Application of GIS and Remote Sensing for Assessing Watershed Ponds for Aquaculture Development in Thai Nguyen, Vietnam

Dao Huy Giap[1], Yang Yi[1*],
Aquaculture and Aquatic Resources Management
School of Environment, Resources and Development
Asian Institute of Technology
P.O. Box 4 Klong Luang, Pathumthani 12120, Thailand
Tel. 66-2-5245454 Fax 66-2-5246200
Email yangyi@ait.ac.th

Nguyen Xuan Cuong, Le Thanh Luu
Research Institute for Aquaculture No.1,
Tu Son, Bac Ninh
Vietnam

James S. Diana, C. Kwei Lin
School of Natural Resources and Environment
University of Michigan, Ann Arbor,
USA

Abstract

This study was conducted in Dai Tu district of Thai Nguyen province during November 2001 - January 2003 to assess the aquaculture development potential for watershed ponds by integrating socio-economic and environmental data into GIS database, detecting land use change, and identifying and estimating potential areas for aquaculture development in watershed ponds. The socio-economic and environmental data were collected using pre-test questionnaires and field measurements. Three SPOT multi-spectral band satellite images were used to detect land use change during three periods of 1994-1998, 1994-2002, and 1998-2002. For land suitability evaluation, the suitability ratings were established according to FAO classification in terms of suitability of land for defined uses. Aquaculture production and economic returns from interviewed farmers were used to verify the results and comparisons among different land suitability levels.

The present study has predicted that about 4.7% (2,725 ha) of the total land area of 57,618 ha in Dai Tu district are suitable sites for watershed pond construction, compared to the existing 404-ha watershed ponds. The present study has demonstrated the usefulness of integration of remote sensing, GIS and attribute data to select suitable sites for the development of watershed ponds, and the importance to be a useful tool for planners to develop strategic plans for aquaculture development.

Introduction

A large number of watershed ponds and reservoirs have been constructed mostly for household water supply and crop irrigation in mountainous areas of central and northern Vietnam. Occasionally, these ponds are also used for fish culture. Thai Nguyen district, situated approximately 100 km north of Hanoi, is a population center serving as a gateway to northern Vietnam. There are numerous small reservoirs and watershed ponds used for irrigation for tea plantations, rice fields and fruit orchards; some are also used for aquaculture. To most inhabitants in mountainous areas of northern Vietnam, supply of animal protein is relatively limited, with very small contributions from fish. Recently, the Vietnamese government has initiated aquaculture development in those areas as a means to increase protein availability. Therefore, the development of aquaculture in Thai Nguyen may also serve as a model for watersheds in other provinces.

In recent years, several surveys had been conducted in Thai Nguyen province to evaluate biological, physical, social and economic conditions for aquaculture development. However, most of the surveys lack systematic spatial data. Planning activities to promote aquaculture in Thai Nguyen province require spatial analysis because of geographical variation in biophysical features and socio-economic status (Kapetsky et al., 1987; Nath et al., 2000). This project proposes to develop a GIS database of watershed ponds, coupled with other physical, biological, and social attributes of northern Vietnam. Development of a GIS database is a first step in formally evaluating the effects of local geographic and social conditions on the production of fish in watershed ponds.

With an adequate database, Geographic Information Systems (GIS) can serve as a powerful analytic and decision-making tool for aquaculture development. Furthermore, it can also be used for management and to test consequences of development (Aguilar-Manjarrez and Ross, 1995). In this paper, we examine the potential of integrated social and environmental data with GIS and remote sensing as a tool for assessing watershed ponds for aquaculture development by integrating socio-economic and environment data with GIS, detect the land use change, and identify and estimate potential area for watershed pond development for aquaculture.

Methods and Materials

This study was conducted in Dai Tu district of Thai Nguyen province, Vietnam during November 2001 to January 2003. Dai Tu district, about 100 km north of Hanoi, is a mountainous area, covering 57,618 ha (Fig. 1). The primary data sources were social-economic survey, field measurement and three SPOT multi-spectral band satellite images for land use change detection. Land use types, roads, and hydrological systems were taken from topographic maps and updated with SPOT satellite images. Field survey, digital topographic, land use map and related information were used to identify suitable sites for watershed ponds to be used in aquaculture.

GIS software and systems used

The GIS software used in this study was ArcView GIS for windows (version 3.2) developed by Environmental Systems Research Institute, Inc. The remote sensing image analysis used in this study was ENVI (version 3.4) developed by Research Systems and MLR XP24 GPS for field sample collection and verification.

Surveys and field measurements

The socio-economic and environment data were collected using pre-test questionnaires and field measurement from randomly selected sixty farmers and sixty watershed ponds respectively. Soil and water samples were collected from these ponds for the determination of soil pH, soil texture, water pH (Boyd and Tucker, 1992. The locations of the selected watershed ponds were recorded by a GPS navigator (MLR SP24).

Remotely sensed data and thematic maps

The primary data sources were three SPOT multi-spectral bands satellite images acquired for the dates of 22 October 1994, 10 November 1998, and 9 November 2002. Cloud-free images of the study area were taken from these three scenes and geo-registered with topographical maps (1:25,000) using reference points.

Fourteen base layers (thematic maps) were used in the study and grouped into 4 main land use requirements for aquaculture: (1) potential for pond construction (slope, land use types, soil thickness, and elevation); (2) soil quality (soil types, soil texture, and soil pH); (3) water availability (distance to water, water sources, and precipitation); and (4) geographical and social economic status (distance to roads, population density, distance to local markets, and distance to hatcheries) (Table 1). Slope, elevation, soil type, soil thickness, precipitation, and local market centers and hatchery locations data were extracted from the digital topographic map of Dai Tu (1:25,000) (Vietnam Cartographic Publishing House, 1999). Land use types, roads, and hydrological systems data were taken from the topographic map and updated with SPOT satellite imagery acquired for 9 November 2002. Soil pH and soil texture were collected during the survey and extracted from soil information in Vietnam (Agriculture Publishing House, 2000). Population density data were taken from Statistical Yearbook of Thai Nguyen (Thai Nguyen Statistics Department, 2002).

Land use change detection

Three SPOT multi-spectral band satellite images were used to detect land use change. Supervised classification was performed for each image. Field surveys, digital topographic maps, and land use maps were combined to evaluate land use coverage and other information. This procedure allowed for identifying training samples to be selected based on land use types. Three classified land use images were combined to determine the changes during three periods of 1994-1998, 1994-2002, and 1998-2002 (Fig 2). The classified image in 2002 was calculated for accuracy through field survey based on Kappa analysis (Congalton and Green, 1999). Two other classified images in 1994 and 1998 were not evaluated for their accuracy because they were short of accurately reference data.

Land suitability evaluation for watershed pond

Criteria of land suitability were divided into two types: factors and constraints. A factor is a criterion that enhances or detracts from the suitability of the specific alternative under consideration. A constraint is a land type or use that restricts or makes it impossible to develop watershed aquaculture ponds, such as land that is currently natural forest, road, river or large water bodies.

Weightings and suitability ratings were based on the level of importance of a factor that influences aquaculture. Suitability ratings were established according to FAO classification (FAO, 1977) in terms of suitability of land for defined uses, and the similar methodology had been successfully used in aquaculture (Hajek, and Boyd, 1994, Aguilar-Manjarrez and Ross, 1995; Salam et al., 2003). The interpretation of suitability classes for each factor was classified on a scale from 4 to 1 as follows. Highly suitable (4) provides a situation in which minimum time or investment is required in order to develop fish farming. Suitable (3) requires a modest time and investment. Moderately suitable (2) requires significant interventions before fish farming operations can be conducted. Unsuitable (1) requires a time or cost or both that is too great to be worthwhile for fish farming (Table 1). Constraints (rivers, roads, natural forests, large water bodies) were coded as 0 and others were coded as 1 to exclude the constraint areas from suitability maps (Nath et al., 2000).

The weight for each factor was determined by pair-wise comparisons in context of decision-making process known as the analytical hierarchy process (Saaty, 1990; Canada et al.1996). The suitability rating for each level of a factor was determined from the result of the survey and expert opinions (Table 2). Suitability scores were calculated as:

$$\text{Score} = (w_1r_1 + w_2r_2 + \ldots + w_nr_n) / n \times 100$$

Where, w_n and r_n are weight and rating score each factor n.

The calculation processes are presented in Figure 3. Higher score values indicate more suitable areas for watershed pond development. The suitability score classification is showed in Table 3.

Verification and economic analysis

Model verification was done by evaluating suitability of sites where existing watershed ponds occur. This verification was to determine whether existing watershed ponds were located in suitable sites or not.

Aquaculture production and economic returns from interviewed farmers were used to verify the results and comparison among different land suitability levels. One-way ANOVA was carried out to compare the difference among different land suitability classes using SPSS (version 10.0) statistical software package (SPSS Inc., Chicago).

GIS database

A digital topographic map (1:25,000) of the study area obtained from Vietnam Cartographical Publishing House (1999) was used as basic information for the GIS database. Information from the socio-economic survey and field measurements were integrated into the GIS database. Land use, land use changes, and suitability models were also associated with the GIS database.

Results

Current situation of watershed pond aquaculture in the study area

Dai Tu district is located in the Northwest of Thai Nguyen province, and covers 57,618 ha, of which there are 24,468 ha of sloping hills and forests, 18,911 ha of rice fields, and about 122 ha of upland crop fields. Among the total area of rice fields, about 110 ha are favorable for integrated rice-fish culture.

Watershed ponds are an important asset of the households. A pond is not only a good source for providing fish for household consumption and generating household income but also an important water source for other household activities. All interviewed household had watershed ponds, among which 94.79% had household ponds that they had built themselves or inherited with the land, while the remaining households (5.21%) rented watershed ponds from others

Almost all watershed ponds were located in valleys. Average size of the surveyed ponds was about 388 m^2, ranging from 90 to 2,160 m^2, while water depths ranged from 0.5 to 2.0 m with an average of 0.99 m. Water depths fluctuated largely between dry and rainy seasons.

About 38% of surveyed watershed ponds currently could not access water supply from irrigation networks. Water levels in these ponds depend solely on rainwater. Accessibility to irrigation water depends on the farmers' position as well as presence of irrigation facilities. Among the surveyed ponds, 29.17% could access irrigation water only at limited levels. These ponds were still largely dependent on rainwater, while irrigation water played a minor role (Table 4).

Land use change

Accuracy of image-interpretation in 2002 was calculated through field survey based on Kappa analysis. The accuracy of classification was 94.6%. Some land-use types were misclassified, such as natural forest and planted vegetation. Figure 4 shows land use composition in 1994, 1998 and 2002 in Dai Tu district. The land use matrix shows the changes in land use pattern in the study area (Table 5). Major changes were in the natural forests, paddy fields, and planted vegetation (including planted forest, tea plants and shrubs). The areas of water bodies and village mixed orchard were increased slightly.

The major loss of natural forests occurred during 1994-1998, with total area declining from 18,411 ha (32.0% of the total area) in 1994 to 14,137 ha in 1998 (24.5%) and to 13,878 ha (24.1%) in 2002. The converted forest area of 4,274 ha was mainly used for planted vegetation, accounting for almost 99% loss.

The area of planted vegetation increased from 24,799 ha in 1994 (about 43% of the total area) to 27,495 ha (48%) in 1998, then declined to 24,307 ha (42%) during 1998 - 2002. Even though many hectares of natural forests were converted into planted vegetation from 1998-2002, there were loss in some other planted vegetation sites. The loss of planted vegetation was turned into paddy fields (76%), village mixed orchard (13 %), and water bodies (11%). Changing the planted vegetation area into water bodies and paddy fields were probably due to expansion of small reservoirs for irrigation.

Village mixed orchard area increased slightly from 1994-2002. Increased orchard area was mainly converted from planted vegetation.

Paddy fields showed increasing trends in size from 1994-2002. The area of paddy fields was only 6,758 ha (12% of total area) in 1994, increased to 7,620 ha (13%) in 1998 and 10,402 ha (18%) in 2002. Paddy field area increased by 12% from 1994 to 1998, and almost 54% from 1994 to 2002. This conversion was mainly from planted vegetation, and some from water bodies and mixed orchard.

The area of water bodies plays an important role in development of aquaculture for the study area. Water bodies occupied 1,056 ha (1.8% of total area) in 1994, increased to 1,163 ha (2%) in 1998, finally reached 1,385 ha (2.4 %) in 2002. During 1994 - 2002, water body area increased by 30% of the original area.

Land suitability evaluation for watershed ponds

The suitability of four main criteria, and the overall potential for watershed ponds, are summarized in Table 6 and displayed in Figure 5. There was a large area along the central line of the study area that was suitable for pond construction due to large suitable land use, low slope and elevation, and suitable soil thickness. Most suitable areas for pond construction were usually distributed along the north-south central line, and northeastern region of the district. The areas of natural forest and water bodies (34.9% of the total area) were considered as constraints, and only 14.7% and 3.6% of total area was classified as marginally suitable or not suitable, respectively.

Not suitable areas were mostly underlain with the humic ferrasols and rhodic ferralsol soil types with pH between 4 and 5. High suitability of soil occurs in the small area in the middle and northeastern parts of the study areas. Because of soil quality, only 3.9% and 8.2% of the area could be classified as highly suitable and suitable, respectively, while 47.9% and 6.0% were classified as marginally suitable and not suitable, respectively. Large areas with marginally suitable soil quality indicate that aquaculture development in the area may require high initial investment to improve soil quality.

Ponds in the study area were mostly rainfed. Several small land evaluation units were close to reservoirs, and the eastern part of the study area was irrigated. Areas with highly suitable or suitable in terms of water availability (19.3% and 41.2%) were distributed in all communes due to extensively river systems and high precipitation rate.

Except for mountainous areas and natural forests in the northeastern region, most areas could access easily to the transportation systems and were not too far from local markets. However, only one hatchery was available, near the reservoir in the southeastern region of the study area. Most areas in the north, west and northwestern regions were too far to access the hatchery and aquaculture extension from hatchery staff. That was the main constraint for areas far from the main roads in those regions. Due to these constraints, areas with high suitability, classified in terms of geographical and socio-economic status, were only 14.4% of the total area and were distributed along main roads and not far from the hatchery. Suitable or moderately suitable areas were scattered along roads and local centers.

Areas with constraints for aquaculture development in this region were mainly mountain, natural forest areas and large water body. Overall, highly suitable areas for watershed ponds covered about 2,725 ha of the study site (4.7%), and nearly 18,862 ha (32.7%) were suitable. These areas occured along main roads and river system at lower elevation, lower slope, with appropriate land use types, and have access to water and markets. The suitable and moderately suitable areas are found mostly in Binh Thuan, Van Tho, Hung Son, Phuc Ninh communes.

Much of the study area was limited by soil quality because most soil types were sandy and rocky. Other factors were often quite suitable for aquaculture development, such as large flat areas, high precipitation rate, extensive road networking, and scattered local markets.

Verification and economic analyses

The sixty surveyed ponds with GPS data were used to verify actual pond locations compared to the suitability map. There were 5, 50 and 5 ponds located in highly suitable, suitable, and marginally suitable areas. Among sixty surveyed ponds, no ponds were found in unsuitable and constraint areas.

Among 60 surveyed ponds, data from 54 ponds with complete information on economic aspects and production were used for economic analysis. The results showed that there were no significant differences among different land suitability levels in term of fish production, gross revenue, total cost and profit (Table 7).

Discussion

The present study demonstrated high efficiency for GIS to analyze complex spatial data. The land suitability map, derived from GIS, for development of watershed ponds was partly verified by locations of current watershed ponds in the study area, analysis of satellite images, published data and field surveys. GIS predicted that 2,725 ha of land were suitable for development into watershed ponds, while the current pond culture area was only 336 ha and rice-fish culture 500 ha. Thus there was a possibility for expansion of aquaculture in the study area.

Suitable areas for watershed ponds used in aquaculture are located near rivers or roads and lower elevation, to ensure easy access to water and transportation. Most surveyed watershed ponds were located within resident lands, or paddy fields. Aquaculture in the study area was small scale, with average pond size less than 400 m^2 and ponds were used for multiple purposes such as household water supply, and crop irrigation. Most of aquaculture products in the study area were used for home consumption. Integrated farming systems such as garden-pond-livestock and garden-pond-livestock-forest systems are popular in Vietnam (Luu et al., 2002).

Land use in the study area has undergone dramatic changes, and was impacted by human activities and development. Overall, only natural forests declined in area, while the most dramatic increase was found in rice fields. Village mixed orchards and water bodies also showed increasing trend from 1994-2002, but the overall changes was not large for these areas. Increases in rice fields and water bodies represented that there is the possibility of increasing aquaculture or increasing the suitability of the study area for future aquaculture.

Paddy fields are physically suitable for building fish ponds. In term of economic returns, aquaculture often gives higher return than rice culture (Salam et al., 2003). However, the decision to convert paddy fields to fish ponds is often related to food security and social aspects. In order to maintain a balance between social and economic aspects, integrated rice-fish culture system should be promoted (Gregory and Guttman, 2002).

The GIS database was dependent on rating, weighting and classifying of suitability scores. These procedures are quite flexible and subjective. Different weighting, rating and classification methods could generate variety of results. Sufficient reference information and decision input from local people, as well as experts, are very crucial (Aguilar-Manjarrez and Ross, 1995). The use of qualified and up to date information is also very importance. An updated land use map or remote sensing satellite image should be used to verify results during the evaluation processes.

The present study shows the modeling power of GIS to evaluate land for development of watershed ponds. An economic component should be incorporated into GIS applications to determine economic suitability in addition to physical suitability (Rossiter, 1995, 1996).

Currently, aquaculture plays a small role in Dai Tu district, and there is potential for further aquaculture development in watershed ponds. In the existing 336-ha of watershed ponds used for aquaculture, fish production is low, contributing only 6.5% of total household income. Almost all farmers were aware of the benefits of watershed ponds to their livelihoods, because watershed ponds are important in integrated household activities as a source of water for gardening, livestock, and household use. However, inaccessibility to the irrigation water network and lack of general aquaculture knowledge seem to be two main problems that cause poor performance of pond culture and slow aquaculture development in watershed ponds. Many farmers cannot access the irrigation network or can do so only at limited levels, thus depending completely or largely upon rainwater to maintain watershed ponds. Infrastructure improvement would further promote aquaculture development in watershed ponds.

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