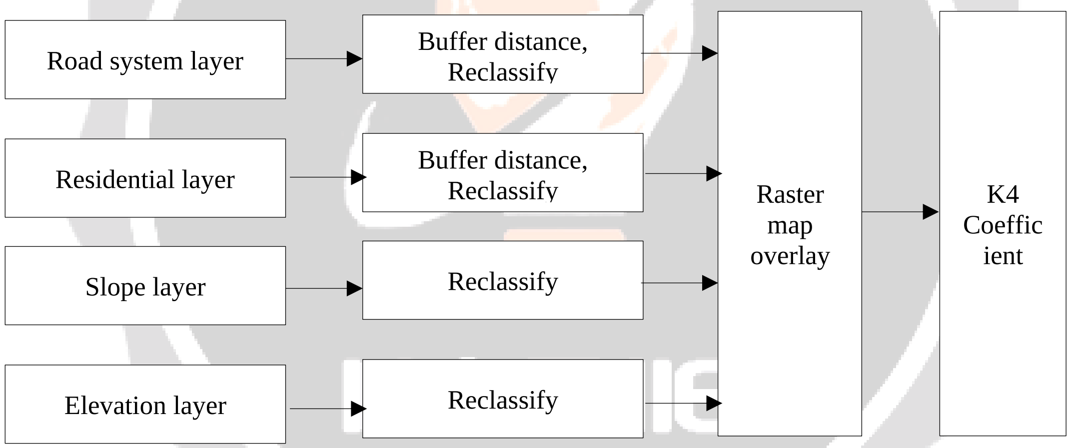

Figure 1. Determine PFES according to coefficient K4

The relative distance from forest plots to residential areas and roads is determined by overlaying and analyzing GIS spatial data layers on forest status, road systems, and existing residential areas. The relative distance is then divided into 3 levels corresponding to the levels of difficulty in forest protection (Table 2). Slope and elevation maps were rendered from DEM data at 30m spatial resolution and then overlaid with forest status data to calculate average values for each plot. Slope and elevation values are also divided into 3 levels corresponding to the difficulty levels in forest protection (Table 2).

Table 2. Hierarchy of criteria to determine the level of difficulty in forest protection

Hierarchy	Altitude (m)	Slope (^{0})	Distance to residential area (km)	Distance to roads (km)	K coefficient
Level 1 - Very difficult	< 400	< 15^0	< 2	< 2	1.00
Level 2 - Difficult	400 - 700	15^0 - 25^0	2 -5	2 -5	0.95
Level 3 - Less difficulty	>700	>25^0	> 5	> 5	0.90

K4 coefficient is determined by superimposing 4 thematic maps of the difficulty factors identified above. Forest plots with distance to residential areas > 5 km, slope > 25^0, altitude over 700 meter are considered less difficult to protect. Forest plots with distance to residential areas < 2 km, slope < 15^0, altitude < 400 m are considered very difficult to protect, the rest are considered difficult to protect. The coefficient K4 has a value of 1 for forests that are very difficult to protect; 0.95 for forests that are difficult to protect; and 0.90 for forests with little difficulty in protection.

- *Method for determining the synthetic K coefficient map*

Based on the results of determining the component coefficients K1, K2, K3 and K4, use the GIS spatial analysis tool to calculate the aggregate K coefficient:

K = K1 * K2 * K3 * K4

Using the technique of overlaying land and forest allocation maps of the area onto the K coefficient map allows determining the K coefficient for each forest plot according to forest owners in Bac Kan province.

3. RESULTS AND DISCUSSION

3.1. Determining the component K coefficient

The results of determining the component K coefficients are shown in Figure 2 and Table 2. The results of determining the 1- component K coefficient according to forest volume show that 81.78% (275,891.90 hectares) of the forest area of Bac Kan province has a coefficient value of K1 = 0.90 (poor forests and restored forests). Only a small area (4.04%) was identified with a K1 value of 1.00 (corresponding to rich forest). Regarding the K2 coefficient according to forest use purposes, the K2 coefficient value = 0.90 (production forests) also accounts for the largest proportion, 69.29% of the entire province's forest area (233,759.56 hectares). When classified by origin, the value K3 = 1.00 was determined for the natural forest area, accounting for 84.85% (286,221.33 hectares) of the total forest area of the province (Table 2). The results of determining the K4 coefficient show that the majority of forest areas are difficult or very difficult to protect, accounting for 55.7%. The most difficult areas to protect forests in the area are located in densely populated areas with high urbanization rates, low slopes and elevations such as Bac Kan city, Cho Moi and Bach Thong districts (Figure 2d).

Table 3. Values of component K coefficients by area

K coefficient	Classification criteria	K coefficient value	Hierarchy	Area (ha)	Ratio (%)
K1	Rich forests	1.00	Level 1	13,626.70	4.04
	Medium forest	0.95	Level 2	47,825.92	14,18
	Poor forests and restored forests	0.90	Level 3	275,891.90	81.78
K2	Special use	1.00	Level 1	19,975.39	5.93
	Protection	0.95	Level 2	83,608.57	24.78
	Manufacture	0.90	Level 3	233,759.56	69.29
K3	Natural forest	1.00	Level 1	286,221.33	84,85
	Planted forests	0.90	Level 2	51,122.29	15.15
K4	It is very difficult to protect forests	1.00	Level 1	44,501.50	13,19
	Difficulties in forest protection	0.95	Level 2	143,291.00	42,48
	Fewer difficulties in forest protection	0.90	Level 3	149,559.50	44.33

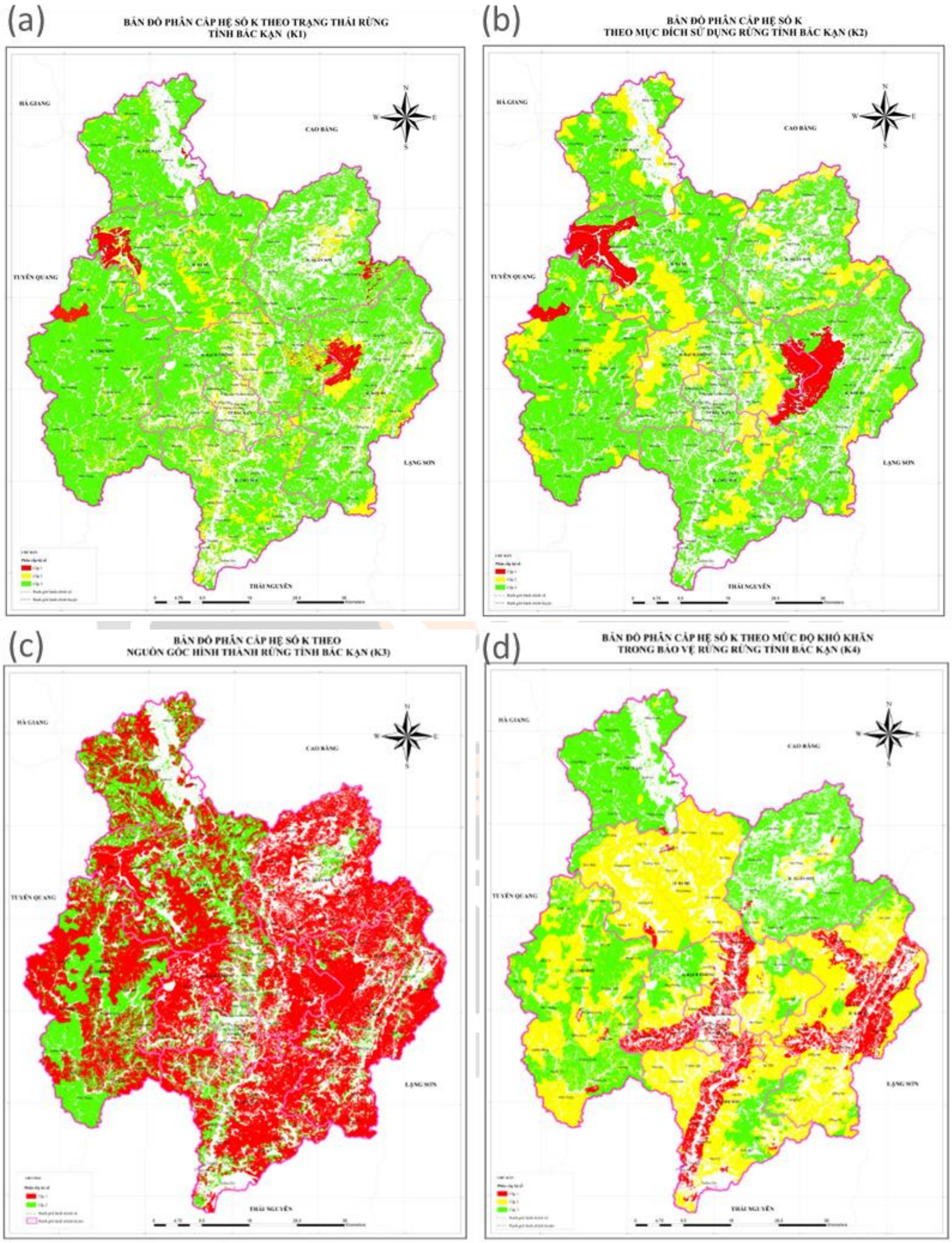

Figure 2. Map showing the results of determining the K coefficients for components K1 (a), K2 (b), K3 (c) and K4 (d)

3.2. Determining the combined K coefficient

The map showing the spatial distribution of the K coefficient value compiled from the component coefficients is shown in Figure 3. Calculation results show that the forest service payment coefficient in Bac Kan province ranges from 0.65 to 1.00.

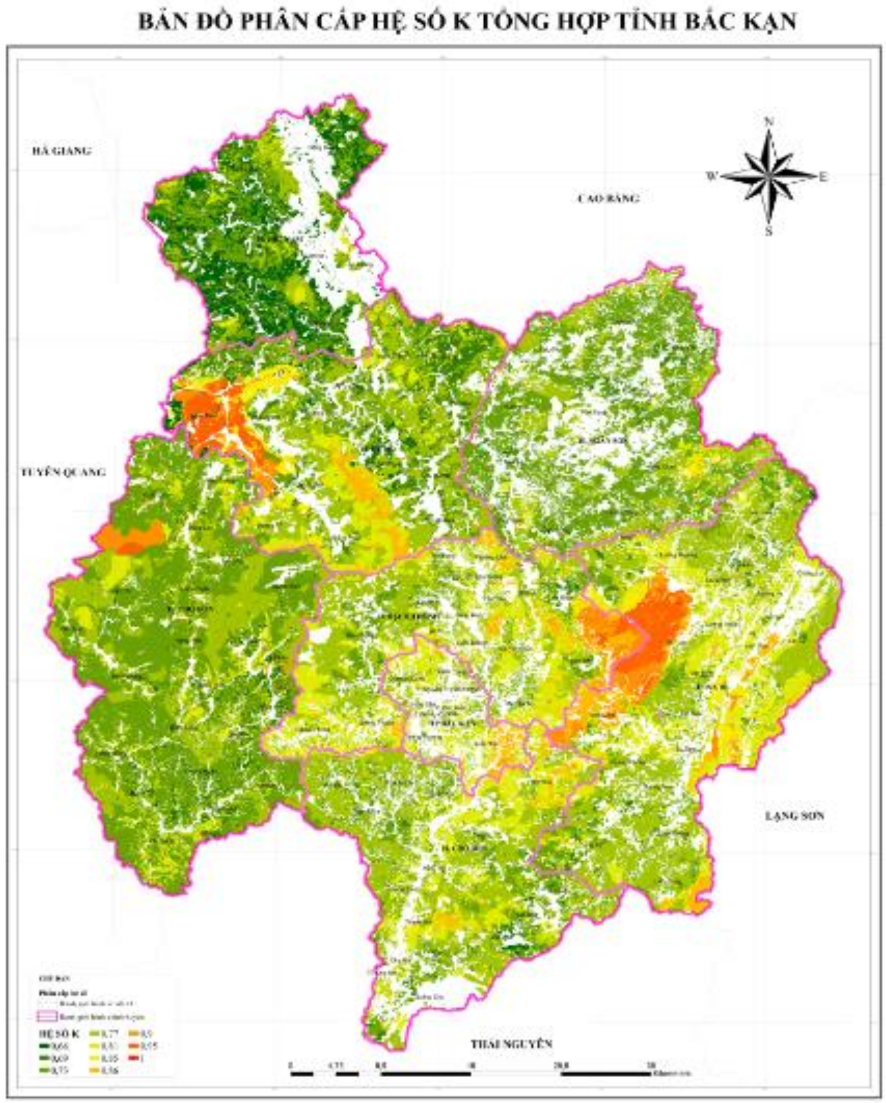

Figure 3. Aggregated K coefficient hierarchy map for Bac Kan province

The number of forest plots with coefficient K = 1.00 accounts for the lowest proportion of 0.01%, the number of forest plots with value K = 0.77 accounts for the highest proportion of 31.79%, compared to the coefficient K = 1. With current payments in Bac Kan province, it can be seen that the actual K coefficient value is much smaller (Table 4). Coefficient K = 1 is currently being paid during the trial period. If payments are carried out accurately and scientifically, building a map of K coefficient to pay for forest environmental services is a method built on the basis Scientific and highly accurate results.

Table 4. Summary table of K coefficient for payment of environmental services in Bac Kan province

No.	K coefficient value	Area (ha)	Ratio (%)
1	0.65	31,710.38	9.40
2	0.69	42,168.07	12.50
3	0.73	72,191.72	21.40
4	0.77	107,241.82	31.79
5	0.81	55,661.85	16.50
6	0.85	16,529.88	4.90
7	0.90	5,397.51	1.60
8	0.95	6,409.55	1.90

9	1.00	33.73	0.01

4. CONCLUSION

Research results show that the K coefficient value for each forest plot in Bac Kan province is in the range of 0.65 to 1.00; in which the coefficient ratio K = 1.00 is the lowest (0.01%), K = 0.77 accounts for the highest ratio (31.8%). The detailed K coefficient map for each forest plot in Bac Kan province is an important document in the management and implementation of PFES payment policy in Bac Kan province, contributing to promoting forest protection, increase livelihoods for people living on forests in the district and Bac Kan province. The GIS method used in this study provides an effective and economical solution to improve the quality of PFES payments in localities.

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