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Full Length Research Paper

Modeling and measuring the economic success of farming families using remote sensing and GIS: An example from mountains of Nepal

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This paper presents the potential of integrating socioeconomic data into GIS that helps to explain spatial differentiation of resources availability, utility potential, market orientation and socioeconomic condition in an area. Socioeconomic data were gathered through the family survey and linked them to GIS by using house position, and continuous thematic raster layers were produced by interpolation. Biophysical conditions were assessed using RS/GIS techniques. Regression analysis was used to assess association between socioeconomic and biophysical condition by taking farm income as dependent variable and cost distance to market and land quality parameters as independent variable. Multivariate linear regression showed that cost distance to market and land quality parameter extracted from RS/GIS explain the income potential of a farm in a given location. Future strategies of reducing cost distance to the market through road improvement and increasing the quality of land through soil and water management activities and their impact on income were tested and presented.

Key words: Geographic information systems, remote sensing, socioeconomic data integration, spatial differentiation, farm income modeling, Nepal.

INTRODUCTION

Farming systems research involves a complex combination of resources and processes, managed by farming families. Research institutions are increasingly aware that a holistic approach, drawing on both local and external knowledge, is necessary if they are to be effective in addressing poverty and sustainability. Farming systems research relates to the whole farm rather than individual elements; it is driven as much by the overall welfare of farming households as by goals of income and living standard (Bahadur, 2005a, b; Doppler et al., 2006). However, development of rural resources and socioeconomic conditions in many mountainous areas of Asia is mostly influenced by their spatial position. Farm families who live at higher altitudinal areas have relatively sloppy land, far from the central areas. They have poor road networks and thus, little market orientation, creating a poor level of living standard. On the other hand, farm families living at lower altitudinal areas occupy and manage the relatively flat land near central areas with infrastructure networks and enjoy a higher living standard. So, the trend of resource availability, use and management and socioeconomic development runs in different directions in the different spatial gradient of the area due to the differentiation of resource availabilities, their management, availability and the condition of infrastructure and access to the market (Bahadur and Doppler, 2004). Poverty, deforestation and land degradation processes are major development challenges as poor socioeconomic condition and natural resource degradation follow a certain spatial gradient leading to further resources degradation and socioeconomic differentiation (Doppler et al., 2006; Bahadur, 2005a, b). Farming systems in these areas are characterized by the inter-relationship of complex natural systems and human society (Doppler, 1998, 2006). Many researchers argue that forest clearing for agriculture should be analyzed by means of a cost–benefit perspective to see trade-offs between forest and agricultural land in a “sustainable development” perspective (Ehui and Hertel, 1989; Kaimowitz and Angelsen and Wunder, 1998; Angelsen, 1999; Barbier, 2001; Wunder, 2001; Alix-Garcia et al., 2005).

Traditionally, socioeconomic and environmental issues were seen as separate, especially by conservation proponents (Adhikari et al., 2004; Oates, 1999; Sanderson and Redford, 2003; Du Toit et al., 2004; Wilshusen et al., 2002). More recent approaches however see poverty and natural resources management as intrinsically connected. They were developed in the sustainable livelihood and resource use approaches (Scones, 1998; Leach et al., 1997; Ellis, 2000) and in vast literature on participatory approaches (Chambers, 1989; Pretty, 1995; Hutton et al., 2005).

Recent trends in environmental and socioeconomic modeling have moved towards the use of integrated assessment methodologies to balance multi-issue problems with multiple stakeholders (Rotmans and Van Asselt, 1996; Jakeman and Letcher, 2003). Park and Seaton (1996) attributed the rise of integrative research in natural resource management as realization the discipline-specific approaches are often not appropriate for policy analysis. McKinney et al. (1999) noted the interdisciplinary nature of problems requires new methods to integrate technical, economic, environmental and social aspects into a coherent framework.

The integrated methodology has to incorporate different kinds of socioeconomic and spatial data and methods. However, the main problem of combining socioeconomic and spatial methods are to link and combine the data and analysis because of the availability of information at different aggregation levels (Lentes, 2003). In recent years researches have attempted to link social science data at household and community level to remotely sensed and other spatial data to study the effects of human activities on land (Rindfuss et al., 2003; Fox et al., 2003; Walsh et al., 2003).

Political ecology can be viewed as referring to the context with in which household land use and related decisions are made, including socio-cultural norms, the economic standard of living, technology local and national government policies, commodity prices at local to global scales and physical infrastructures such as roads (Lentes, 2003). Studying the effect of human activities on land typically involved joining social sciences data with remotely sensed and other spatial data (Walsh et al., 2003). Biophysical and socioeconomic data are quite different types of data that are collected using different techniques and linking social science and spatial science has proven a major challenge (Lentes, 2003). Under this context, this paper address the issue of linkages to the socioeconomic data with the remote sensing and GIS derived biophysical and infrastructure data in order to model the current economic success of farming families and to test the future strategy of the improvement of physical and infrastructure condition to the economic success of farming families in a small rural mountainous watershed in Nepal.

This study is based on the hypothesis of a direct relationship between resource availability, utility potential use and management and socioeconomic development and seeks to reach a differentiated view of problems in an area of spatial differentiation with regard to rural resources and socioeconomic development. This study, therefore, addresses the problem of how the differentiation in resource availability and utility potential, use and management under the different physical and environmental condition leads to differentiation in resource use, management and living standards of farm families. It also examines the impacts of natural resource use according to differentiation in farming systems on the socioeconomics of farm families as well as the prospects for the future development of these families. It analyses the influence of the resources availability, use and, management particularly land resources on decision-making within these mountain families, their income, the tendency to further impoverishment, and the future development of these mountain-farming systems in different assumed conditions. The study seeks to analyze the complexity of systems interaction in an interdisciplinary approach combining socioeconomic and spatial methodologies.

METHODS

Study area

Research has been carried out in a small rural mountainous watershed in Nepal, which represents remote high mountain zones, moderate slope areas in the intermediate section and river valley and suburban center in the lowland part of the watershed which is shown in Figure 1 in three different altitudinal zones as highland (1151 to 2000 m) middle land (651 to 1150 m) and lowland (300 to 650 m). The area is characterized with decreasing production potential and degree of market orientation from lowland to highland areas, as a result, decreasing the farm income from low to highland areas.

Information base

This paper is based on a methodological concept of combining socioeconomic situation with biophysical condition in a GIS environment. Information was gathered from household survey, satellite image, global position system survey, analog maps and digital GIS data. House-hold survey was based on spatial random sampling of the household in the watershed. Ninety households were chosen for the household survey. Standardized questionnaires were applied for the interviews to obtain the socioeconomic data. During the household survey, the geographical position of each sample household was recorded using GPS. The sample is split in three groups of equal size dividing the watershed into three zones: lowland, middle land and highland. Descriptive statistics were used to describe socioeconomic characteristics of households. All reported incomes are sums of annual cash and subsistence activities. Farm income is calculated as the difference between farm revenue and farm expenses. It is derived from a calculation where it is the residual after deducting all expenses excluding the costs and income of family owned resources (Doppler and Jirawan, 2003). Cost of own labor is not included in the income calculations. Off-farm income is defined as income earned by family members by engaging in activities other than the farm and/or the household which includes earnings from permanent employment and from self-generated income activities.

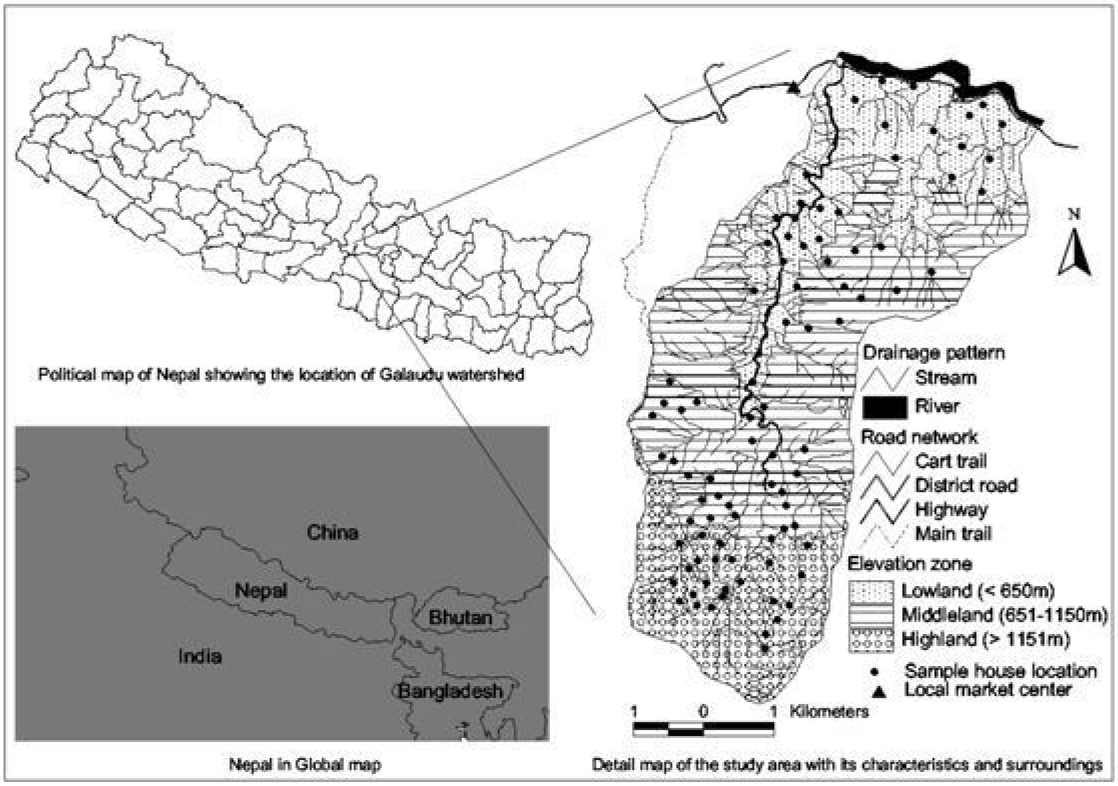

Figure 1. Location of study area showing altitudinal zones and the sample households.

Crop income is the economic value of subsistence and cash crop production over a year grown by a household less costs of production. Income from fruit production is included in crop income. Remittances are all income transfers in cash and in kind between households. Family income is calculated as the sum of farm income, off-farm income and income on family owned resources.

Biophysical condition of the watershed was assessed using RS/GIS based spatial data management and analysis techniques. Spatial data were gathered from satellite images, Global Positioning System (GPS) survey, analogue maps and digital GIS data. The spatial database consisted of land use maps derived from remote sensing data (Landsat MSS acquired on 10th October 1976, Landsat TM of path/row 141/41, acquired on 4th February 1990 and 13th March 2000), air photos of scale 1:50,000, 1992 and topographical maps of 1:25,000, 1995. Land use maps of 1976, 1990 and 2000 were obtained by performing supervised digital image processing (Bahadur, 2008, 2009) for satellite images of the respective years of the study area. Aggregated socioeconomic information such as farm family income in different level e.g. per family, per person, per hectare of cultivated land, food security situation were assessed and linked to the GIS by using each family's respective geographical position and their spatial autocorrelation were observed then continuous thematic raster layer were produced for those factors that had found spatially auto-correlated by performing interpolation. Cost distance to nearest market center from each of the sampling household was measured using cost weighted distance model and distance grid cells to travel from each of the sampling location to nearest market center.

Database integration

Household level socioeconomic and the regiona l level biophysical results were integrated to each other to transfer the use of dataset (Bahadur, 2005a). Thus, relation between socioeconomic and biophysical condition can be observed and established then based on the relation, aggregated socioeconomic parameter such as farm and family income, food availability can be estimated from the biophysical conditions of the area. Identical land quality in different places is expected to provide the same production and income generating potential for farms. Thus the land quality indexes of the agricultural land uses were estimated across the watershed, based on the slope, state of agricultural land whether irrigated or not which are not only relevant for direct comparison of available land resources but also serves to relate the socioeconomic conditions, assessed by the micro survey to the physical conditions of the farm land by means of functional relations.

Modeling

GIS based multiple regression model was constructed to estimate the farm income. Continuous thematic raster layers of the socioeconomic factors such as farm income at different level for example at family, per hectare of cultivated land, per person together with other factors, for example, cultivated land size, crop yield were available. On the other hand, biophysical (terrain slope, irrigated and non-irrigated farm land, infrastructure condition) indicator of the watershed was obtained from land use information derived from satellite images and terrain, drainage patterns and infrastructure (irrigation structure, road network) derived from topographic maps respectively using GIS methodology. Cost distances from the different parts of the watershed to nearest market canter was measured using GIS based cost weighted distance model (ESRI, 1997) and distance grid cells to travel from different location of the watershed to nearest market center were

Table 1. Available infrastructure in Galaudu watershed, Nepal, 2003.

Road type	Travelling speed (km/h)	Time for crossing 25 x 25 m cell (Min)
Highway	60	0.05
District road	60	0.05
Cart trail	30	0.10
Main trail	20	0.15
Others (off-road area)	4	0.75

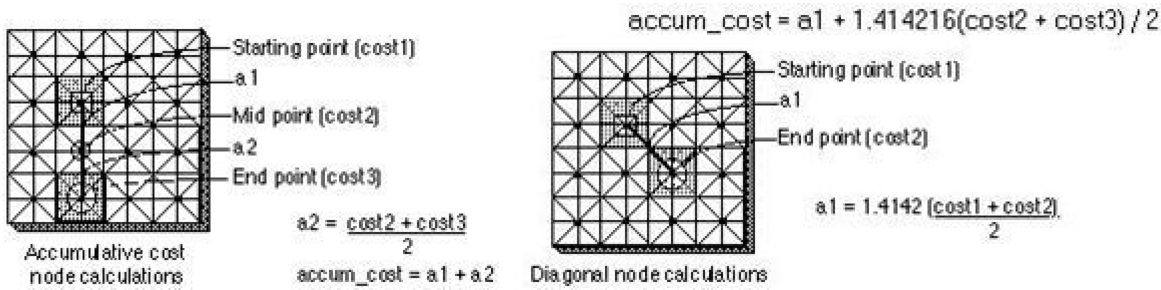

Figure 2. Accumulative cost calculation.

prepared.

In general, cost distance functions are similar to Euclidean distance functions. The difference between these two functions is that Euclidean distance functions calculate the shortest distance from one point to another in a geographic sense. In contrary to that, the shortest cost distance represents the accumulated travel cost or travel time from each cell to the nearest cell in the set of source cells. Here, distance is not applied in geographic units but in cost units, which can be set to monetary units or time units. A cost grid assigns impedance in some uniform-unit measurement system that depicts the cost involved in moving through any particular cell. The value of each cell in the cost grid is assumed to represent the cost-per-unit distance of passing through the cell, where a unit distance corresponds to the cell width. For the building of a cost grid, two components were combined. The existing infrastructure and the slope map. The analyses of transportation infrastructure are based on dry weather conditions and passable roads.

The different road types were weighted according to the travelling time required, as shown in Table 1. This means that a cell in the 25 x 25 m grid, which lies on a highway, gets the value 0.05 min, to cross the cell with a speed of 60 km/h. For the areas between the roads, walking speed was set at 4 km/h. The travelling speed values were estimated according to own measurements in the field and experience. A grid was created with these values. Since inclination makes a difference in travelling speed, another weighted grid was created with the slope map. In this map, the slope classes were used to give weights to each class. These weights are between 1 for the flat areas and 2 for the very steep slopes above 30°. The multiplication of the weighted infrastructure map and the weighted slope map yields the cost grid, in which the time needed for crossing the cell is the z value of each cell. The cost distance to the goal is calculated as the least accumulative cost. Figure 2 shows how the calculation is done for straight cell crossing and diagonal cell crossing.

Land quality indexes were prepared using the different indicators of the land such as terrain condition and whether the agricultural land is irrigated or not. For the weighting of the slope conditions, watershed is classified into 5 classes according to their slope features than each slope class was given a weight between two and one, meaning that a positive deviation in the class below 5% slope results two times better land valuation for this area than for an area in the steepest class (>30%), that is weighted with 1. The gradual changes of the slope weight between 2 and 1 were approximated for the intermediate class assuming linear relation between weights and per cent slope. Higher (2) weight was given to the land that is nearly flat or slope less than 5%. Moderate (1.75) weight was given to the land that has slope from 5 to 10 %. Medium (1.5) weight was given to the land that has slope 10 to 20%. Low (1.25) weight was given to the land that has slope 20 to 30% and very low (1) weight was given to the land that has slope greater than 30%.

The weights for the land use classes were derived from the socioeconomic assessment of household information. In order to give different weight to different types of agricultural land, the difference in the gross margin between paddy rice and maize were considered. In the average of the three sub study zones, the gross margin of paddy is 1.5 times higher than that of maize. Therefore, the weight was estimated to be 1.5 for the paddy (irrigated agricultural land) and 1 for the non-irrigated agricultural land.

The individual weight for each of the 10 slope/land use classes were calculated by multiplication of the weights for the slope classes and the ones for the land use classes. The highest weight (3.0) got the irrigated agricultural lands that are situated on flat areas. The lowest weight (1.0) got the upland agriculture lands situated on very steep slopes. In the weighting, the land use types play a more decisive role than the slope condition. This is because the land use weights only range between 1 and 1.5, while the slope weights are differentiated in a more detailed way, ranging from 1 to 2. The difference resulting from this split valuation was accepted for the purpose.

At last, the entire grid cells were combined thus both socioeconomic and biophysical condition of each and every grid cell was available together. By exporting the grid cell information to spread sheet and then to SPSS program correlation between variables were observed. Cost distance to nearest local market center and land quality parameters had found significantly highly correlated with farm incomes. Finally, multiple regression analysis was carried out by taking farm income as dependent variable and cost distance to nearest market center and land quality parameters as independent variables. Estimated income and impact maps for different scenarios were constructed by bringing back the regression result into the GIS (Bahadur, 2005 a, b).

Application of models for the future strategies testing

The GIS based multiple regression model used for income estimations (Equation 1) was used to estimate potential future income generation in different scenarios of farm management. For this purpose, the land quality index of the grid cells and cost distance from the each of the grid cell to the nearest market center was modified from the current situation. To explain how the farm management model work, it is first referred to the preparation of land quality index for each of the gird cells throughout the study area. This model is the based on the changes of land quality index according to the requirements of the defined scenarios. The value of the land quality index depends on the terrain slope, state of agricultural land, whether irrigated or not, of the grid cells (Bahadur, 2005a). Weight that is associated with the state of land whether irrigated or not and soil and nutrient loss according to the slope and practiced or assumed management of the land were modified (Bahadur, 2005a). Since the index represents the differences in the quality of the land, different land qualities can be simulated with the model by changing the weighting factors of the individual classes as required for the setting up of scenarios. Modifications of the weights of individual grid cell of different themes allow the simulation of future land quality index of the respective grid cell. Modifications can be applied to the grid cells that can be expected developments in land qualities based on the management assumed. The final land quality index for each grid cell is calculated by multiplication of weight given to each of the individual grid theme. Higher the land quality index, better the land quality. In the multiple linear regression models, this was used alone and together with the cost distance to explain the farm income.

In future farm management model construction, consideration should have been given for example what would happens when the given weights are modified to match the desired scenario. If the final weight of a grid cell increases for example from 1 to 1.1, the higher future land quality index for the given cell can be expected. Likewise, if the final weight of a grid cell is decreases for example from 1 to 0.9 than smaller value of future land quality index for the given cell can be expected. Cost distances values after the improved road scenarios were used for simulating the effects of improved infrastructure on the income/ha of the sample household. For this purpose, the functional relationship found in the current situation was applied with the new cost distance values. So the new income/ha for each and every grid cell was estimated and compare with the current situation and differences were taken as the impact of improved road.

RESULTS

Model results

A regression model was constructed to explain the income as dependent variable and the cost distance to nearest market center and land quality index constructed using the slope and land use information as independent variable. The following equation was observed. Spatial distribution of estimated income is presented in Figure 3a:

$$y = 76021.82 - 547.4\, x1 + 3189.97 x2 \qquad (1)$$

y = farm income/ha (NRS); x1 = cost distance (traveling time to nearest market center in minutes); x2 = land quality index n= 24047 grid cells R^2=0.729; F test = 13508.786; sig. F=0.000; T-Stat for constant = 186.642; p-value = 0.000; T-Stat for coefficient of land quality index = 14.866; p-value = 0.000; T-Stat for coefficient of cost distance = -145.196; p-value = 0.000.

The features of this GIS based multiple linear regression model indicated a good explanatory value of the relationship with a measure of determination (R^2) of 0.729 and sufficiently high levels of significance for the whole function (F-test) as well as its components (t-tests), which exceeded a probability level of 99% in all cases. The model does not intend to predict farm incomes on a spatially explicit basis. It aims at regionalizing the current income situation and uses statistical dependencies for the simulation of the effects of future strategies.

A further evaluation of the regression model was done by estimating sub study zone wise average income and compared them to that of the average income calculated from the data acquired through family survey. Results (Table 2) showed that all the estimated incomes were located within the 10% confidence limits to the mean estimation from family survey data. However the difference between the means from family survey to that of regression estimated for the highland zone is higher than that of other two zones. This indicates the tendency of the regression function is still to overestimate the income for areas far from the market center.

In general, the transfer of the estimation to all the sample location showed reliable results. In highland areas, income declines with the distance from road and market center, higher elevation with upland areas. These low-income zones are reflecting the combined effect of remoteness and the less favorable land conditions. The high-income areas are located relatively near to the main road, local market center, at lower elevation areas of valley bottom where as low incomes areas are located more on the hilltops at higher elevation, mainly steep slopes, far from the road and market center. This difference again reflects the resource (especially land) quality of the areas and their connection to market center through road networks.

Future strategies testing

Soil degradation scenario

Change in fertility of soils depends on the balance between the inflow and the outflow of nutrients. The topsoil usually fulfills these functions much better than the lower parts of the soil, because of the presence of organic material, like humus, which has much higher capacities in holding water and nutrients than the mineral soil components (Grüninger, 2001). Soil loss in the study

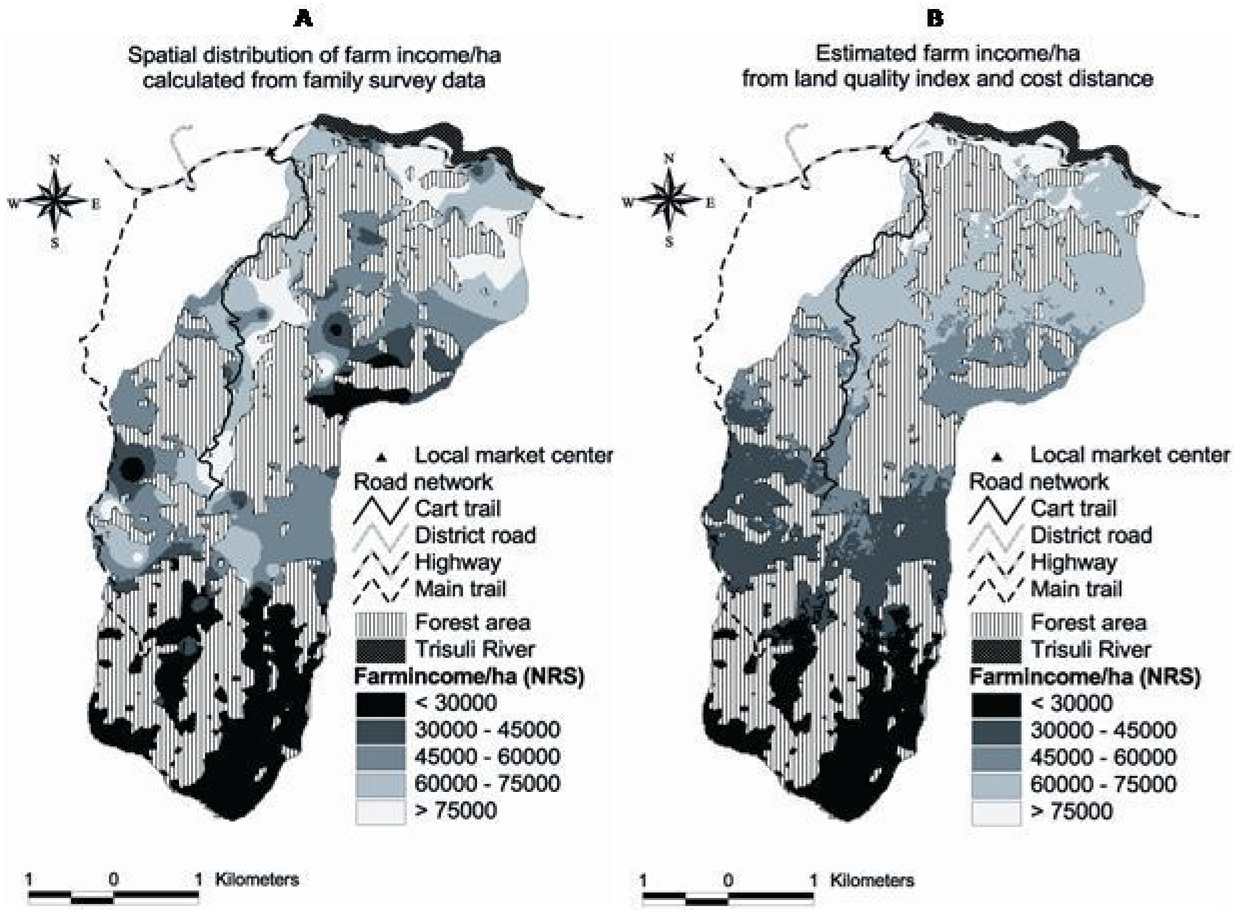

Figure 3. Spatial distribution of farm incomes/ha (a) calculated and interpolated from family survey data (b) estimated from land quality indexes and cost distances.

Table 2. Farm income per hectare in NRS: comparison of estimated values with survey results, 2003.

Study zone	Estimated from regression model	From family survey	Confidence limits to mean calculated in family survey	Estimated - calculated/ confidence limit
Lowland	68720.7	72661.6	14176.56	-0.277
Middle land	47263.5	48067.3	4744.36	-0.169
Highland	20826.2	18346.7	3624.93	0.684

NRS = Nepali Rupees (1Euro= approximately 90 NRS).

was estimated using the Universal Soil Loss Equation (Bahadur, 2008; Wishmeier and Smith, 1978). The models estimated the annual rate of soil loss from each of the 25 m grid cell of the watershed in ton/ha.

Soil degradation and its impact on income

There is impact of soil degradation on income if the present soil loss remains continuously than the loss that would happen on income. If the present soil loss continues, the nutrient content on soil will reduce; hence crop yield will reduce so that the land quality index would be calculated accordingly. When land quality index becomes small in the future due to soil loss than its impact on income, lower income can be seen as compared to the present.

Income under soil degradation scenarios

Income under the assumed soil degradation condition

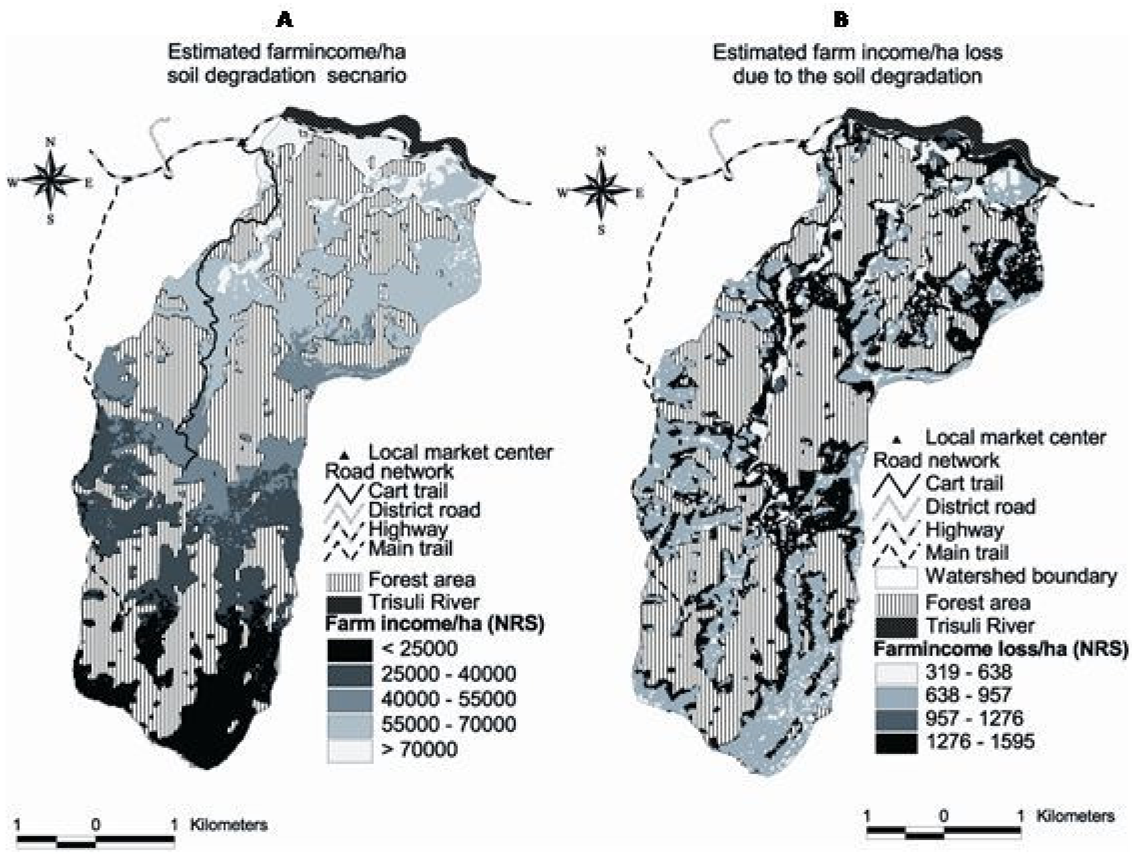

Figure 4. Application of spatial simulation model: Assessment of the future strategies of the soil degradation on farm income (a) simulated farm income situation under soil degradation (b) impact of soil degradation on income.

was estimated using the regression model that was constructed for the estimation of current income then the incomes between current and under the soil degradation scenario were compared and differences were taken as a result of soil degradation. Figure 4 shows the predicted income per hectare modeled according to the assumed scenario from land quality index and cost distance. In Figure 4b, the impact of soil degradation is displayed by subtracting Figure 4a from Figure 3b. In Figure 4b, three types of areas can be distinguished. The high-income area around low elevation areas and around Galaudu River is slightly affected by soil degradation. The difference between the current income and the income after soil degradation scenarios mostly lies between 300 and 750NRS/ha/year. Rest of watershed in particular higher elevation areas of middle altitude zone and nearly all the areas of highland zones are expected to lose between 750 and 1600NRS/ha/year. Figure 4b shows the absolute impact that the model assigns to soil degradation. These figures shows how much income will be lost through soil degradation, there is no difference made on the spatial variety of farming systems, because all the sub study zones are compared only by the difference of income before and after degradation. In this respect,

Table 3. Negative impact of soil degradation by sub study zone, Galaudu watershed, Nepal.

Income (%) lost in soil degradation situation	Area (%)		
	Lowland	Middle land	Highland
<5	100	98.4	49.3
5 – 10	0	1.6	48.6
>10	0	0	2.1

Table 3 is more informative because this shows the impact of soil degradation in relation to the development of income; in other words, the income declination in the soil degradation scenario is compared with the current income situation.

Improved land management scenario

With this scenario, the possibilities that are offered by the model on land quality improvement are demonstrated. Underlying this model of improved land management are some basic assumptions, which are estimated. For a

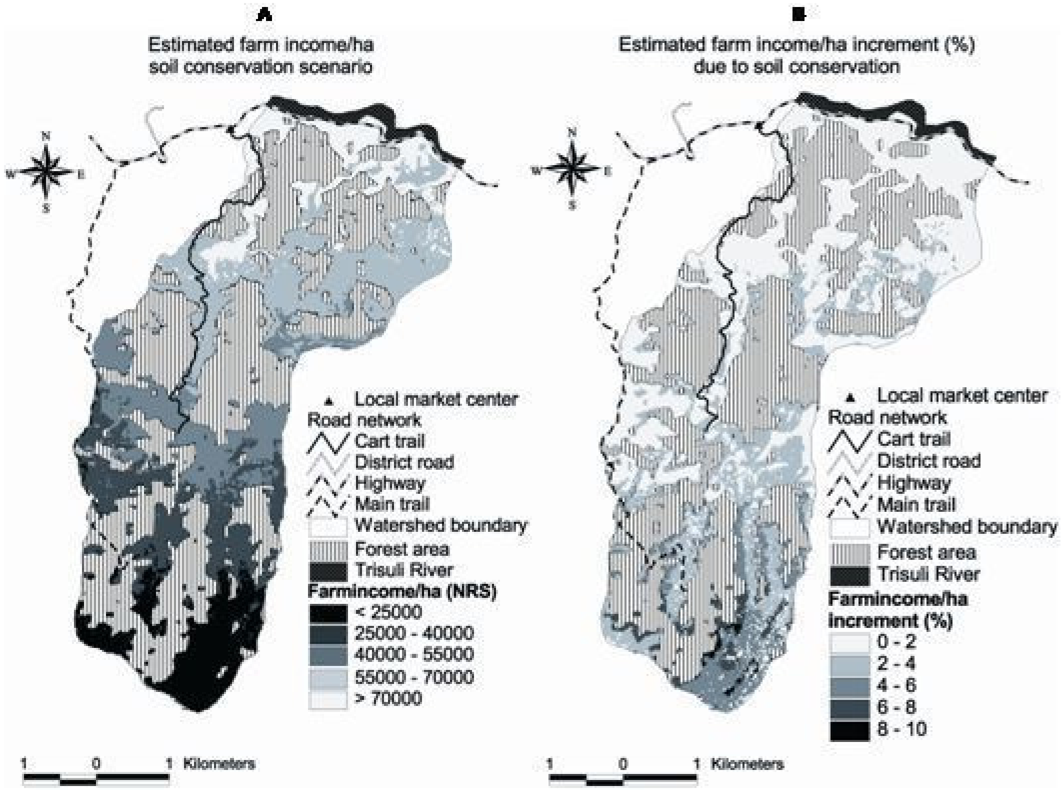

Figure 5. Application of spatial simulation model: Assessment of the future strategies of the soil conservation on farm income (a) simulated farm income situation with soil conservation (b) impact of soil conservation on income.

validation of these assumptions, measurements that assess the impact of land rehabilitation on the yields per hectare and on income parameters are necessary. The income generating potential is increased through improvement of land management in this scenario. For setting up of the scenario, it was assumed, that all possibilities of land rehabilitation and soil conservation are used.

The prevention of soil erosion and the improvement of land quality are closely connected to measures of soil rehabilitation and stabilization. Capital-intensive soil conservation techniques are considered inappropriate for the study area, because the income level of the farmers is low. The family survey showed that labor resource is still under used in the study area. Measures for soil conservation are usually labor intensive, while only little or no capital investment is involved. Development agencies, like Denmark funded NARMSAP (Natural resources management sector assistant program) and department of soil and water conservation are active in soil and water conservation and watershed management sector in Nepal. Other soil conservation measures, promoted by ICIMOD in mountains of Nepal include cultivation without burning, cultivation of different plant species (ICIMOD, 1994). Further possibilities to reduce soil erosion and sustain soil fertility are intercropping with legumes, building of terraces, building of stone barriers and grass filter strips, as assessed and suggested by different research and researcher.

The results of on station and on farm trials in the mountains of Nepal, and south East Asia, lineout the function and relevance of different soil conservation activities. If different kinds of soil management program are conducted together with suitable cropping patterns, then the bigger land quality index should be assigned for the grid cells based on the assumption and impact on income, which thus result to bigger income amount as compared to that of the current one.

Income with soil conservation measures

Figure 4a shows the estimated income under the assumed land management condition and 4b shows the impact of soil rehabilitation measures. Even after the implementation of assumed land management scenarios, estimated income will not be distribute evenly throughout the study area. Estimated income will still be the highest in the area of the highest income and in the area where the impact of changed management is estimated to be highest. The income- and change surfaces are not smooth, but show that there is great spatial variation between peak- and neighboring areas. As in the current situation, the high-income areas remain same as they were before and the same applies for the low-income areas. Nevertheless, the situations in the low-income zones, especially in highland zone, were changed. While the current income in much of the highland zone is below 20,000 NRS, the improved situation predicts the income per hectare to reach and exceed 25,000 NRS (Figure 5a).

This can be clearly seen from Figure 4b that the percentage increase of income with soil conservation measures is based on the current situation. From this point of view, the low-income areas in highland zone benefit most from the changed management. Here, an increase of income up to 10% will provide much to the amelioration of living standard and sustainability. In the high-income areas, the income situation is changed little. An increase of income below 4% (Figure 5b) in many parts of the watershed is predicted. This relatively low impact of soil conservation measures on income is expected to have the consequence that the farmers would not decide to start with soil conservation.

Improvement of infrastructure offers the possibilities for development and enhances the exchange capacities in an area. Several effects of improved road infrastructure can be imagined. The improvement of infrastructure can take place on different scales. Here, the linkages between centers are enhanced, while the regional infrastructure development aims at a better opening up of peripheral areas to the local centers. According to Doppler (1998), decisions on infrastructure development in a region depend on availability of funds, collaboration between public investments and the private sector, competition between regions for infrastructure development and Interdependencies between different types of infrastructure. In the study area, efforts were undertaken to connect the watershed area with local market center than the different area of watershed has access to nearby markets and capital Kathmandu through the national highway.

Development and improvement of road infrastructure

For the study area, it was analyzed, how the farmers would benefit from an extension of the road network that opens up much of the peripheral areas of the watershed. This could be achieved by the construction of new roads. Tables 4 and 5 compare the current and improved road infrastructure. Most of the new roads could be built by improving the existing main trails. About 8166 m of trails would have to be extended to main trails and 6971m to cart trails. The enhancement of accessibility through improvements of the road network was measured with the cost distance function, incorporating the new roads with their traveling speed in the calculation. Figures 5a and b show the cost distances (current and after the improvement of infrastructure) from the different part of the watershed to the nearest market center respectively. The differences in traveling time before and after the improvement and development of road networks are shown in Figures 6a and b.

On spatial level, improved situation (Figures 6c and d) show the great differences over the current situation. Significant impact on income of farmers was observed before and after the improvement and development of road networks in the remote areas of highland zone. The average traveling time from the sample house location to nearest market is reduced by about 50 min, as compared to the current situation. As in the current situation, the accessibility to the market from highland zones still differs significantly from the other zones, when the roads are improved. Consequently, the greatest impact of improved infrastructure on the development is expected in particularly highland areas. Nevertheless, the Figures 6c and d show that there is also high potential for improvements in the other areas as well, when the focus is set on the peripheral areas. In general, it can be said that the remote parts of the study area will benefit most from the new roads. The chances for the development of the road network are seen in the combination of these developments. A better accessibility of the peripheral area is expected to enhance market production and to provide more effective marketing channels.

Income development with improved infrastructure

The results of the cost distance calculations were used for simulating the effects of improved infrastructure on the income/ha of the sample household. For this purpose, the functional relationship used for the income estimations under current land use was applied with the new cost distance values. So, the new income per hectare for each and every grid cell was estimated and spatial distribution of new incomes is presented in Figure 6c and the change in Figure 6d that relates the simulated road scenario to the current situation.

As it could be expected from the results of the cost distance calculations, the highest increase in income was found in the remote areas of highland zone and the remote parts of the other zones. In highland zone, the 20,000 NRS margin, that divides the zones in two parts, is pushed up the hill in the area south and east of the new road that connects the area with the marketplace. The situation of the high-income areas in middle land and lowland zones is expected to improve only slightly less than 16%, increasing with the distance from the marketplace. There are still areas that are not yet connected to the market adequately. This applies for the most remote areas with little population, where the construction of new roads was not simulated. In addition to this, the.

Table 4. Current and expected road network.

Road type	Current length (m)	Expected length (m)	Change length (m)	Traveling speed (km/h)	Time for crossing 25 X 25 m cell (min)
Main trails	4572	12738	8166	20	0.15
Cart trails	5924	12895	6971	30	0.10
District road	-	-	-	60	0.05
Highway	3461	3461	-	60	0.05
Others (off road area				4	0.75

Table 5. Average traveling time (in minutes) from the sample household to nearest market center, by sub study zone, 2003, Galaudu watershed, Nepal.

Statistics	Lowland (1)	Middle land (2)	Highland (3)
Average	31.97	70.18	107.41
Standard deviation	16.96	18.44	8.80
Highest value of the zone	74.60	92.04	126.58
Lowest value of the zone	8.28	38.82	93.32
Differences between (1) and others		***	***
Differences between (2) and others			***

*** = Probability that the hypothesis of non-significant differences between groups can be rejected according to the MANN-WHITNEY test: ≤ 99%

development effects of improved infrastructure are expecyted to be even higher than what the model shows, because the effect of a simultaneous development of the national roads network and its possible consequences on marketing, crop production and off farm jobs is not considered in the model

Combined strategy to improve land management and road network

This scenario was built to show the combined effect of the previously discussed two scenarios. If road network are improved and improved land management will be adopted then the combined effects of both measures on the income can be seen. Previously in both scenarios, only one variable of the GIS based regression model (Equation 1) was changed to represent the results of the respective strategy. Now, the change of both variables is considered, as elaborated before. This shows joint effect on income/ha after the development of road network and land management activities as assumed.

The impact of improved road network was the highest in the remote areas. Since these areas are also identified as the ones with the highest potential for income boost through the introduction of improved land management practices, the combination of both measures yields the best response in the highland areas. Still, the level of income is low in this area, when it is compared to the high-income areas. Currently the scenario predicts the highest increase for areas with the lowest income (about 20,000 NRS/ha). For most of the area, the income/ha is predicted to be between 25,000 and 30,000 NRS. While this is still low, the increase is substantial. The model results (Figures 7a and b) show an increasing trend of income can be achieved by the implementations of improve road network and the improve land management practices. For the low-income areas in the extreme southern part of the watershed, less than 20,000 NRS were estimated at current conditions. The combined scenario shows a higher increase in this area than in the rest of the watershed, where the income under current conditions is higher.

For lowland areas together with the lower elevation areas of middle land areas, the monetary benefit of the measures is less substantial. For the high-income zone around Galaudu River and around the areas where there is the road network, currently, the increase of income is predicted to be less than 16% (Figure 7b). Better response is found in the rest area of the middle altitude and most area of the highland zone, where up to 104% (Figure 7b) increase of income is predicted. Nevertheless, the impact of improved road network and improved land management on the sustainability of the farming system is expected to be substantial in these zones, since the cultivation of slopes induces heavy soil loss in this area too.

Improve water resources management

Improvement of water resources management offers the

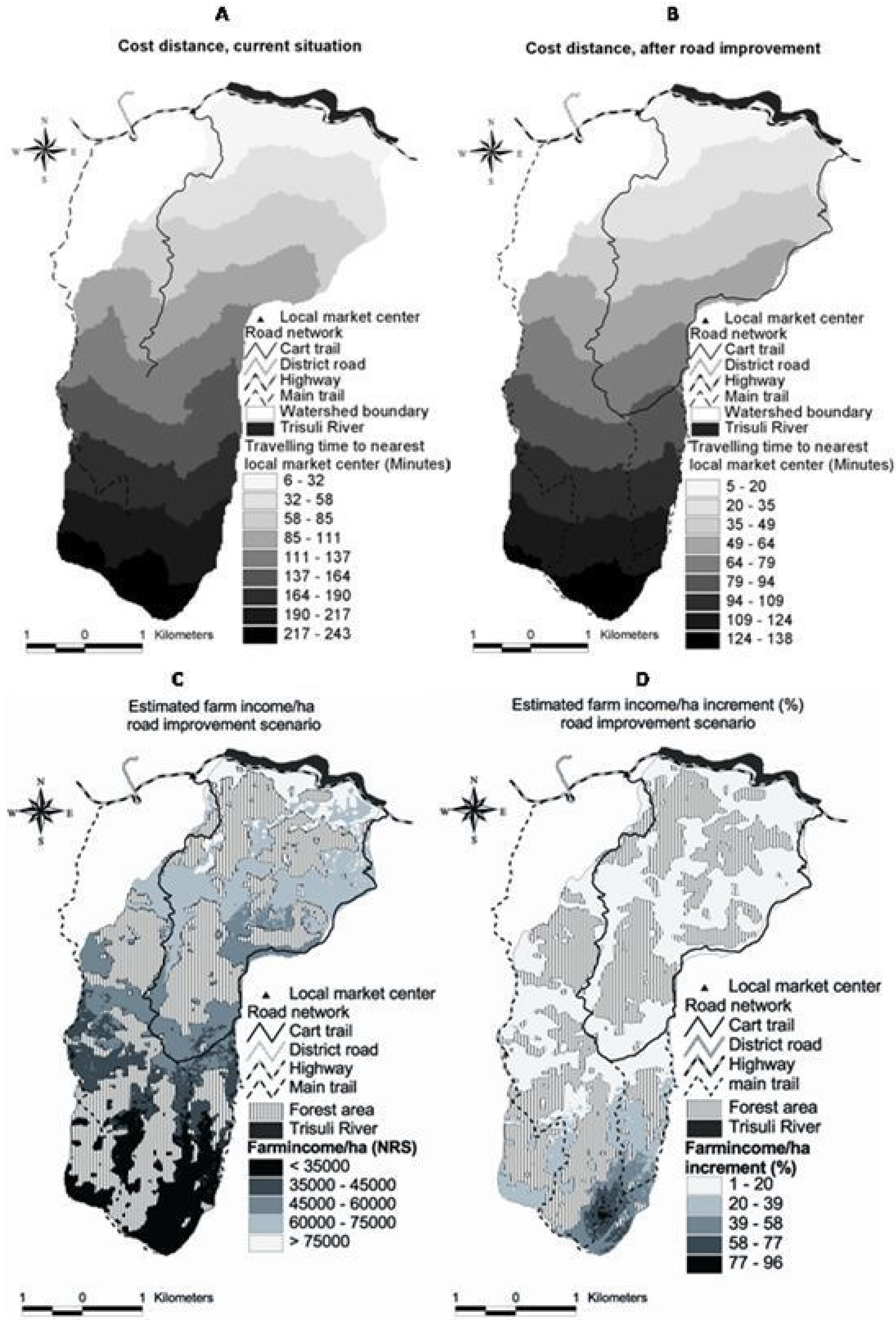

Figure 6. Application of spatial simulation model: Assessment of the future strategies of the road improvement on farm income (a) cost distance (traveling times in minutes from different part of the watershed to nearest market center) current situation (b) cost distance after the improvement of the road network (c) simulated farm income with improvement of road network (d) impact of road network improvement on income.

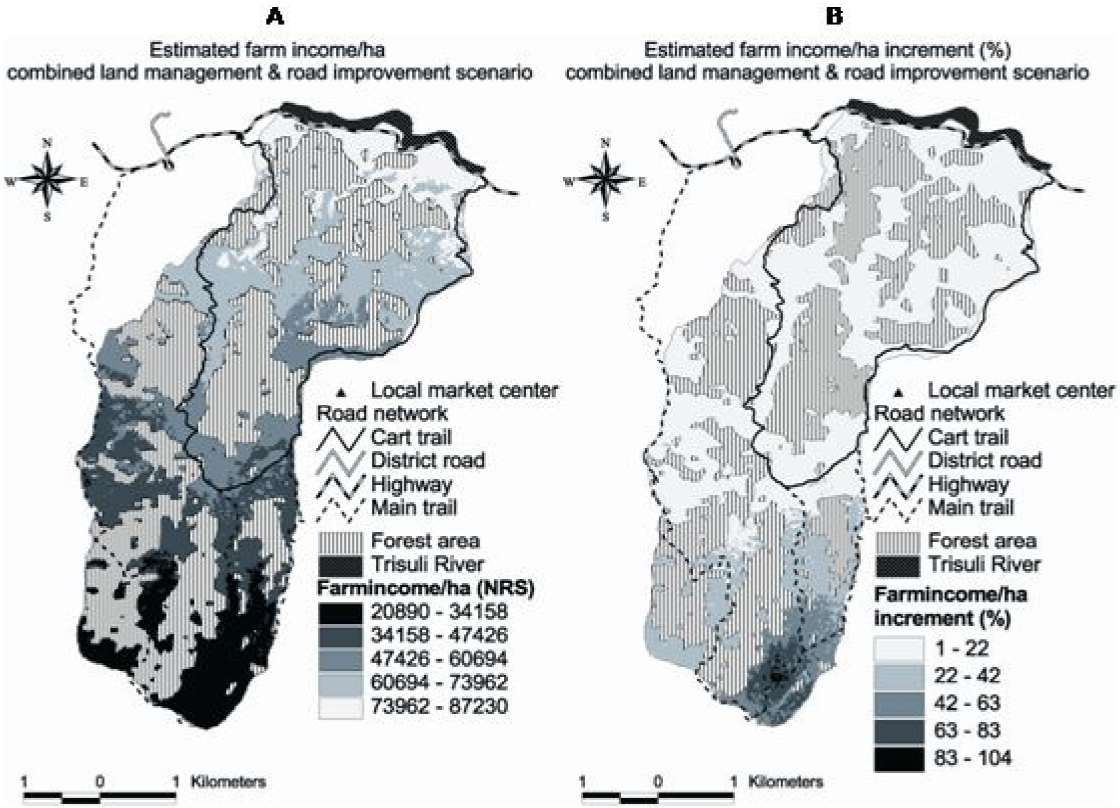

Figure 7. Application of spatial simulation model: Assessment of the future strategies of the land resources management and the improvement of road infrastructure on farm income (a) simulated farm income situation with improvement of land resources management and the road network (b) impact of combined road and land resources development on income.

possibilities for the development of farming system and raising the farm income in an area through the intensification of different agricultural and cash crops. Several effects of improved water resources management can be imagined. The improvement and management of water resources can take place on different ways such as improving the currently available water resources management infrastructure, which includes small irrigation canal, constructed, and regulated by individual farmers and/or water user groups; introducing new water harvesting technologies such as conservation ponds. Construction of small-scale irrigation schemes is donefor local areas as some already exist in the lowland areas of the watershed, where construction and regulation of such kinds of water management structure is rather easy as compared to highland areas where construction and management of such systems are difficult due to the terrain characteristics. Thus, there is need for more strong or permanent type of structures to be constructed using cement pipelines and so on, which are rather difficult in developing such structures. However, if state provides certain support to develop such structure, farmer will surely get profit from such kind of structure. They will be able to intensify their agricultural activities as lowland and they can diversify their crops from their subsistence oriented system to little bit market oriented system, which makes farmers earn a little bit cash as well. In the study area, there are currently efforts undertaken to construct and manage the local level water resources management such as conservation pond, construction of small water regulation structures and maintenance of the existence but not operating old small canals, identification of springs and their maintenance.

On the spatial level, improved situation (Figure 8a) shows the great differences over the current situation. Significant impact on income of farmers was observed before and after the improvement and development of water resources management especially in the areas of highland zone. As in the current situation, the quantity of irrigated land in highland areas is still very low from the other zones, when the irrigation systems are improved. Consequently, the greatest impact of improved water management on the development is expected in particularly highland areas. Nevertheless, the results (Figures 8a) show that there is also high potential for improvements and development of water resources management system in the other areas as well. In general, it can be said that in the different parts of

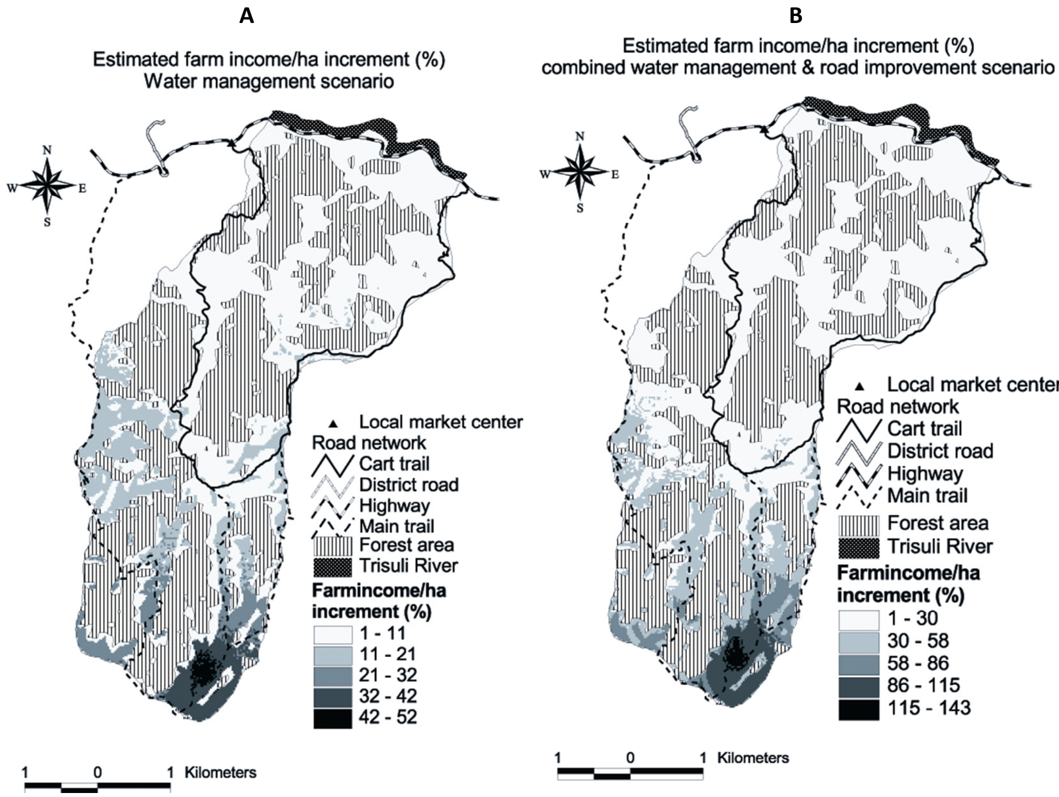

Figure 8. Application of spatial simulation model: Assessment of the future strategies of (a) impact of water resources management on farm income (b) impact of combined road and water resources development on income.

watershed, those that are not facilitated with water resources management schemes will benefit mostly from the new water resources management activities.

As it could be expected from the results of the quantity of water resources management calculations, the highest increase in income was found in the highland zone and the remote parts of the other zones. In highland zone, the 20,000 NRS margin that divides the zones in two parts, is pushed up the highland zone. The situation of the high-income areas in middle land and lowland zones is expected to improve only slightly by about 10%, increasing with the quantity of irrigated land.

Combined strategy to improve water resources management and road network

The scenario was built to show the combined effect of water resources management and road network. When water resources management and road network are improved, the combined effects of both measures on the income can be seen. Previously in both of the scenarios, only one variable of the GIS based multiple regression models (Equation 1) were changed to represent the results of the respective strategy. Now, the change of both variables is considered, as elaborated in the previous sections. This shows, joint effect on income/ha after the development of both road network and water resources management activities as assumed.

The general trend of the two separate scenarios also prevails in their combination. The impact of improved road network was the highest in the remote areas. Since these areas are also identified as the ones with the highest potential for income boost through the introduction of water resources management activities, the combination of both measures yields the best response in the highland areas. Still, the level of income is low in this area, when it is compared to the high-income areas. In the zone with the lowest income (about 20,000 NRS/ha) under current conditions the scenario predicts the highest increase. For most of the area, the income/ha is predicted to be between 25,000 and 30,000 NRS. While this is still low, the increase is substantial. The model results (Figure 8b) show an increasing trend of income can be achieved by water resources management and enhanced accessibility in this area. For the low-income areas in the extreme southern part of the watershed less than 20,000 NRS/ha were estimated under current conditions. The combined scenario also shows a higher increase in this area than in the rest of the watershed.

For lowland areas, together with the lower elevation areas of middle land areas, the monetary benefit of the measures is less substantial. For the high-income zone around Galaudu River and around the areas where there is the road network currently, the increase of income is predicted to be less than 16% (Figure 8b). Better response is found in the rest of area of middle altitude and most area of the highland zone, where 31 to 104% (Figure8b) increase of income is predicted.

DISCUSSION

GIS based farm income modeling shows the relation between the income to the quality of agricultural land and the accessibility to the marketplace can be found which can be used to simulate the future development of income situation in the different spatial gradients of the area. Study shows the use of different RS and GIS generated biophysical variables to estimate income of a given location and their impact at different assumed scenarios.

Result show that impact of soil degradation due to soil erosion will be low around the high and medium income areas. In contrast, income loss would be higher around low-income areas, particularly areas around highland zone, if current situation will continue, such as, no conservation measured will be applied. An improvement of land quality through different soil conservation activities including building terraces shows the promising results especially in the currency low-income areas. According to the model results, there will be only a little increment of income around high-income areas of lowland but income increment will be higher around low income areas of highland zone and income could be increased by 10%.

Strategy of development and improvement of the road network shows its impact will be highest in the remote areas, which are currently least accessible. The model estimate an increment of income in the periphery where currently there is no road and increment reaches up to 96%, while the area closer to the road benefited slightly. Combination of road network and soil conservation strategies also shows the highest increase of income especially the areas those have currently low income. The areas close to market center, road and irrigated lowland show only slight impact.

Strategies of water resources management show the increment of income especially to those of upland agricultural areas, which has currently no irrigation. Model show the increment of income by 30 to 52% on most of the areas of high and middle altitude zone those currently practices rain fed upland agriculture, normally only one crop a year. Combined strategy of water resources management and road network shows their impact would also be the highest in the remote areas, as each of them shown separately. The model results show an increasing trend of income can be achieved by water resources management and enhanced accessibility in this area. Model shows an increment of income by 45 to 104% for the low-income areas in the extreme southern part of the watershed. The combined scenario also shows a higher increase in this area than in the rest of the watershed, where the income under current conditions is higher. For lowland areas, together with the lower elevation areas of middle land areas, the monetary benefit of the measures is less substantial. For the high-income zone around Galaudu River and surrounding areas where there is the road network currently, the increase of income is predicted to be less than 16%. Nevertheless, the impact of water resources management on the sustainability of the farming system is expected to be substantial in the higher altitudinal areas, since the cultivation of slopes induces heavy soil loss in this area too.

Conclusions

Result from GIS based multivariate linear regression showed that cost distance to market and land quality parameter extracted from RS/GIS techniques can explain the income potential of a farm in a given location. Based on the functional relationship between income and cost distance to market and land quality parameters, future strategies of reducing cost distance to the market through road improvement and increasing the quality of land through soil and water management activities and their impact on income shows the increasing trend of the farm income of farmers and decreasing the spatial differentiation of incomes among the farmers living in the different spatial gradient of the watershed.

Test of future strategies suggest that if the tested strategies will be implemented, an improvement of living conditions, in the currently disadvantaged areas with low levels of natural resource endowment and poor living standard could be achieved. The development strategies at different scenario tested in this study do not necessarily solve the problem of low level of living standard especially in highland areas fully, but strategies would help to increase the economic success of farming families and living standard in one hand and on the other hand, it would reduce the level of resources degradation and living standard gaps between high and lowland. In respect to the sustainability of the farming systems, the results of the study show that managed land use, yields a better economic response in zones with marginal land endowment. The soil degradation scenario has shown that the need for interventions towards more sustainable resources use is the highest in the remote mountain zones, where the chances for positive effects of the development strategies are also the highest and at the same time there will be the positive impact on the living standard and resources at the lowland as well.

Hence, this has demonstrated the potential contribution of GIS as an appropriate methodological option for formulating and testing long-term problem solving strategies towards a better planning for improving living standard of rural farming people in general and farm income in particular. The results of the papers shows a methodological concept suitable for dealing with such type of problems and empirical results which can be relevant for strategy testing in other similar regions in mountainous zones.

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