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Indigenous knowledge of terrace management for soil and water conservation in the Sikkim Himalaya, India

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The main objective of this study was to understand the farmer's indigenous knowledge of terrace management in the Sikkim Himalaya with reference to Rani Khola watershed. Primary data were collected through a mix of questionnaire surveys, focused group discussions, and field observations with a sample size of 300 households. Detailed documentation of the evolution of the terraces and their types, bunding material, types of risers, the relationship of slope and terraces dimensions, soil and water conservation (SWC) practices were performed. Remote sensing data was used to derive information pertaining to elevation, slope and land-use/cover of the watershed. The study reveals that dimensions and types of terraces are subjected to the elevation, slope gradient, local soil and vegetation cover. Leveled terraces were constructed on lower slopes while outward sloping terraces were more common on higher slopes. It was also observed that with the increase in slope angle, width and length of the terraces decreased. Terrace riser height was also correlated with slope; riser height unavoidably increased as slope increased. The study concludes that terraces in the study watershed are effective in reducing the slope gradient and length, and in turn helpful in trapping eroded soil, slowing soil movement and in due course reducing soil erosion and increasing agricultural productivity. It is suggested that for overall management of terraces, it needs to be combined with additional soil and water conservation practices.

Keywords: Agriculture, GIS, Sikkim Himalaya, Soil and water conservation, Terraces management, Watershed

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The loss of agricultural lands and fertile soils through erosion is one of the major environmental issues of Himalayan region[1-5]. More than 80% of the world's agricultural land suffer soil erosion[6,7] and water-induced soil erosion is one of the main reasons for land degradation[8-10]. Soil erosion leads to the depletion of soil fertility and decreases soil moisture storage capacity, resulting in low crop production. Soil erosion affects not only agricultural productivity but also disturbs environmental and ecological functions performed by soil. To understand the sustainability of agriculture practices on steep sloping land, the sophisticated understanding of both soil erosion and soil conservation practices is required. A steady and increasing amount of studies all over the globe reflects the complexity of indigenous soil and water conservation technologies[11-17].

Farmers have developed various soil and water conservation techniques to protect soil and water loss from agricultural areas and to improve crop productivity. The awareness to conserve soil started around 9000 years ago when human civilization shifted from more transitory 'nomadic hunting and gathering existence' to permanent settled and intensive soil dependent plant and animal farming system[18]. Since then several land management practices have been evolved by indigenous people throughout the world in order to conserve soil and increase agricultural productivity. According to various studies, indigenous agricultural knowledge is proved to be sustainable and improves soil fertility[19-21]. Terracing is one of the oldest means of saving soil resources. Various studies throughout the world reported that agricultural terracing has significantly reduced soil loss and increased soil fertility and emerged as one of the most promising mechanical measures of soil conservation[3,14-16,22-25]. More recently, intensive investigations have been conducted on terracing in the mountains and it's considered as one of the most successful SWC techniques for cultivation in hilly areas[26-29].

Terracing is one of the oldest indigenous conservation practices in the Sikkim Himalaya[3] used

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by indigenous people for effective soil conservation, increasing crop yields, and socio-economic development. It is a combination of several practices which includes agro forestry, the construction of terraces and terrace risers, vegetative barriers, contour strips and construction of drainage channels. The present study is an attempt to understand the characteristics of indigenous knowledge of terrace management in the Rani Khola watershed of East Sikkim.

Study area

The present study was conducted in Rani Khola watershed located in the East District of Sikkim State, India (Fig. 1). The watershed lies between 27°13'9 N to 27°23'51N and 88°29'31E to 88°43'18E covers an area of 254 km^2. There are 44 villages with a total population of 1,61,395 in the watershed (COI, 2011), which ranges from 311 to 4112 m above mean sea level. Rani Khola is one of the major tributaries of the Teesta River and is also known as *Rongni Chu* in the local dialect. Rani Khola watershed is one of the very prominent watersheds of Teesta basin and it is characterised by a variety of landforms. Most of the area in this watershed falls in high mountain regions with very steep slopes, the average angle being 30°–40°. The vegetation in this area consists of dense forests, open forest and alpine scrubs. Reserved forests, namely, *Martam Reserved Forest*, *Bhusuk Reserved Forest* and *Assam Reserved Forest* enrich the floral diversity of the study area. The watershed has climates ranging from subtropical to alpine conditions. The average annual rainfall is more than 3300 mm, most of the rainfall occurs from July to September. Many areas in the higher reaches of the watershed also receive heavy snowfall during the month of January. Surface water and underground water are abundant during the monsoon season while it gets scarce during winter seasons. The average annual temperature of the watershed ranges from 0°-26°C. Agriculture is the main source of livelihood in the rural areas of the watershed.

Methodology

The present study is based on both primary and secondary data sources. Primary data were collected through field observation, group discussions and a questionnaire survey of 300 households in three different ecological zones, i.e. lower, medium and higher ecological zones of Rani Khola watershed

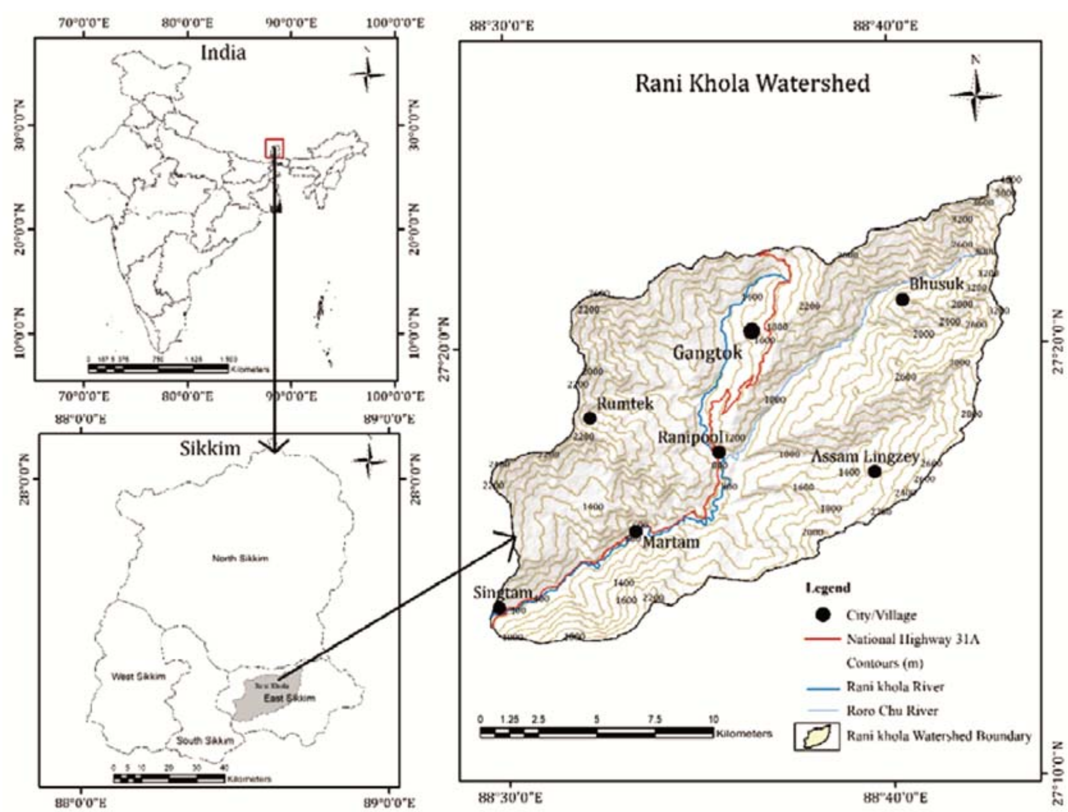

Fig. 1 — Location map of Rani Khola watershed in east district, Sikkim

during 2017-2018 (Table 1). The stratified random sampling method was used to select households for the questionnaire survey and 100 households were selected in different villages of each ecological zone. The questionnaire was designed to obtain information regarding land management and slope maintenance practices, preferred terraces type, bunding, the material used in construction and maintenance terraces, and crop preferences. Separate focus group discussions were carried out in different villages of all three ecological zones regarding farmer's perception of soil erosion, conservation practices and their preference regarding agriculture and natural resources. Relevant secondary data and other information were collected from the concerned District and State Departments of Sikkim.

To map land-use/cover of the Rani Khola watershed, Sentinel 2A Level 1C data was used. The data is composed of 100x100 km^2 tiles (ortho-images in UTM/WGS84 projection). Sentinel 2A dataset consists of 13 multispectral bands out of which only five bands have been used in the present study. Land-use/cover classification was carried out using maximum likelihood classification technique and the accuracy of the results was assessed using kappa accuracy assessment technique using a high-resolution image of planet scope satellite.

Along with this, an Aster DEM was also used to generate watershed boundary and to classify slopes into four different classes later it was merged with agricultural land to assess the distribution of agricultural land under different slope classes.

Characteristics of the farmers

Data obtained through field survey revealed that about 47% of the farmers in all ecological zones are marginal with less than 0.5 ha of land. Farmers with medium size land holdings (0.5-1 ha) are 30% in all ecological zones while farmers owning larger landholding (>1 ha) were about 22% in all ecological zones (Table 2). Farmers have constructed terraces in their field along with the inherited terrace which is age-old in the watershed.

Results and discussion

Land-use/cover analysis

The land use map (2017) of the watershed shows that out of the total geographical area of 25464 ha, 74.75% area is under dense and open forest. Agricultural lands and built-up area covered 17.63% and 4.95%, respectively. Agriculture is the main activity and one of the most important land-use in the watershed. Agricultural land includes irrigated land, rain-fed and fallow land. The agricultural system is characterised by mixed farming, viz., agriculture, agro-forestry, horticulture, floriculture, livestock and animal husbandry. The spatial distribution pattern of the agricultural land revealed that the central and southern part of the watershed was under intensive agricultural practices because of small land holdings. Most of the crops are grown as food crops from March to September. A large number of landraces of maize, paddy, buckwheat, beans, pulses, finger millets, yams, tubers and ginger are grown in rotation and maize holds the highest rank followed by paddy in the watershed. Maize is grown up to 2,700 m elevation while paddy is primarily grown up to 1500 m. The Land: Man ratio is low (0.15 ha) due to population growth and migration, and future projection show further declining trend in the watershed.

Agriculture and spatial relationship

During the field visit, the bulk of settled agriculture fields were visible on the steep hillsides. The slopes

Table 1 — The area under agro-ecological zone in the Rani Khola watershed of Sikkim Himalaya

Agro-Ecological Zone	Altitude Range (m)	Sample Villages	Area	
			(ha)	(%)
High	1501-4112	*Bhusuk, Rongyek, Parbing, Luing, Assam Linzey*	13819	54.27
Middle	801-1500	*Ranka, Rumtek, Nandok, Assam Lingzey Namcheybong, Lingdum, Temphyak Mendu*	10230	40.17
Lower	<800	*Singtam, Chuba, Chisopani, Martam, Rapdang, Namli, Namcheybong*	1415	5.56
			25464	**100.00**

Table 2 — Type of farmers in different ecological zones

Type of Farmers	Lower ecological zone (n=100)	Middle ecological zone (n=100)	Higher ecological zone (n=100)
Marginal (<0.5 ha)	47	49	46
Medium (0.5-1 ha)	35	26	29
Large (>1 ha)	18	25	25

of some agricultural land exceed 50^o, but most of them fall between <20^o and 40^o. Farm field extends from the valley of the Teesta river at about 350 m above mean sea level, to the upland upto about 2,500 m elevation.

Slope and agricultural land

From satellite imagery and field surveys, a typology of land-use/cover and slope gradient was prepared (Fig. 2). However, significant areal variations in the land-use/cover are observed. Lower gradient slopes are characterised by intensive agricultural usage. The agricultural area (17.63%) of the watershed was classified with slope classes and it was found that 46.11% of the agricultural area was under <20^o slopes followed by 38.25% between slope class 20^o to 30^o (Table 3). The probable causes for the higher percentage of agricultural land within this slope class may be abundance of permanent terraces, good irrigation facilities and moreover, most of the geographical area of the watershed falls in this slope class. While steep and very steep slopes account about 15.46% of the total area under agriculture, is predominantly under dry land farming and rain-fed agriculture. Some part of the watershed, very steep slopes areas and degraded slopes are more prone to erosion and should be devoted to permanent tree cover and agro-forestry practices. This supports frequently cited observation on management relationship between land-use/cover and slope steepness[30]. The Kappa accuracy assessment technique was selected to assess the accuracy of the classified map. Accuracy assessment was done using a high resolution (3.9 m) satellite imagery of planet scope. Overall users and producer's accuracy of the agricultural land was found to be 88.64% and 75.00%, respectively.

Altitude and land-use

The relief of the watershed agricultural-land area approaches 2500 m above mean sea level. The land-use shows an uneven distribution of land-use area as

Table 3 — Rani Khola watershed slope classes and their respective agricultural areas

Slope Class	Slope (º)	Agricultural Area (ha)	% of Total Agricultural Area
Lower Slopes	< 20	2069	46.11
Moderate Slopes	20-30	1717	38.25
Steep Slopes	30-40	579	12.90
Very Steep Slopes	>40	123	2.74
Total		**4488**	**100.00**

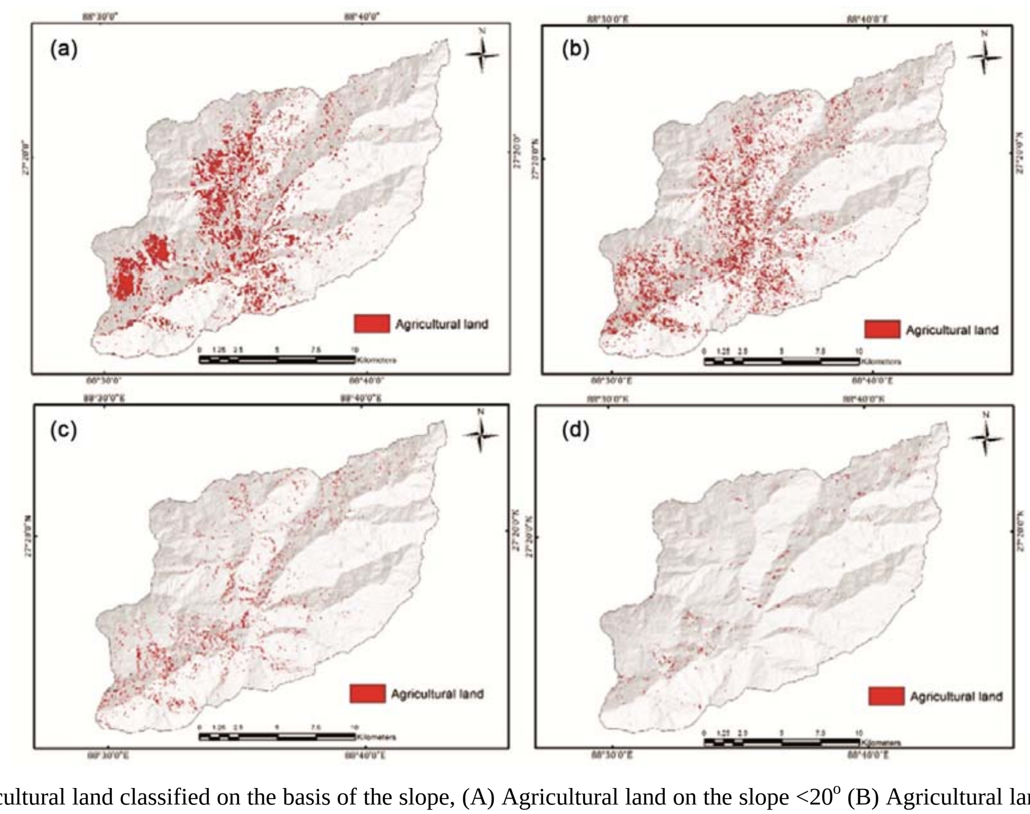

Fig. 2 — Agricultural land classified on the basis of the slope, (A) Agricultural land on the slope <20^o (B) Agricultural land on the slopes 20^o to 30^o (C) Agricultural land on the slopes 30^o to 40^o (D) Agricultural land on the slope >40^o

against altitudinal class. Land-use varies significantly when one moves from low to high ecological zone. The majority of the agricultural area comes under 400 m-1500 m of altitudes is characterised by irrigated area and dry land agriculture. High altitudinal land-use comprises of dry land and rain-fed agriculture, agro-forestry and livestock rearing with a significant area under dense forest cover.

Slope aspect and land-use

In the watershed, slope aspect plays a significant role in land use/cover and agricultural productivity. Almost all the farmers agreed and are aware of the role of slope aspects and steepness during the preparation of the agricultural terraces and management of agricultural land. In the watershed, there are more areas with south-facing than the other and about 50% of the land in this aspect is used for agricultural production and showed the highest intensity of cultivation. North-eastern slope, aspect has a very limited area in watershed and mainly utilised for horticulture and floriculture. Forests are located to a large extent in all slope aspects, but the major chunk is south-facing. Land-use/cover types are not randomly distributed across slope aspects but from a part of the ordered arrangements of land for maximum productivity.

Evolution of terrace farming

It is too easy to see the terraces as simply erosion control plots, built at an exact point in time, but terraces may have several modes of origin. The indigenous farming system of Sikkim Himalaya dates back to even before the seventh century[31]. Sikkim was named as To-Ban by Chinese in the seventh century[32], which subsequently changed as *Demazong* the valley of rice by *Mahaguru Padma Sambhava* during the 8th Century, for the first time he showed paddy seeds in the Chungthang valley of north Sikkim[33]. The agriculture in the Sikkim Himalaya was evolved amidst several upheavals to the kingdom of Sikkim since ninth century[31]. Agro-ecosystems were adopted, innovated, managed and evolved over 600 years by local indigenous communities initially by the *Lepchas* and *Limboos*, followed by the *Bhutias* after 1275 AD and later on by other Nepalese communities[31]. Major indigenous farming systems in Sikkim are classified into three broad categories agro-pastoralism of nomadic Tibetan herders, slope land agricultural systems and terrace rice cultivation system. The shifting agricultural system gradually conversed into the sedentary system over a period of time[31]. Traditionally terraces are known as *Pakho Khet*, have been used to cultivate rice on the sloppy hills as there is not a single square km flat land area present in Sikkim. Farmers terraced their lands on their own initiatives with the help of bunding, stone walls and vegetative barriers[33]. Except terraces, all other cultivated lands are dry fields (*Ghyya-Dhan*). The majority of the terraces concentrate on lower regions, while dry fields (sloping lands) are in the upper zones. About 20% of all agricultural lands are properly terraced and nearly all the terraces come under the slopes of 5^{o} to 40^{o}, farmers believe that plant nutrients cannot be conserved without terracing and massive conservation programs are essential for the cultivation of various crops[33].

Terrace types

As farmers are already well aware that terraced land helps in reducing soil loss and enhances crop productivity, they are encouraged to convert their sloppy land into sustainable terraced fields as per the availability of time and resources. The traditional method used for terracing focuses on, quickly stopping the loss of plant, foods, soil and water, which is also feasible for ordinary farmers to use. This method shows quick and profitable results and is sustainable and efficient regarding labour and results in increasing fertility. Based on the fieldwork we found the following three basic types of terraces in the watershed, i.e., levelled, sloping and reversed terraces. As per the household survey, it was recorded that levelled and sloping terraces constitute 33% and 51%, respectively, the remaining 14% consists of reverse terraces. Levelled and reverse terraces are both typically found in moderate upper slope classes and constructed similarly. Due to the wide altitudinal and slope variation within the watershed, variety of crops is cultivated.

Levelled Terraces

Levelled terraces are one of the dominant structural measures adopted by farmers in the watershed to stabilise irrigation water required for paddy cultivation. Paddy is the second most grown crops of the watershed after maize. Availability of irrigation water is a significant factor for paddy cultivation, wherever there are adequate irrigation sources available farmers are gradually converting their steep sloping terraces into levelled terraces. Farmers reported that it not only helps to reduce the rate of soil erosion it also prevents mass wastage during heavy rainfall and it helps in water conservation which results in overall increased land productivity.

During the field survey, it was observed that the length and width of levelled terraces decreased with increasing slope Table 4. The levelled terrace that is mostly used for paddy cultivation dominates the middle and lower zone of the watershed. Rain or irrigated water is used for paddy cultivation. Water channels are constructed for irrigation in most of the fields; each terrace receives water either from the same row or from terraces above. Small openings on terrace bunds are used to passes excess water from one terrace to other terraces. An average number of terraces on a hill slope vary according to the degree of slope. In the lower and middle ecological zones, an average number of terraces on a hill were 15 to 20 with wider width while in the upper ecological zone or steep slopes less than 10 terraces with a smaller width. Most of the sediment from upslope brought with irrigation water is trapped in these numbers of terraces as the water passes all the terraces from upper to lower terraces before entering a stream (Table 4 and Table 6).

Outward sloping terrace

It is the most common type of terrace in the watershed, observed on the higher slopes/gradients around a slope's contour of the upper and middle ecological zone. This terrace type is located at the base of steep slopes and built on large retaining walls located at the base of a steep slope that collects slope wash. These structures are probably built up to entrap eroded sediment and also help in arresting extreme soil erosion. Constructing a stone wall is a common phenomenon in making terraces in the agriculture field. Making sloping terrace is cheaper than the other two terraces and also known as dry fields (*Bari*). Farmers on their own initiatives have terraced their land by bunding with roughages, line paving with stones and gravels. By-line plantation of fodder trees also considerable areas are converted into terraces (Table. 6).

Reverse Slope terrace

Less common are reverse slope terraces, which are found on the higher class slope (>40^o) mostly in the upper zone. 100% of the farmers agreed that reverse terracing is more effective in soil conservation as compared to other two terraces types. Construction and maintenance cost is relatively higher compared to other types of terraces and is less prone to terrace failure (Table. 5).

Construction of terraces

In the watershed, farmers considered a slope as stable if an exposed massive base rock is present at the top of hill slope; lack of such kind of rock indicates

Table 4 — General attributes of levelled and reversed terraces in the Rani Khola watershed

Attributes	Slope Classes			
	Lower Slopes (< 20^o)	Mod. Slopes (20^o-30^o)	Steep Slopes (30^o-40^o)	Very Steep Slopes (> 0^o)
Average length (m)	15-35 m	8-10	5	5
Top width (m)	2-5 m	3	2	1-2
Base width	0.3 m (+)	0.5 m (+)	0.5 m (+)	0.5 m (+)
Depth of foundation	0.5 m to 1 m	0.5 m to 1 m	0.5 m to 1 m	0.5 m to 1 m

Table 5 — Types of the terrace and their respective characteristics

Terrace Types	Farming Practices	Dominant Crop	Barriers and Risers
Levelled and Reversed	Paddy based farming system followed by maize, mustard, field pea, potato, wheat, and vegetables as secondary crops	Paddy and vegetables	Beans, pulses, earthen bunds
Outward Sloping	Vegetables, horticultural crops, banana, fodder grasses, fodder trees, other multipurpose agroforestry species and pulses etc. are grown	Maize, vegetables, large cardamom	Banana, bamboo, peach, gagun, broom grass, Stone bunds, Tea plants

Table 6 — Characteristics and dimensions of terraces in different slope classes

Type of slope	Terraces preferred (Leveled/Sloping/Reversed)	Average Length (m)	Average Width (m)	Cost (Rs.)	Time Needed for Construction/Mandays	Terrace failure
Very Steep Slopes (> 40^o)	Sloping	5	1-2	30000	10	Very few incidences
	Levelled/Reversed	5	>2	67,500	15	Very few incidences
Steep Slopes (30^o-40^o)	Outward Sloping	8-10	3-5	30000-43200	10-12	Sometimes
	Levelled	5	2	43200-67500	12-15	Sometimes
Moderate Slopes (20^o-30^o)	Levelled	8-10	3	19200-30000	8-10	Rare
Lower Slopes (< 20^o)	Levelled	15+	3-5	43200-67500	12-15	Absent

instability. These criteria are also taken into consideration when houses are constructed in the watershed. However, almost all the farmers claimed that while constructing a terrace the availability of irrigation for paddy cultivation is the most preferred choice. While constructing new terraces, the basic idea is that rather than try to terrace the whole slope, a staged process is used. In the first stage terrace are only made at sufficient intervals of 2, 3 or 4 strip distances, to stop the run-off, and with its soil and plant foods. When the land is covered with the first step, the process is repeated with the strips in between the first terrace. The method does not terrace all the land at once but uses a step by step approach. Contour lines are marked out and interceptor ditches are dug to divert outside water from running onto the area. In next stage one in two, three or four contour strips are made into terraces. The terraces are made with full width of the strips, this means that the area can be covered quickly, the run-off water, plant foods and eroded soil are checked by the terraces and so erosion stops. When this is completed the terrace is widened to join up with those above and below; finally, fodder and or green manure trees are planted in steps in the terrace walls; and green leaf is planted to cover the terrace walls and banks known as terrace riser. In such type of terrace preparation, it can be said that the terraces are not built on a sloping surface but are keyed into the hillside and so if done properly, there are fewer chances of terrace failure. After all the terraces are made they are widened and steps cut out into which suitable legume tree seedlings and cuttings of grasses (broom grass) are planted. The fodder trees hang down and roots into the terrace wall and it helps to hold and protect the terrace wall and bank and also produce high-quality livestock feed or cut and used as mulch. A similar method of construction of the new terrace was reported in Nepal[34].

Construction material

It was observed during the field survey and discussion with farmers that most common materials used in the construction of terrace risers and benches are soil and locally available stone of different grade and sizes. Homogenous clay was commonly used for bunds construction. Stones along with clay are also used, especially in higher slope areas. Vegetative barriers, grasses and pulses were also grown by farmers to check soil loss from the terraced land. A vital part of the terrace making is the correct building of the walls and two types of terrace walls are observed in the watershed, *(i) Earth wall*- the fields where there are few or no stones are available for building the walls and the subsoil is hard, clods of subsoil are used for wall making instead of stones. Turves (soil held together by the root of the plants) are also used by the majority of the farmers. The height of such walls does not exceed more than one meter. The wall is made carefully firm by thumping with the back of the spade, when soils become firm and it is held protected by plant roots, grasses etc. act in helping and binding soil together. Thereafter the top part of the wall is prised out and soil packed in to straighten the wall and the lower part is trimmed back to make more room for crops. Secondly, *(ii) Stone wall*-the fields where enough suitable stones are available, a stone wall is built by the farmers. These stone walls are constructed in different ways according to the type of stones and the height of the terrace. After making the firm foundation, the stone is placed with clay in such a way that they firmly stand and bear the load of the above terrace. All the gaps, hollow and wholes are filed properly with the soil and clay. The thickness and angle of the wall are very important and the farmers of the watershed using their traditional knowledge judge the angle according to the slope and terrace size. The more straight up and down the wall is – the more land is available for crops, but less if the weight of the fall of the soil is more, the thickness of the wall and lean of the wall is more. The height of the stone walls exceeds more than 1 m and the foundation varies from 0.60 m - 0.90 m. If a high wall is needed farmers use to build it in two sections instead of one high wall. The division of the sections is planted with legume plants, fodder and green manure trees.

Relation between slope and terrace dimension

The majority of the agricultural land falls between 20^{o} and 40^{o} slopes. Terraces constructed in the higher slope classes had a narrower width as compared to the terraces in lower slope classes. All the farmers agreed that on the steep slopes, wider width of terraces requires more maintenance and terraces with smaller width last longer and are more stable during heavy rainfall. The average width of the terraces decreased with an increasing slope (Fig. 3), the average length of levelled terraces in lower slopes was 15 m while it decreased to 5 m in very steep slope class (Table 6). Average time and cost needed for construction of levelled terraces were more in higher slopes as compared to sloping terraces. According to farmers incidences of terrace failures occur mostly during monsoons when the watershed receives heavy rainfall, levelled terraces on higher slopes were more prone to slumping as compared to outward and reversed sloping terraces in very steep slopes.

Levelled terraces were common in all slope classes, while outward and reversed sloping terraces were present on steep to very steep slope classes. The construction and maintenance of levelled and reversed terraces are more labour intensive in comparison of sloping terraces. On very steep slopes (>40°) the outward-sloping terraces were 46.7%, 34.6% and 49.3% in lower, middle and higher ecological zones, respectively. Reverse-slope terraces were visible only on the very steep slopes (>40°), and found about 4.5% and 13.2% in the middle and higher ecological zone respectively (Table 7).

Farmers in group discussion revealed that most of the terraces in the watershed are old, only a few of them are newly constructed terraces due to the fragmentation of land holdings, increasing food demand for steadily growing household size. Maize and paddy are the most common crops grown on terraces. Wherever sufficient water was available paddy was the preferred crop, on the other hand large cardamom agro-forestry was the dominant crop on non terraced cultivated lands. Slight variation between ecological zones in terms of terrace cultivation was also observed. About 98% of farmers in lower ecological zones have terraced agricultural land while in middle and higher ecological zones it has decreased to 90% and 83%.

Relation between slope and risers

Terrace risers in the watershed are commonly made of stone-line, vegetated, or purposely cut to bare soil. About 50% of the total risers were natural vegetation/agro-forestry while 10% were improved varieties of natural grasses such as Napier (*Pennisetum agrostis*) and amlisho (*Thysanolaena maxima*). Another 40% were made of stone lines and bare soil with 20% each. Vegetation on the riser surface is used as a binding element and land under risers has been intensively utilized for legume crops. Farmers reported that this practice is relatively new because of reducing land man ratio caused by increasing population pressure. Paudel and Thapa (2001) also reported similar observation in Nepal Himalayas[14]. Farmers also tried to keep the riser height to a minimum as higher riser height is prone to terrace failure during the monsoon season. However, in the study villages, it is observed that the riser height unavoidably increases as the slope increases (Fig. 4).

Terrace maintenance

Terrace maintenance is laborious, time consuming and expensive, but it is necessary[35] to maintain the

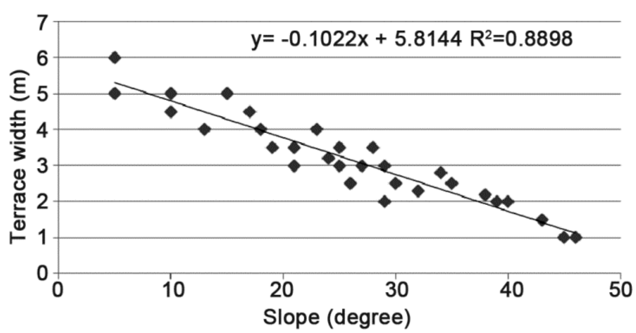

Fig. 3 — The relation between slope and terrace dimension

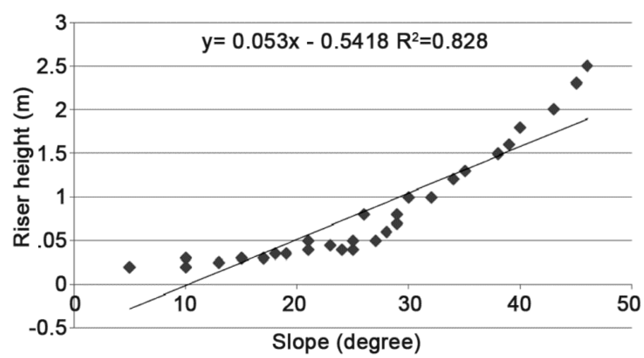

Fig. 4 — Relation between slope and risers

Table 7 — Terrace frequencies in different slope classes

Slope Type	Terrace Preferred	Low	Mid	High
Very Steep Slopes (> 40°)	Levelled	9.2%	8.1%	10.5%
	Outward Sloping	46.7%	34.6%	49.3%
	Reversed	-	5.4%	13.2%
Steep Slopes (30°-40°)	Levelled	26.4%	25.7%	31.6%
	Outward Sloping	35.6%	40.4%	38.4%
Mod. Slopes (20°-30°)	Levelled	29.9%	32.4%	34.2%
	Outward Sloping	17.8%	25.0%	12.3%
Lower Slopes (< 20°)	Levelled	34.5%	28.4%	10.5%

terraces against failure. Farmers used locally available materials such as mud and stones to fill the cracks in paddy fields. Farmers usually cut the elevated portions of land to fill depressed areas. Local grasses are also grown on risers to strengthen the risers and reduce soil erosion. Farmers in the watershed practice following measures in order to maintain healthy terraces; (a) inspect the channel, ridge, and blocks at least in the spring and fall after harvest; (b) inspect for damage after all heavy rainstorms; (c) remove obstructions such as debris or sediment to maintain capacity; and (d) inspect and repair any rodent damage to prevent settling and washouts.

Evaluation of terrace management

Terraces are the most promising land management strategy on the pillars of sustainability in the watershed. 100% farmers observed and reported that without terracing they could not grow much in their fields, which in turn create livelihood security problems in the future as the majority of the inhabitants in the watershed depend on agriculture. The study results show that considering the complexity of the terracing in the watershed, about 90% of the farmers protect and conserve the sloping terrain by terracing their field. It was observed that slope length after terracing of the sloppy lands was reduced significantly. 100% of the respondents agreed that terracing reduces soil erosion. The overland flow and soil loss was estimated in monsoon season from 3×3ft plots in replicates of 4 plots in ago-forestry, open land, terraces and outward sloping terraces following various studies[2,36,37]. In these experiments the physical effectiveness of ago-forestry, open land, terraces and outward sloping terraces was assessed and compared. Overland flow varies in different land use based on their capacity to stand against erosion during heavy rainfall. The data obtained from the experimental plots indicated that overland flow was highest (1.41%) in barren land or vegetation devoid zones followed by outward sloping terraces (1.21%), terraces (1.11%) and lowest in agro-forestry (1.07%). When it was focused on the soil loss, it was observed that soil loss is directly proportional to overland flow. The data revealed that the soil loss followed the rate of overland flow.

There are lots of challenges associated with terrace farming, some of them were mentioned by farmers in the watershed include socio-economical, environmental and technical challenges. Socio-economic challenges include the shortage of labour, the higher maintenance cost of the terraces, small land holdings, dispersed distribution of lands and ban on chemical fertilisers, poor accesses to services, markets and limited resources. Environmental challenges include heavy rainfall during monsoon associated with increased surface water runoff, soil erosion, land degradation, climate change and water scarcity during peak winter and summer season. Technical challenges include very less use of machinery, limited tools, maintenance of narrow terraces on steep slopes, a terrace with a width of fewer than 2 m prevents the use of machinery or animal power. However, the watershed has a strong natural resource base (land and forest) along with indigenous knowledge system regarding land and crop management practices, soil fertility management, strong community support system, which provides an opportunity to diversify and intensify terrace agriculture. To increase the productivity and income mixed cash crops may be grown on the terraces. The use of permanent vegetation barriers on terrace walls is an alternative for constructing terraces bunds, which requires higher maintenance cost, time and raw material. Utilisation of vertical slopes and edges, a wide variety of cash crops and high demand for organic vegetables also creates an opportunity.

Terraces are suitable on financial and environmental ground though, for initial two years, cost of construction and maintenance is high[38]. This is due to higher investment costs and low yield in initial years caused by soil disturbances during terrace construction. Taking into consideration that nearly half of the farmers in this watershed are marginal with limited cash resources, this can be a major obstacle in establishing terraces.

Conclusion

The study highlights the indigenous knowledge of terrace management, their evolution, construction and maintenance and agricultural land use/cover of the Rani Khola watershed area. Agriculture being the major economic activity in the rural areas of the watershed is directly related to the well being and economic growth of the area. Due to increasing population landholdings are shrinking, which causes immense pressure on farmers to enhance the yielding capacity. The majority of farmers in this watershed are concerned about Soil erosion as it directly affects the production capacity of their farmlands. To intensify the yielding capacity majority of the farmers in this watershed are practicing different soil and water conservation (SWC) techniques, among these practices terracing is one of the major SWC practices which is practiced by about 90% of the farmers in this watershed. During group discussions, all the farmers agreed that terracing is required to maintain the plant nutrient and conserve soil from erosion. The farmers have a common opinion that the crops grown on terraces yield better than those grown on the slopes. This encourages the farmers to make more terraces. Bund risers are also popular soil conservation measures in the watershed and about 100% of the respondents have constructed bunds on their fields. It was also observed that better crop productivity was the major factor that encouraged most farmers to convert their sloping lands into terraces and to maintain these terraces other SWC techniques were practiced. Marginal farmers who are not able to convert their sloping terraces into levelled due to lack of capital and resources are using other low-cost and sustainable SWC practices that aim to keep the fertility of the soil and increase the overall yielding capacity. To help these marginal farmers it is necessary to provide financial incentives and credit link schemes from the Government’s side.

In conclusion, it can be said that terracing is one of the most promising and most effective long-term alternatives for combating land degradation in the watershed. Due to the lack of confidence, most of the local farmers are often not able to give an explanation regarding their conservation practices and traditional agricultural knowledge. Farmers are often not visible to researchers, but using their traditional knowledge wisely to minimise the soil erosion and maximise their crop production despite adverse climatic conditions could be useful to generate technologies that aim to help local farmers. Combining traditional and scientific knowledge is must and requires a partnership between local farmers and researchers in the region.

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