Land cover changes for enhancing water availability in watersheds of Tanahun and Kaski, Nepal
Jay Krishna Thakur, Kapil Khanal and Kabita Poudyal

ABSTRACT
Land use and land cover practices play a crucial role in balancing ecosystems and maintaining water supply services, including watersheds. The main objective of the current research is to assess the land cover change (LCC) and its specific influence on water runoff in the catchment and to study specific catchment characteristics such as LCCs through the years, soil properties, and recommendations for potential vegetation. The research area is located in two main districts of Chitwan Annapurna Landscape (CHAL), in four watersheds. Soil organic carbon was measured using the dry combustion method, the land use classification was done using Geographic Information System (GIS) software and potential vegetation analysis was based on several criteria. The complex relationship between factors was evaluated to account for the effect of separate factors to determine the outcomes in the basin. The Lund–Potsdam–Jena model was used for the purpose of characterisation of the study. The clear trend of change was not observed; however, there are obvious connections between various parameters as slope, aspect, soil properties and water runoff occurring in the catchment. According to the results obtained, land use planning could consider the relationship within the catchment and factors such as soil type, peoples’ interests, etc., which are important within the catchment.

Key words | land cover changes, potential vegetation enhancing water availability, soil properties influences, watersheds of Tanahun and Kaski, Nepal

INTRODUCTION

Land use and land cover practices play a crucial role in balancing ecosystems and maintaining water supply services, including watersheds (WWF 2012; Thakur 2015). The impact of changes have become an important issue in the last few decades (Marhaento et al. 2016). Natural and anthropogenic factors are having a great impact in forming such water sources. Topography, soil characteristics (Shrestha & Shrestha 2017), vegetation and climate (Talib & Randhir 2017) interact in a complex manner to determine the types, intensities, and locations of runoff production and the transport of sediments, chemicals, and organic debris in a landscape. Vegetation plays an important role in the amount of retention, both in terms of interception and transpiration. The effect of interception on retention is more significant when precipitation comes in low intensity and small amounts.

Land cover changes (LCCs) studies combine primary and secondary data as well as information referring to the study location and then, to combine all of it, include the terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges in the modular framework (Calder et al. 2007; UIZ 2017). Land use change and LCC are very pervasive so, when aggregated, significantly affect all the key aspects of earth system functioning (Chhatkuli 2003).
The aim of the current research is to make land cover classification and to map and see the changes in land cover over the last two and a half decades. Soil productivity and the role that it plays in retaining water for the ecosystem could be understood by the community as interrelated factors (Subedi & Poudel 2013). Research has shown that soil organic carbon (SOC) is affected by land use change/LCC (Lawrence et al. 2002; Keninger 2012). Moreover, it can be concluded how potential vegetation can be effectively established/re-established in the area in order to gain/provide susceptible output to the community as well as to help to conserve the natural heritage of the region. The sustainable landscape means to conserve the space for the sustainable supply of ecosystem services which are the priority at the population level (van Lier 1998). The objective of this research is to assess the LCC and its specific influence on water runoff in the catchment. The research studies specific catchment characteristics, such as LCCs through the years, soil properties, and recommendations for potential vegetation.

STUDY AREA

The research area is located in two main districts of Chitwan Annapurna Landscape (CHAL), in four watersheds. Chhabdi Khola and Guhe Khola watersheds belong to Tahanhun, whereas Gharmi and Bhoti Khola are located in Kaski district (Figure 1, Table 1).

The meteorological data were obtained from the meteorological stations in the main districts of CHAL. Soil texture, soil bulk density and soil moisture content were calculated based on the field-based soil analysis in addressed regions in the local laboratories. Land use classification was carried out for 1990, 1995, 2000, 2005, 2010 and 2015 using LANDSAT images available from the U.S. Geological Survey. The acquired data consist of DEM (Digital Elevation Models), district boundary data, from the International Centre for Integrated Mountain Development (ICIMOD), Nepal. Several topographic and base maps were obtained from the Survey Department, Ministry of Land Reform Management, Government of Nepal.

MATERIALS AND METHOD

Assessment of soil properties in the catchment

Soil organic carbon

SOC was measured using the dry combustion method (Atkinson et al. 2002). Air-dried samples were taken and sieved through 0.5 mm mesh. Around 20–25 g of oven dried soil was taken in a crucible and placed into a muffle furnace heated at 400°C for 1 hour in order to burn the carbon out and left in the oven to cool down. After this, it was allowed to cool in desiccators. The weight was taken to analyse carbon content.

Soil carbon content (SOC) = Carbon content burnt * 0.585 (1)

Bulk density

Soil bulk density was measured through the core method (Schmidt et al. 2011). The aluminium core was used to take core samples from the topsoil and subsoil. Soil from each core was transferred to a crucible and weighed. These were then oven dried for 24 hours at 105°C. After cooling in desiccators, it was weighed again to check moisture content. It can be calculated with the following formula:

Bulk density (g cm⁻³) = Mass Volume (2)

Soil texture

For texture analysis, the hydrometer method using Sodium-Hexametaphosphate (Na-HMP) as a dispersing agent was used (Merz et al. 2006). Soil sieved through 2 mm mesh was used for texture analysis. Around 50 g of air-dried soil was taken in a conical 20–25 g of oven dried soil was taken in a crucible and placed into a muffle furnace heated at 400°C, in order to burn the carbon out for 1 hour, and left in the oven to cool down. It was placed in a mechanical shaker for 2 hours. Later, it was transferred in 1,000 mL
cylinders and the volume was marked. It was inverted 8–10 times and left to settle for at least 2 hours. Later, a hydrometer reading was taken, allowing it to stabilise in the suspension which gives its clay content. The content of cylinder was poured into 300-mesh sieve (0.003 mm) and washed with excess tap water until all fine material passed through the sieve. The sand left was transferred to a crucible and oven dried at 105°C which provided the sand content. This can be calculated with the following formula:

\[
\% \text{ Clay} = 2 \times \text{Hydrometer reading}
\]

\[
\% \text{ Sand} = 2 \times \text{weights of sand retained on sieves}
\]

\[
\text{Silt}\% = 100 - \% \text{ Clay} - \% \text{ Sand}
\] (3)
Land cover mapping

The land use classification was carried out using Geographic Information System (GIS) software (Pielke et al. 2007; Singh et al. 2011). First, training areas of known land use sites were selected for each class. Second, areas of each class were merged and a signature file was generated. Finally, the signature was classified by the classes which were developed by selecting the training sites.

The basis for classification of the map was the acquisition of satellite images. First, the DEM’s were mosaicked together and then clipped with the districts Kaski and Tanahun as the clipping extent. Then the areas whole surface hydrology was analysed with the hydrology tools in order to finally delineate the watersheds. In order to better visualise the areas, several other analyses have been conducted (for example hill shade, slope, climate, elevation points, etc.). Several statistics such as the stream length, density, land cover percentages, catchment area size, etc., were also calculated using GIS.

The acquired data consist of DEM, district boundary data, land cover data, LANDSAT Imagery (for 1990, 1995, 2000, 2005, 2010 and 2015), and various topographic maps and base maps. The land-use classification was conducted in a GIS environment. The exact method was ‘maximum likelihood classification’ (supervised image classification) (Lise 2000). In order to accurately assess the change in land cover over a period of years, it is important to always use imagery from the same period of the year (Dolisca et al. 2007). LANDSAT data from the end of March to the beginning of May (just before the monsoon season) were used for the classifications (Schmithüsen & Wild-Eck 2000).

In relation to data analysis, this project was implemented using spatial analysis, which is analysis related to space and location. To derive the land use/cover classification at the level of the three basins (Chhabdi Khola, Guhe Khola and Bhoti-Gharmi Khola river basins), the polygons of the basin areas were added to the map and were used to clip out land use/cover from Kaski and Tanahun land use/cover classification.

Software development

An important task associated with the project is to understand the relationship between water cycle and water budget distribution occurring in the watershed (Foody 2002). The watersheds can be characterised by having or not having the sustainability parameters that are required for independent functioning of the watershed under natural but changing conditions.

A review of relevant and vegetation specific models for assessment of implying relationship with water budget, through incorporation of various parameters of vegetation

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Area, stream length, drainage density</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chhabdi Khola</td>
<td>Area: 28.411 km², stream length: 19.73 km, drainage density: 0.694</td>
<td>More bilaterally symmetrical than the other catchment areas. The slopes on the northern side of the river/catchment area are slightly steeper; the geomorphology is mostly similar to the northern and southern part. The steeper slopes area (&lt;28.42°) are bilateral, symmetrically fragmented around the whole catchment area</td>
</tr>
<tr>
<td>Guhe Khola</td>
<td>Area: 2.275 km², stream length: 1.68 km, drainage density: 0.738</td>
<td>The southern Guhe Khola catchment area has steeper slopes than the northern part of the catchment area</td>
</tr>
<tr>
<td>Gharmi Khola</td>
<td>Area: 2.958 km², stream length: 1.72 km, drainage density: 0.581</td>
<td>Steep slopes in the northern part of the catchment area, mostly in the steepest category (36.84–89.08°). More plain areas in the southern part of the catchment area and less steep slopes (slopes steeper than 28.42° are rare). There is a (slim) plain area around the river</td>
</tr>
<tr>
<td>Bhoti Khola</td>
<td>Area: 6.036 km², stream length: 3.86 km, drainage density: 0.639</td>
<td>The steeper slope on the northern side of the river/catchment area, mostly in the steepest slope category (36.84–89.08°) as well as some plain high areas. The slope is less steep in the southern part of the river/catchment area, with nearly no slopes falling in the steepest slope category. The area around the downstream part of the river (mostly just north of the river) is plain</td>
</tr>
</tbody>
</table>
and soil characteristics relating to such an area of concern, has to be carried out (Ghimire et al. 2014).

The major factor during choice of the model was to access if it considers important parameters and its capability to incorporate factors related to vegetation as well as soil properties at an optimum proportion. It should be able to address:

- defined role of land use and/or plant functional types;
- predict the final runoff/sub-surface runoff with respect to various catchment specific properties.

The databases used in the software were .txt files, making it easier for the developer to change them. Two instructions and developer’s manuals were developed. The development of software consists of a few steps such as model selection, identification of inputs and outputs of the model, storing of required data, and searching of missing data. Data need to be acquired from DMH and from the field, and further inputs necessary for the model added. As a last step, development of the software has to be completed. Finally, a software named LUPWY for Land Use Planning for Water Yield was developed based on the model.

Potential vegetation recommendation

According to the relevancy of plant and forest species to the study area, the analysis was carried out based on the following criteria:

1. The range of distribution (horizontal and vertical). The basic theory behind selection for the appropriate vegetation is also related to the potential niche distribution of a particular species (Gautam et al. 2005).
2. Ease of cultivation/propagation. The propagation suitability of a specific species is the function of appropriate air, water, soil as well as other parameters necessary for the growth and development of such species (El Alfy 2016).
3. Regeneration/rotation period. The shorter the regeneration period, the easier will be the adaptability to a particular environment and its establishment in the area of interest.
4. Ethnobotanics importance. The ethnobotanical importance sheds light on the potential importance of the region as a preference to the specific area (Tang et al. 2016).
5. Multipurpose usage. Multiple use of any relevant vegetation is the function of its parts and whole use to the community (Kerr 2002). In addition, some types of trees and shrubs are native to the area and have the potential of bringing multiple values to the community where they are grown.
6. Economic return. The economic return to the community is also one of the factors determining the importance value to the community.
7. Annual industrial demand in Nepal. Annual industrial demand of the products originating from the re-establishment of the species in the area will help determine the focus of local producer groups to be able to function in the area.
8. Market value/price. Established price in the local, national as well as international market is the pre-determinant in order to make the community understand and act according to their concern for enterprise development.
9. Royalty rate as % of market price. The royalty rate as the percentage of market price will be a pre-disposing factor to delineate the importance value for each vegetation type and its commercial viability.
10. Social acceptance for promotion. Any plant species estimated to be established in the area should have social acceptability by the local community.
11. Threat category/conservation status. Some of the designated species of flora are recognised by national commitments as well as international obligations to be preserved and given special priority.
12. Quality improvement potential. The potential of the selected species for quality improvement and yielding more improved varieties will also play an important role in determination of the importance of the defined species (Dale 1997).

RESULTS

Assessment of soil properties

Soil organic carbon

The average SOC content in Chhabdi was found to be 0.69%. The average SOC was 0.43% for the Guhe Khola watershed. As low as 0.1351% was present. Similarly, in the case of the Gharmi Khola watershed, soil organic
matter was found to be the highest for forest followed by fallow land and some sampling areas near roadsides as well as some upland areas. Similarly, the SOC content was least in barren areas. The average SOC content for this watershed was 0.519%. The soil organic matter content varied in accordance with the sample grounds and type of sample present (van Lier 1998). The average value of SOC for the Bhoti Khola watershed was 0.59%. The value ranged from 0.258 to 0.987% (Figure 2).

SOC was also assessed during the second stage of the study in the post-monsoon season of the project period. In the second stage assessment (i.e. in post-monsoon season), soil organic matter was found to be a little higher than the previous stage assessment. The average soil organic matter content was 0.818, 1.062, 2.804 and 2.250% respectively for Chhabdi, Guhe, Gharmi and Bhoti Khola watersheds (Figure 3).

Soil moisture content

The analysis of the soil moisture of the Chhabdi Khola watershed shows that the outlet area or the area near Chhabdi river contains more moisture in the upper layer of soil, as depicted by the results of the study. Similarly, other areas of high moisture content were attributed to the regions of forest area and other regions were found to be sequentially drier for moisture content, ranging from grassland to settlements and drier lands. The average soil moisture was, however, found to be 18.35% in the watershed.

For the Guhe Khola watershed, the area near Kawadi was also detected to contain a comparatively higher percentage of soil moisture. Another type of sample with higher moisture content was from a shrub-land and forest area. The average soil moisture contents for all type of soil found in the watershed was found to be 17.47%.

The soil moisture content for soil samples taken from Gharmi Khola watershed depicted the maximum soil moisture content to be 43.71% for forest (source) and 31.29% for shrub land. The average value of soil moisture was found to be 31.29% (Figure 4).

For the Bhoti Khola watershed, the maximum soil moisture content occurred for scattered trees, near a bridge (river edge), orchard, and lowland-other side of river. The average soil moisture content for the Bhoti Khola watershed was found to be 20.915%. Scattered trees along the tip of the watershed were also the area with higher soil moisture.
Bulk density

The bulk density, which represents the compaction setting of the soil in terms of occupancy/non-occupancy of structural pores, was found to be 1.41 gm/cm³ for the Chhabdi Khola watershed. Bulk density was found to be higher for compacted areas near the road side than that for other land use categories. Similarly, the measure of bulk density for samples in Guhe Khola depicted values ranging from 1.3 to 1.716 gm/cm³ with an average of 1.55 gm/cm³ for all the samples. Bulk density was found to be the highest for fallow/barren land as well as other upland and some roadside samples for the Gharmi Khola watershed, the average value of which was noted to be 1.37 gm/cm³ for all the sampled locations. Bulk density of the samples ranged from 1.06 to 1.468 gm/cm³ for the Bhoti Khola watershed. The average bulk density was 1.26 gm/cm³ (Figure 5).

Soil texture

The average texture class found in the soil sample for the Chhabdi Khola watershed was silt loam type, followed by silty clay and silt. The major texture type in the Guhe catchment was found to be silt loam. The textural representation of the Gharmi Khola watershed was silt loam, consisting of 50% or more silt and 12–27% clay, or 50–80% silt and less than 12% clay. In the context of soil texture for the Bhoti Khola watershed, the dominated texture type was silt, i.e. soil material contains 80% or more silt and less than 12% of clay material (Figure 6).

Land cover classification

In an area of the Chhabdi Khola river basin, opened and closed forest are dominant, fluctuating at around 60% of the total area from 1990 to 2015 (Figure 7). Closed broad-leaved forests were located on less amounts of land as can be observed in the pre-monsoon season; however, it will rise significantly in the monsoon with great probability, due to the density of canopy. The open broadleaved forest had a peak in 2000 with 41.86%, while closed broadleaved forest had its lowest point; however, in 2010 the share of closed broadleaved forest reached 30.77%.

In the north and southeast are located the most part of the agricultural area. Figure 7 shows that the agricultural area in the Chhabdi Khola river basin is fluctuating around 35%. Within five years, from 1990 to 1995, the agricultural land increased from 34.68 to 38.61%, afterwards, in 2000 a decrease to 36.62% was observed. From 2000 to 2010...
Figure 4 | Soil moisture content (%) for soil samples in the study area.

Figure 5 | Bulk density (gm/cm³) for soil samples in the study area.
another increase was noticed, from 35.25 to 36.62%, and in 2015 a decrease of over 6.5% was observed, resulting in the Chhabdi Khola river basin having 32.17% agricultural land. There is a weak negative correlation ($r = -0.31$) between the progression of the years and the amount of agricultural area. Another small correlation between the progression of years and the share of agricultural area is observed, which makes it complicated to define whether the agricultural area is actually improving over a period of time. However, the lowest agricultural area share is in 2015, which may decrease in the future.

**Model and software development**

The Lund–Potsdam–Jena (LPJ) model was used for the purpose of characterisation of the study catchment. The site-specific data available through primary and secondary sources are incorporated into the model to develop an understanding on the basic criteria needed for the model (Zolfaghari et al. 2015). The processing and development of software on the basis of the chosen model has been carried out. The primary basis of development of software is the relationship between various components of water budgets in the chosen watersheds of study.

Prepared under Java-Eclipse, the package explorer consists of data, images and various accessory information under achieving file name as LUPWY. Data consist of, among others, countries.txt, districts.txt, information of the species.txt, landuse.txt, precipitation.txt, temperature.txt, watershed.txt and image files consisting of a watershed map with land cover included for the Chhabdi, Guhe, Gharmi and Bhoti Khola watersheds. Similarly, a district map of Kaski and Tanahun and country map of Nepal is also included. The organisation’s logo is also included as a .png file. Mainscreen.java consists of data coded into the system. Data coding is carried out for, among others, land-
Land cover of the Chhabdi Khola River Basin from 1990 to 2015 *Buildup area is not shown

Figure 7 | Changes in land cover for Chhabdi from 1990 to 2015 (Cook et al. 2007).

cover, latitude, \(I\) (dimensionless biome dependent proxy for rainfall regime), \(E_{\text{max}}\) (maximum transpiration rate that can be sustained under well-watered conditions), \(f_v\) (fraction of the grid cell covered by vegetation) (Merz 2004).

Some data coding for constant values include that for ambient CO\(_2\) (398.55), air temperature (Cullis & Regan 2004), \(R_n\) (net radiation values), \(A_{\text{dt}}\) (daytime net photosynthesis – user defined), \(\lambda\) (stomata-controlled ratio between intercellular and ambient CO\(_2\) partial pressure in the absence of water limitation (0.8), \(k\) (texture dependent conductivity), soil moisture (defined by the user) (Merz 2004). As a source code, .txt files were defined (Cook et al. 2007).

When the equations and functions defined by the model are coded, finally, an executable JAR file is prepared with the help of Launch4j (Sullivan 2011).

LUPWY is desktop-based software built on Java (Eriksson et al. 2009). This software calculates the rate of interception loss, rate of transpiration, rate of soil evaporation, rate of percolation as well as the rate of surface runoff, subsurface runoff and total runoff based upon the value provided to the software through an input panel. It also contains information about different plant species along with their habitat, usage and economic value. It works on two aspects of the land use type, LANDSAT and SENTINEL-2 (Eriksson et al. 2009).

LUPWY makes the calculation of the surface runoff and subsurface runoff easier with an interface to enter the values required for the application with its easy to use GUI. The user needs to provide temperature, daily precipitation, net radiation, day time net photosynthesis, texture dependent conductivity, etc., to calculate the total runoff (Cook et al. 2007). For user convenience, some important values are already provided in the software according to the research year. The user can change these values on their own in order to calculate the total runoff in different conditions (Eriksson et al. 2009).
Potential vegetation recommendation

Successful and sustainable forest management is the key to integrated watershed management and conservation (Sullivan 2002). The criterion such as altitudinal range, soil characteristics, temperature, climate, ease of cultivation, demand of local people, ethno-botanical importance, economical returns, etc., act as the primary determinants on making decisions regarding selection of specific species for specific locations (Hussain & Giordano 2004). The need to consider a wider portfolio of species is a prudent component of management strategy that aspires to adapt our forests and woodlands to projected changes followed by its social acceptance.

Tanahun district, being elevated above 869 m from sea level and temperature fluctuating between 25.8 and 2.2 °C with a yearly rainfall of about 2,058 mm, is comprised of lower tropical to sub-tropical vegetation types whereas Kaski district, which is situated at an altitudinal range of 450–8,091 m, covers upper tropical to Trans-Himalayan vegetation types. Considering the altitudinal and climatic variation, Shorearobusta, Acacia catechu, Bombaxceiba, Adina cardifolia, Lagerstroemia parviflora, Terminalialata, Albiziaprocera, Dalbergiasisso and Syziumcumini would be suitable species for Tanahu district. Scimia wallichiana, Quercus semecarpifolia, Aesculus indica, Alnus nepalensis, Michelia champaca, Betula utilis, Cupressus torulosa, Pinus roxburghii and Bombaxceiba seem to be suitable for Kaski district considering the climatic zone.

In terms of recommendations for vegetation, Alnus nepalensis would be suitable for planting in abandoned areas (barren areas), rough soil composition and river sides of mid-hill areas of these districts. Alnus nepalensis would be suitable for planting in abandoned areas, rough soil composition and river sides of mid-hill areas of these districts as an anti-erosion species. Similarly, grass species of the Bambusa family play a vital role in preventing and stabilising gullies which is also the main issue of Kaski region. Schimia wallichiana would be the most suitable species if the purpose is to rehabilitate the degraded areas rapidly and reliably.

From the point of medicinal use, Castanopsis indica can be marked higher as its bark can be used for anti-cancer activities. The consideration of social acceptability of recommended species has always been the main and final procedure of choice of species. There are many factors to be placed into special consideration before deciding on the final choice of the species and its suitability of establishment in the area. These factors have been defined in the methodology section of this report.

Therefore, considering all the factors, the recommendation for Shorea robusta in the lowest belt, Acacia catechu in the lower river sides, Bombax ceiba in oven pasture areas, Syzium cumini in waterlogged areas and Pinus roxburghii in the uppermost zone for Tanahun district is made. Similarly, in the case of Kaski district, Acacia catechu, Alnus nepalensis and Albizia procera in lower river sides and abandoned areas, Gmelinia arborea and Anogeissus latifolia in private lands, Quercus species in natural forest and Cupressus torulosa at the upper most region of Kaski district. Similarly, in terms of non-timber species, Baas (Bambusa nutans), Nigalo (Drepanostachyum intermedium), Kota (Daphne Bhoula), Pipal (Ficusreligiosa), Chabo (Piper chaba), Chiraito (Swertia sps.), Cardamon (Amomum subulatum) and Cinnamon (Cinnamomum zeylanicum) are recommended in terms of their site-specific relevancy as well as output generated in terms of people’s perception residing in the area. Table 2 highlights the criteria based ranking.

Considering three things, conservation and sustainable use of the rich bio-resources of the country, increased equity in the distribution of benefits from the commercial utilisation of the resources and the contribution of different sector to overall social and economic development of the country, the strategies related to policy, sustainable resource management and marketing are suggested:

1. Revise Non-Timber Forest Product (NTFP) related national policy to support the harvesters and local entrepreneurs.
2. Make NTFP policy and development process more effective through participation.
3. Improve the implementation of NTFP regulations.
4. Undertake support to raise policy awareness among forest users, collectors, and traders.

The following are recommendations for sustainable potential vegetation management:
<table>
<thead>
<tr>
<th>S.N.</th>
<th>Species</th>
<th>Scientific name</th>
<th>Range of distribution (horizontal and vertical)</th>
<th>Ease of cultivation / propagation</th>
<th>Regeneration / rotation period</th>
<th>Ethnobotanical importance</th>
<th>Multipurpose uses</th>
<th>Economic return</th>
<th>Annual industrial demand in Nepal</th>
<th>Market value / price</th>
<th>Royalty rate as % of market price</th>
<th>Social acceptance for promotion</th>
<th>Threat category / Conservation status</th>
<th>Quality improvement potential</th>
<th>Total score (out of 60)</th>
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<tbody>
<tr>
<td>1</td>
<td>Sal</td>
<td>Shorearobusta</td>
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1. The economic mapping and inventory of NTFPs.
2. Exploring and testing possible options for increasing production in a sustainable way, such as improving production from the wild, domestication, and improving harvesting technologies.
3. Ecosystems, habitats, species and products for research should be well prioritised.
4. Participatory learning and innovation in combination with indigenous knowledge with the help of external expertise for improved management practices should be promoted.
5. It is necessary to ensure the equitable distribution of benefits within the forest user groups (FUGs) by empowering women and disadvantaged sub-groups.
6. Providing the appropriate technical support in order to manage wild collection on NTFPs and domestication where it is feasible.
7. Providing training and conducting educational activities on NTFPs for extension works and forest users in order to improve technical skills.
8. There should be adequate communication, coordination and linkages between FUGs and other potential organisations that are involved in the field of NTFP development.
10. Promotion of market competition to provide fair NTFP prices for the collectors and FUGs.
11. Promotion of local value to NTFPs by introducing or developing appropriate processing technology.
12. Providing marketing support services to the local groups index to analyse the market system so that information that is needed for sustainable management, fair prices, and efficient market can be generated and also can be used to help in identifying the potential markets for NTFPs which will provide credit facilities for processing and trade, entrepreneurship training development.

**DISCUSSION**

The complex relationship between factors was evaluated to account for the effect of separate factors to determine the outcomes in the basin.

**Relationship between runoff and total vegetation cover in the study areas/catchments**

Runoff is the function of rainfall type and catchment characteristics dominant in the area. Within this domain, the runoff is also influenced by vegetation cover whose relationship is represented by Figure 8. It is observed from the accessory information and data that runoff is the characteristic of changes in rainfall occurring in the area. The analysis was made in terms of total vegetation cover in the area.

The graphs plotted for six years for the Chhabdi Khola basin show the general inverse relationship between runoff and total vegetation. An increase in the total vegetation cover in the watershed consequently decreases the runoff and vice versa. As can be seen from Figure 8, there is a high relationship between the vegetation cover and the amount of runoff. The higher the total vegetation cover, the less the amount of runoff is. This tendency can be seen in each of the four watersheds in each of the years.

As an example, year 1990 and 2015 can be compared and matched. In year 1990, Chhabdi and Guhe watersheds had a total vegetation amount of 65 and 62 respectively, together with the amount of runoff of 11 and 15. In the same period, Gharmi and Bhoti watersheds had less of a total vegetation amount of 29 and 29 respectively. At the same time, the amount of runoff decreased to 33 and 31 respectively.

From the graphs in the year 2015, it can be seen that the amount of agriculture covers in Chhabdi and Guhe watersheds have increased to almost 68 and 67 respectively. In turn, the amount of runoff decreased to almost 9 and 11. As for the Gharmi and Bhoti watersheds, the amount of vegetation increased to 40 and 40 respectively. At the same time, the amount of runoff decreased to 27 and 25 at the watersheds. The results from analysis of the graphs show that with an increase of vegetation cover, the runoff amount decreases and vice versa.

Relationships among various factors are briefly summarised as below:

The impact of LCCs on the landscape features of watersheds greatly affects slope and channel flows. Urbanisation increases the imperviousness and reduces infiltration of precipitation. Vegetation removal causes a reduction of rainfall interception and storage and, in arid/semiarid regions, the creation of physical crusts.
Land cover and soil properties

The specific types of soil in the catchment also determine the amount of runoff occurring in the catchment. In terms of particle size, smaller particles have more surface area for a given volume or mass of particles than larger particles. Soil texture and structure influence porosity by determining the size, number and interconnection of pores. Unlike texture, porosity and structure are not constant and can be altered by management, water and chemical processes.
Land cover and aspect

North facing slopes receive less heat from the sun. Conversely, south facing slopes tend to be warmer. Soil temperature affects the speed of chemical reactions. Moreover, aspect has a role to play when it comes to determining the types of vegetation. Soil temperature is important as it also affects how quickly plants take up water and nutrients. Soil covered in plants is protected (insulated) from fast heating or cooling of the soil (temperature fluctuations). With respect to our study areas, except the Gharmi Khola, the north aspect is covered with broadleaved closed forest. Studies showed that soils of the north-facing slope had higher SOC content, moisture, faunal abundance and diversity, and lower temperature and pH. Variations due to topographic aspects induced varied microclimates, causing differences in faunal abundance and diversity; soil moisture, temperature and organic matter trends affected soil fertility and ultimately soil quality. Further studies are required to clarify the complex interactions between soil properties (physio-chemical and biological), vegetation and slope aspect in Nepal, as well as to develop soil biological indicators as a tool to assist in sustainable land management.

Land cover type and runoff characteristics

Some studies show that a reduction in the forest area amounts to 60 and 32% in the analysed watersheds. However, the changes in the surface runoff for these watersheds are not comparable with the changes in the forest area but are within 20%. Similarly, the maximum (peak) value of runoff increased by an amount of 15% only. Negash Wagesho (Sullivan et al. 2003) aimed to research on catchment dynamics and its impact on runoff generation within the two watersheds. It has found that forest cover decreased by 34.5 and 50.7% during 1976–1986 and 1986–2000 respectively at the bilate watershed. The response of a catchment as a result of changing land use/land cover condition was modelled using the Soil and Water Assessment Tool (SWAT) for three different (1976/1986/2000) temporal land use conditions. The SWAT model separates overland flow components from total
catchment water yield. The simulated surface down cutting runoff component has increased progressively since the 1970s.

From 1990 to 2015, the Chhabdi Khola and Guhe Khola watersheds showed an increase in overall forest cover and a decrease in percentage of agricultural lands. This means that it will create good water storage by increasing percolation of the soil during rainfall and therefore slow down the runoff flow. In turn, agricultural lands are located mostly on the plane area of watershed areas and in a smaller percentage. Hence, the area is not very prone to heavy runoff events.

**Land cover type and slope**

Recent studies show that slope may cause water to run off rather than enter the soil, depending on the vegetation cover. Vegetated areas (grassland and forest land) help to reduce runoff by slowing water velocities. Forest on the steep slopes tends to hold the ground in place due to the root system and therefore prevent it from erosion processes. At the same time, naked ground is prone to heavy runoffs and landslides.

In the case of the Guhe Khola basin, a very low slope degree is found with moderate permeability. High slopes are present at the southern part of the catchment area and are covered with broadleaved closed forest. The Gharmi Khola catchment area is represented with mostly silt loam and silt soil types which provide the area with a moderate permeability class. For the Bhoti Khola watershed area, high slopes are present at the northern part of the catchment area and are covered mostly with an agriculture zone.

Studies have shown that there is a relationship between various forms of land cover types in a watershed and the nature of slope gradient in a watershed. Two groups of land cover classes, namely agriculture and grassland, were mainly found at gentle slopes between 6 and 20°, while scrubland and forests (both Erica-dominated and mixed forests) had their dominant occurrence at steeper slopes between 21 and 45°.

Slope may act as an important input for microclimatic conditions affecting the growth and distribution of vegetation. Steeper slopes generally receive greater concentrations of incoming solar radiation and therefore experience warmer, dryer climates than slopes with decreased steepness. Slope also affects soil moisture through downslope drainage, with greater rates of drainage occurring on steeper slopes.

For Chhabdi Khola, the lower part of the catchment is represented mostly with an agriculture area and a flat surface with a slope of 0–13.33°. There is also a presence of middle slopes (21.4–28.41°) near the outlet point which are represented with open broadleaved forest. In the higher slopes (28.42–36.83°) area there is a dense open broadleaved forest and on the maximum elevation (slope of 36.84–89.08°) slopes there is a dense closed broadleaved forest.

The Guhe Khola river basin is surrounded by a flat area (0–13.33°) covered mostly with an agriculture area and percentage of open broadleaved forest. High slopes (from 28.42–36.83 to 36.84–89.08°) are covered with broadleaved open and closed forests. The Gharmi Khola river basin is surrounded mostly by agricultural land and low slopes. The slope in the catchment area reaches 36.84–89.08° and is covered mostly with open broadleaved forest. For Bhoti Khola, the lower part of the catchment is represented mostly with an agriculture area and a flat surface with slope of 0–13.33°. There is a dense open broadleaved forest and closed broadleaved forest in the higher slopes’ area from 28.42–36.83 to 36.84–89.08°.

**CONCLUSIONS**

According to the present research, it can be concluded that land cover practice plays a crucial role in the study area. Nevertheless, a clear trend of change was not observed. The open broadleaved forest takes the major share in most of the cases, while the closed broadleaved forest has few increasing values during the last years. The trend is changing from increasing to decreasing, which is caused by community improvements and management practices. In the case of the Gharmi-Bhoti Khola watershed, the agricultural land proportion is more, which also shows a decreasing trend.

There are obvious connections between various parameters such as slope, aspect, soil properties and water runoff occurring in the catchment. However, the analysis of total vegetation and runoff in the catchment showed the
existence of a relationship between them. With the increase and decrease of vegetation cover, the runoff volume showed an inverse relationship. On this basis, land use planning could consider this relationship within the catchment, while also considering other factors such as soil type, people interests and other various factors important in the catchment. Along with that, it is important to make considerations of the changing climate in the region in order to be able to adapt to the future scenario. In addition, potential vegetation of the changing climate in the region in order to be able to catchment. Along with that, it is important to make considerations of the changing climate in the region in order to be able to adapt to the future scenario. In addition, potential vegetation on the basis of 12 criteria – range of distribution (horizontal and vertical), ease of cultivation/propagation, regeneration/rotation period, ethno-botanic importance, multipurpose uses, economical return, annual industrial demand in Nepal, market value/price, royalty rate as percentage of market price, social acceptance for promotion, threat category/conservation status and quality improvement potential – have been accessed in order to make recommendations for favourable species of plants in the area.

The present research recommends the management of the community forest with an accent on sparse distribution of trees and vegetation in order to minimise it. It is important to give priority to non-timber forest species since they are not well spread. The priority for the crops with lower organic matter requirement should be given due to the relatively low SOC content. Compensatory plantation could be done in the areas of source conservation. Potential vegetation recommended for each type's location should be taken into consideration. It is necessary to consider the relationship among soil types, slope and aspect to determine the type of land cover/vegetation. The soil types and slope nature as proposed by this study could be used as a guideline for the establishment of appropriate soil protection and river training works in the study area. On a local level, planning should be the focus on the demands of people, such as the means and methods for obtaining increased productivity, especially in the Chhabdi Khola watershed where SOC is low. However, future research is needed in order to observe more data and estimate the correlations among them.

ACKNOWLEDGEMENTS

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