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Integrating Micro Level and Remote Sensing Data in GIS Analyses for Natural Resources Management and Socio-economic Development: A Case in Mountainous Watershed in Nepal

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Abstract: Poor socio-economic condition and resource degradation follow a certain spatial gradient leading to further resources degradation and socio-economic differentiation in watershed area. Watershed degradation in mountainous areas is often a core problem with serious implication for sustainable resource use and living standard of rural households. Achievement of watershed conservation and people livelihood simultaneously is not feasible with a single suitable strategy. But, a best option to address it is to divide watershed area into homogenous zones based on resource availability, utility potentials and the socio-economic situation. Then zone-based problem solving strategies can be tested in producing best possible recommendations for future.

This paper presents a methodological concept of integrating socio-economic assessment with biophysical environment with a GIS. Biophysical indicators were assessed using RS/GIS technology. Socio-economic conditions of the people were assessed based on a survey with in-depth interviews with randomly sampled families. Then these data were linked to the GIS by using each family's respective geographical positioning, and their spatial distributions were observed by interpolation. The zones were formed by integrating spatially significant socio-economic and biophysical indicators. Zone 1 characterises high level of resources degradation and low level of the living standard while that of Zone 3 features with low level of resources degradation and high level of the living standard. The Zone 2 stands for medium level of resources degradation and moderate living standard.

The results show differences in the long-term development of land use in the past following different gradient in the area. Forest resource degradation, soil losses were found to be directly correlated with the altitude and slope of the land. Similar trend was observed with spatial differentiation of living standard parameters including farm family income, food availability, dependency on resources, etc. There was direct negative correlation in between the distance from the road, market and the altitude, and the socio-economic status-e.g. family income, education level, crop production and selling. Hence it is concluded that integration of socio-economic data into the GIS system is an appropriate tool for zone delineation as well as to formulate and test long-term problem solving strategies achieving both sustainable natural resource management and better livelihood simultaneously.

Key words: Watershed, resource use, degradation, land use change, soil loss, socio-economic situation, rural development, integration, zone, GIS, RS, Nepal

1. Introduction:

Resource use and watershed management has become an increasingly important issue in many countries including Nepal as government agencies and non-governmental groups struggle to find appropriate management approaches for improving living standards in rural mountain areas. Principles, concepts and approaches related to watershed management have experienced a vast change during the past few years but yet there is no universal methodology for achieving effective resource and watershed management (Naiman et al., 1997; Bhatta et al., 1999). It is generally agreed that sustainable development and management of upland natural resources for the welfare of local populations should be the key objective to improve living standard in a sustainable and even more in a progressive way. For ensuring an environmentally sustainable development a sustainable utilization and conservation of forest resources at community or watershed level is considered as one of the important rural development components (Sharma and Krosschell, 1996).

The utilization of a watershed area beyond its carrying capacity to provide food, fibre, and shelter for the exploding population has resulted in its deterioration in most part of the world (FAO, 1985). However, such deterioration is more severe in developing mountainous countries including Nepal (Thapa and Weber, 1990). Being an integral part, the natural resources and socio-economic status of a watershed should be paid equal attention (Erickon, 1995). Unfortunately until now most of the people are confined only to the resources degradation, keeping the social factors aside. Watershed degradation is a phenomenon by which the potentiality of the watershed is getting reduced over time, which can be confined to the forest loss and the rate of soil erosion increment, if other factors are negligible (Kelly, 1983) and results in an unsustainable development of the living standard of the people.

The socio-economic data base received from micro level surveys are still central to any sound family level analyses, but the use of remote sensing and geographic information system (RS/GIS) technologies can greatly support the base of information. Repeated satellite images and/or aerial photographs are useful for both assessment of natural resources dynamics occurring at a particular time and space as well as quantitative evaluation of land use/land cover changes overtime (Tekle and Hedlund, 2000). Analysis and presentation of such data, on the other hand, can be greatly facilitated through the use of GIS technology (ESCAP, 1997). A combined use of RS/GIS technology, therefore, can be invaluable to address a wide variety of resource management problems including land use changes and the spatial distribution of soil loss in a particular time and its change in the course of times. Soil loss can also be monitored by using RS/GIS in conjunction with Universal Soil Loss Equation (USLE). For the assessment of the socio-economic conditions, household survey along with other ancillary data can be used. These two aspects can be linked for the better understanding of the degradation phenomena of the watershed. Under this context, a study was carried out with the objectives (i) to assess the condition of natural resources (estimate the forest and soil loss in the watershed) (ii) to assess the socio-economic situation of people (iii) to establish the relationship between resources and socio-economic condition by linking micro-level socio-economic situation with biophysical condition and (iv) to classify the watershed into small homogenous units by integrating micro-level socio-economic situation with the biophysical condition of the watershed and evaluate the applicability of RS and GIS for this purpose

2. The study Area:

The study area constitutes a mountainous watershed named Galaudu/Pokhare Khola sub-watershed (hereafter refer as Galaudu watershed) situated in Dhading district of Nepal (Figure 1). Topography of the watershed is mountainous with an average slope exceeds 30 percent and shows features which are often found in mountain zones of Asia. Most part of the watershed is the mountainous region under hill forest and upland cultivation. The soils of the watershed are loam, sandy loam, clay loam, silt loam and sandy clay loam. The area has a sub-tropical climate with a mean annual rainfall of 1404 mm. The elevations of the highest and lowest point are 217 m and 1960 m above mean sea level respectively.

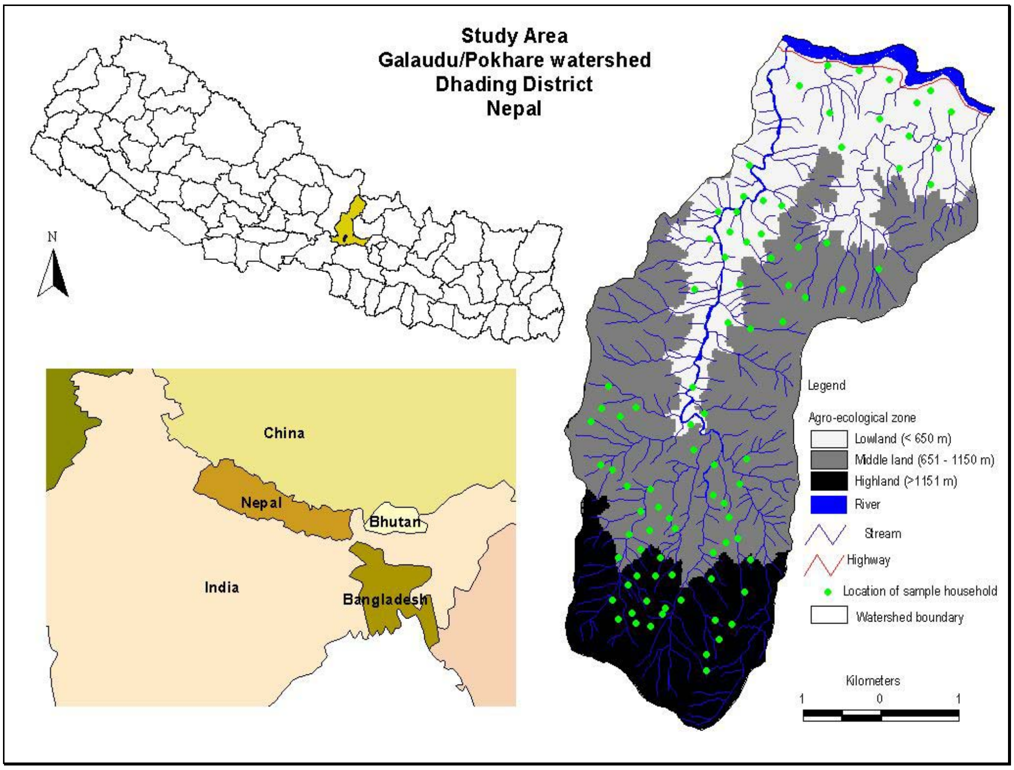


Figure 1: Location of study area

The development of the watershed is not uniform. The lowland valley stretching from Galaudu and Pokhare Khola near to highway and local market centre is one of the most fertile and economically important areas of watershed. The local economy and employment opportunities of these semi-urban areas differ from rural areas. Semi-urban centres are directly connected to Kathmandu valley by highway, have alternative sources of energy, and alternative source of income in addition to agriculture. Rural people in the surrounding areas are primarily dependent on arable agriculture and livestock raising for their livelihood. This high variability in the ecological and economic conditions makes the watershed an appropriate site to study land use dynamics and factors associated with it.

3. Methodology:

3.1 Information base

An integrated approach of digital image processing of satellite data combined with GIS and USLE was carried out for resources assessment (Landsat TM of path/row 141/41, acquired on 4 Feb: 1990 and 13 March 2000; air photos scale 1:50,000, 1992; topographic maps of 1:25,000, 1995 and land use maps of 1:50,000, 1978 were used). Family survey (90 families were interviewed) with a standardised questionnaire was conducted for the socio-economic analyses and their respective geographic position was recorded using GPS. In a soil survey 90 soil samples were taken for soil fertility and texture analysis. Different statistical and econometric analysis were carried out for analysing the socio-economic as well as physical data and linked their results to the results from resources assessment in order to find out the cause and consequences. The ancillary data were used wherever it was relevant.

3.2. Methodological concept and approach

By using these data, the general methodology was followed as presented in Figure 2. Land use map of 1990 and 2000 was obtained by performing supervised digital image processing for satellite images of respected year over the study area from Landsat TM. After comparison of land use of 1990 and 2000, the change trends had been obtained. Widely adopted USLE model was taken to estimate the soil loss (Schawab et.al. 1993). (for details see K.C., 2001). The soil samples were analysed for soil nutrients and texture at Nepal Agriculture Research centre Kathmandu, Nepal. As the socio-economic study involves both qualitative and quantitative information, both descriptive as well as analytical statistics measures had been used. Furthermore, weighted index were also formulated wherever essential. Finally, spatial differentiation of resources degradation and socio-economic situation in the different spatial location of watershed were observed by linking the point level socio-economic data into GIS then by performing the interpolation. Based on the spatial relation observed all the biophysical and socio-economic GIS layer those have found spatially different were imported into ERDAS Imagine software and classify the watershed into three homogenous zones by performing unsupervised classification using ISODATA clustering algorithm.

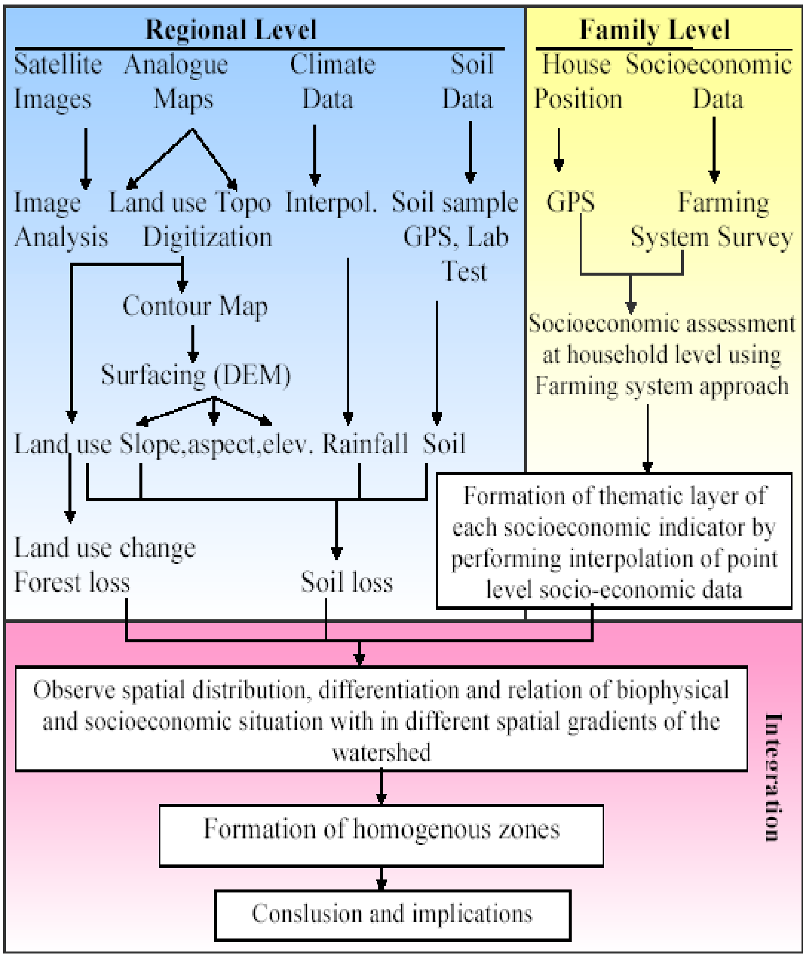


Figure 2: General methodology

4. Results and discussion

4.1. Land use dynamics

To characterize the volume and quality of land resources available and even more the decision-making of people who use this land, the development of land use over time as well as differentiated according to the location in the area and the conditions of the locations in the space is to be understood. Land use has changed in the past. An analysis of land use change from 1990 to 2000 shows that forestland declined by 10,6 % (Table 1) while upland agriculture increased by 9,6 % and lowland agriculture by 1 % (Figure 3 and 4). The annual rate of forest loss in the study area was about 1.06 percent. Land use change may be attributed to the change in spatial location of land because due to unproductive agricultural land in high zone, people might have converted the forestland into agricultural activities for fulfilment of their basic needs.

The conversion of forestland to agricultural activities was not similar through out the watershed (Figure 4). In the highlands more forestland were converted to agricultural land as compared to lower elevation (low land) area.

Table 1: Land use change

Land cover	1990		2000		Change	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area %
Forest	1475.9	54.7	1189.7	44.1	-286.2	-10.6
Upland Agriculture	414.7	15.3	671.3	24.9	+256.6	+9.6
Lowland Agriculture	809.8	30.0	839.40	31.1	+29.6	+1.0
Total	2700.4	100.0	2700.4	100.0	0	0

Two reasons may explain higher amount of forest loss in higher elevation areas. First, most of the settlements in the upland area do not have good quality (less productive, out facing sloping terraces, not level terrace, no irrigation facilities or possibilities) of land compared to lower elevation areas because of which a higher level of human-forest interaction can be expected in these areas thereby bringing more pronounced forest lost compared to the other zones. Second, most of the community forestry activities that are expected to have positive influences on the balance of forest cover were concentrated in lower elevations. A lower amount of forest loss in lower elevation zones suggests that forest conservation efforts by the local communities and concerned agencies played important roles by bringing positive outcomes in the balance of forestry land use in the watershed. The same could not happen at higher elevations (highland) because of the inability of community-based forest management programs to cover those areas and virtually non-existent forest monitoring by the forest department thereby leading to an open access condition of the high altitude forests.

4.2. Soil degradation and soil loss estimates

Farming in mountain areas is mostly associated with the danger of soil degradation and especially soil erosion. Economically, this means loss of potential for production and income generation as long as the eroded soil is not naturally replaced without costs. Such processes lead to a reduction of economic bases over time and may have long-term consequences not only on living standard of people but also loss from the society's point of view. In the following the estimates of soil loss and the loss of farming potential is estimated (for the methodology see K.C., 2001).

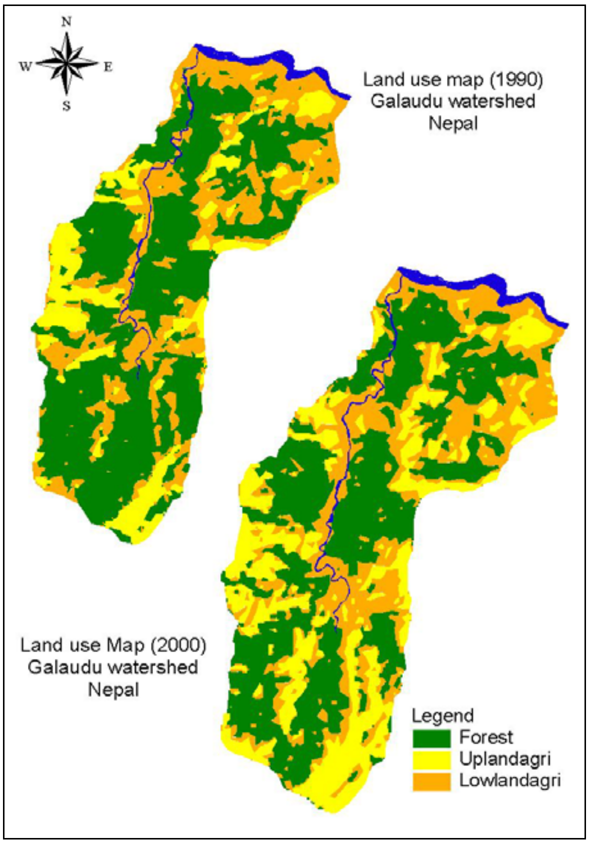


Figure 3: Land use map 1990 (upper left) and 2000 (lower right)

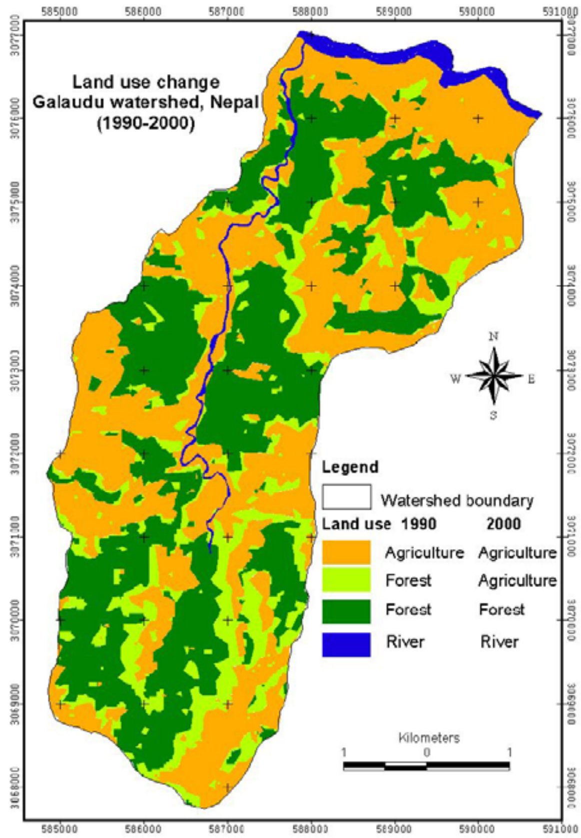


Figure 4. Land use change map

Average estimated rate of soil loss ranged from 0 to 589.29 tons/ha/yr for the year 1990 and from 0 to 619.47 tons/ha/yr for the year 2000 is presented in Figure 5 and 6. The rate of soil loss ranged from as low as 0 to a maximum of more than 100 tons/ha/yr. The erosion rates were regrouped into six classes as presented in Table 2. Categorizations of hazard severity are found with different soil erosion rates by various researchers depending on the erosion class range in specific locality. In this case, area with more than 100 tons/ha of soil erosion annually were classified as extremely severe hazard severity and such area accounted to 9.0% at 1990 and it was increased to 14.5 percent at the year 2000 of the total area. Severe classes collectively comprise about 8 percent in 1990 and it was increased to about 10% at the year 2000 of the total area.

Table 2: Soil erosion classes, rating and percentage of area coverage for 1990 and 2000 for the watershed studied

Class	Soil loss rating (tons/ha/yr)	Hazard severity	Area (%) on the year1990	Area (%) on the year 2000
1	0 - 1	Very slight	30.8	30.8
2	1 - 10	Slight	27.6	23.4
3	10 - 20	Moderate	24.9	21.3
4	20 - 50	Severe	7.6	9.7
5	50 - 100	Very severe	0.1	0.2
6	> 100	Extremely severe	9.0	14.5
Total			100.0	100.0

The spatial distribution of soil loss was not similar through out the watershed (Figure 5 and 6). Higher amount of soil loss from the higher elevation area (highland) were seen as compared to lowland area. Two reasons may explain higher amount of soil loss in higher elevation areas. First, most of the area falls on highland area with higher slopes and second, most of upland cultivation were practised even above the 35% slope and conversion of forest to agricultural activities could be the reason for the higher rate of soil loss from these areas as compared to areas from lowland.

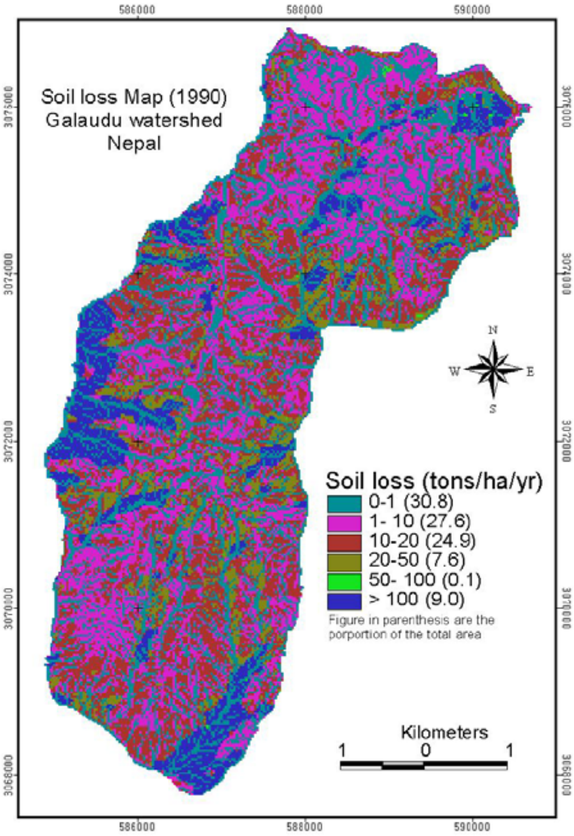


Figure 5: Spatial soil loss during 1990

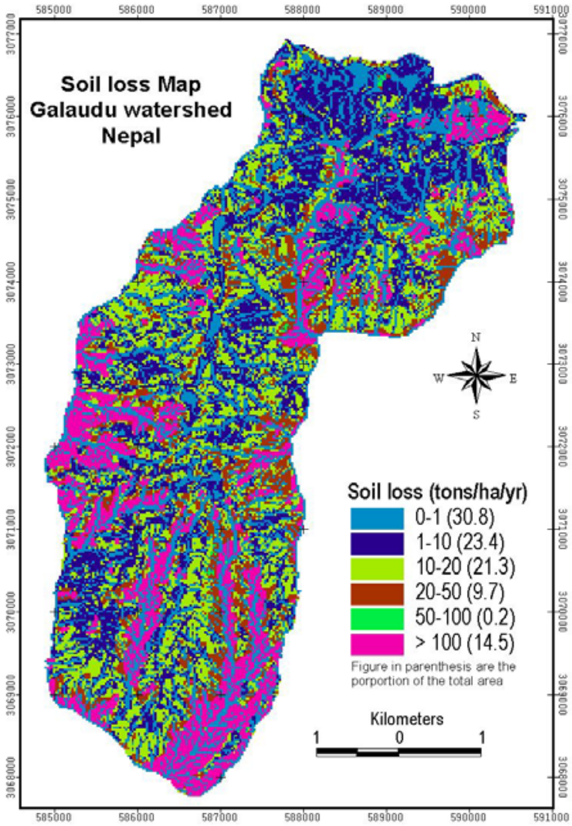


Figure 6: Spatial soil loss during 2000

4.3. Socio-economics of family resources and their integration into GIS

4.3.1. General

The availability, quality and use of resources determine to a great extent the socio-economic success of farming families decisions and actions.

Educational background of household members is believed to be an important feature that determines the readiness of the household members to accept new ideas and innovations. The empirical result shows that the educational status of farmers in the study area is considerably low. In the study area as a whole, a significant share (about 48%) of the household members was illiterate. The spatial distribution of weighted mean index obtained after the interpolation of each of household education weighted index shows clear differentiation from the area near to road and market centre to that of remote areas at higher altitude. Bigger value of weighted education index at lower altitude areas might be due to the good access to educational institution as compared to other zones. Highland zone has very low level of weighted index that might be due to the very low level of access to education.

The quality of the available land determines on the production potential and real production volume from that land. Thus types of lands and their average sizes were observed. Most of the land owned by the families is mainly used for cultivation. The main types of land are *Khet*[1]and *Bari*[2]land. *Khet* land is levelled terrace land that can be used for paddy and intensive farming while *Bari* land are sloping land that can only be used either for maize or millet or both these lands are not facilitated with irrigation. Hence, spatial distribution of *Khet* land was observed using the similar methodologies as mentioned earlier and result shows the clear differentiation of Khet in different spatial location of the watershed. The result of spatial differentiation shows that bigger size of *Khet* land is confined at the lower altitude of the watershed as compared to highland areas. It might be due to the difficulties of converting the sloping land into level terraces and also might be due to the difficulties to have irrigation facilities.

Due to the differentiation of spatial distribution of better quality of soil and level terraced land with irrigation facilities in the different part of the watershed different level of crop productivity are expected in the different spatial gradient of the watershed. Thus an analysis of crop productivity was carried out by performing an estimation of average yield of paddy and maize. Results of the spatial distribution of paddy yield shows that agricultural lands at higher elevation were significantly less productive compared to lower elevations. This kind of different productivity of land might have leaded to different level of socio-economic situation in the different spatial location of the watershed.

[1] Terraced land used for paddy cultivation

[2] Non irrigated sloping land used for maize and millet field

4.3.2. Food production and food security

Due to the differentiation of spatial distribution of quality of land and crop productivity different level of amount of food crop production and thereby different level of food security situation in the different part of watershed can be expected. Thus, an analysis of food crop production, selling and percentage of food buy situation of each household were assessed and their spatial distribution in the watershed was observed. Result of the spatial distribution of food crop production (Figure 7) and percentage of food bought (Figure 8) shows there is a very big differentiation in food production and food bought in the different spatial location of the watershed. It can be seen from the map that the zone of highest food bought from the market is the one far away from markets and with lowest production and income potential in the remote area. Thus it can be concluded that there is strong relation between food production and the level of food security situation. Higher the food crop production is more secured in food availability and vice versa.

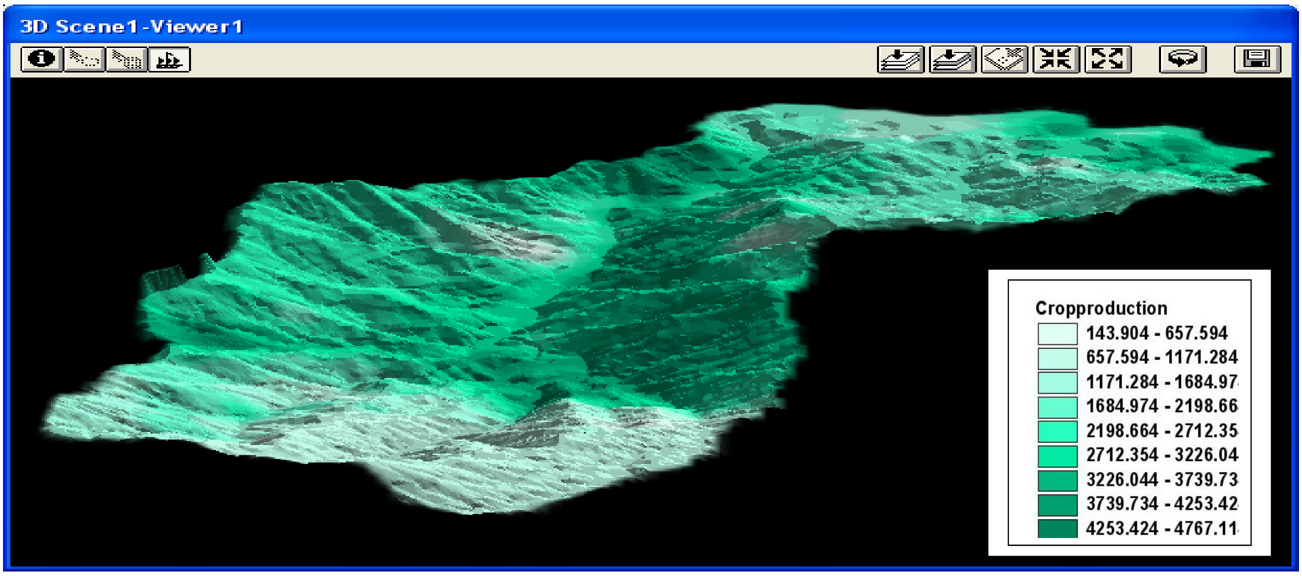


Figure 7: Spatial distribution of food production draped on the three dimensional view of watershed studied

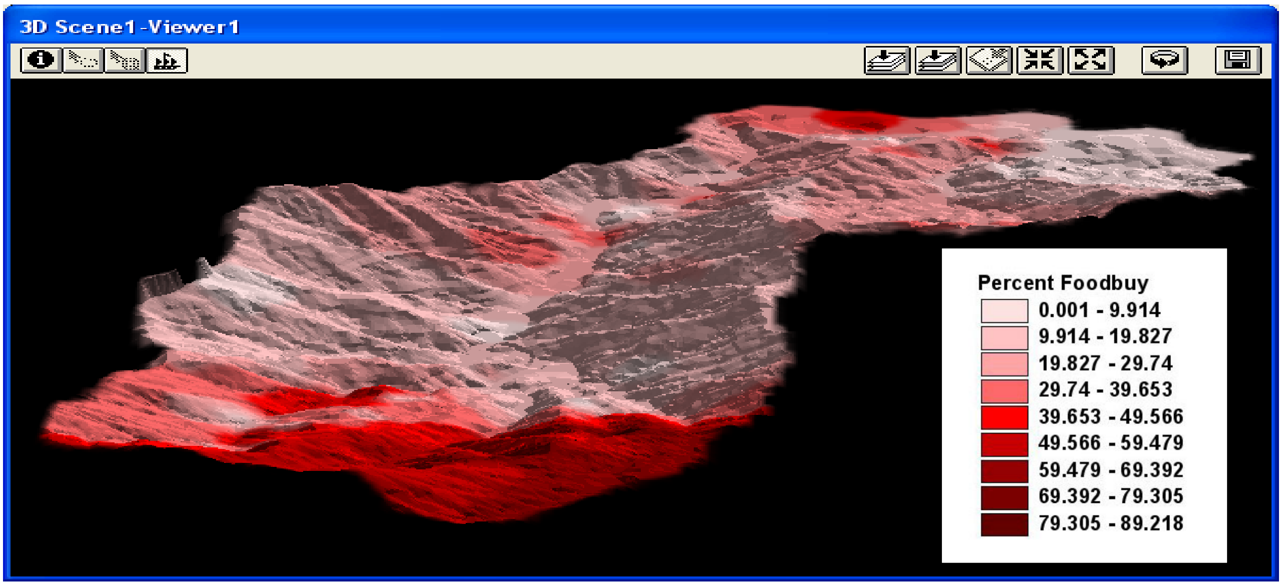


Figure 8: Spatial distribution of percentage food bought draped on the three dimensional view of watershed studied

4.3.3. Farm and family income

Farm income is the economic ability of a farm in a year to provide an economic surplus to be used by the farming family. 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, 2000).

Due to the differentiation of spatial distribution of quality of land, farm input and crop productivity different level of farm income in the different spatial location of watershed can be expected. Thus, farm incomes of each household were estimated using the micro level information derived from farmer's interviews and their spatial distribution in the watershed was observed. Based on the randomly selected spatial distribution of the farms and families location in the area, the income differentiation in the space presented. Figure 9 shows a clearly higher farm income in the most favourable zones. The spatial differences in farm income in the different location of the watershed is mainly due to the proportionally smaller size of *Khet* land per family in highland areas and their productivity as compared to lowland. Besides, vegetable farming, which is the intensively practiced in lowland areas, could be another reason for having high farm incomes at lowland areas. Which also confirmed from the higher farm income per ha of cultivated land and per person from the lowland areas as compared to highland areas. Farm income was more or less similar in lowland and middle land. Families in these areas were able to earn similar level of farm income because of well-terraced land, more intensive use of external input and crop diversification that allows crop rotation and reduces risk of crop failure.

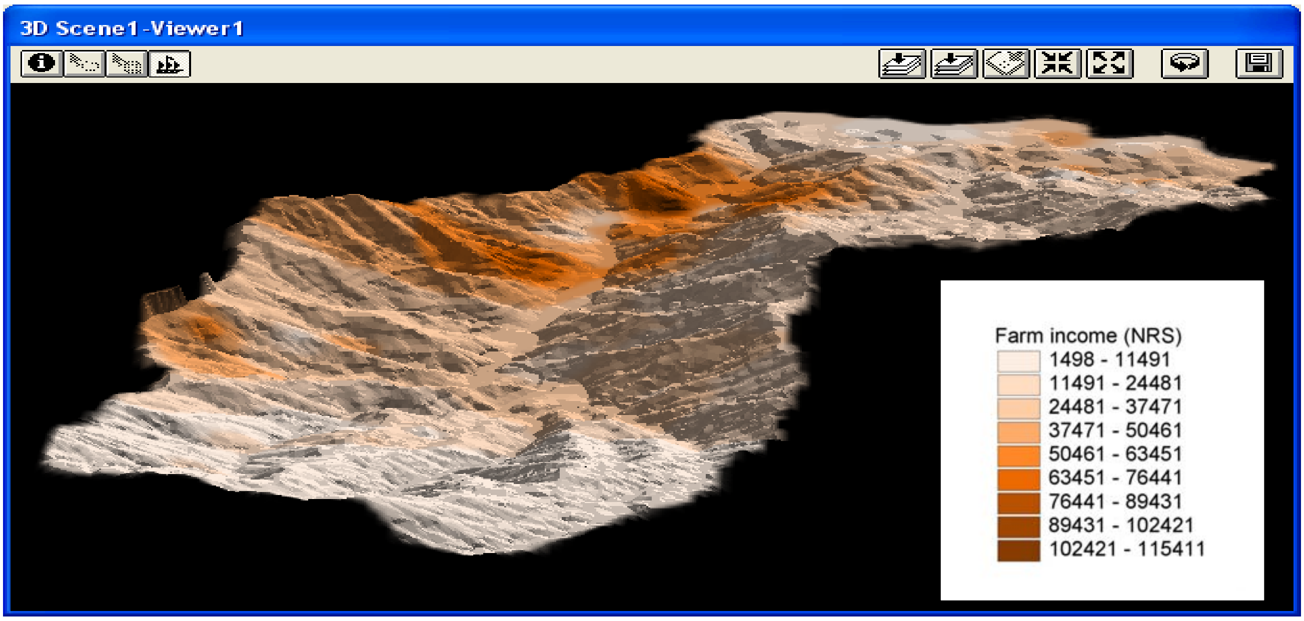


Figure 9: **Spatial distribution of farm income/family draped on the three dimensional view of watershed studied**

Off-farm income is defined as income earned by family members by engaging in activities other than the farm and/or the household. In about 75% of the sample families in lowland, 68% in middle land, and 63% in highland at least one of the family members was involved in off-farm/off-household activities. The main types of activities include labour work in urban centre for building construction and others are job, trade, handicraft and production and sale of alcoholic drinks. The amounts earned from off farm does not look very much difference is because of most of the people from high land zone also come down to lowland area for construction labour while they do not have their farm activities.

Family income is calculated as the sum of farm income, off-farm income and income on family owned resources. Following the same approach as described above in using family level information and integrate them into GIS the spatial distribution can be shown as in Figure 10. Through out the study area farm income accounts for greater share of the family income. Family income per person and per labour unit were significantly higher at low land as compared to highland which could be due to the accumulated effect of land quality, education level of farmers, distance from market and road. The results of farm and family incomes and per unit basis shows that both farm and family incomes were significantly lower at higher elevation (highland) as compared to lower elevations (lowland). So this kind of economic differentiation could lead to different level of watershed degradation in the different location of the watershed.

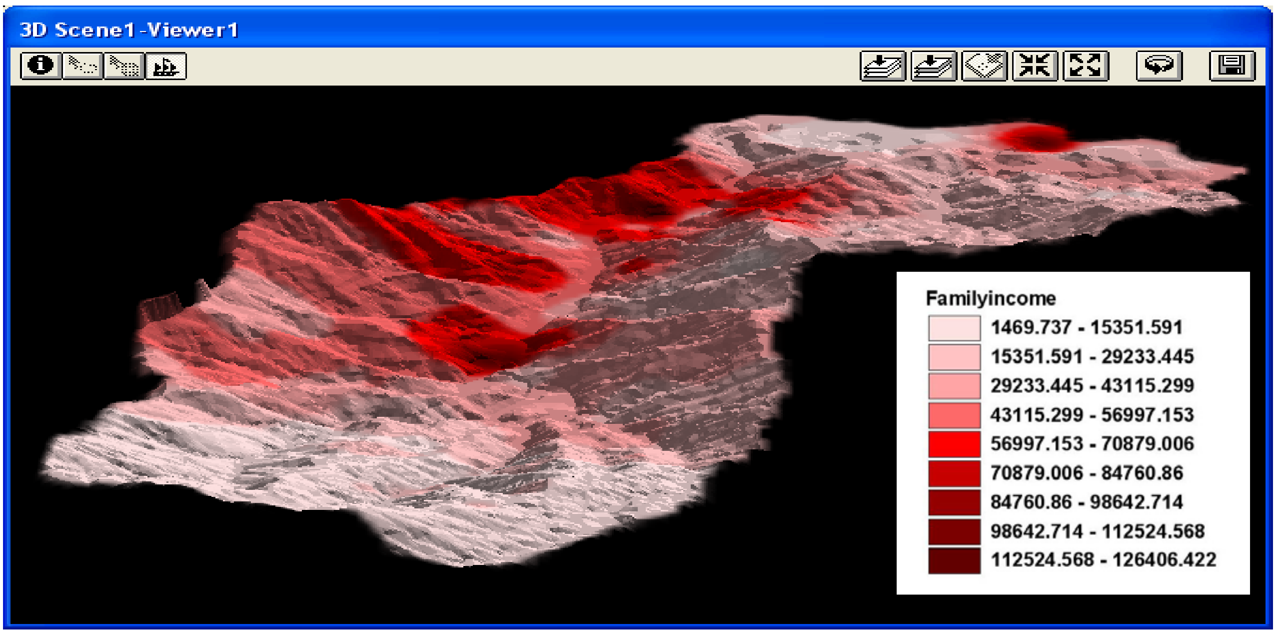


Figure 10: **Spatial distribution of family income/family draped on the three dimensional view of watershed studied**

4.4. Farm income modeling and testing the impact of future development strategies

A GIS based regression model was established to estimate the farm income. Different methods and analytical steps were carried out to generate the variables in order to integrate both socio-economic and biophysical indicators in the model.

At first, farm income in different levels for example at family, per ha of cultivated land, per person together with other factors e.g. cultivated land size, crop yield were estimated using the micro survey data. Spatial autocorrelation of each the socio-economic indicators were observed and continuous thematic raster maps were produced for those socio-economic factors that have found significant spatial autocorrelation by performing the interpolation of household location. On the other hand, biophysical (irrigated and non irrigated farm land, slope, infrastructure condition, travelling time to nearest market) condition of the study area was prepared using GIS methodology. Distance of each of the household location from nearest market centre was measured using GIS methodology and distance grid cells to travel from each of the sampling location to nearest market centre were prepared.

Finally, all the grid cells were combined thus both socio-economic 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 centre (Figure 11) and quantity of irrigated land (Figure 12) have found significantly highly correlated with farm incomes so finally multiple regression analysis was carried out by taking farm income per person as dependent variable and cost distance to nearest market centre and size of available irrigated land as independent variables and following equation was observed.

Farm income/person = 5205.851+6720*irrigated land in ha-44.956*cost distance (travelling time in minutes from market centre to the house location)

The model aims at regionalising the current income situation and uses statistical dependencies for the simulation of the effects of future strategies. Based on the functional relationship between income and cost distance to market and the quantity of irrigated land, future strategy of reducing cost distance to market through the development and improvement of road structure and the increment of irrigated land through the development of small scale irrigation system wherever possible and their impact on income were tested and presented (Figure 13 and 14)

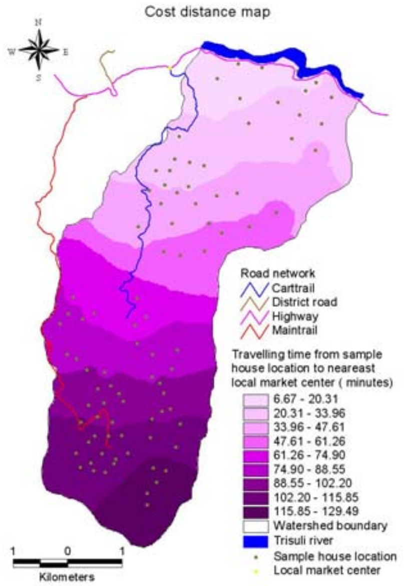


Figure 11: Cost distance map, 2003

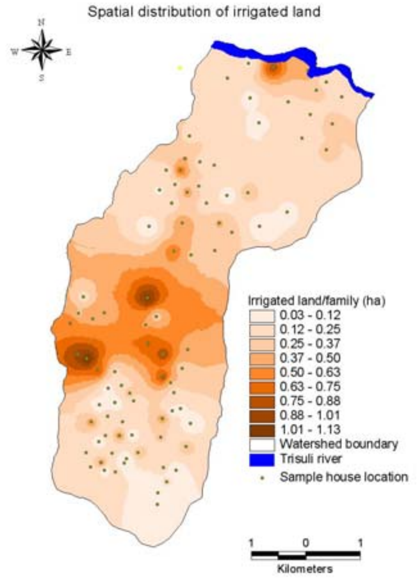


Fig12: Spatial distribution of irri. land, 2003

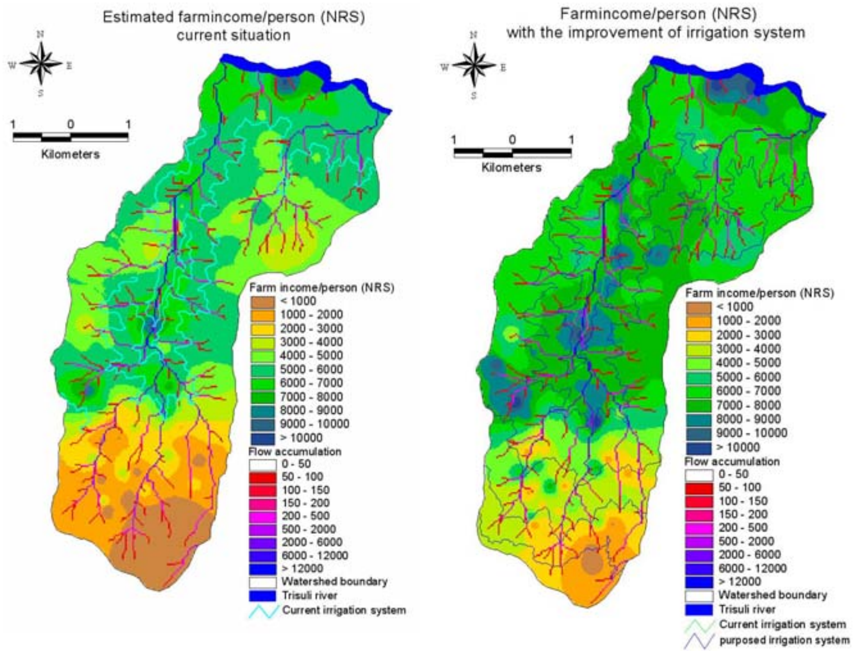


Figure 13: Estimated income/person before and after the development of local irrigation system

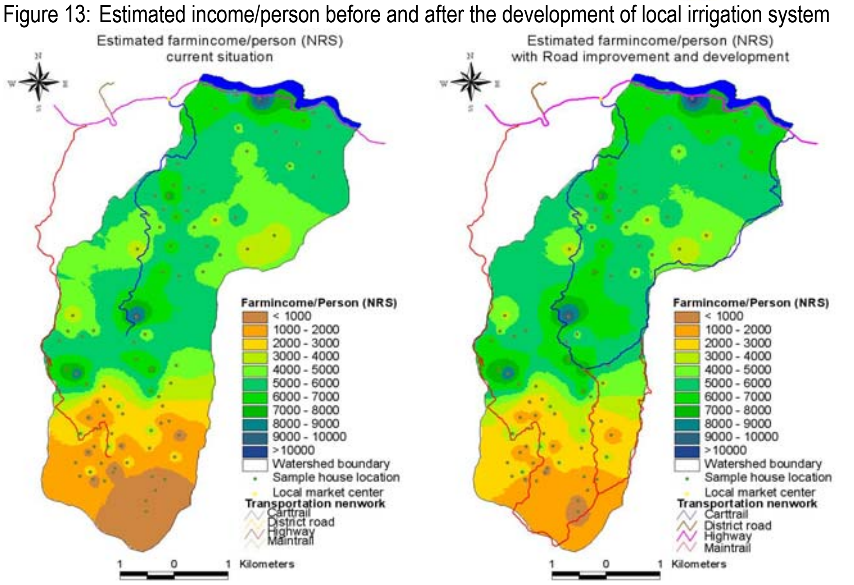
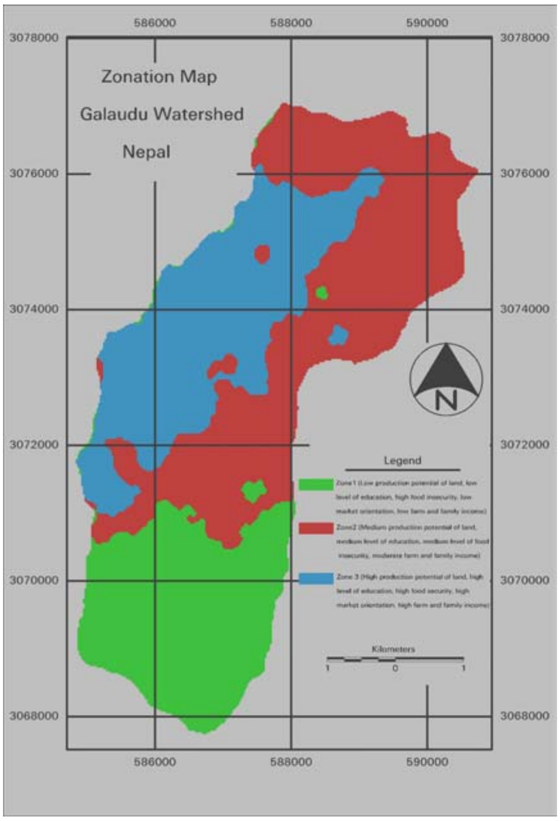


Figure 14: Estimated income/person before and after the road improvement

4.5. Classification of the watershed into homogeneous zones

Individual GIS layer of socio-economic situation and biophysical condition as presented above, those found spatially different, were imported into the ERDAS Imagine software and combining them together by performing the layer stacking command. Then unsupervised classification was run for the stacking layer to automatically cluster the class signatures. Of the unsupervised classification techniques, Iterative Self-Organising Data Analysis Technique (ISODATA) was used and classified the watershed into three zones. As a result of unsupervised classification three clear zones (Figure 15) were formed that can be clearly interpreted using the information of individual GIS layer as presented above and expert knowledge as: Zone 1 characterises higher slope, high rate of soil loss, lower education level of people, low crop yield, low market orientation (lower share in percentage of crop sold), less secure in food security (higher percentage of food buy) in comparison of other two zones. While that of Zone 2 features with average slope is < zone 1 > zone 3, average rate of soil loss is < zone 1 > zone 3, education level < zone 1 > zone 3, crop yield, market orientation also follows the same trend as others, more secure in food supply than zone 1 but less secure than zone3. The Zone 3 stands for lower slope, relatively flat land low rate of soil loss, higher education level of people, high crop yield, high market orientation (bigger share in percentage of crop sold), more secure in food security (lower percentage of food buy) in comparison of other two zones.



Variables	Zone1	Zone2	Zone3
Education (WMI)	0.12	0.26	0.34
Paddy field (ha)	0.19	0.33	0.34
Paddy yield (kg/ha)	1706	4072	477
Maize yield (kg/ha)	1636	2680	323
Crop pro. (kg)	1373	2447	268
Vegetable revenue (NRS)	256	5018	15355
% Crop sold	4.9	24.0	47.7
Food buy (%)	46.9	17.5	19.3
Slope (Degree)	27	21	24
Soil loss (t/ha/yr)	160	68	115
Farm income(NRS)	9807	2183	413
Family income(NRS)	15029	28100	5017
Forest loss (%)	35	13	9

Figure 15: Zoning map showing three clearly distinct zones of Galaudu watershed combining the socio-economic and resources condition for prioritisation and planning the zone specific development and problem solving activities

5. Conclusions

1. The methodological focus in this research is on the development and improvement of the methodology to investigate complex problems in rural development in a systems context. The results are expected to be used in areas of similar conditions. It has been proven that the integration of family survey information and data from remote sensing can be used in a combined approach of the classical economic tools and the RS/GIS concepts. Still, further research is to be done, but the stage is reached where RS/GIS is not only a tool of presenting complex data in an easy way, but do carry out quantitative and statistically based analyses. In the process of research globalisation, those methodological developments contribute to quicker increase of research quality.

2. The empirical analysis gives an example of the concept of the empirical relationship under real conditions. The way those complex relations in rural development can be structured in the case of a mountain region and the concept of information and knowledge systems required for such analyses as well as the analytical results as a basis for future strategy assessment provide an overall approach for empirical analyses and definition of problem-solving strategies.

3. The specific results show differences in the long-term development of land use in the past following different gradient in the area. Forest resource degradation, soil losses were found to be directly correlated with the altitude and slope and remoteness of the area. Similar trend was observed with spatial differentiation of living standard parameters including farm family income, food availability, dependency on resources, etc. There was direct negative correlation in between the distance from the road, market and the altitude, and the socio-economic status-e.g. family income, education level, crop production and selling. Hence it is concluded that

integration of socio-economic data into the GIS system is an appropriate tool for zone delineation as well as to formulate and test long-term problem solving strategies achieving both sustainable natural resource management and better livelihood simultaneously.

References:

Bhatta, B. R., Chalise, S. R., Myint, A. K., and Sharma, P. N. (Eds), (1999): Recent Concepts, Knowledge, Practices, and New Skills in Participatory Integrated Watershed Management: Trainers Resource Book. ICIMOD, PWMTA-FAO, and Department of Soil Conservation and Watershed Management, Nepal.

Doppler, W. (1998): Setting the Frame: The environmental Perspectives in Rural and Farming Systems Analyses. In proceedings of the Third European Symposium on Rural and Farming Systems analyses: Environmental Perspectives. Hohenheim, Germany, March 1998.

Doppler, W. (2000): Farming and Rural System Approaches. Published Lecturing Material. Universithy of Hohenheim, Stuttgart; Germany

ERDAS (Earth Resources Data Analysis System) (1998): ERDAS Imagine 8.3.1. ERDAS Inc., Atlanta, Georgia, USA.

ESCAP, (1997): Guidelines and Manual on Land-use Planning and Practices in Watershed Management and Disaster Reduction. Economic and Social Commission for Asia and the Pacific (ESCAP), United Nations.

FAO (1985): Tropical Forestry Action Plan, Committee on Forest Development in the Tropics, FAO, UN, Rome.

Gautam, A. P., Webb, E. L. and Eiumnoh, A., (2002): GIS assessment of land use-land cover changes associated with community forestry implementation in the Middle Hills of Nepal. Mountain Research and Development 22(1): 63-69.

Gibson, C., McKean, M. A., and Ostrom, E. (Eds.), (2000): *People and Forests: Communities, Institutions, and Governance*. The MIT Press.

Grüninger, M. (2001): The socio-economic impact of soil degradation on Upland Farming Systems in West Sumatra, Indonesia. In: Doppler, W. and Bauer (Eds.) Farming Systems and Resource Economics, Vol. 101 Kiel: Wissenschaftsverlag vauk

(ICIMOD) International Centre for Integrated Mountain Development, (1994): Application of GIS in rural development planning in Nepal. ICIMOD, Kathmandu, Nepal.

Jackson, W. J., Tamrakar, R. M., Hunt, S., and Shepherd, K. R., (1998): Land-use changes in two Middle Hill districts of Nepal. Mountain Research and Development 18(3): 193-12

K.C., Krishna Bahadur (2001): Mapping Soil Erosion Susceptibility Using Remote Sensing and GIS. A case study of Upper Nam Wa watershed, Nan province, Thailand Thesis No. NR-01-03, AIT, Bangkok

Lentes, P. (2004): The Contribution of GIS and Remote Sensing to farming Systems Research on Micro-and Regional scale in North west Vietnam. In: Doppler, W. and S. Bauer (Eds.) Farming and rural System Economics, Vol. 52. Kiel: Wissenschaftsverlag vauk

Moore, I. D. & Burch, G. J. (1986a): Physical basis of the length slope factor in the Universal Soil Loss Equation. *Soil Sci. Soc. Am. J.* 50(5), 1294-1298.

Morgan, R.P.C. (1986): Soil Erosion and Conservation, Long man group UK Ltd., London.

Naiman, R. J., Bisson, P. A. and Turner, M. G., (1997): Approaches to management at the watershed scale. In: Kohm, K. A. and Franklin, J. F. (Eds.), Creating a Forestry for the 21st Century: the Science of Ecosystem Management. Island Press.

Schawab, G.O., Fangmeier, D.D., Elliot, W.J. and R.K. Frevert (1993): Soil and Water Conservation Engineering, 4th edition, John Wiley & Sons, Inc., NY.

Sharma, P. N. and Krosschell, C., (1996): An approach to farmer-led sustainable upland watershed management. In: Sharma, P. N. (Ed.), Recent Developments, Status and Gaps in Participatory Watershed Management Education and Training in Asia (PWMTA). PWMTA and FARM Programs, Kathmandu, Nepal.

Tekle, K. and Hedlund, L., (2000): Land cover changes between 1958 and 1986 in Kalu District, Southern Wello, Ethiopia. Mountain Research and Development 20(1): 42-51.

Thapa, G.B. & K.E. Weber (1991): Soil Erosion in Developing Countries: Causes, Policies and Programs, HSD working paper 35, AIT, Bangkok.

Wishmeier, W.H. and D.D. Smith (1978): Predicting Rainfall Erosion Losses A Guide to conservation Planning, USDA Handbook 537, Washington.