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Sustainable soil management practices and farmers livelihoods: A spatial perspective

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ABSTRACT

Diverse soil management practices exist even within a narrow transect of farming areas in Nepal. This variation is principally due to location of farm households along the spatial gradient, infrastructure availability, market demands and farmers' awareness to on-farm resource conservation. Over-exploitation of farm resources was negligible and disturbance to agro-ecology was minimal in the past couple of decades. In the last decade, however, due to a massive sprawl in the available farmlands along with a shift of subsistence farming towards market-oriented conventional approach, prime agricultural lands have been over-exploited. This led to negative repercussion on production base and farmers' livelihoods. This paper concerns with the simulation of farm income through spatial modeling considering the strategy of sustainable soil management practices. Spatial modeling shows higher farm income gains due to intervention in rural areas (low income zone) and peri-urban areas (high income zone) with existing unsustainable soil management practices. Spatial explicit assessment shows that integration of micro-survey into spatial environment and subsequently modeling of present and future situation would add more information on the results from conventional surveys. Therefore spatial effects should be duly considered while formulating agriculture and rural development policies.

Introduction

Diverse soil management practices exist within a short transect of farming zones in Nepal. This variation in farming practices are basically due to location of the farm families along the spatial gradient, access to infrastructures and farmers' awareness to on-farm resource conservation (Bhatta and Neupane, 2010).

Biophysical factors such as variation in weather, soil types and resource availability (Verbung *et al*., 2004) as well as socio-demographic attributes such as family needs, market demands, external influence and technological availability also lead to a variation in farming practices (Briassoulis, 2000).

In Nepal, there was negligible encroachment on available farm resources in the past couple of decades. Last decade, however, showed a massive sprawl in the available farmlands along with the shift of farming practices. This has led to over-exploitation of prime agricultural lands and adoption of conventional farming practices. Now, the problem of fertility decline is reported in many parts of Nepal; however, the intensity of fertility decline is higher in the peri-urban areas (PUAs) where agro-chemicals are applied in injudicious manner (Bhatta and Doppler, 2011; Bhatta, 2010a).

Although the fulfillment of subsistence requirements is the primary objective of the majority of the farmers since centuries (Brown, 1997; Carson, 1992), market-oriented production is a key factor driving land-use intensification in the densely populated farming areas of the Nepal (Brown and Shrestha, 2000). While cultivation of the sloping marginal hills leads to severe soil erosion in the hilly areas, reduction in factor productivity is realized in PUAs.

Intensive cultivation of crops depletes soil nutrients if organic and inorganic fertilizers additions are insufficient (Brown and Shrestha, 2000). With growing food demands in the cities along with farmers' short term economic gain, family farms are facing several challenges: traditional agricultural systems are changing, landholding are getting steadily smaller in size, farming is getting more sophisticated, focused and intensive with the use of agro-chemicals (Bhatta and Doppler, 2011).

While farming towards rural areas is still subsistence which is based on locally available resources with minimal or no external market influence, shifting subsistence-based farming towards market-oriented intensification is more pronounced towards PUAs. This spatial effect is related to the road access (Brown, 2003). Households with poor road access, for instance, have relatively larger holdings, lower productivity and are more reliant on the subsistence agriculture. Sustainability issues of high external input use farming have widely been raised along the spatial gradient (Bhatta *et al*., 2009), particularly in the areas with market accessibility. Meanwhile, agriculture based on balanced inputs use has shown a wide degree of resilience (Sharma, 2006). Spatial explicit analyses are now getting more importance in dealing with farmers' livelihoods at the regional level (Bhatta and Neupane, 2010; Bhatta *et al*., 2009; Codjoe, 2007; Evans and Moran, 2002; Schreier and Brown, 2001; Bowers and Hirschfield, 1999).

The ability of geographic information system (GIS) to integrate maps and databases, using the geography as the common feature has been extremely effective in the context of agriculture development and resource management. The Collecting socio-economic data in a geographic realm and maintaining the original location information could reveal patterns in the data, which would otherwise be missed (Brown, 2003).

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Socio-economic data integration in the GIS environment has implications for policy development, particularly infrastructure development policies that require the socio-economic assessment in the spatial context (Brown, 2003). It is with this background information that this research is based on the concept of spatial differentiation on fertility management practices and it simulates farm income at regional scale by integrating socio-economic and biophysical information.

Methodology and data integration

Study area

The study was conducted in the peri-urban areas of Kathmandu Valley, Nepal. This covers Lalitpur and Bhaktapur districts (Figure 1). These districts represent the typical biophysical and socio-economic characteristics of the rural and peri-urban farm families in Nepal (Bhatta, 2010b). The study area is composed of vivid altitudinal gradients ranging from 900 to 2500 meters above sea level (Table 1, Figure 2). While a sizeable portion of the area possesses elevation that ranges from 1500 to 1800 meter above sea level, area with less than 1000 meters of elevation is negligible. Almost 49% of the study area possesses flat or nearly flat (0 to 5%) lands while the remaining part has steep to vey steep slope (10% to >30%) (Table 2). The rural hills in Nepal have relatively higher slopes than that of the PUAs. Slope along with the fragile landscape leads to a severe soil erosion in the hill farming systems throughout the country (Brown and Shrestha, 2000).

In order to facilitate comparison in spatial explicit analysis, the study area was divided into two zones viz., high income and low income zones. The underlying assumption was that farmers living towards rural areas have less access to infrastructures and their production is lower while opposite is true towards PUAs.

Figure 1: Map of Nepal showing study districts (Bhaktpur and Lalitpur districts)

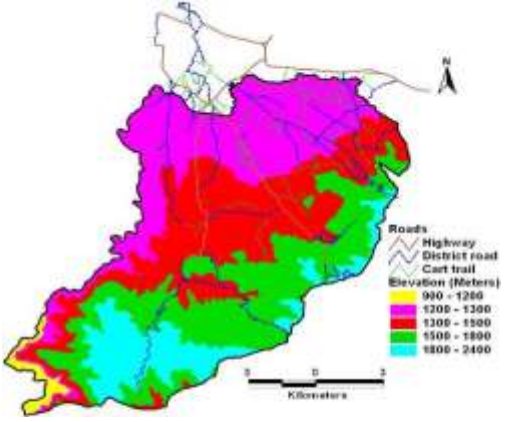

Figure 2: Elevation (meters) ranges in the study area derived from digital elevation model

Sampling and the data

This research was based on cross-sectional study of 130 farm households selected through spatial and random sampling procedures. Using spatial sampling and simple random sampling, 95 and 35 farm households were selected respectively from within the study area. Spatial sampling was adopted because information on the number of households that had settled down was not available and the settlement was scattered throughout the region with wider distance between each household. Furthermore, as the study focuses on spatial simulation of farm income, the conventional sampling design would not justify their use. The spatial sampling method is based on the concept of spatial dependency which relies on the principle of proximity of locations to one another (Tobler, 1970). The selection of this method is based on the principle that all households settled down in the study area were surveyed. Spatial buffers were prepared and an attempt was made to select centrally located household from each buffer.

Data related to farm income were collected using structured questionnaire administered through personal interview. Different analogue maps were purchased from the Nepal Department of Survey and baseline GIS data for the study area was prepared using such maps. These maps cover roads, rivers and streams, settlements, administrative boundary, contour lines (100-m spacing) and elevations.

Spatial data integration

The strength of the GIS lies in its ability to integrate socio-economic data into a common spatial platform. Geographic locations of the sampled households were taken using geographic positioning system (GPS) and after linking GPS receiver to a computer, the recorded data were exported into ArcView 3.3. Farm income was finally integrated into GIS after testing for spatial autocorrelation, which measures two things within the geo-space: the proximity of the locations and the similarity of the location attribute (Lee and Wong, 2001). It was then interpolated using inverse distance weighted (IDW) method which is one of the commonly available methods (Longley *et al.*, 2004). This method assumes that each point has a local influence which is inversely proportional to a selected power of the distance. Therefore, the variable being mapped decreases in influence with the distance from its sampled location. With IDW, farm income throughout the region (more precisely, in each pixel) was calculated.

Cost distance analysis

The basic principle of the cost distance analysis is that farm activities have a close link with market. Production practices, farm-family income and living standard follow spatial tendency. Therefore, it is based on the J. H. von Thünen model which incorporates agricultural market to illustrate the importance of spatial location and the resulting transport costs to a central market and its effect on production at various locations (Nelson, 2002).

Cost distances from different parts of the study areas to the market was measured using a GIS-based cost weighted distance model (ESRI, 1997) and distance grid cells to travel from different locations of the study area to the main market were prepared (KC, 2005). This technique is based on the idea that each cell in a map can be given a relative “cost” associated with moving across that cell (ESRI, 1992). The “cost” of moving across a cell is calculated as the cell size (in meters) times a weighting factor based on the quality of the road and associated factors of the cell such as slope.

Scoring landforms

Regional spatial model considers the cost distance to the market, dominant landforms and existing soil management practices along the spatial gradient. The study area is composed of four dominant landforms (Figure 3) each with differing soil quality and production potential.

Soils with dark color and alluvial deposits, for instance, have better water holding and nutrient supplying capacity, thick soil layer, well-drained soil and almost neutral in reaction (Singh *et al.*, 2007) and these are the essential requirements of the majority of the crops such as rice and wheat (Rajbhandari and Bhatta, 2008).

Lands rich in this type of soil were given a higher score because of the higher potency to produce crops. The second group of land quality is composed of the soils around the ancient lakes and river terraces which have a higher rate of erosion than the former class. Lands dominated by this type of soils grow food crops successfully but comparable yields could not be achieved as of the former landform and hence it is weighted lesser than the former class.

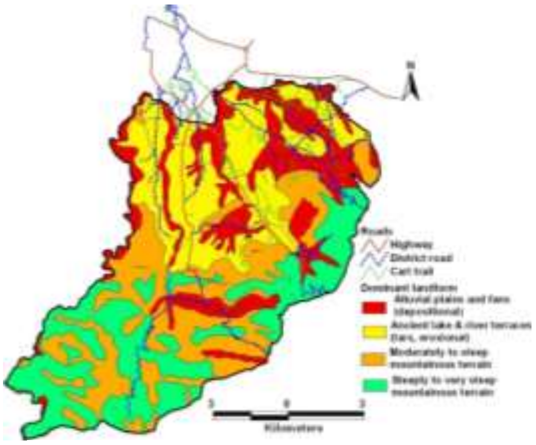

Figure 3: Dominant landforms available in the study area

The third group of the landform is composed of mountain terrains with moderate slope, generally suitable for the subsistence farming and has higher cost of land management than the alluvial lands. This landform was given lower value than former classes.

The fourth landform class is the mountain terraces with steep to very steep slope, thin soil layer, stony subsoil and is subjected to severe erosion caused both by wind and water (Müller-Böker, 1991). This group of lands was allocated the lowest score.

The difference in the score between two classes of landform (alluvial flat lands and mountain terrains) was calculated using gross margin of rice (Bhatta, 2010b). The ratio of the gross margin of rice in both classes is almost equivalent to 1.5. The differences in the productive potential of two landforms composed of the alluvial soils are very narrow.

They were, therefore, given higher values with a narrow difference. Similarly, for giving weight to steep slope and very steep slope, gross margin of maize was considered and the ratio was equivalent to 1.2. Therefore, 1.70 was given to steep land while 1.40 was assigned for highly steep land.

Scoring existing soil management practices (current scenario)

Four existing soil management practices namely sustainable management, conventional, unbalanced application and farm manure application were considered for preparing a comprehensive soil quality weighting of the study area. These existing soil management practices are considered as current scenario for modeling purpose.

Sustainable soil management is the production practice followed by the limited number of organic growers around the peri-urban areas. Farmers with this practice give due attention towards the use of organic manure and other locally available resources to meet the plant needs to nutrients and indigenous knowledge in controlling pests and diseases. In contrast to this, use of agro-chemicals is intensive, particularly with commercial conventional farming.

Nearness of the family farms to the market also motivates farmers to follow this practice (Bhatta and Doppler, 2010). Use of farm manure is the dominant practice of supplying nutrients to plants in the rural areas. Even if some farmers apply inorganic inputs, the amount applied is negligible to be considered as the conventional farming. As such, this farm production is frequently referred to as ‘organic by default’ or ‘organic by neglect’ (Scialabba, 2000).

Under this practice, nutrient supplied is far below than requirements and also the organic manure applied in the field is not enough to hold the soil against soil erosion. Therefore, this practice of soil management is not considered sustainable. There is an intermediate practice that embraces the unbalanced use of manure and fertilizers. Farmers give credence to organic manure and they also apply chemical fertilizers. However, application of chemical fertilizers is higher than the buffering ability of the applied organic manure. Farmers with this practice notice the problem of fertility decline.

Sustainable soil management practice is considered very important for getting good yield and hence one of the key components of sustainable agriculture (Bhatta, 2010b). It was, in this realm, given a higher value (2.00) followed by the soil managed intensively using inorganic inputs mainly through urea fertilizer (1.90). Application of high amount of inorganic fertilizer is enough to get good yield, however, application of farm manure is not enough to maintain good structure of soil. Therefore, this land received lower weight (1.80) than former practices of soil management. The last practice of soil management is based on application of farm manure only and the amount applied is not enough to supply nutrients to the plants. Such lands were given the lowest value (1.50) among all existing practices.

Soil quality weighting

After having weights assigned, a combined land quality weighting map was produced using GIS overlay technique. Current scenario considers present state of arts in soil management along with dominant landforms while future scenario takes into account the improvement in the soil quality provided soil is managed sustainably.

Mathematically,

$$(SQ_{present})_i = (W_{lf}\ x\ W_{mp})_i \qquad (1)$$

$$(SQ_{future})_i = \{W_{lf}\ x\ (W_{mp} + W_{mp}\ x\ \%\Delta)\}_i \qquad (2)$$

Where, SQ_i is the soil quality of the i^{th} cell in the space, W_{lf} is the weight given to the landform, W_{mp} is the land weight to the soil management under different scenarios and each of the value is associated to the i^{th} cell.

Equation (1) represents the current scenario while equation (2) represents soil quality in the future scenario (intervention) after resorting sustainable soil management practices.

Following equation (1), altogether 16 classes are formed in which the highest weight (4.00) goes to the alluvial plain lands with sustainable fertility management practices while the lowest weight goes to the mountain terrains with a steep slope (Table 3) in which only farm manure is applied (2.10).

Results and discussion

Sustainable soil management and soil quality weighing (future scenario)

Sustainable soil management strategy, an assumed scenario, is intervention in existing fertility management practices to simulate farm income along the spatial gradient. For simplicity, this strategy is named as future scenario. The underlying assumption is that farm income will be improved by resorting to sustainable soil management practices that would enhance soil fertility, prevent erosion, provide good yields and hence improve farmers' livelihoods. This practice encompasses adoption of efficient crop rotation, intercropping, adequate use of better quality farm manure, use of terracing and contouring in the hills, agro-forestry system and application of inorganic fertilizers considering the nutrient supplying capacity through other means. Lands with balanced or sustainable practice at present were assumed to have same land quality in the future too. The scope of quality enhancement, therefore, lies on those lands where only inorganic fertilizers or organic manures are applied. Adopting sustainable soil management practices would assume to increase quality by 3% in alluvial plains and 5% in other landforms. Similarly, it is assumed that sustainable management would increase land quality score associated to land management by 5% under existing unbalanced application in alluvial plains and by 10% in other landforms. With sustainable management, 5% of the land management value is expected to increase with existing manure application in alluvial plains, 10% in river terraces and 20% in the rest. The higher percentage increment in soil quality in the hills is principally owing to the bigger scope of quality enhancement through sustainable soil management practices. In the slope lands, more farm manure application (2-3 tonne ha^{-1} more) than the present amount would replace organic matter lost through soil erosion (Tiwari *et al.*, 2009; Weber, 2003; Subedi and Sapkota, 2001; Brown and Shrestha, 2000). Existing practices of farm manure collection, handling and overall management is inefficient (Jaishy *et al.*, 1999; Dahal, 1996) and there is big room for getting higher yields with sustainable management practices (Bhatta, 2010b). The comprehensive soil quality weighing under existing practice and sustainable soil management practices is depicted in Table 3. The combined soil quality weighing after sustainable soil management (future scenario) is derived using equation (2). Values in the parentheses indicate the increase in the score by a given percentage due to sustainable soil management practice

Combined soil quality weight follows the patterns of individual weighting with some variations (Table 3). Most of the farmlands situated in the higher altitude get a poor combined score as compared to those which are situated on the valley bottom (relatively plain lands). Alluvial plains and river terraces with existing practice of farm manure application only got land quality increment compared to the mountain terraces with existing sustainable soil management practices. However, soil quality weight in steep and very steep slopes of mountain terrains has been increased through intervention. With some increment in soil quality would increase farm income appreciably in the hills and hence enhance livelihoods of the families.

For the purpose of our calculations, the prices of inputs as well as outputs were kept constant with the assumption that the impact of future inflation will be approximately equal on both sides of the ledger. It is also assumed that there is no technological development in the short span of time. Consequently, land management is the one largest factor influencing the performance production and farm income in our model.

Base model

GIS-based multiple regression model was employed to estimate farm income using soil quality and cost distance to main market as explanatory variables. The results show significant effects of explanatory variables on farm income and have expected direction of relationship (Equation 3). The model has 61% of predictive power. A unit change in cost distance affects farm income by NRs 2615 while that of land quality by NRs 163200, *ceteris paribus.*

$$Y = -110504\ (-57^{**}) - 2615\ X_1\ (-135^{**}) + 163200\ X_2\ (301^{**}) \qquad (3)$$

$R^2 = 0.61$, $F\ stat\ (2, 282212) = 212500\ (p<0.01)$

Where, Y is the farm income (NRs ha^{-1}), X_1 is the accumulated cost distance to the market (minute), X_2 is the land quality weight.

** highly significant at 0.01 level of probability

Values in the parentheses indicate t statistic

Note: 1 US $ = 73 NRs

Estimated farm income along the spatial gradient using regression equation (3) shows that it is higher towards PUAs and it declines towards rural areas (Figure 4). This proves that the assumption of regional stratification based on income seems correct. Although several classes within the region could be noticed, broadly there are two regions: upper half region towards the north (towards PUAs) show higher income (>186474 NRs) and lower half region towards the south (towards rural hills) show lower income. It is further clear that the farming areas with road access have higher estimated income as compared to those without road access. It is because farmers with road access do have easy access to other infrastructures, particularly market and hence they could buy the inputs and sell outputs very easily with lower cost distance to the market. In contrary, farmers without road access have to spend much time to reach to the market and hence farming is subsistence-based with less dependency to the market. This leads to poor livelihoods of the rural farmers.

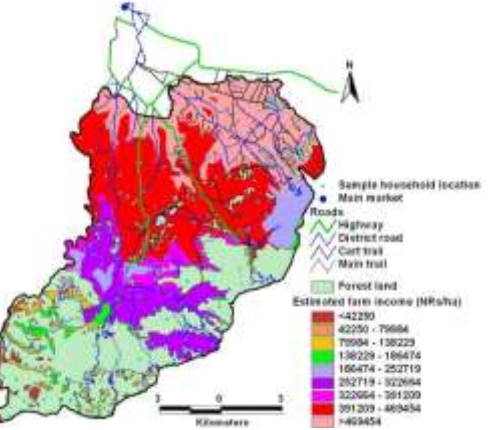

Figure 4: Estimated farm income (NRs ha^{-1}) along the spatial gradient

Simulated model under sustainable soil management scenario Farm income under sustainable soil management scenario was estimated using spatial regression model and the resulting functional form is presented in equation (4). The impact on farm income due to intervention (sustainable soil management practices) was calculated by deducting the estimated income through future scenario (Figure 5) and present scenario (Figure 4) and expressed in percentage increment (Figure 6).

Empirical model shows that both cost distance and land quality weighing after sustainable soil management practices have significant effect on predicting farm income. The degree of prediction is 58%. With one unit increase in cost distance in terms of travelling time in minutes, there is consequent decrease in farm income by NRs 3632, ceteris paribus, while with a unit increment in land quality, farm income will be improved by NRs 160200.

$$Y = -110338\ (-44^{**}) - 3632\ X_1\ (-186^{**}) + 160200\ X_2\ (238^{**}) \qquad (4)$$

$$R^2 = 0.58,\ F\ stat\ (2,\ 282212) = 180200\ (p<0.01)$$

Where, Y is the farm income (NRs ha^{-1}), X_1 is the accumulated cost distance to the market (minute), X_2 is the land quality weight

Note: Values in the parentheses indicate t-statistics and ** indicates highly significant (p<0.01)

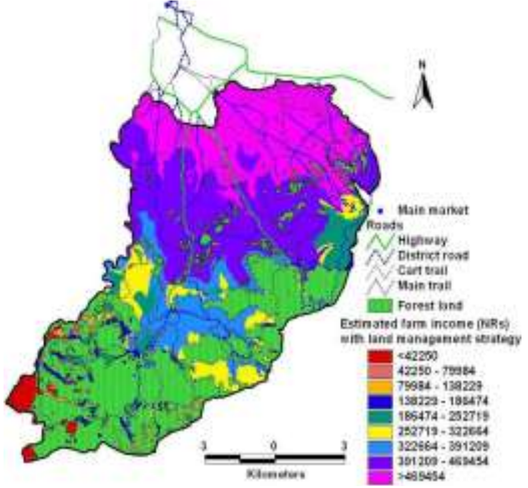

Figure 5: Simulated farm income (NRs ha^{-1}) under sustainable soil management strategy

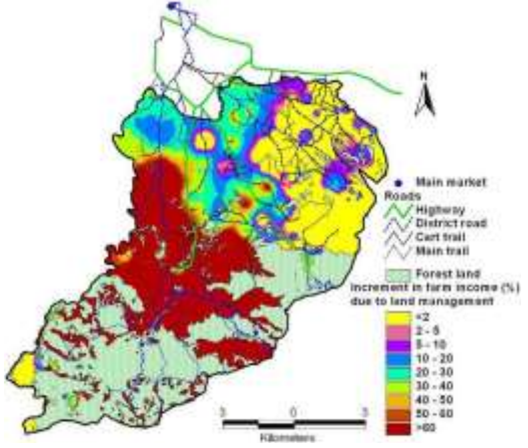

Figure 6: Impact of sustainable soil management on farm income (% increment)

Estimated farm income under future scenario still reflects similar tendency as of current scenario (Figure 5). However, there has been a substantial increment in farm income in the future as compared to the existing situation. Farm income increment due to soil quality improvement lies between no increments to as high as more than 60%. The improvement in farm income in the PUAs, particularly in the areas with existing sustainable soil management practices is almost negligible (<2%) while areas with the intensive commercial inorganic farming have higher improvement that goes as high as 40% (Figure 6). This is basically due to increment in soil quality by employing sustainable soil management practices instead of intensive conventional farming. Similarly, increment in the farm income in the poor income zone (rural hills) is very high (>60%). Since rural farm families depend heavily on local resources, especially on land, this increment in the farm income due to sustainable land management practices in the rural areas would have substantial impact on the local livelihoods.

Conclusion

The future scenario illustrates how land quality weighing could be improved by employing sustainable soil management practices. The baseline model shows spatial effects on farm income: rural hills with relative inaccessibility have lower farm income while it is higher towards PUAs. The same is true in the future scenario too. There is substantial increment in farm income in the rural areas after intervention. As farm-families living in the higher altitudes have the lower standard of living and they depend much on farming for their subsistence, sustainable soil management practices provide more economic incentives to them. Similarly, peri-urban areas with existing unsustainable soil management practices should also be replaced by sustainable practices for getting farm income improved and fertility restored. As spatial location of the farm family plays crucial role in livelihoods, any projects for rural development should take spatial effects into account.

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Table 1: Area distribution under different elevation ranges in the study area

Elevation range (meters)	Total area (ha)	Percentage of total
900-1200	251.69	1.41
1200-1300	493.63	2.76
1300-1500	8640.81	48.26
1500-1800	5462.38	30.51
1800-2400	3054.81	17.06
Total	17903.32	100

Table 2: Area distribution under different slopes in the study area

Slope range (percentage)	Total area (ha)	Percentage of total
<5	8707.56	48.64
5-10	1338.16	7.47
10-20	1449.66	8.10
20-30	1945.25	10.87
>30	4462.69	24.92
Total	17903.32	100

Table 3: Soil quality weighting based on landforms and farmers' practices of soil fertility management under current and the future scenarios (sustainable soil management practices)

Landform	Land management	Current scenario			Integrated management scenario	
		Landform	Management	Combined	Management	Combined
Alluvial plains and fans (depositional)	Sustainable	2.00	2.00	4.00	2.00	4.00
	Conventional	2.00	1.90	3.80	1.96(3)	3.92
	Unbalanced	2.00	1.80	3.60	1.89(5)	3.78
	Manure	2.00	1.50	3.00	1.58(5)	3.16
Lake and river terraces (tars, erosional)	Sustainable	1.90	2.00	3.80	2.00	3.80
	Conventional	1.90	1.90	3.61	2.00(5)	3.80
	Unbalanced	1.90	1.80	3.42	1.98(10)	3.76
	Manure	1.90	1.50	2.85	1.65(10)	3.14
Mountain terrains with moderate slope	Sustainable	1.70	2.00	3.40	2.00	3.40
	Conventional	1.70	1.90	3.23	2.00(5)	3.40
	Unbalanced	1.70	1.80	3.06	1.98(10)	3.37
	Manure	1.70	1.50	2.55	1.80(20)	3.06
Mountain terrains with steep to very steep slope	Sustainable	1.40	2.00	2.80	2.00	2.80
	Conventional	1.40	1.90	2.66	2.00(5)	2.80
	Unbalanced	1.40	1.80	2.52	1.98(10)	2.77
	Manure	1.40	1.50	2.10	1.80(20)	2.52

Values in the parentheses indicate the increase in the score by a given percentage due to sustainable soil management practice