CHAPTER 10

TRADE-OFF ANALYSES

This chapter deals with the results of the comparative agro-ecosystems management at the watershed level. The results were extrapolated to the watershed level from the farm-level results obtained by the equal weight and AHP methods. The farm level results of the optimal land use for each method were extrapolated to the watershed level based on the proportion of land occupied by each farm type.

The study also looks at the results of the trade-off analyses at the farm level and the watershed level. With agricultural land use, conflicts between objectives are likely when planning to optimize the benefits using a multiple-goal linear programming modeling. A trade-off analysis is used to find the relationships between objectives. Trade-off relationships will help to understand how to adjust the target value of each objective in order to find the optimal outcome.

10.1 Comparative agro-ecosystems management at the watershed level when compared with the extrapolated results from the farm-level

The results for the optimal land use at the farm level were extrapolated to the watershed level based on the proportion of land occupied by each farm type. The calculation was explained in chapter 7. However, optimal land use for the farm level was not always optimal for the watershed level but this study would compare patterns of land use management between the equal weight and AHP methods.

10.1.1 Equal weight method

The optimal land use at the watershed scale obtained from MGLP recommended that it was planted with fruit trees (87.05 %) and cash crop systems (12.95%). However, the extrapolated farm level analysis assessed the land use for the watershed level as being composed of mixed fruit trees (61.45%) and annual crops (38.55%).

For the irrigated upland, the watershed level was assessed by MGLP as being optimal when all the land was planted with citrus (17,131 hectares). In contrast, the extrapolated results to the watershed level presented a land use pattern composed of citrus (13,952 hectares), coffee (946 hectares) and sweet corn followed by sweet corn (2,234 hectares). With the extrapolated result, the citrus production would be lower by 19 percent from the optimal watershed result by MGLP and the pattern of land use would change to allow mixed crop production. This would make the irrigated upland more environment-friendly by a decrease in chemical use in the citrus production while the mixed crop would spread the risk by diversifying crop production.

For the rainfed upland, the watershed was assessed by MGLP as being optimal when the land was planted extensively with coffee (36,976 hectares) and to a smaller extent, a double crop of sweet corn (4,439 hectares). The extrapolated results from the farm level showed a land use pattern comprising coffee at 18,331 hectares which was a large reduction on what was recommended by the analysis at the watershed level and a larger quantity of double crop of sweet corn (23,084 hectares). The results show that the land use pattern demonstrated by the watershed results were more environment-friendly with double the area of coffee and a smaller crop of sweet corn from the extrapolated results. This gave the best management for highland areas especially the upstream areas in the watershed. These crops would grow together with the forest and could also decrease soil erosion if the coffee area was increased. Coffee production uses lower amounts of chemicals and fertilizer so if coffee was planted in the upland areas, it would have a positive impact on the environment.

For the irrigated lowland, the watershed was assessed as being optimal when the land was planted only with citrus (19,378 hectares). Similarly, the extrapolated results from the farm level analysis comprised citrus (17,126 hectares), longan (298 hectares), rice followed by sweet corn (944 hectares) and rice followed by a double crop of sweet corn (1,010 hectares). This gave the best pattern of land use for the irrigated lowland with a mix of fruit trees and annual crops. This would also minimize the risk to crop production and raise food security.

For the rainfed lowland, the watershed was assessed as being optimal when the land was planted with rice (6,494 hectares). The extrapolated results from the farm level analysis comprised rice (5,274 hectares) but also recommend a sizable area of lychee (1,220 hectares) (Figure 10.1).

In general, for the analyses at the watershed level, the optimal plan recommend citrus for irrigated areas for both upland and lowland areas, while it recommended coffee for the rainfed upland and rice for the rainfed lowland. The analysis extrapolated to the watershed level recommended a more diversified pattern of land use, mixing fruit trees, coffee and vegetables. These results minimized the risk to the farmers by diversifying crop production and increasing the possibility of a secure and sustainable livelihood.

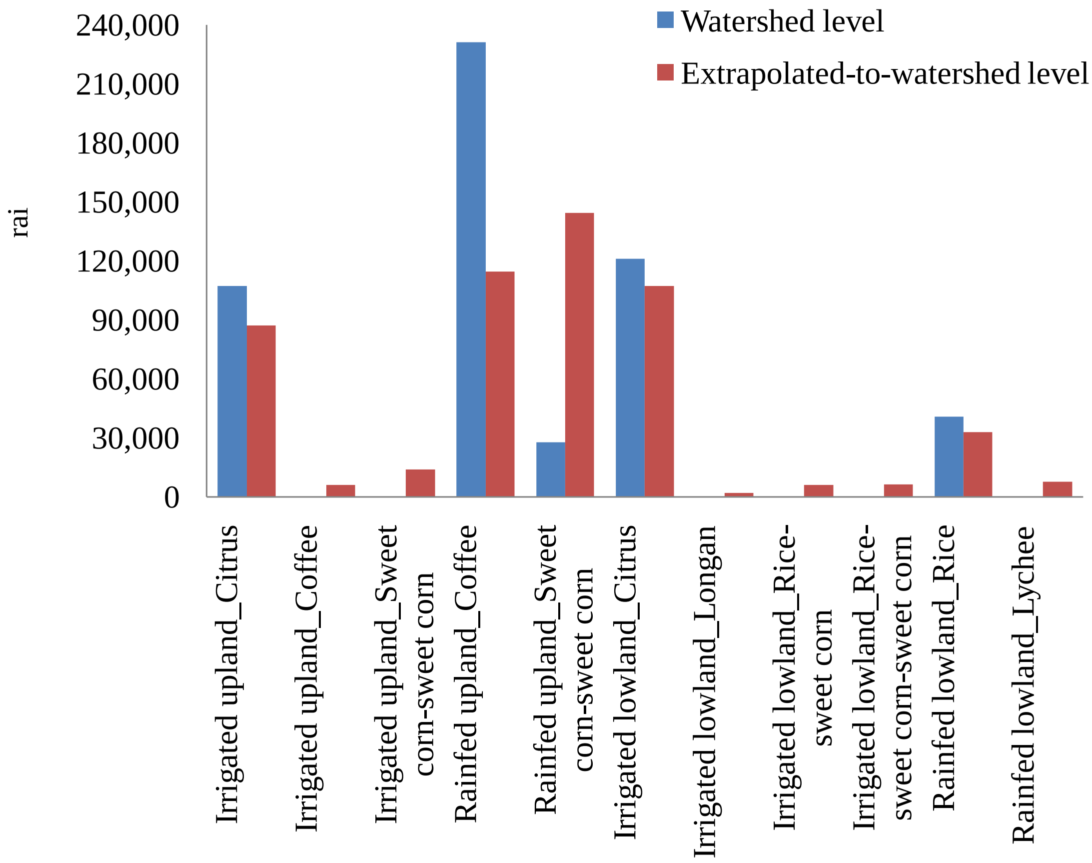


Figure 10.1 Comparative agro-ecosystems management at the watershed level when compared with the extrapolated results from the farm-level by the equal weight method

11.1.2 AHP method

The optimal land use for the watershed as assessed by MGLP were fruit trees (68.38%) and forest (29.76%). This was the only method which recommended that the watershed was planted with forest trees, especially in the rainfed upland. The extrapolated farm level analyses assessed an optimal land use when it comprised of mixed fruit trees, but at a lower level than that recommended by the watershed analysis (40.49%) and annual crops (59.51%). The watershed results gave a land use pattern for the environment which recommended an increase in the forest area while the extrapolated results recommended the economic objective which used the total area for citrus crop production.

For the irrigated upland, the watershed was assessed by MGLP as being optimal when the land was planted with longan (11,756 hectares), tea (2,451 hectares), sweet corn followed by sweet corn (1,570 hectares) and forest (1,354 hectares). The extrapolated results from the farm level analysis presented a land use pattern comprising of citrus (16,996 hectares) and a double crop of sweet corn (135 hectares). The watershed results gave the best land use pattern which recommended an environment-friendly mix of crops comprising of longan and tea. The longan and tea need lower chemical use when compared to the citrus production which the extrapolated results recommended. This would have a positive impact on the environment if this land use pattern was used in the irrigated upland, especially in the upstream areas in the watershed.

For the rainfed upland, the watershed was assessed by MGLP as being optimal when the land was planted with coffee (10,614 hectares), lychee (13,526 hectares) and forest (17,274 hectares). The extrapolated results from the farm level analysis showed a land use pattern comprising of coffee (864 hectares) and sweet corn followed by sweet corn (40,550 hectares). The watershed results gave a better land use pattern than the extrapolated results as it recommended a mixed crop of fruit trees and an increase in the forest area. The extrapolated results recommended a double crop of sweet corn in twice the area at the expense of the forest area which was recommended by the watershed results. If this land use pattern were used in the upstream areas, there would be a high risk of soil erosion and it would have a negative impact on the environment.

For the irrigated lowland, the watershed was assessed by MGLP as being optimal when it was planted with citrus (19,378 hectares). The extrapolated results from the farm level analysis comprised of citrus (16,324 hectares), rice followed by a double crop of sweet corn (2,642 hectares), rice followed by garlic and sweet corn (382 hectares) and rice followed by onions and sweet corn (29 hectares). Both results recommended a main crop of citrus but the extrapolated results gave a better land use plan as it provided for more annual crops. This would result in higher food security, low risk marketing and low revenue variance.

For the rainfed lowland, the watershed was assessed by MGLP as being optimal for forest (6,494 hectares). The extrapolated results from the farm level analysis showed only rice (6,494 hectares) (Figure 10.2). Both results gave good land use patterns in terms of their different objectives. The watershed results were better for the environment which would lead to an increase in the natural habitat for wildlife and an increase in the availability of non-timber forest products. It would also benefit the climate and improve water retention. The extrapolated results were better in terms of the economic and social objectives through increased revenue and food availability from rice production.

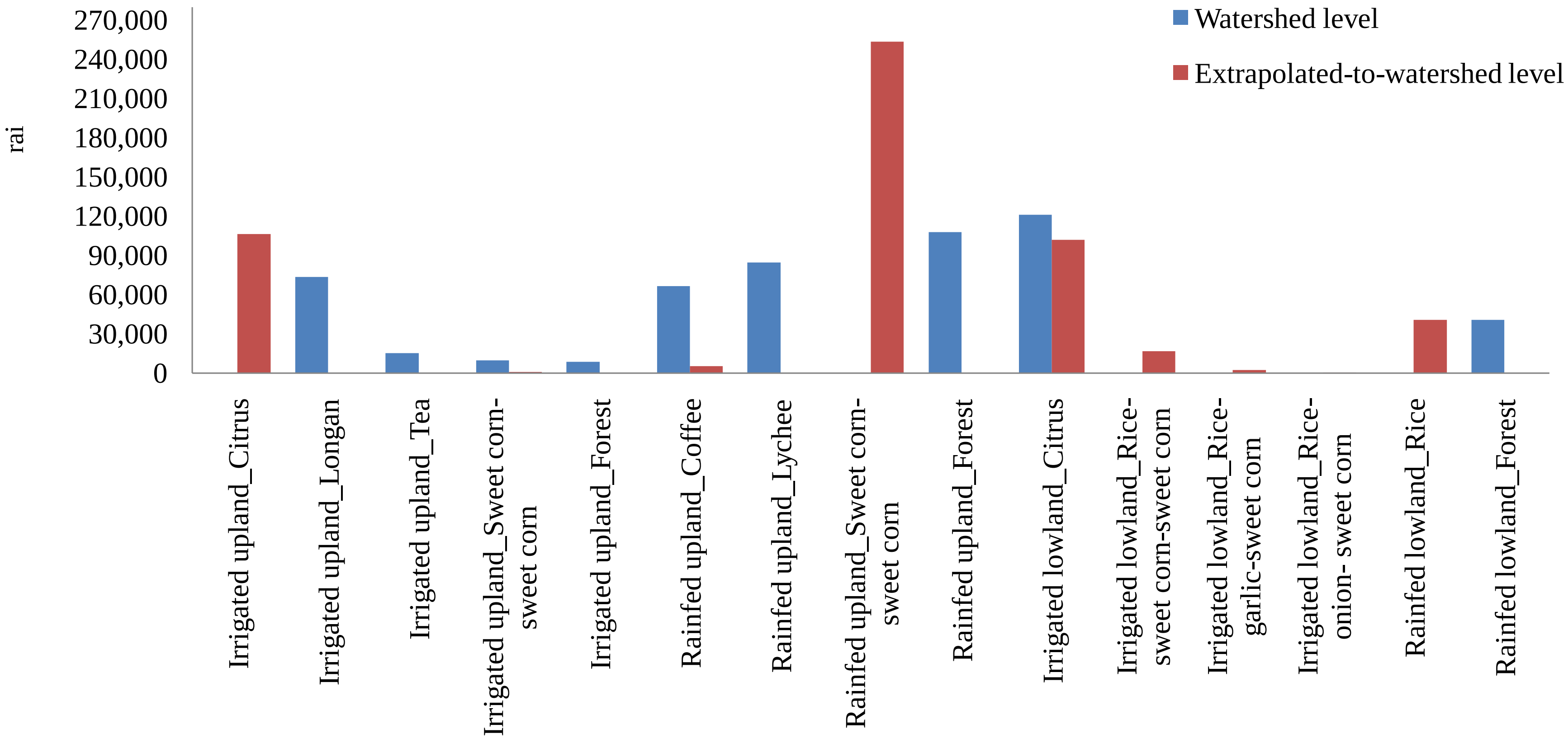


Figure 10.2 Comparative agro-ecosystems management at the watershed level when compared with the extrapolated results from the farm-level by the AHP method

10.1.3 Comparing the equal weight and AHP methods

When comparing the watershed level by the MGLP results using the equal weight and the AHP methods, it found that at the watershed level using the AHP method, the analysis recommended an optimal land use comprising of fruit trees (68.38%), forest (29.76%) and annual crops (1.86%). The equal weight method recommended an optimal land use as being planted with more fruit trees (87.05%) and annual crops (12.95%). It did not recommend any land set aside for forest. This means that the AHP method for the watershed level recommended a more environment-friendly pattern of land use than the equal weight method. This recommended that the upland area was optimal with a mixed crop of fruit such as longan, lychee tea and coffee and ignore citrus production. That would lead to a decrease in fertilizer and chemical use which would benefit the farmers and their families' health as well as improving the environment. It would also lead to an increase in the forest area in both the upland and rainfed lowland. It would also increase the wildlife habitat and the area available for non-timber products as well as increasing water retention and decreasing soil erosion.

On the other hand, when the results were extrapolated to the watershed level by the AHP method, the analysis recommended land use comprising of mixed fruit trees (40.49%) and annual crops (59.51%). The equal weight method analysis recommended an optimal land use comprising of mixed fruit trees (61.45%) and annual crops (38.55%). These patterns of land use are more agriculture-orientated as compared to the analysis at the watershed level as presented by MGLP. Both patterns of land use gave more food security as they recommended more cropping systems than the watershed results. The cropping systems would minimize marketing and revenue variance in the economic objective.

The extrapolated to the watershed level using the AHP method recommended a higher level of annual crops. This is in sharp contrast to the MGLP's analysis at the watershed level using the AHP method. This gave the optimal land use as a majority of the land being used for a variety of different fruit trees. The extrapolated to the watershed level results and the MGLP analysis at the watershed level using the equal weight method gave similar results which recommended a high level of fruit trees. The watershed level results especially recommended the increased use of fruit trees (87.05%) than the analysis at the extrapolated to the watershed level (68.38).

When we compared the cropping systems in each land unit, the results found that all the analyses suggested that the irrigated lowland was optimal when an area of between 16,324 and 19,378 hectares was planted with citrus and the remaining area being used for annual crops.

The results for the rainfed upland showed a widespread coffee production. The results showed a maximum area of coffee production using the watershed level MGLP analysis from the equal weight method (36,976 hectares) and a minimum using the extrapolated to watershed level results from the AHP method (864 hectares).In contrast to the extrapolated to watershed level results by the AHP method, the AHP method watershed level results gave the largest area for a double crop sweet corn (40,550 hectares) and the watershed level MGLP analysis by the equal weight method suggested a smaller area of only 710 hectares. The watershed level MGLP analysis from the AHP method recommended planting a slightly bigger area of lychee than coffee and the extrapolated to watershed level results from the equal weight method gave slightly bigger area for a double crop of sweet corn than the coffee crop.

The watershed level MGLP analysis for the irrigated upland by the AHP method did not include citrus but gave the optimal land use for longan (11,756 hectares), tea and annual crops. The other analyses recommended citrus production at between 13,952 and 16,996 hectares.

The watershed level MGLP analysis for the rainfed lowland by the AHP method gave the optimal use for the total area as being suitable only for forest and the other analyses as being suitable for rice production.

The watershed level MGLP analysis using the AHP method showed three differences from the other results which were within a small spread of each other. For the irrigated upland, citrus was not recommended but longan was, for the rainfed lowland, rice was not recommended but forest was and for the rainfed upland, a double crop of sweet corn was not recommended but coffee, lychee and forest was (Figure 10.3).

The overall results of the watershed analysis assessed by MGLP and the AHP method gave an environment-friendly pattern of land use for both the irrigated and rainfed upland areas. This will have a positive impact on the environment in the upstream areas for the watershed. The extrapolated results gave the best land use patterns for the economic and the social objectives in terms of revenue variance and food security. The best overall pattern of land use would be to model the upland area by followed by watershed results and lowland area by following the extrapolated results by the AHP method.

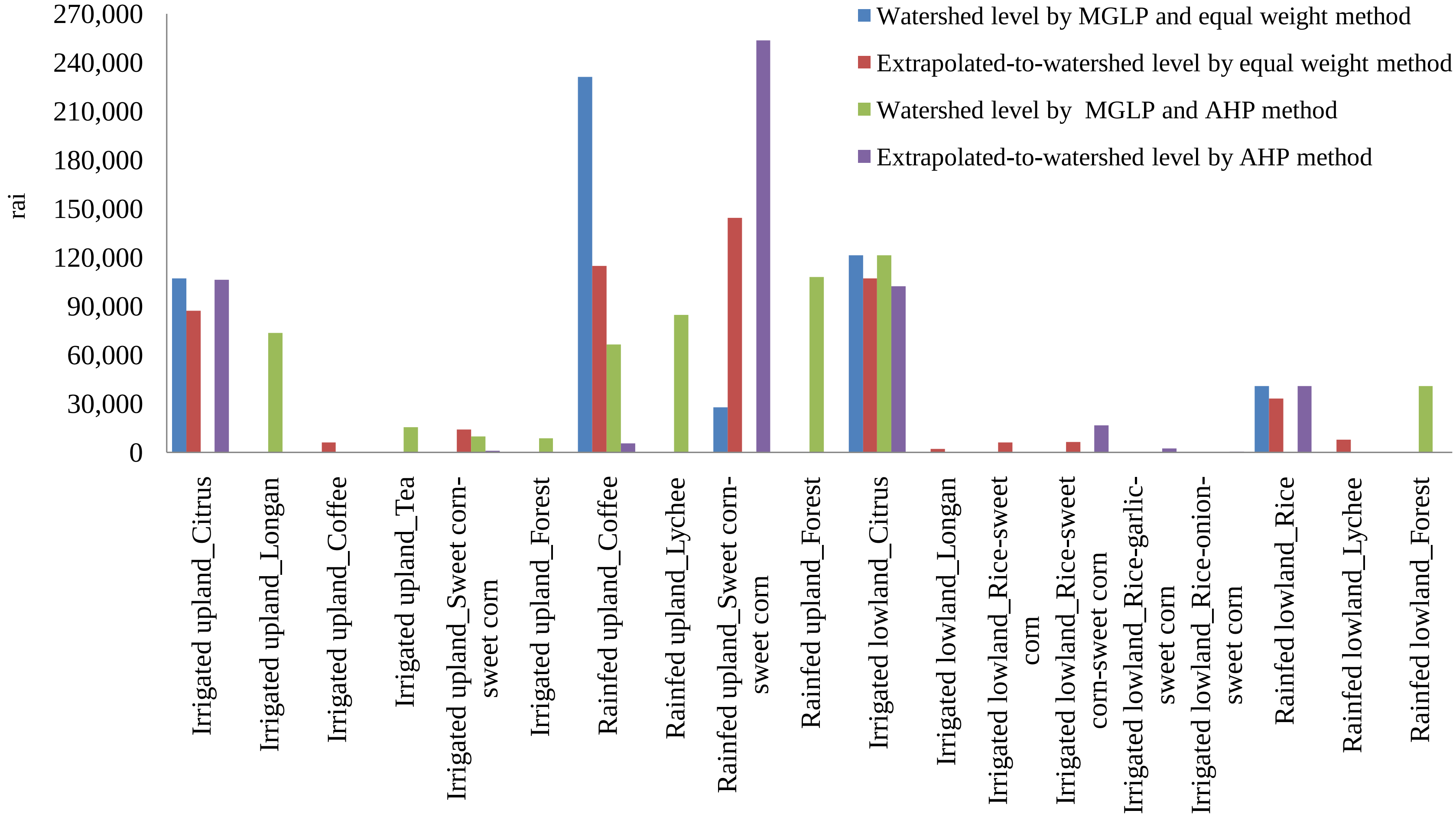


Figure 10.3 Comparative agro-ecosystems management comparing the four methods

10.1.4 Comparing the goal achievement rate between the watershed level and the extrapolated results from the farm-level

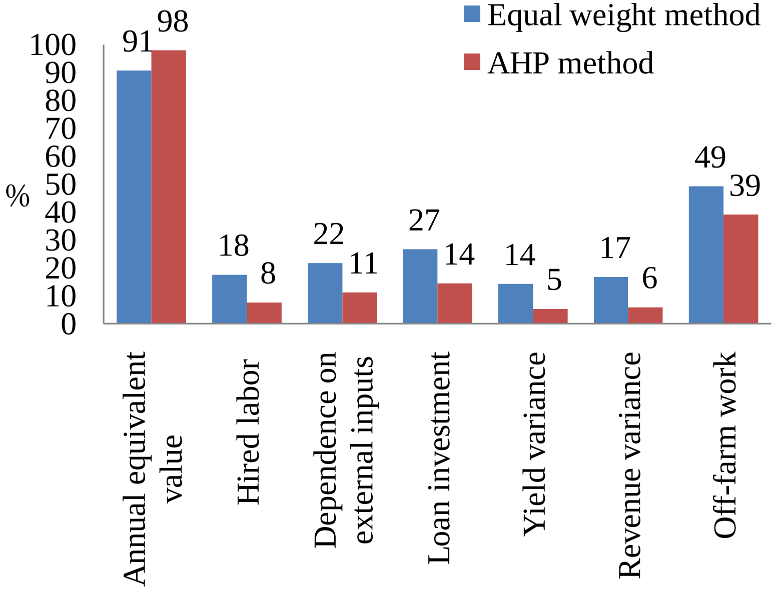
The extrapolated results from the farm level had 7 goals and the watershed level results had 8 goals. This was a divergence between the stakeholder objectives as at the farm level, the stakeholders are farmers who give priority to the economic objective followed by the social and the environmental objectives. At the watershed level, the stakeholders are represented by government organizations and NGOs whose work is related to citrus production activities and whose priority is usually the environmental and social objectives. When the goal achievement rates between watershed level and the extrapolated results from the farm level are compared, it is clear that the results may not be similar. This study will compare the results to show the differences, and suggest the best optimal resource management for the Fang watershed.

The results showed that the watershed level results by AHP method gave the best goal achievement rates with a close spread (23%) between the highest (69%) and the lowest goal achievement rate (46%). These results give the best optimal resources management at the watershed level as they give more balance between the economic, social and environmental objectives when compared with the other analyses.

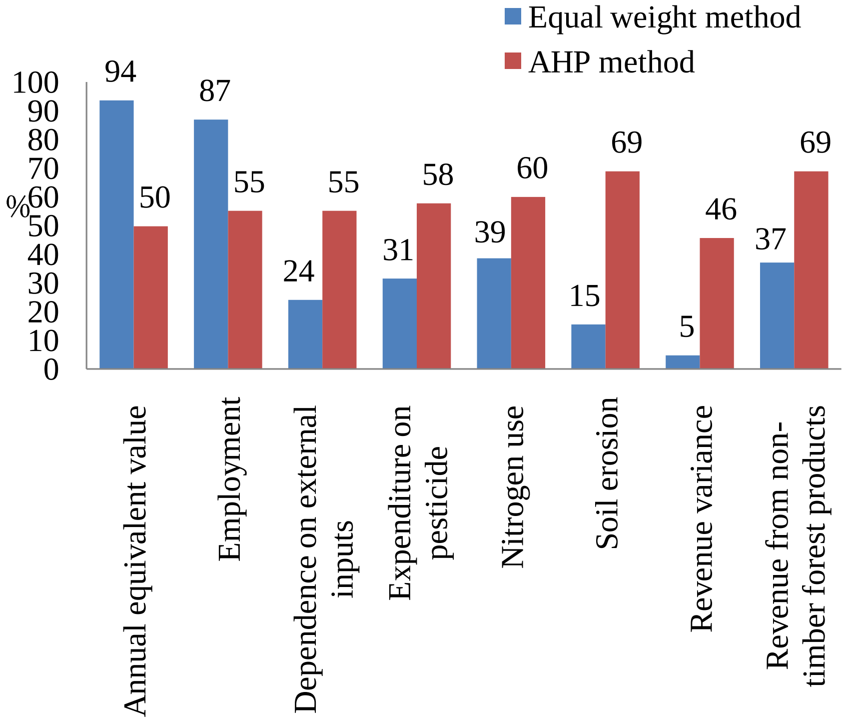
The watershed level results by the equal weight method gave high goal achievement rates for the economic and social objectives. The results showed a goal achievement rate for the annual equivalent value at 94 percent and employment at 79 percent. The environmental objective goals showed a very low achievement rate, for example, soil erosion only achieved a 15 percent score.

The extrapolated results from the equal weight and AHP methods gave similar results to each other. There had high goal achievement rates for the annual equivalent value for the economic objective (91 and 98 percent respectively) followed off-farm work (39 and 49 percent respectively) but the other goals had a low achievement rate. The other analyses results had a wide spread between the goal achievement rates (Figure 10.4).

When the results for the goals from the extrapolated and watershed results were compared, they showed that the annual equivalent value for the watershed level results by the AHP method were half the goal achievement rate (50 percent) when compared with the other analyses results (91 and 98 percent). The hired labor (at the farm level), or employment labor (at the watershed level), and the dependence on external inputs, showed that employment and the dependence on external inputs at the watershed for both the equal weight and the AHP methods gave higher goal achievement rates than the extrapolated results from the farm level which would mean higher employment in the watershed. The dependence on external inputs results show that the watershed level results by the AHP method gave the highest goal achievement rate at 55 percent with the other analyses results showing lower achievement rates. All the results are shown in Figure 10.4.



Objective goals achieved when extrapolated at the watershed level by the equal weight and the AHP methods



Objective goals achieved using the equal weight and the AHP methods at the watershed level

Figure 10.4 Comparative the goal achievement rate between watershed level and the extrapolated results from the farm-level

10.2 Trade-off analysis at the farm level

The trade-off analysis is expressed as the inter-relationship between two objectives. The situation involves losing one quality of one aspect in return for gains in another. If one thing increases, something else must change, for example, an increase in citrus production could lead to an increase in soil erosion. The results will provide the decision maker with a deeper understanding into the relationship between the indicators, such as, if we increase the farmers' income, how will it affect other resource use?

In this study, the trade-off analysis used a software program called IMGP-*LPlan* developed by Ekasingh et al (2011). The IMGP-*LPlan* gives optimal results over repeated runs, each time, the program finds the restriction value (RV) of the second objective (Lu et.al, 2004). The formula is as follows:

$$RV = MRV + f \times (ORV - MRV) \qquad \text{…………… (11.1)}$$

Where RV = Restriction value

MRV = Minimum value of the second objective

f = Fraction value (0-1)

ORV = Value of the second objective while achieving the optimum value of the first objective.

From the above equation, the values of MRV and ORV in each objective are constant. It was shown in the pay-off matrix table that the maximum or minimum results of one objective are without regard to the other objectives. Therefore, the RV depends on the f value.

For the RV value of the second objective and the optimum of the first objective, any analysis will be compared as a percentage value of ORV and a maximum value of MOV of the first objective. The equation is as follows:

$$rsv = \left(\frac{RV}{ORV}\right) \times 100 \qquad \text{………………… (11.2)}$$

$$obv = \left(\frac{OV}{MOV}\right) \times 100 \qquad \text{………………… (11.3)}$$

Where rvs = RV value of the second objective as a percentage of the ORV
obv = OV value of the first objective as a percentage of the MOV

The rvs and obv value of each comparison will be used to generate two-dimensional graphs. This is called a trade-off curve which represents the compensation between the two objectives.

This study looked at the trade-off analysis at the farm level using the equal weight method. A trade-off analysis is used to find the relationship between the objectives such as the trade-off between the economic and the environmental, the economic and the social and the social and the environmental objectives. The economic objective's goal was the annual equivalent value and the social objective is represented by hired labor. The environmental objective is represented by 4 sub-objectives; independence from external inputs, loan investment, revenue variance and off-farm work.

We will see the results of the trade-off analyses on the graph. If the slope is not steep, it means that a large reduction in one variable will have small negative effect on other variable. If the slope is steep, it means that a small decrease in one variable will lead to a large reduction of another variable (Figure 10.5)

10.2.1 Trade-off analysis for the small farms using chemicals

1. Trade-off between the annual equivalent value and the dependence on external inputs

The results of the trade-off analysis between the annual equivalent value and the dependence on external inputs showed that if the dependence on external inputs was reduced by 20 percent, there was only a 2 percent reduction in the annual equivalent value. If there were a 70 percent reduction in the dependence on external inputs, it led to a 22 percent reduction in the annual equivalent value. This means that a large decrease in the dependence on external inputs will have a small negative effect on the annual equivalent value (Figure 10.5).

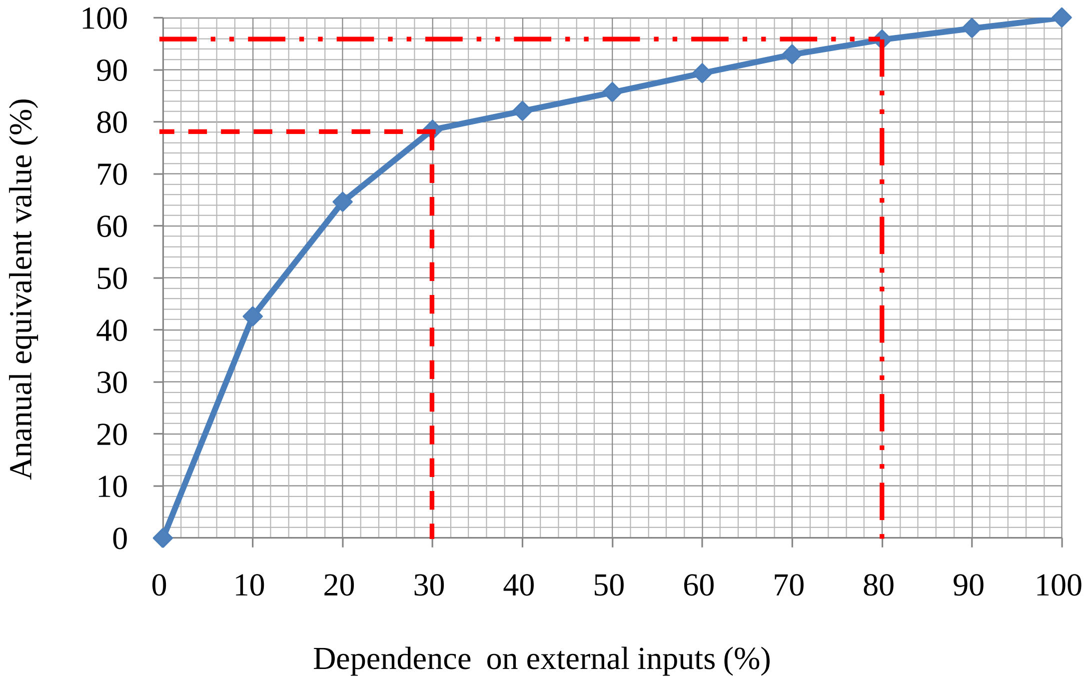


Figure 10.5 Trade-off between the annual equivalent value and the dependence on external inputs for the small farms using chemicals

2. Trade-off between the annual equivalent value and the investment loan

The trade-off analysis between the goals of annual equivalent value and the investment loan showed that when the investment loan was reduced by 20 percent, there was only a 2 percent reduction in the annual equivalent value, while an approximate 90 percent reduction in the investment loan led to a 28 percent reduction in the annual equivalent value. This means that a large decrease in the loan investment will have a small negative effect on the annual equivalent value (Figure 10.6).

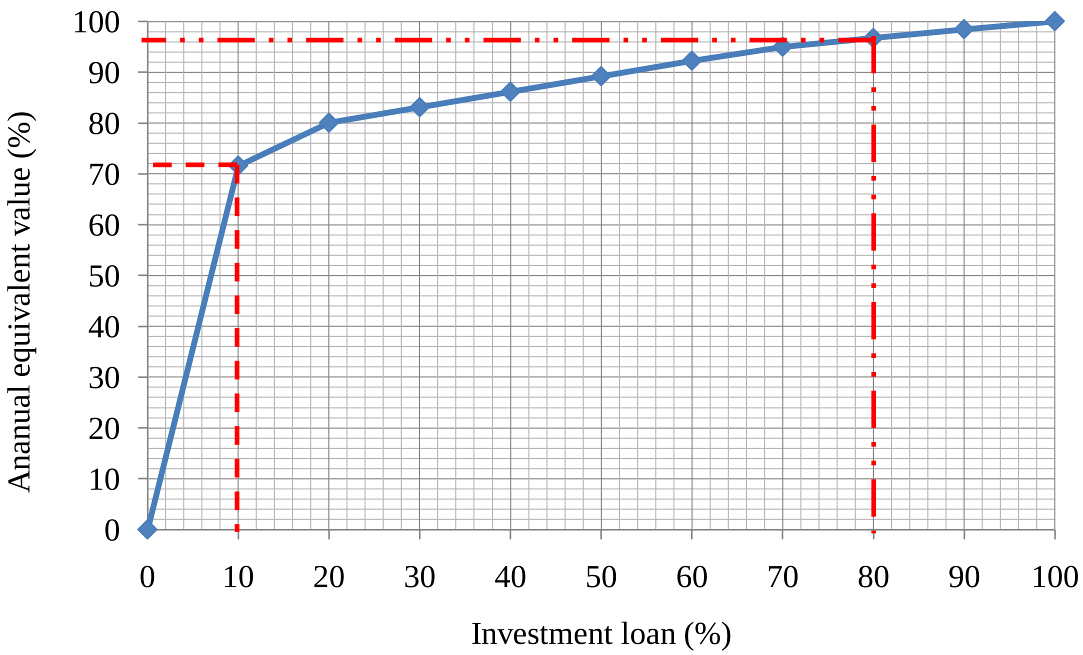


Figure 10.6 Trade-off between the annual equivalent value and the loan investment for the small farms using chemicals

3. Trade-off between the annual equivalent value and the revenue variance

The trade-off analysis between the goals of the annual equivalent value and the revenue variance gave similar results. When the revenue variance was reduced by 20 percent, there was only a 2 percent reduction in the annual equivalent value, while an approximate 90 percent reduction in the revenue variance led to a 28 percent reduction in the annual equivalent value. This means that a large decrease in the revenue variance will have a small negative effect on the annual equivalent value (Figure 10.7).

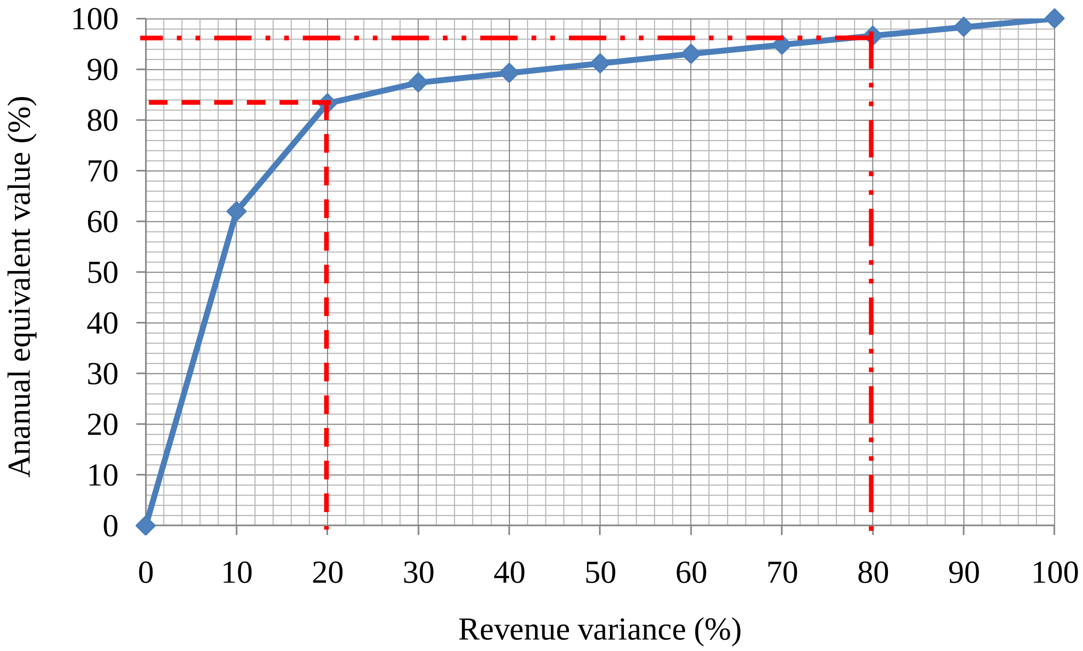


Figure 10.7 Trade-off between the annual equivalent value and the revenue variance for the small farms using chemicals

4. Trade-off between the economic and the social objectives

The economic objective was to maximize the goal of the annual equivalent value in a trade-off with the social objective which minimized the goal of hired labor. The results found that in the trade-off analysis, when hired labor was reduced by 60 percent, the annual equivalent value was reduced by 20 percent. After a 60 percent reduction in hired labor, the reduction in the annual equivalent value increased at a faster rate. This means that a large decrease in hired labor will have negative effect on the annual equivalent value (Figure 10.8).

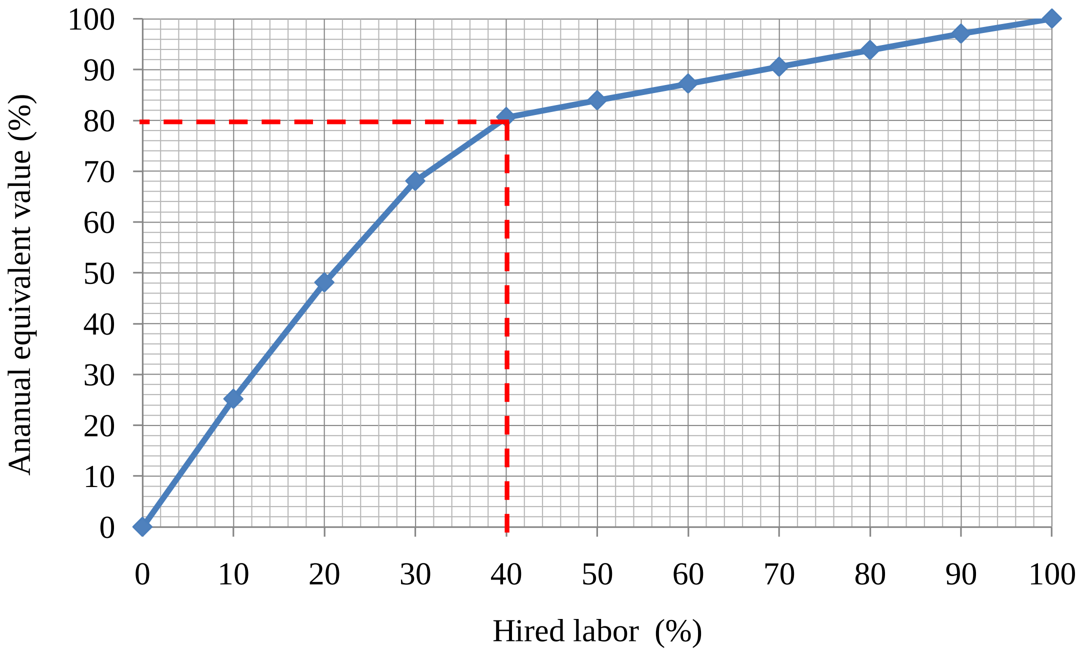


Figure 10.8 Trade-off between the economic and the social objectives for the small farms using chemicals between the annual equivalent value and hired labor

5. Trade-off between the social and the environmental objectives

In this analysis, the social objective was to minimize the goal of hired labor in a trade-off with the environmental objective which maximized the goal of off-farm work. The results found that if the trade-off analysis reduced the hired labor by 10 percent, there was no effect on off-farm work. If hired labor was reduced by more than 10 percent, the reduction in off-farm work increased until we saw that no hired labor resulted in a 20 percent reduction in off-farm work. This means that a large decrease in hired labor will have small negative effect on off-farm work (Figure 10.9).

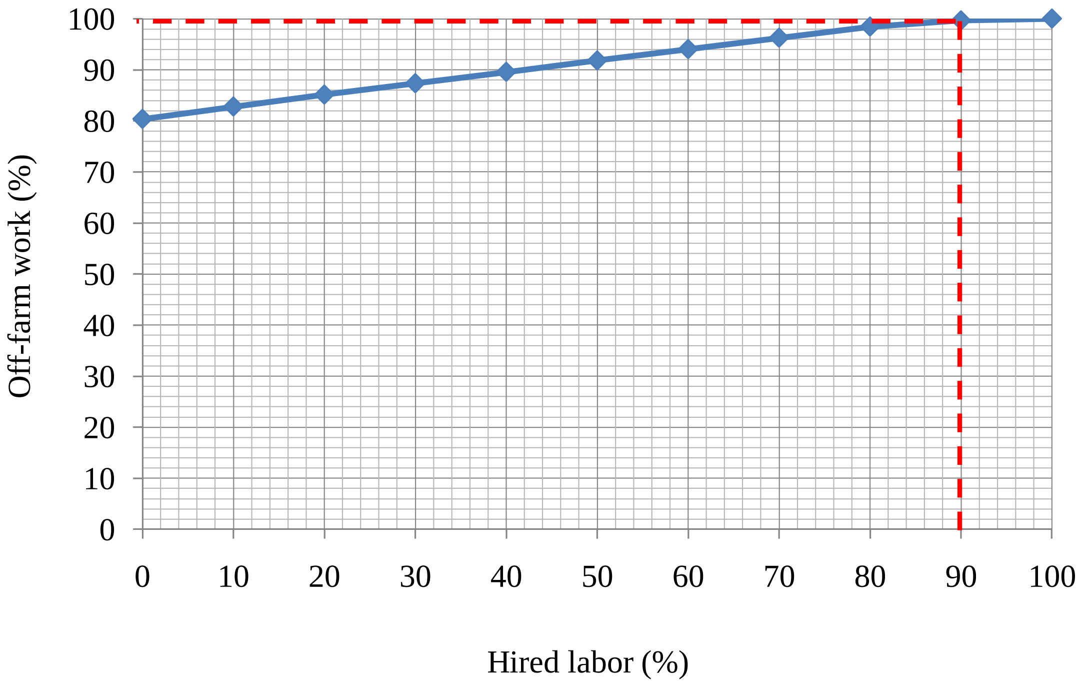


Figure 10.9 Trade-off between the social and the environmental objectives for the small farms using chemicals between hired labor and off-farm work

10.2.2 Comparison of the trade-off analyses between the farm types

When comparing the trade-off analysis between the farm types, the results found that the trade-off between the economic objective (annual equivalent value) and the dependence on external inputs, loan investment and revenue variance for both the small farms using chemicals and the small farms using chemicals and bioextract, the model showed that sizable decreases in fertilizer and chemical inputs, loan investment and revenue variance would not have a serious negative impact on the economic objective. For both the large farms using chemicals and the large farms using chemicals and bioextract, the model showed that a decrease by the same amount as on a small farm would have a greater negative impact on the economic objective (Table 10.1 to Table 10.3).

Table 10.1 Trade-off analysis results between the annual equivalent value (GA) and the dependence on external inputs (GI) at the farm level

Fraction value	Dependence on external inputs (GI)	Annual equivalent value (GA)			
		SFC	SFCB	LFC	LFCB
0.0	0	0	0	0	0
0.1	10	2	2	3	3
0.2	20	4	4	9	9
0.3	30	7	6	16	16
0.4	40	11	9	24	22
0.5	50	14	12	31	29
0.6	60	18	15	39	36
0.7	70	22	23	46	43
0.8	80	35	44	57	56
0.9	90	57	64	71	72
1.0	100	100	100	100	100

Table 10.2 Trade-off analysis results between the annual equivalent value (GA) and the investment loan (GL) at the farm level

Fraction value	Investment loan (GL)	Annual equivalent value (GA)			
		SFC	SFCB	LFC	LFCB
0.0	0	0	0	0	0
0.1	10	2	1	2	2
0.2	20	3	3	7	7
0.3	30	5	4	12	13
0.4	40	8	6	18	19
0.5	50	11	8	25	24
0.6	60	14	11	31	30
0.7	70	17	14	38	36
0.8	80	20	17	44	42
0.9	90	28	37	52	52
1.0	100	100	100	100	100

Table 10.3 Trade-off analysis results between the annual equivalent value (GA) and the revenue variance (GR) at the farm level

Fraction value	Revenue variance (GR)	Annual equivalent value (GA)			
		SFC	SFCB	LFC	LFCB
0.0	0	0	0	0	0
0.1	10	2	1	4	4
0.2	20	3	2	8	8
0.3	30	5	4	12	12
0.4	40	7	5	18	15
0.5	50	9	6	24	21
0.6	60	11	7	31	27
0.7	70	13	12	37	33
0.8	80	17	16	44	39
0.9	90	38	55	58	55
1.0	100	100	100	100	100

The results show the same pattern between the economic objective (annual equivalent value) and the social objective (hired labor) for both the small farms and the large farms. The small farms can take a decrease in hired labor without significantly affecting their annual equivalent value whereas a large farm will show a higher negative impact (Table 10.4).

Table 10.4 Trade-off analysis results between the annual equivalent value (GA) and hired labor (GH) at the farm level

Fraction value	Hire labor (GH)	Annual equivalent value (GA)			
		SFC	SFCB	LFC	LFCB
0.0	0	0	0	0	0
0.1	10	3	2	5	4
0.2	20	6	5	11	10
0.3	30	9	8	18	15
0.4	40	13	11	26	22
0.5	50	16	14	34	30
0.6	60	19	22	42	37
0.7	70	32	40	50	46
0.8	80	52	58	65	62
0.9	90	75	77	82	79
1.0	100	100	100	100	100

The trade-off between the social objective (hired labor) and the environmental objective (off-farm work) for all farm types gave similar results. Hired labor could be reduced up to a certain point before any serious negative effects would be noticed (Table 10.5).

Table 10.5 Trade-off analysis results between off-farm work (GS) and hired labor (GH) at the farm level

Fraction value	Hire labor (GH)	Off-farm work (GS)			
		SFC	SFCB	LFC	LFCB
0.0	0	0	0	0	0
0.1	10	0	1	0	1
0.2	20	2	2	2	1
0.3	30	4	5	4	2
0.4	40	6	7	6	3
0.5	50	8	10	7	5
0.6	60	10	13	8	7
0.7	70	13	16	10	10
0.8	80	15	19	10	13
0.9	90	17	21	13	16
1.0	100	20	24	15	19

10.3 Trade-off analysis at the watershed level

In this study, a trade-off analysis was made between three objectives by pairwise comparisons such as the trade-off between the economic and the environmental objectives, the economic and the social objectives and the social and the environmental objectives. This study selected some goals from the objectives to determine the trade-off analysis.

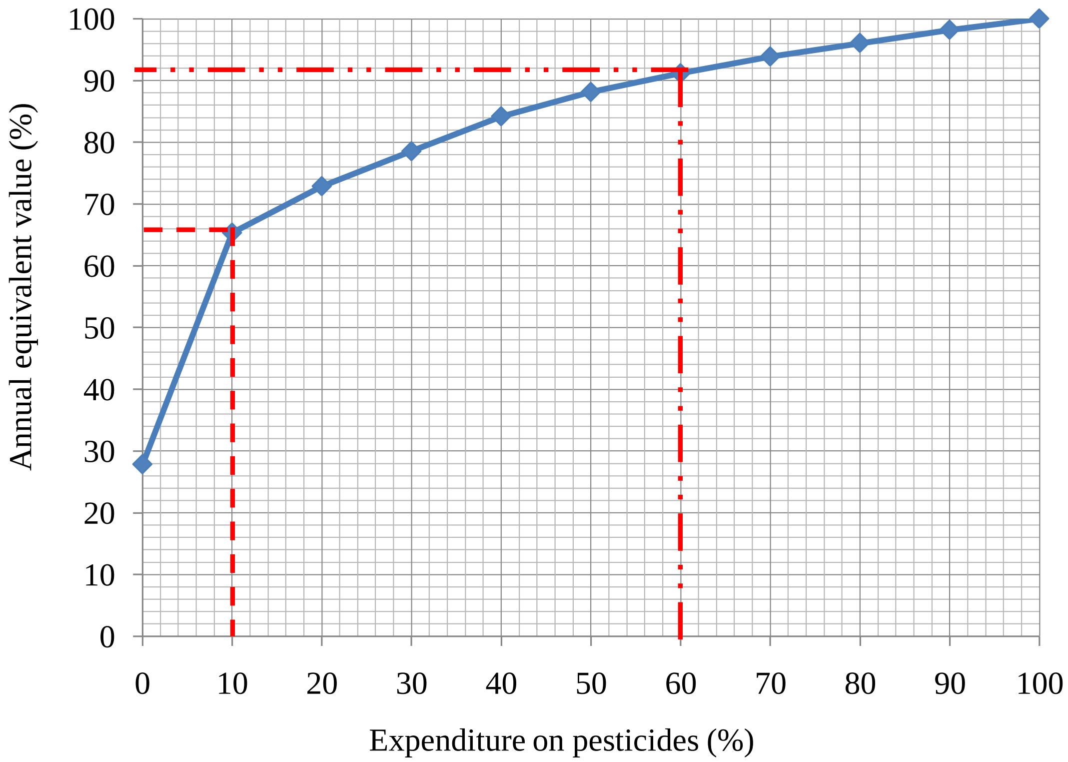
1. Trade-off between the economic and the environmental objectives

The study wanted to maximize the annual equivalent value as the main economic objective to trade-off with the three goals of the environmental objective. The expenditure on pesticides, nitrogen use and soil erosion was minimized.

For the results of the trade-off analysis between the annual equivalent value and the expenditure on pesticides, we saw that when the expenditure on pesticides was reduced by 40 percent, there was only a 9 percent reduction in the annual equivalent value and a 90 percent reduction in pesticides led to a 35 percent reduction in the annual equivalent value. This means that a substantial reduction in the expenditure on pesticides would be needed before it has a serious negative effect on the annual equivalent value (Figure 10.10 (a)).

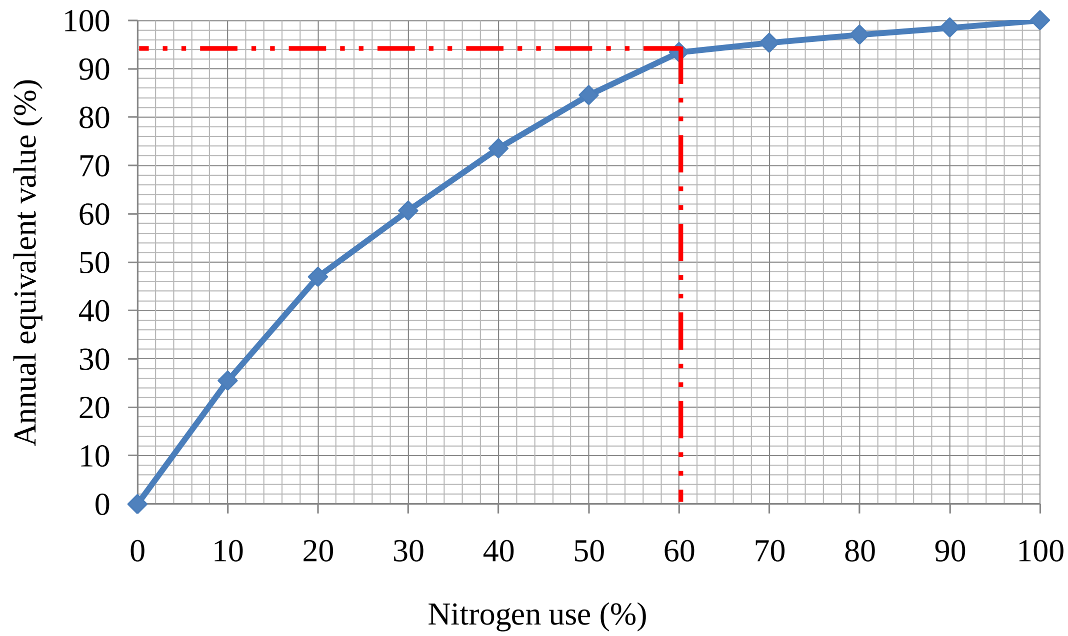
For the trade-off analysis between the goals of the annual equivalent value and nitrogen use, the comparable figures were a 40 percent reduction in nitrogen use meant a 7 percent reduction in the annual equivalent value but after a 40 percent reduction in nitrogen use, there was a steep decline in the annual equivalent value. This means that a large reduction in nitrogen use is possible before it will have a significant negative effect on the annual equivalent value but after a 40 percent reduction, it will have a proportionally larger negative effect on the annual equivalent value (Figure 10.10 (b)).

For the trade-off analysis between the goals of the annual equivalent value and soil erosion, we saw that when soil erosion was reduced by 70 percent, the annual equivalent value was reduced by 19 percent. After a 70 percent reduction in soil erosion, the reduction in the annual equivalent value increased at a faster rate. This means that a substantial reduction in soil erosion will be needed before it has a serious negative effect on the annual equivalent value (Figure 10.10 (c)).



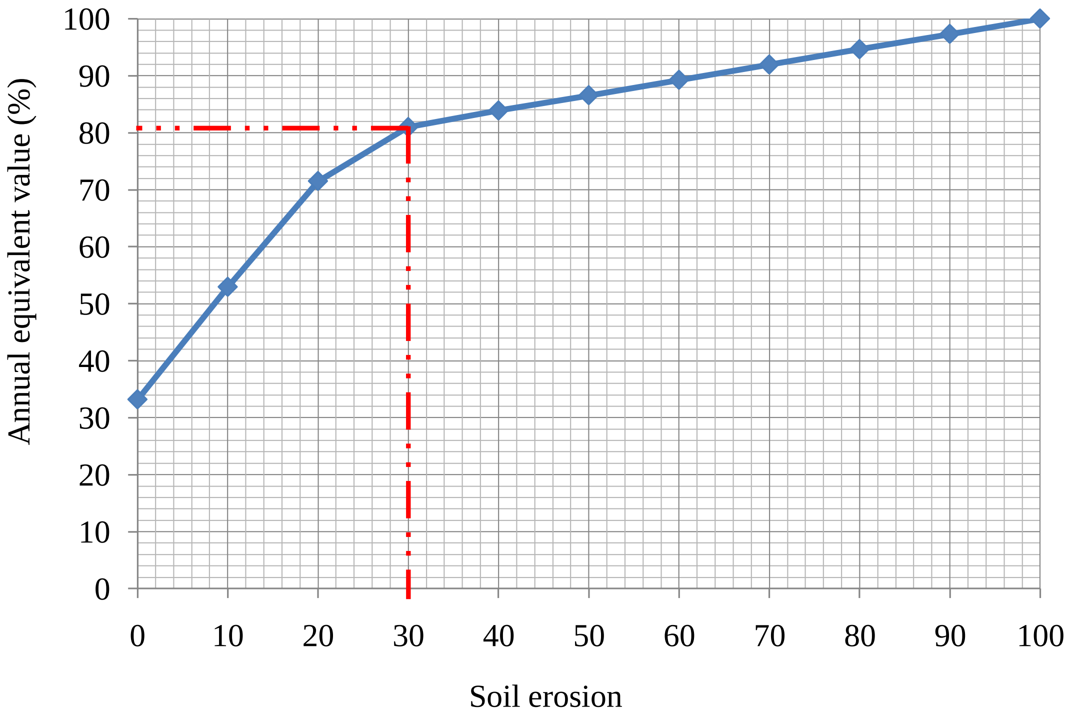
Annual equivalent value (%)
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Expenditure on pesticides (%)

(a)



Annual equivalent value (%)
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Nitrogen use (%)

(b)



(c)

Figure 10.10 Trade-off between the economic and the environmental objectives at the watershed level (a) annual equivalent value and expenditure on pesticides (b) annual equivalent value and nitrogen use (c) annual equivalent value and soil erosion

2. Trade-off between the economic and the social objectives

The economic objective was to minimize the goal of revenue variance in a trade-off with the social objective which maximized the goal of employment in the watershed. The results found that when the revenue variance was reduced by 20 percent, there was a 10 percent reduction in employment with a constant decline until an 80 percent reduction in the revenue variance gave a 47 percent reduction in employment. After an 80 percent reduction in revenue variance, there was a rapid reduction in employment. This means that there can be a substantial reduction in the revenue variance before it has a significant impact on employment (Figure 10.11).

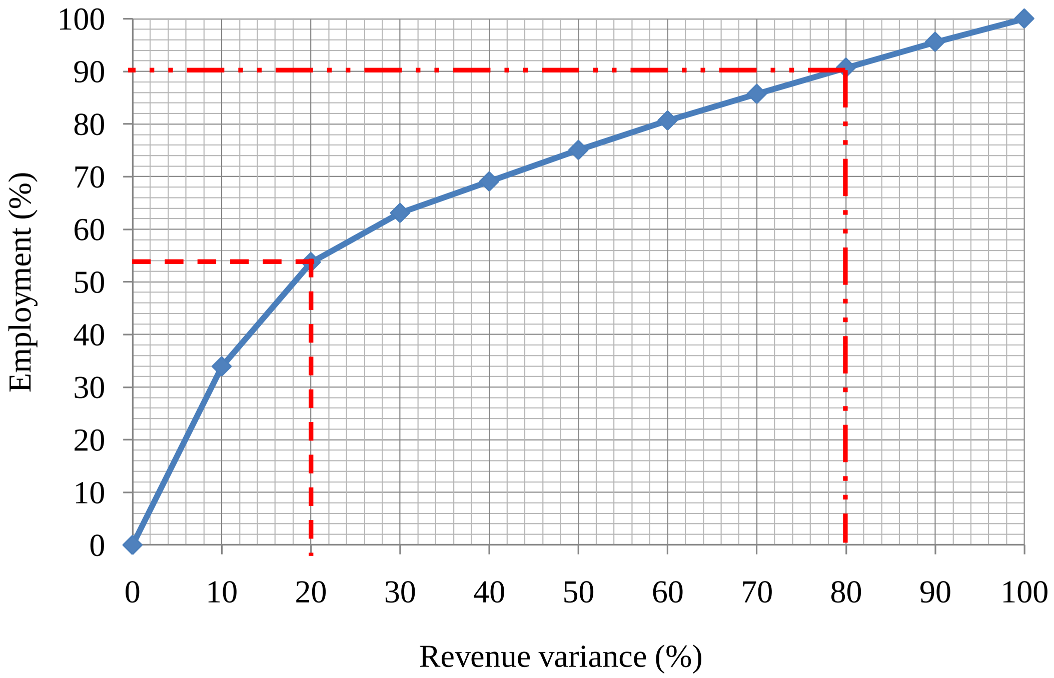


Figure 10.11 Trade-off between the economic and the social objectives at the watershed level comparing employment and revenue variance

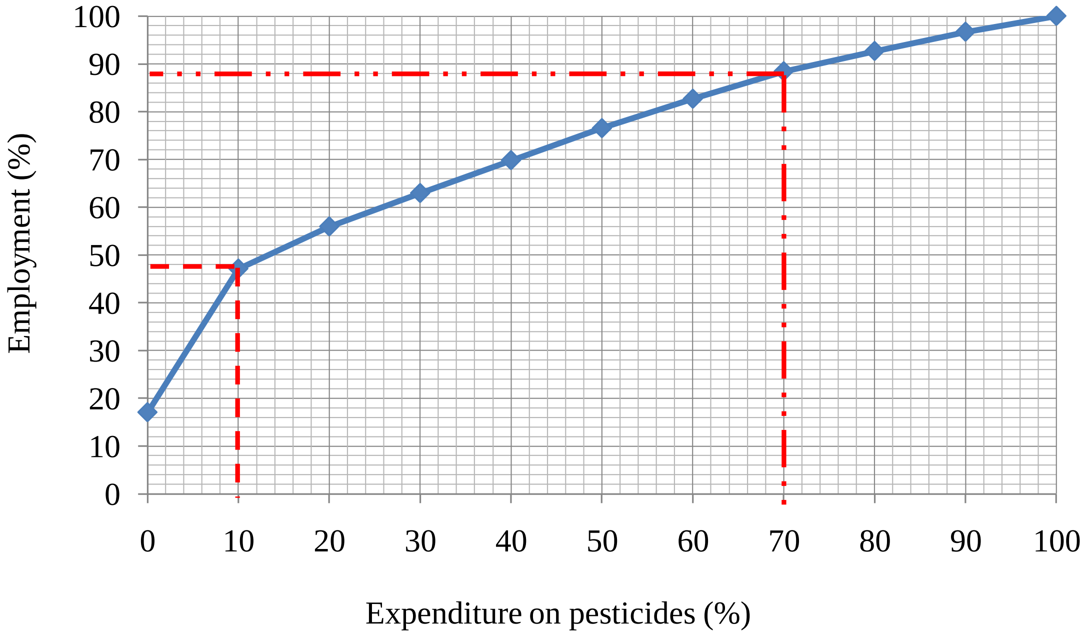
3. Trade-off between the social and the environmental objectives

In this analysis, the social objective of employment in the watershed was maximized in a trade-off with the three goals in the environmental objective. The aim was to minimize the expenditure on pesticides, nitrogen use and soil erosion.

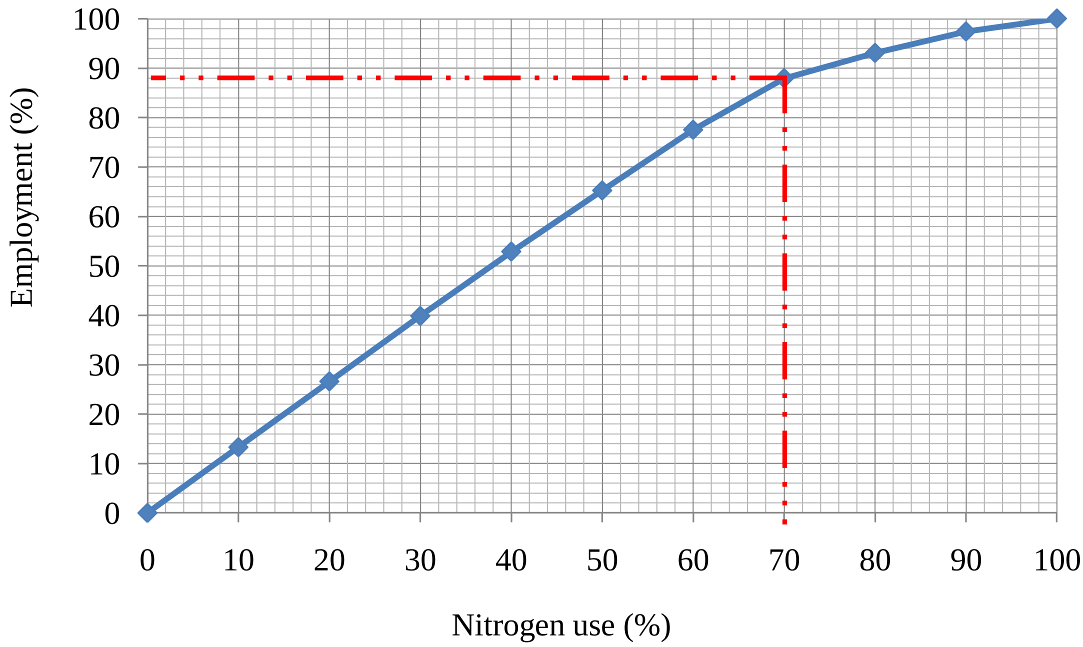
For the results of the trade-off analysis between employment and the expenditure on pesticides, it was shown that when the expenditure on pesticides was reduced by 30 percent, there was a 12 percent reduction in employment with a constant decline until a 90 percent reduction in the expenditure on pesticides gave a 54 percent reduction in employment. After a 90 percent reduction in the expenditure on pesticides, there was a rapid reduction in employment. This means that there can be a substantial reduction in the expenditure on pesticides before it has a significant impact on employment (Figure 10.12 (a)).

For the trade-off analysis between employment and nitrogen use, it was shown that when nitrogen use was reduced by 30 percent, there was a 12 percent reduction in employment. After a 30 percent reduction in nitrogen use, the reduction in employment increased at a faster rate. This means that an initial small reduction in nitrogen use will have a minimal impact on employment but further decreases will have a proportionally larger effect (Figure 10.12 (b)).

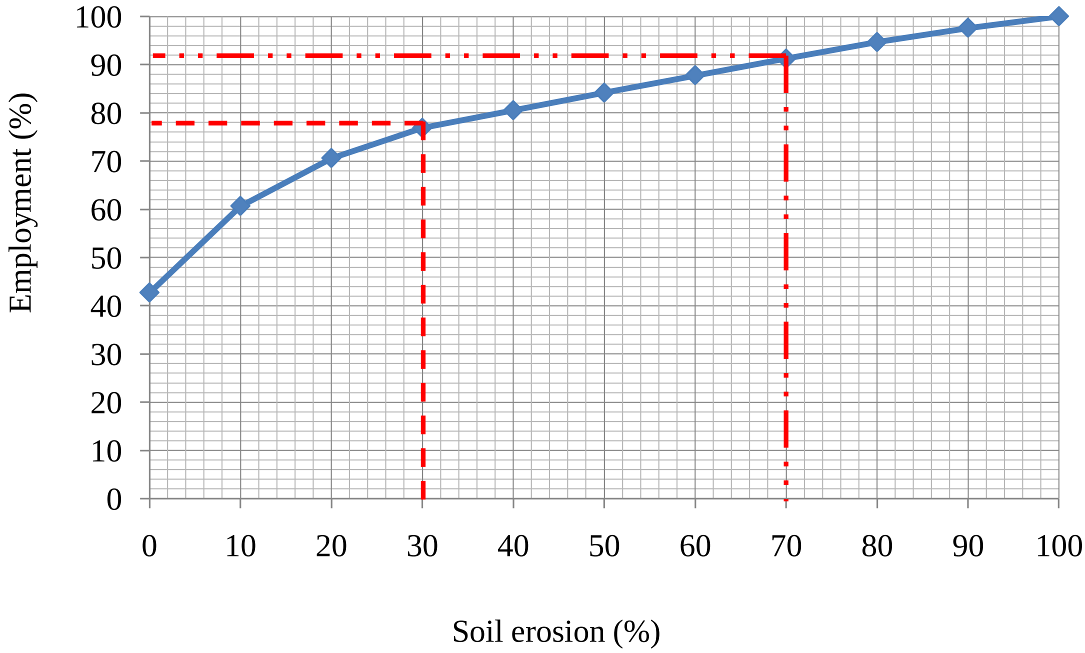
For the trade-off analysis between employment and soil erosion, it was shown that when soil erosion was reduced by 30 percent, there was a 10 percent reduction in employment with a constant decline until a 70 percent reduction in nitrogen use gave a 24 percent reduction in employment. After a 70 percent reduction in soil erosion, there was a rapid reduction in employment. This means that there can be a substantial reduction in soil erosion before it has a significant impact on employment (Figure 10.12 (c)).



(a)



(b)



(c)

Figure 10.12 Trade-off between the social and the environmental objectives at the watershed level (a) employment and expenditure on pesticides (b) employment and nitrogen use (c) employment and soil erosion

10.4 Comparison of the trade-off analyses between the farm level and the watershed level

When comparing the trade-off analyses between the farm level and the watershed level, the results found that the trade-off between the economic and the environmental objectives followed the pattern suggested by the small farms. Large scale reductions in nitrogen use, soil erosion and expenditure on pesticides could be made with only a minimal negative impact on the annual equivalent value.

The trade-off between the economic and the social objectives at the farm level and the watershed level followed the pattern suggested by the large farms. A reduction in the revenue variance led immediately to a noticeable negative effect in employment.

The trade-off between the social and the environmental objectives at the farm level and the watershed level showed a slightly different pattern. Significant reductions could be made in soil erosion, nitrogen use and expenditure on pesticides with proportionally minor reductions in employment but there reached a point, especially with nitrogen use, where the decrease in employment increased rapidly although this was less noticeable with soil erosion.