Research article

Effect of Land Use Change on Land Quality and Water Resources in Phatthalung Watershed, Thailand

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Abstract A watershed scale study was conducted to assess the effect of land use change on land and water quality using selected indicators in the Phatthalung watershed, Thailand. The changes in water quality in the study area were assessed by computing a Water Quality Index (WQI) using some important water quality parameters, including pH, suspended solids and plant nutrients. Water quantity was also assessed through estimating soil moisture storage. Land quality was assessed by developing a Land Quality Index (LQI) based on indices of soil resource, land degradation status and water resource. The quality of land from two different areas, i.e. where land use has changed, and where no change has occurred, was assessed using the selected indicators. The computed WQI decreased during the study period. The highest WQI was 97.5 in 1997 and 2003 and the lowest was 80.0 in 2005 and 2006. Suspended solids (SS) was the major factor influencing WQI. Water quantity, in terms of soil moisture storage, showed positive results as the number of months of water surplus increased from one month per year in 1976 to 4 months in 2006. This was due to the decline in paddy field area. For LQI the indices of soil resource and land degradation status were higher, and water resource lower, in areas where land use did not change compared to those where land use did change.

Keywords: Land use change, land quality, water quality, Phatthalung Watershed

INTRODUCTION

Recently the pressure on land and water resources has increased due to the expansion of population and economic development. The major pressure on land is attempts to increase agricultural production from land, as intensification of agricultural activities increases food production for an increasing population. However this causes impacts on the agricultural inputs, such as soil and water resources.

Land use change has positive and negative effects on land and water, the key resources for agricultural production. Land use and land use change generally reflect changes in agricultural activities, and give rise to issues in land and water quality (Dalal and Mayer, 1986; Bushchbacher et al., 1988; Fu et al., 1990). Excessive and careless use of fertilizers and pesticides can have negative effects on land and water resources through impacts on groundwater and runoff and associated ecological damage (George et al., 2002). Eventually such changes can be dangerous for human health. Moreover runoff of excess nutrients, especially phosphorus, leads to eutrophication with taste and odour impacts on public water supplies and excess algae growth leading to deoxygenation of water and fish kills (FAO, 1996). Using heavy machines also plays an important role in the deterioration of land and water resources due to soil compaction, decreased soil porosity, increased soil erosion and loss of top soil nutrients and organic matter. Therefore recognition of the current situation with regard to land use and its consequences can be useful for planning future land uses to protect land and water resources.

Phatthalung watershed, a major agricultural area of southern Thailand has experienced land use change, particularly the replacement of paddy areas by rubber plantations. These changes of land use are driven by of internal and external factors, economic return being one of the major drivers. Therefore, an assessment of quality of land and water is needed to understand the current situation, and to provide an early warning and guide for future land resource management and development. The establishment of land and water quality indicators can measure changes in the land resource due to external disturbances; especially land use for agricultural activities.

METHODOLOGY

Water quality assessment

The water quality of Phatthalung watershed over the period 1994 to 2006 was determined on the basis of the WQI proposed by Rodriguez de Bascaron (Pesce and Wunderlin, 2000; Sanchez et al., 2007; Wu et al., 2008) as follows:

$$WQI_{sub} = k \frac{\sum_i C_i P_i}{\sum_i P_i} \qquad (1)$$

where, WQI_{sub} is the water quality index of surface water of Phatthalung watershed, k is a subjective constant with a maximum value of 1 for good quality water and 0.25 for highly polluted water (in this study the k value was not considered and hence assigned as 1), C_i is the value assigned to each parameter after normalization (Table 1), and P_i is the relative weight assigned to each parameter. This weight was assigned as 1 in all cases in this study to account only for variation due to measured parameters. The WQI used in this study included four parameters as follows:

$$WQI = \frac{C_{pH} + C_{SS} + C_P + C_N}{4} \qquad (2)$$

where, C_{pH}, C_{ss}, C_P and C_N are the values of pH, suspended solids (SS), and Phosphate and Nitrate values after normalization, respectively.

Table 1 Values of normalization factor (C_i) for selected parameters of water quality

Parameter	Normalization factor (C_i)										
	100	90	80	70	60	50	40	30	20	10	0
pH	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	3-12	2-13	1-14
SS	<20	<40	<60	<80	<100	<120	<160	<240	<320	<400	>400
Nitrate	<0.5	<2.0	<4.0	<6.0	<8.0	<10	<15	<20	<50	≤100	>100
Phosphorus	<0.16	<1.6	<3.2	<6.4	<9.6	<16	<32	<64	<96	<160	>160

All values, except pH, in mg/l (Pesce and Wunderlin, 2000; Sanchez et al., 2007)

Water quantity assessment

In this study, soil moisture storage was used as the indicator for water quantity assessment. Soil moisture can be affected by various types of agricultural activities and changes in land use. Soil moisture storage and its change were assessed in this study by using Eq. (3):

$$\Delta SM = P - ETc - q \qquad (3)$$

where, ΔSM is the change in soil moisture (cm), P is rainfall (cm), ETc is crop evapotranspiration (cm), and q is runoff depth (cm).

Land quality assessment

The quality of land resource was assessed through the LQI. In this study the LQI was developed to address changes in land quality due to land use change. LQI consisted of major components of the land resource included soil properties, water resource, and land degradation status. The set of indicators used is presented in Table 2.

Because of the different scale and unit of selected land quality indicators, it was necessary to standardize the values in order to compare between land quality indicators for land use changes compared to the no change area. Therefore the linear scaling method was used to normalize the different scale values.

Table 2 Land quality indicators

Indicator suite	Component attributes	Measurement and method
Soil		
Physical property	Water holding capacity	Laboratory analysis
	Soil texture (sand and clay content)	Laboratory analysis
Nutrient status	Cation exchange capacity (CEC)	Laboratory analysis
Water resource	Water sufficiency	Effective rainfall
Land degradation status	Erosion status	Erosion model

RESULTS AND DISSUSSION

Land use in Phatthalung watershed has been undergoing change, significantly so since 1976. The major change has been the rise in rubber plantations, continuously increasing due to rapidly increase in rubber prices in the local and global market during the period 1990 to 2006, The forest area decreased continuously and significantly and the rubber plantation area rapidly increased (+37.3%), resulting in a decreasing of paddy field (-36.1%) and forest area (-12.4%). Fig. 1 shows the areas where land use change occurred.

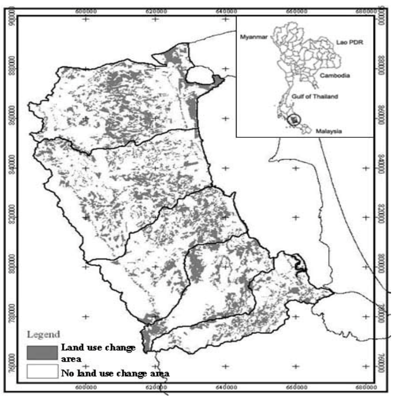

Fig. 1 Land use change area during 1990-2006

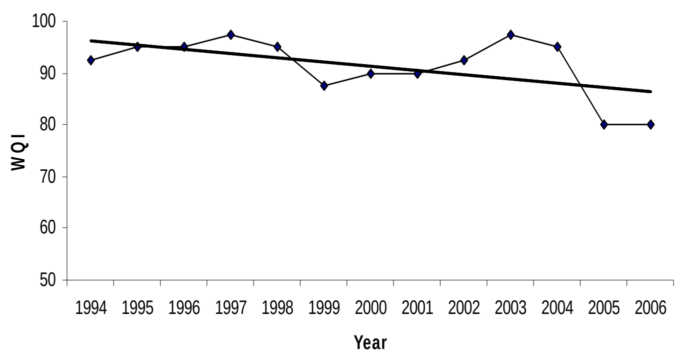

Fig. 2 Computed WQI during 1994-2006

Water quality analysis

Based on the parameters presented in the above section, the computed WQI varied ranging from 80 to 97.5 in the study area (Fig. 2). The WQI declined in the period 1998 to 2003 and slightly increased in 2003 due to lower amounts of suspended solid being loaded into water bodies. The index decreased again from 2004 to 2006. The highest water quality was in 1997 and 2003 (WQI = 97.5), and the lowest WQI (WQI = 80) was in the most recent years (2005 and 2006). The computed WQI for all periods indicated that water quality is of "good" and "excellent" condition, as described by Jonnalagadda and Mhere (2001). However, the WQI trend indicates declining water quality during the study period, implying that the quality of water is degrading based on the parameters used in this study.

Water quantity analysis

The quantity of water can mean different things in different contexts. From an agricultural point of view soil moisture is very important and was used in this study to refer to water quantity. Soil moisture is important for agriculture as it is an input to plant production. It can be lost through many channels including runoff, deep percolation, evaporation and transpiration. Land use is a major factor capable of controlling the level of moisture loss through its influence on surface runoff.

The soil moisture change of Phatthalung watershed during the study period was computed using the concept of soil moisture balance. The number of months in which surplus water implied high soil moisture increased during the study period. Surplus water was found only in November in 1976 (Fig. 3) and 1990 (Fig. 4) but it had increased to four months (January, October, November and December) in 2006 (Fig. 5).

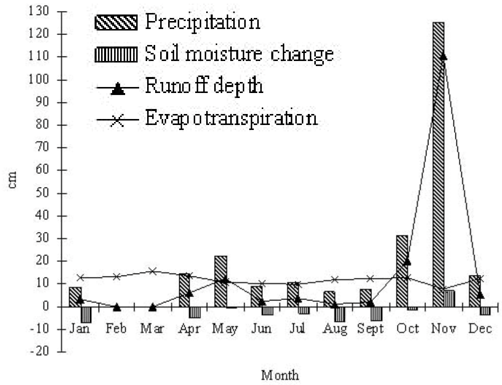

Fig. 3 Soil moisture of Phatthalung watershed in 1976

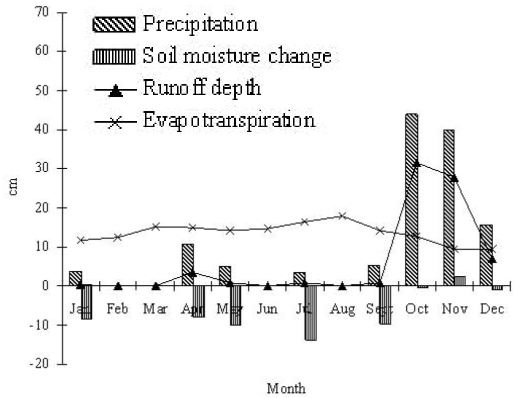

Fig. 4 Soil moisture of Phatthalung watershed in 1990

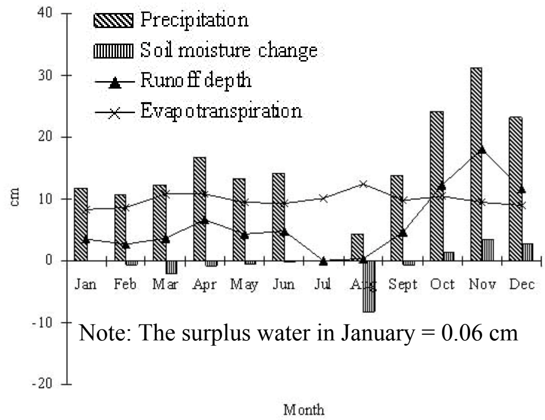

Fig. 5 Soil moisture of Phatthalung watershed in 2006

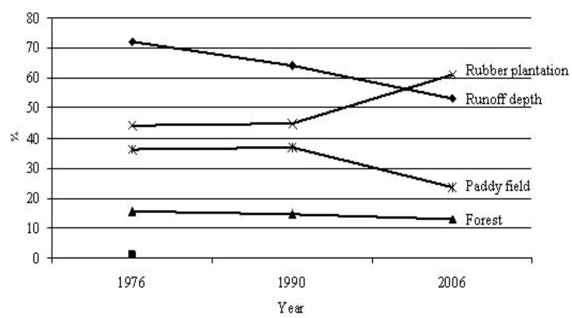

Fig. 6 The relationship of land use types and the surface runoff

The moisture of soil in 2006 increased because of the reduction in runoff. Fig. 6 shows the relationship between land use and annual runoff depth of the three main land uses. Note that the increasing area of rubber plantation and decreasing area of paddy field resulted in the reduction in runoff depth. Hence, the decline in paddy field area and the increase in area of rubber plantation can cause positive effects on soil moisture storage

Land quality analysis

Land quality of the study area was assessed through three selected indicator sets, which included soil, water resource and the status of land degradation. Four indicators were used to assess the quality of soil resource; those were sand and clay content, CEC and water holding capacity (WHC). Water sufficiency and soil erosion rate were the selected indicators used to assess water resources and land degradation status, respectively. Table 3 presents the detailed computed score for each indicator under each land use scenario. The overall LQI, an aggregated index value for the whole study area, was 0.452 for the land use change area and 0.629 for no use change area. However, there was no statistically significant difference between the groups.

The no change land use areas have higher LQIs than the land use change areas. the overall soil resource index of the two areas was significantly different, but the water resource and land degradation indices were not significantly different. For the soil resource index, the score for the no change area (0.785) was significantly higher ($p<0.05$) than for the area of land use change (0.708).

For individual indicators the area of no land use change has higher scores in most of the indicators, except for clay content. This was because the soil sample points that represented the land use change were mostly located in the areas that had been paddy field in the past, and which usually contain higher clay content.

This is to note here that the computed land quality scores of no change area were higher than the area where land use change occurred in terms of the selected indicators.

Table 3 Land quality assessment

Land quality indicators	Land use change	No change	Significance
Soil resource			
Physical property			
%Sand	0.705	0.804	0.051
%Clay	0.965	0.827	0.025*
Water holding capacity	0.468	0.689	0.277
Nutrient status			
CEC	0.675	0.819	0.361
Overall soil resource index	0.708	0.785	0.045*
Water resource			
Water sufficiency	0.327	0.337	0.065
Land degradation status			
Soil loss	0.643	0.878	0.086
Overall LQI	0.452	0.629	0.377

CONCLUSION

Land and water resources of the Phatthalung watershed are influenced by various factors, and land use is the influencing factor investigated in this study. The computed WQI indicated that the overall water quality of Phatthalung watershed has declined during the observed period (1994 to 2006). Suspended solid has been increasing over the years. Overall the water quantity status of Phatthalung watershed has increased during the study period because about half of paddy field area was replaced by rubber plantation, with positive impacts on the water quantity in terms of increased water storage. The reason is that paddy field areas have the capability to generate higher surface runoff compared to rubber plantation and forest areas, which can reduce the amount of the moisture in soil.

The computed LQI of the no change in land use areas tended to have better land quality in terms of the selected factors, however the changes were not significantly different between two areas. In the individual indicator level, no land use change areas had relatively better scores for most of the land quality indicators compared to the area where land use changed, except for water sufficiency and clay content. The rubber plantation area has higher water sufficiency as it can utilize higher amounts of rainfall with lower water loss through surface runoff. In other words, rubber plantation areas which have not undergone land use change may exhibit higher LQIs in terms of water sufficiency. Similarly, the long term rice cultivation areas can have higher clay content compared to the areas where soil disturbance occurred due to land use change.

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