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ORIGINAL ARTICLE

LUPWY: land use planner for water yield for environmental change analysis

Jay Krishna Thakur[1,3] · Kapil Khanal[2] · Kabita Poudyal[1]

Abstract Sustainable land use of watershed is an important aspect for the development and conservation of nature. Unconcerned use of the resources may lead to irreversible consequences and overall misbalance. The main aim of the research was to create a software, which could be useful for estimation of the catchment's nature conditions and assessment of changes on the basis of which the prediction of possible consequences can be made. In the given work, the influencing factors have been considered: precipitation and temperature analysis and land cover change over the last 30 years. With the help of the developed model based on the provided data, the representation of changes in climate, land cover and water dynamics were calculated. As a result, the software establishes the characteristics of the catchment area and makes it possible to see the changing pattern of the selected factors. The primary and secondary outcomes of the model provide precise calculation of surface runoffs, interception losses, and transpirations. In order to assess the effectiveness of the model, the results of the model and the river discharge were compared with estimation of the possible error rate. Different territories with similar characteristics can implement developed software for daily use on the local level. However, for successful applying in a new area the model has to be localized. Further evolvement is necessary in order to make the model applicable to any different location with specific features which can be different from the original example provided.

Keywords Land use planner · LUPWY · Water yield · Environmental change

Introduction

Land use planning plays an important role in sustainable conservation and management of catchment specific resources (Lal 2003). Certain properties of catchments determine various sub-parameters that play crucial role in water budget within the catchment (Bonan et al. 2003). Land cover and land use practices are unorganized in most river basins of Nepal (Kaly 2004).

In order to determine the optimum land use practice for enhancing the water service in Tanahun and Kaski districts in Chitwan-Annapurna Landscape (CHAL) (Osti 2005) a certain software model was developed and used. The target of the model is such that it combines the primary and secondary data as well as information pertaining to the study location and then combine the process based representations of terrestrial vegetation dynamics and land–atmosphere carbon and water exchanges in the modular framework (Sitch et al. 2003). Prediction of the results changes in vegetation patterns, water quality and runoff production requires an accurate representation of the relationships between hydrology, vegetation and climate (Wigmosta et al. 1994). The objective of the research was to develop the software providing the possibility to assess the changes of nature conditions over the years in the watershed areas.

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Study area

The study has been conducted in 3 watersheds of 2 districts of CHAL region.

The proposed watersheds of the research location are as follows:

- Tanahun district:

  – Chhabdi Khola watershed, Damauli;
  – Guhe Khola watershed, Khairenitar.

- Kaski district:
  – Bhoti Khola watershed.

The outlet point location of Bhoti Khola watershed in Kaski district is 83°57′5.888″E longitude and 28°17′17.982″N latitude. Guhe Khola is located in the western part of Tanahun district represented by latitude of 84°5′53.083″E and 28°0′50.063″N whilst the Chhabdi Khola located at the eastern part of Tanahun has point location represented by 84°16′37.048″E and 27°57′51.994″N. Chhabdi Khola has the largest catchment area of the three study areas with an area of about 28.4 km^2. Guhe Khola has the smallest catchment area with about 2.3 km^2. The Bhoti Khola catchment area is about 6 km^2.

Material and methodology

Model selection

To assess the current status of vegetation cover and other land use categories, detailed land cover mapping of watersheds in Tanahun and Kaski districts were carried out (Nepal 2013). Information obtained from land use classification were re-evaluated with the help of field verification through a representative field survey (Eiumnoh and Shrestha 2000). The methods of field verification constitute the observation and responses from locals and key informants (Schwartz et al. 2001). In order to assess the properties of soil and other field estimates that play vital role in determining the capacity of the watershed to contribute to the stream flow or to feed up the water supply, representative

sampling of the soil was done and the properties were determined through the laboratory analysis (Matteo et al. 2006; Mouazen et al. 2007). Inputs and outputs of the model were identified, based on the data of the software/model. Several existing models were studied and compared, in order to find the most suitable one. As a result, the Lund-Potsdam-Jena model (LPJ) was selected (Gerten et al. 2004).

Land cover classification

The land cover analysis was done in GIS environment. The required data was assessed to achieve the desired results and included DEM (Digital Elevation Models), district boundary data, land cover data, LANDSAT Imagery (for 1990, 1995, 2000, 2005, 2010 and 2015), and various topographic maps and base maps.

Climatic trend analysis

Analysis of climatic trend was carried out with the help of temperature and precipitation data of 30 years from the available stations. The stations were selected in response to their locations within the basin and/or close surroundings with the basin. The trend analysis has been made for 30 years' available data from the stations (Palmer et al. 2008). The details of stations and data availability are presented in the Table 1.

Data from available stations represents 30 years' meteorological measurements (except for Damauli station, where data availability initiates from 2004 only) and was used for climatic trend analysis. For temperature trend analysis, average annual temperature was calculated using the available data from monthly temperature values (Alexander 2006). The annual temperature trend was carried out for maximum temperature (t_{max}), minimum temperature (t_{min}) and mean temperature (t_{mean}) for each of the stations i.e. Pokhara airport, Khairenitar and Damauli. Similarly, precipitation trend was estimated by calculation of total annual rainfall from monthly precipitation from January to December.

Table 1 Details of meteorological stations for climatic data

SN	Station	Catchment	Location coordinates (lat, long, altitude)	Data types available	Period of data available for use
1	Pokhara Airport	Bhoti	28°13′; 84°00′; 0827 m	Precipitation, temperature	1985–2014 (30 years)
2	Khairenitar	Guhe	28°02′; 84°06′; 0500 m	Precipitation, temperature	1985–2014 (30 years)
3	Damauli	Chhabdi	27°58′; 84°17′; 0358 m	Precipitation, temperature	Precipitation (1985–2014) Temperature (2004–2014)

Development of the software

Several existing models were compared, in order to find the most suitable. Inputs and outputs of the model were identified, based on the data of the software/model. As a result, the Lund-Potsdam-Jena model (LPJ) was selected. To make the calculation of the water budget, the zone of study was defined, separated by watershed and by land use, and the results were provided by day.

The model calculates and solves equations by itself, which allows user to interact with the software easily. The software is coded in Java language and named LUPWY, for Land Use Planner for Water Yield. It can be run as an .exe file (only for Windows OS), or as a .jar file (for Windows, Mac and Linux OS). The internal databases are programmed in .txt files, which simplify the possibility to change them. As a result, three manuals were made: user and developer manual, and the model description where all the equations and parameters are explained.

Calibration and implementation of model in software

The LPJ model was used for the purpose of characterization of the study catchment. The site specific data available through primary and secondary sources are incorporated into the model to develop the understanding on the basic criteria of the model. The process of development of the software was based on the selected model. The primary criteria are to identify existing relationship between various components of water budget in the chosen watersheds of study. To fulfill the calculations there several data numbers user has to provide manually, which are year of the data, percent of needle leaved closed forest, needle leaved open forest, broadleaved closed forest, broadleaved open forest, agriculture percentage, scrubland, grassland and built up area. After calibration of data user will be asked to provide species of the territory and some climate features.

Eclipse is the platform where data are added to the workspace. To import existing Eclipse projects, the file is selected on the computer in a .zip format. The data is exported to the local file system. Java-Eclipse package explorer consists of data, images and various accessory information under file name Land Use Planning for Water Yield (LUPWY). Data consist of countries.txt, districts.txt, information of the species.txt, landuse.txt, precipitation.txt, temperature.txt, watershed.txt and image file consists of watershed map with land cover included for Chhabdi, Guhe, and Bhoti Khola watersheds. Similarly, district map of Kaski and Tanahun and country map of Nepal is also included. Organization's logo is also included as .png file.

Mainscreen.java consists of data coded into the system. Data coding is done for land-cover, latitude, I (dimensionless biome dependent proxy for rainfall regime), E_{max} (maximum transpiration rate that can be sustained under well-watered conditions), f_v (fraction of the grid cell covered by vegetation).

Some data coding for constant values include that for ambient CO_2 (398.55), air temperature, R_n (net radiation values), A_{dt} (daytime net photosynthesis (user defined)), λ (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) (Paudel et al. 2015). As a source code, .txt files were defined. With the availability of the information, the user is able to add/remove information.

When the equations and functions defined by the model are coded, finally, an executable JAR file is prepared with the help of Launch4j. Necessary equations and data usage are briefly described below:

• Potential Evaporation

Daily equilibrium evapotranspiration rate (Eq, in mm/d) depending primarily on net radiation and temperature is given by:

$$Eq = \left[\Delta/(\Delta + \gamma)\right]R_n/L \tag{1}$$

Where R_n (J.m^-2. d^-1) is net radiation (net short-wave flux minus net long-wave flux) given by the user. Δ is the rate of increase of the saturation vapor pressure with temperature given by:

• Actual evapotranspiration

Actual evapotranspiration is the sum of (a) interception loss and (b) plant transpiration for all vegetation types, plus (c) evaporation from bare soil, calculated as follows.

• Interception loss

Canopy storage capacity (Si, mm/d) is defined as a function of biome, leaf area index and precipitation amount (Pr, mm/d)

$$Si = Pr * LAI * i * f_v \tag{2}$$

Where f_V denotes the fraction of the grid cell covered by vegetation. The value of f_v is determined on the basis of land cover data in the basin. The factor I is a dimensionless biome-dependent proxy for the rainfall regime.

Storage capacity is relatively high in boreal forests, and lower in tropical forests due to high rainfall intensity. Also, the value of I is lower for grasslands than for forests.

We consider that all the precipitation is rain, and there is no snow. Daily interception loss (Ei) is then given by:

$$Ei = Eq * \alpha * w \tag{3}$$

Where, w represents the fraction of day-time that the canopy is wet, defined as follows:

$$w = \text{Min}\left(Si/\left[Eq\alpha\right], 1\right) \tag{4}$$

Night-time fluxes are neglected; the remaining day-time canopy-available energy (1−w) is used for plant transpiration.

- Transpiration

Transpiration is modelled as the lesser of an atmosphere-controlled demand function (D) and a plant-controlled supply function (S)

$$E_t = \text{Min}(S, D).f_v \tag{5}$$

Transpiration supply is determined by the maximum transpiration rate that can be sustained under well-watered conditions (E_{max},), and declines linearly with relative soil moisture (wr).

$$S = E_{max} * wr \tag{6}$$

Relative soil moisture values (Table 2) are the average of the values measured from the soil samples taken in the field.

The soil is treated as a simple bucket consisting of one layer. Atmospheric demand represents 'unstressed transpiration', which occurs when stomata opening is not limited by reduced water potential in the plant. Daily demand is a hyperbolic function of canopy conductance (the sum of stomata conductance of all leaves for a given PFTs):

$$D = (1 - w)\, Eq * \alpha m/\left(1 + gm/g_{pot}\right) \tag{7}$$

A maximum Priestley–Taylor coefficient, αm = 1.391, and a scaling conductance, gm = 3.26 mm/s; is defined. Demand approximates $E_{q\alpha m}$ when the canopy is dry and g_{pot}—the potential canopy conductance that can be achieved when there is no water limitation—tends to infinity. g_{pot} (mm/s) is directly related to the photosynthesis rate as follows:

$$g_{pot} = g_{min} + 1, 6 * A_{dt}/[Ca(1 - \lambda)] \tag{8}$$

Here, g_{min} is a PFT-specific minimum canopy conductance (CaC) that accounts for plant water loss not directly linked to photosynthesis (e.g. guttation). A_{dt} is day-time net photosynthesis (g C /d_m^{-2}). Adt value was user defined; Ca is ambient CO_2 (mole fraction). The value taken is 398.55 ppm (http://co2now.org/current-co2/co2-now/annual-co2.html). λ is the stomata-controlled ratio between intercellular and ambient CO_2 partial pressure in the absence of water limitation; it is lower for warm-zone C4 grasses (0.4) than for C3 plants, i.e. trees and cool-zone grasses (0.8). We took λ = 0.8.

- Soil evaporation

Daily evaporation from bare soil (ES) occurs at the simulated fraction of the grid cell (1-fV) not covered by vegetation, which may extend towards the plant-covered area according to the daily status of PFT-specific leaf phenology.

$$E_s = Eq\alpha * wr20 * \left(1 - f_v\right) \tag{9}$$

Where, wr20 represents the relative moisture in the upper 20 cm of the soil column. As we considered that there is only one layer, we assumed that wr20 = wr.

Capillary rise from groundwater is not taken into account due to the lack of global data on the height of the groundwater table.

- Soil water storage and runoff generation

Water content of both soil layers is updated taking account of snowmelt (M), through fall (Prt = Pr–Ei); transpiration, evaporation, percolation through the layers, and runoff:

$$\Delta w1 = (Prt + M - \beta1 * Et - Es - p1 - R1)/\left(w_{max} * d1\right) \tag{10}$$

$$\Delta w2 = (p1 + M - \beta2 * Et - Es - p1 - R2)/\left(w_{max} * d2\right) \tag{11}$$

Here, Δw1 and Δw2 are changes in soil water content of both layers (expressed as a fraction of the respective wmax); β1 and β2 represent the fractions of water extracted for transpiration from each layer (such that β1 + β2 = 1).

As we considered only one soil layer and we neglected snowmelt, we can change these equations:

$$\Delta w1 = (Prt - Et - Es - p1 - R1)/\left(w_{max} * d1\right) \tag{12}$$

$$\Delta w2 = (p1 - R2 - p2)/\left(w_{max} * d2\right) \tag{13}$$

Percolation rate from the upper to the lower soil layer (p1, mm/d) depends on soil texture and layer thickness, and declines exponentially with soil moisture:

$$p1, 2 = k * w1^2, \tag{14}$$

where k is the texture-dependent conductivity, determined by the user. The model diagnoses surface runoff

Table 2 Average relative soil moisture measured from field assessment

Watershed	Relative soil moisture %
Chhabdi Khola	18.3
Guhe Khola	17.5
Gharmi Khola	31.3
Bhoti Khola	20.9

Table 3 Average soil texture for watersheds obtained from field assessment

Watershed	Texture type
Chhabdi	Silt loam
Guhe	Silt loam
Gharmi	Silt loam
Bhoti	Silt

Table 4 Land-cover mapping classes for Kaski-Tanahun districts (2015)

SN	Land use/cover type	Percentage covered (%)
1	Closed Broadleaved forest	13.67
2	Opened Broadleaved forest	27.15
3	Agriculture	29.80
4	Built-up areas	18.59
5	Water	5.62
6	Snow	5.17
Total		100.00

(R1) and subsurface runoff (R2) from the excess of water over field capacity of the upper and the lower soil layer, respectively.

$$R1 = Prt * (1 - FC1) \tag{15}$$

$$R2 = p1 * (1 - FC2) \tag{16}$$

The texture data has been used from the calculations done through analysis of soil. The soil texture for various watersheds is presented in the Table 3.

LUPWY is desktop based software built on java. This software calculates rate of interception loss, rate of transpiration, rate of soil evaporation, rate of percolation as well as rate of surface runoff, subsurface runoff and total runoff based upon the value provided to the software through input panel. It contains the 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 (Table 4).

LUPWY makes the calculation of the surface runoff and subsurface runoff without complicated interactions, since software provides output data based on input characteristics. User is required to provide temperature, daily precipitation, net radiation, day time net photosynthesis, texture dependent conductivity etc. to calculate the total runoff. For convenience purposes some important values are already provided in the software according to the research year. User can change these values on their own in order to calculate the total runoff in different conditions.

Results

Based on the above written methodologies, the results of each step of the project are given below.

Model selection

On a global scale, the largest change in terms of land area, and arguably also in terms of hydrologic effects, is deforestation and afforestation" (Calder 1992). Removal of forest cover from a watershed can result in significant hydrologic changes, including: decreased interception of rainfall by the tree canopy (net precipitation); decreased evapotranspiration; decreased rainfall interception by surface litter; and increased runoff volumes (Bruijnzeel 2004). Many researches and studies have shown a concrete relationship that exists between changes in runoff with changing land cover pattern in the basin (Tu 2011). The runoff in turn determines the amount of water storage in the catchment and sedimentation (Croke et al. 2005).

Various available models pertaining to the objectives of the study were reviewed and studied in detail. Among the relevant and available ones, the ones most favorable to the objective of the study were selected on the basis of their suitability for application as per geo-physical settings of the watersheds, site-data availability of the requisite study site, performance evaluation of the model in the context of its use for others purposes.

Major models of the review were:

- Lund-Potsdam-Jena model (LPJ Model) ;
- Modified dynamic global vegetation model for simulating large spatial scale land surface water balances ;
- A distributed hydrology-vegetation model for complex terrain ;
- Modified Morgan, Morgan and Finney model.

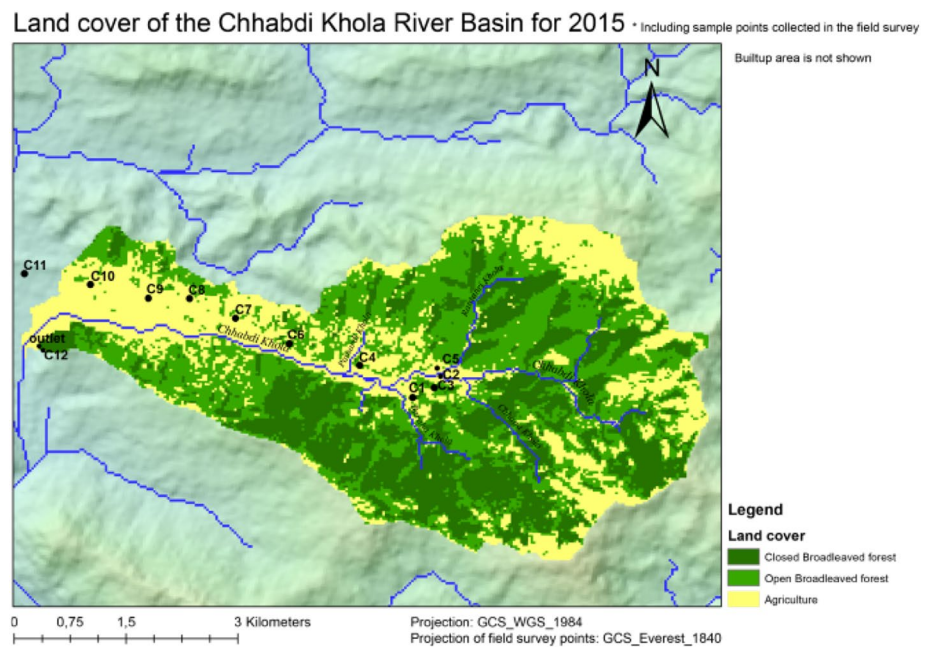### Land-cover classification

One of the important aspects of this project was to generate the land cover maps for various years in order to track the changes occurring in the study areas for the subsequent years (1990, 1995, 2000, 2005, 2010 and 2015) (Parker et al. 2003).

Results obtained for various watersheds are presented on the Fig. 1.

Chhabdi Khola watershed

The Fig. 1 shows of the land cover map of Chhabdi Khola basin for the year 2015 shows that 28.84% is covered by closed broadleaved forest, 38.99% by open broadleaved forest and 32.17% of the area of the basin by agricultural land.

Fig. 1 Land cover mapping for Chhabdi for 2015

Land cover of the Chhabdi Khola River Basin for 2015 · Including sample points collected in the field survey

The sampling points are going to be used as a basis for the verification of land cover maps obtained through classification processes (Foody 2002).

Land cover change analysis for Chhadbi Khola watershed is depicted in the Fig. 2 from year 1990 and 2015. As can be observed, Chhabdi Khola river basin is an area largely covered by open and closed forest with fluctuations at around over 60% of the total area from 1990 to 2015. It is highly likely that the percentage of the closed broadleaved forest class is going to rise significantly in the monsoon season, as the canopy will get denser in the wetter season (this also applies to the other study areas) (Carpenter and Zomer 1996). While the share of closed broadleaved forest was at its lowest in 2000, the share of open broadleaved forest peaked with 41.86%. In the year 2010 can be observed the other tendency: while the share of closed broadleaved forest was 30.77%, the share of open broadleaved forest was at its lowest with 31.35%.

From 2010 to 2015 the decrease of over 6.50% can be observed, resulting in the Chhabdi Khola river basin having 32.17% agricultural land. There is a weak negative correlation between the progression of the years the amount of agricultural area with a correlation coefficient of R=−0.31 and, as can be observed in the Fig. 3 by the fluctuation in agricultural area.

Most of the agricultural area is located in the north and southeast part and in the downstream of Chhabdi Khola. The agricultural area in the Chhabdi Khola river basin is fluctuating around the mid 30.00%. The agricultural land increased from 34.68% in 1990 to 38.61% in 1995, and then decreased to 35.26% in 2000. Subsequently there is an increase in agricultural land from 2000 to 2010 (from 35.26% in 2000 to 36.62% in 2005, followed by a further increase to 37.88% in 2010). There is a very little correlation between the share of agricultural area and the progression of years, which makes it difficult to assess whether the agricultural area is actually improving over these years. Although, in year 2015 the share of agricultural area is at its lowest (compared to the other 5-year intervals), this is not the evidence that the agricultural area is going to decrease in the future.

Guhe Khola watershed

The land cover classification for Guhe Khola watershed for the year 2015 accounts 30.79% of closed broadleaved forest, 35.88% of open broadleaved forest and 33.33% of agriculture land cover (Fig. 4). The Guhe Khola river basin is covered with over 60% of forest. A significant share of it is distributed in small patches of open broadleaved forest throughout the agricultural areas. There is generally more open broadleaved forest than closed broadleaved forest. There is noticeable a big difference in 1995 and 2010, with the share of open broadleaved forest being approximately double with 42.85%, then the share of closed broadleaved forest 21.88% for 1995 and 42.19% open broadleaved forest vs. 19.39% closed broadleaved forest for 2010.

The larger agricultural areas are mainly located in the northern and central parts of the river basin. As can be observed in the Fig. 5, there are some fluctuations in the share of agricultural area cover from 1990 to 2000. The share of agricultural is 37.20% in 1990 vs. 33.33% in 2015. With a correlation coefficient of R=−0.24 there is a weak negative correlation between the progression of

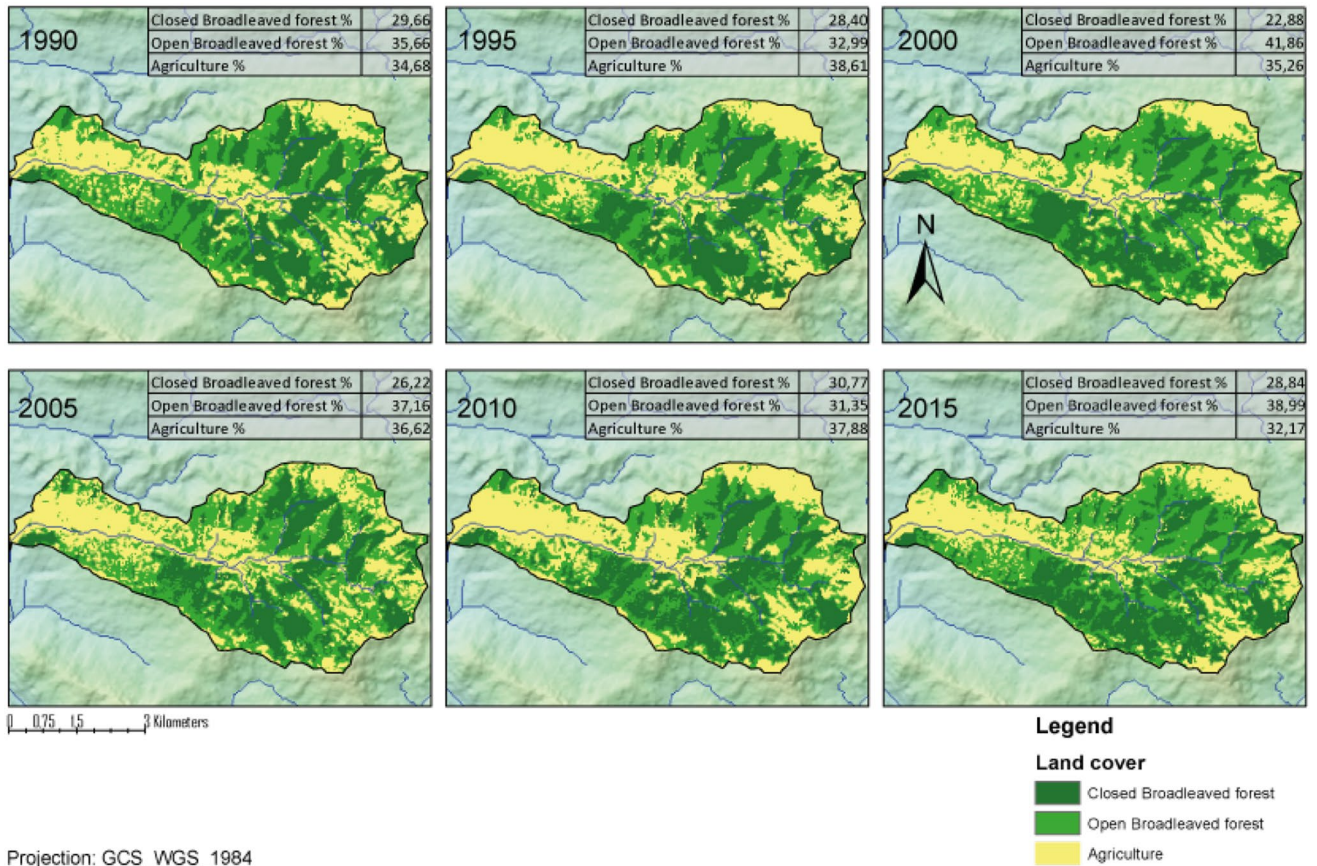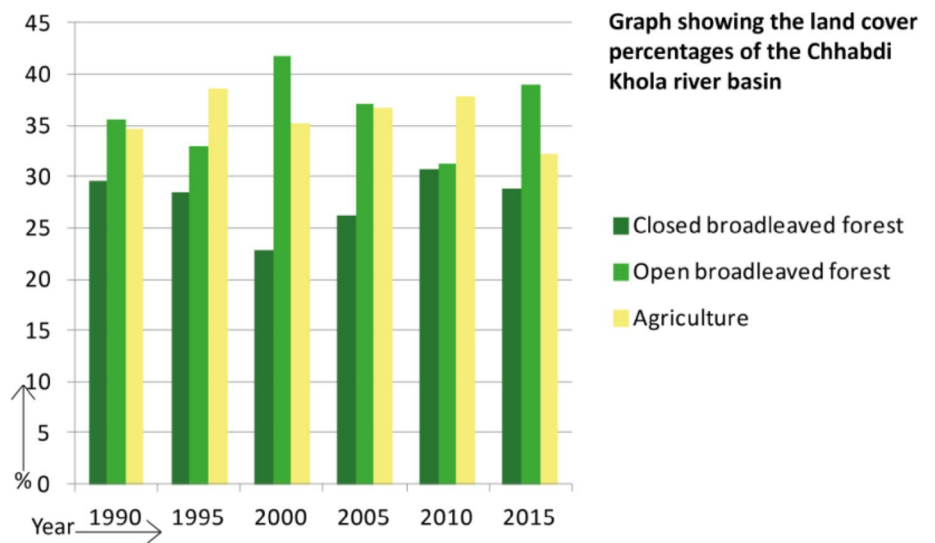## Land cover of the Chhabdi Khola River Basin from 1990 to 2015 *Builtup area is not shown

1990	Closed Broadleaved forest %	29,66
	Open Broadleaved forest %	35,66
	Agriculture %	34,68

1995	Closed Broadleaved forest %	28,40
	Open Broadleaved forest %	32,99
	Agriculture %	38,61

2000	Closed Broadleaved forest %	22,88
	Open Broadleaved forest %	41,86
	Agriculture %	35,26

2005	Closed Broadleaved forest %	26,22
	Open Broadleaved forest %	37,16
	Agriculture %	36,62

2010	Closed Broadleaved forest %	30,77
	Open Broadleaved forest %	31,35
	Agriculture %	37,88

2015	Closed Broadleaved forest %	28,84
	Open Broadleaved forest %	38,99
	Agriculture %	32,17

0   0,75   1,5   3 Kilometers

Legend

Land cover

- Closed Broadleaved forest
- Open Broadleaved forest
- Agriculture

Projection: GCS_WGS_1984

Fig. 2 Changes in land cover for Chhabdi from 1990 to 2015

Fig. 3 Graph showing changes in various land cover for Chhabdi Khola watershed

Graph showing the land cover percentages of the Chhabdi Khola river basin

- Closed broadleaved forest
- Open broadleaved forest
- Agriculture

Land cover of the Guhe Khola River Basin from 1990 to 2015 *Builtup area is not shown

1990	Closed Broadleaved forest %	30,48
	Open Broadleaved forest %	32,31
	Agriculture %	37,2

1995	Closed Broadleaved forest %	21,88
	Open Broadleaved forest %	42,85
	Agriculture %	35,27

2000	Closed Broadleaved forest %	24,94
	Open Broadleaved forest %	35,32
	Agriculture %	39,75

2005	Closed Broadleaved forest %	25,14
	Open Broadleaved forest %	36,03
	Agriculture %	38,83

2010	Closed Broadleaved forest %	19,39
	Open Broadleaved forest %	42,19
	Agriculture %	38,42

2015	Closed Broadleaved forest %	30,79
	Open Broadleaved forest %	35,88
	Agriculture %	33,33

N

0 0.25 0.5   1 Kilometers

Legend

Land cover

■ Closed Broadleaved forest
■ Open Broadleaved forest
■ Agriculture

Projection: GCS_WGS_1984

Fig. 4 Changes in land cover for Guhe from 1990 to 2015

Fig. 5 Graph showing changes in various land cover for Guhe Khola watershed

Graph showing the land cover percentages of the Guhe Khola river basin

■ Closed broadleaved forest
■ Open broadleaved forest
■ Agriculture
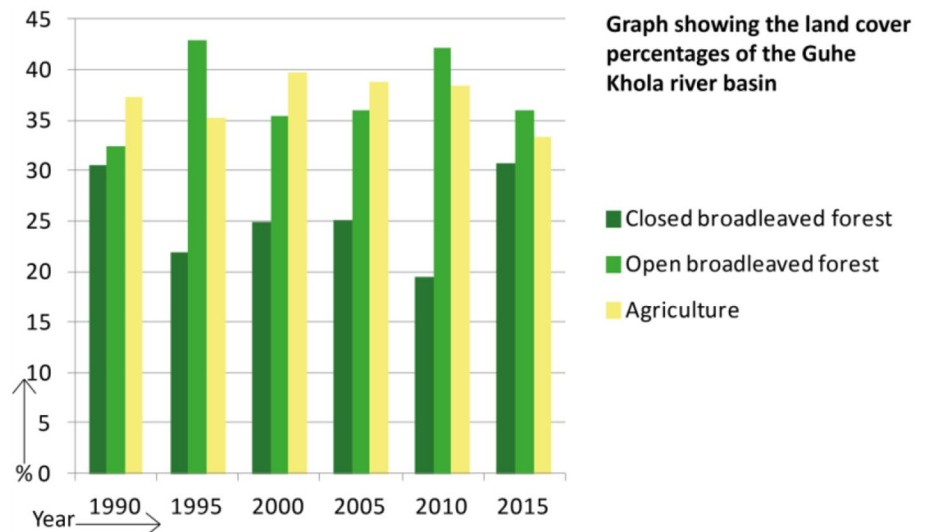
the years and the amount of agricultural area. Between the years 2010–2015, a significant amount of open forest has been disturbed over the watershed area. Overall, since 1990 the share of agricultural area has decreased. This
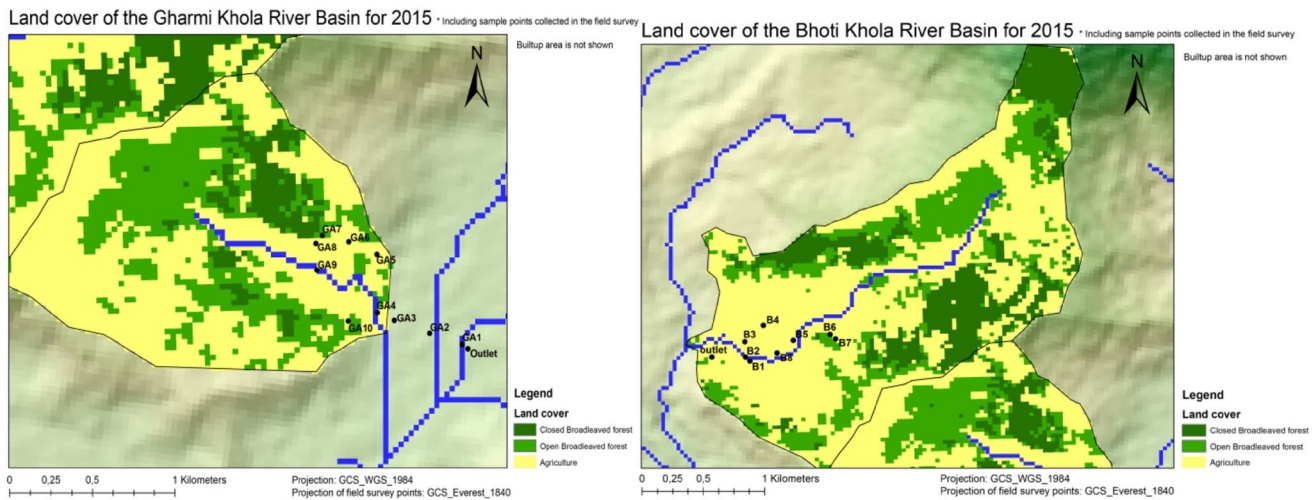
Fig. 6 Land cover classification for Bhoti Khola catchment for 2015

Fig. 7 Graph showing changes in various land cover for Bhoti watershed
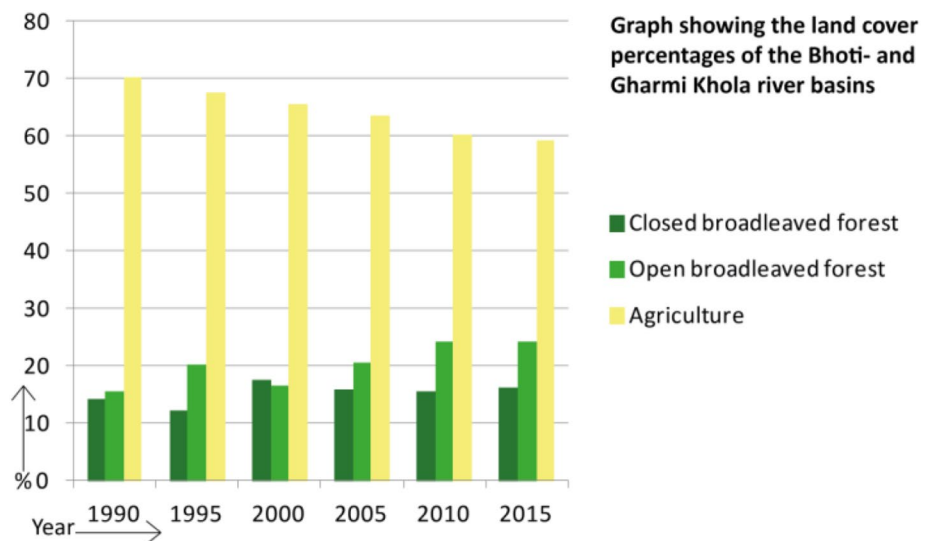
change could have a positive effect on the water balance in the area.

Bhoti Khola watersheds

As can be observed in the Fig. 6, the Bhoti Khola river basins are largely covered by agricultural area. The agricultural area in the Bhoti Khola river basins seems to be decreasing in each 5-year interval (Fig. 7). Overall the share of agricultural area decreased a sizable 11%, from 70.41% in 1990 to 59.41% in 2015. From the Fig. 8 can be stated that there is a near perfect negative correlation between the amount of agricultural area and the progression of the years with a correlation coefficient of R = −0.99. As a result, future decrease in agricultural area could be expected. This could have a positive effect on the water balance.

Climate trend analysis

The trend of climatic changes in the area was analyzed with the help of trend analysis of temperature and rainfall.

Trend of Annual Rainfall

As represented by all three stations in the study area, the thirty-year total annual rainfall shows decreasing trend. On the basis of coefficient of determination (R^2), the decrease in rainfall was not statistically significant (Singh et al. 2014). The highest rainfall (in mm) that was received in each stations (Lamachaur, Pokhara Airport, Damauli and Khairinitar) were 5365.2 mm in 2007, 4879 in 1998, 2254.1 in 1999 and 3057.6 in 2002) respectively. On the other hand, the lowest rainfall (in mm) that each
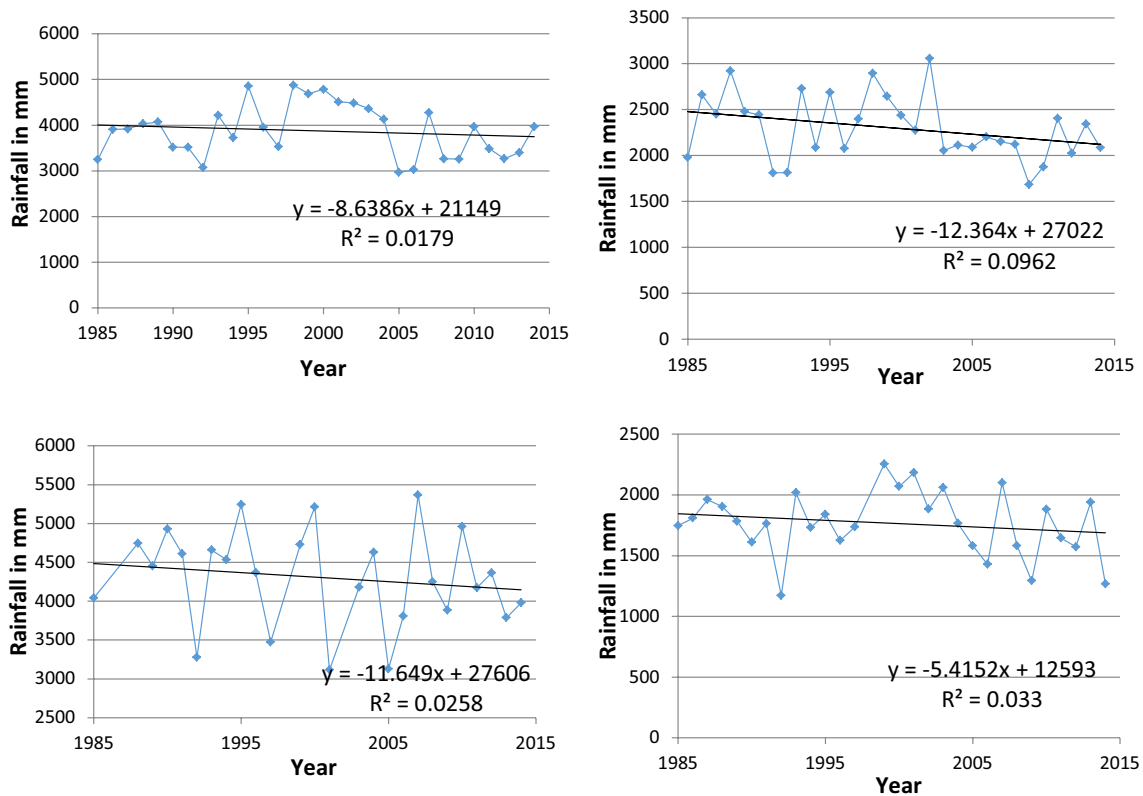
Fig. 8 30 years of total annual rainfall (1985–2015) trend in the study area (a. Pokhara airport, b. Khairinitar, c. Lamachaur, d. Damauli)

Fig. 9 30 year's maximum, minimum and mean temperature trend for Pokhara Airport Station
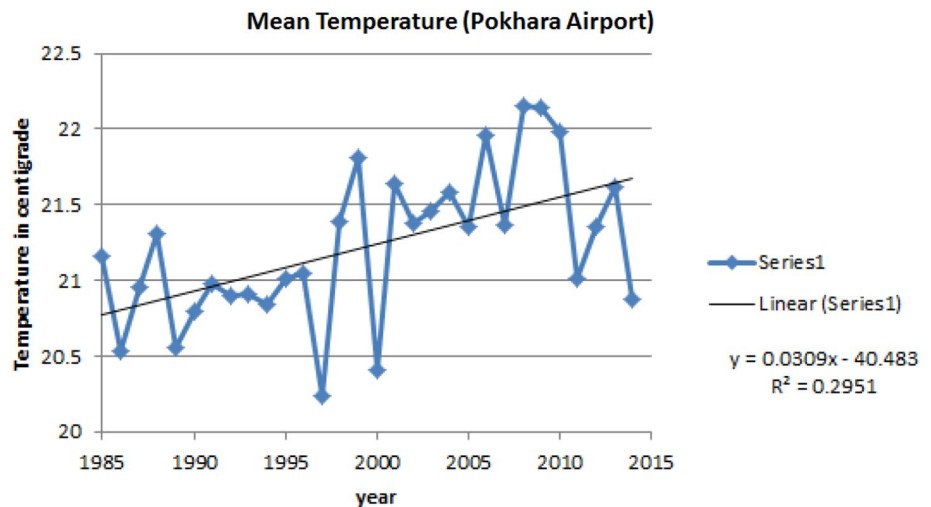

of the stations received are 3114.2 2001, 2967.1 in 2002, 1171.2 in 1992, 1684.9 in 2009.

Trend of Temperature.

1. Pokhara Airport station

The Fig. 9 shows the mean temperature for Pokhara Airport from 1985 to 2015. Tempeture as depicted by the station showed the increasing trend. The mean temperature was found to be highest in 2008 with the temperature of 22.2 °C and lowest was in 1997 with 20.2 °C. The trend for mean temperature was seemed to be increasing which was also statistically significant.

Fig. 10 30 years' average of mean temperature of Khairinitar
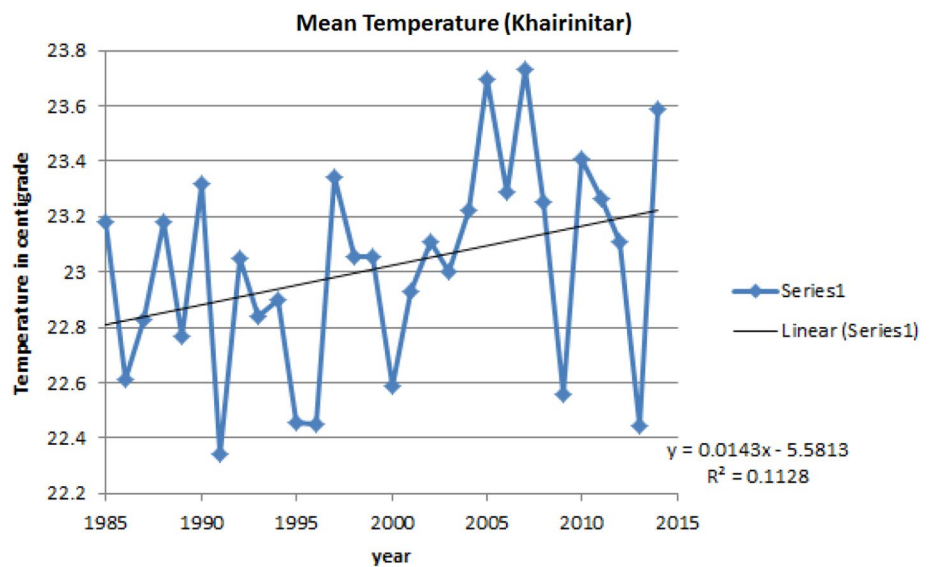
2. Khairinitar station

Looking at the 30 years' average of the mean temperature in Khairinitar station (Fig. 10), can be observed the increasing tendency although there was a great fluctuation in between 30 years with highest temperature in 2007 (23.7 °C) and lowest temperature in 1991 (22.3 °C) with statistically significant value with respect to R^2.

3. Damauli station

The data for the temperature in case of Damauli station (Fig. 11), was available only from 2004 to 2014. Mean temperature was found to be highest with the value of 25.3 °C in 2004 and lowest with 22.5 °C in 2008. The tendency has decreased by 0.012 °C.

Development of the Software

The developed software makes it possible to see how topography, soil characteristics, vegetation and climate 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 (UIZ 2015).

Eclipse is the platform where data are added to the workspace. To import existing Eclipse projects, the achieve file is selected on the computer, which must be a *.zip* file. The resources are exported to and archive file on the local file system. Prepared under Java-Eclipse, the package explorer consists of data, images and various accessory information under achieve file name as Land Use Planning for Water Yield (LUPWY) (UIZ 2015). Data consist of countries. txt, districts.txt, information of the species.txt, landuse.txt,

Fig. 11 10 years' average of mean temperature for Damauli station

precipitation.txt, temperature.txt, watershed.txt and image file consists of watershed map with land cover included for Chhabdi, Guhe and Bhoti Khola watersheds. Similarly, district map of Kaski and Tanahun and country map of Nepal is also included.

Mainscreen.java consists of data coded into the system. Data coding is done for land cover, latitude, I (dimensionless biome dependent proxy for rainfall regime), E_{max} (maximum transpiration rate that can be sustained under well-watered conditions), f_v (fraction of the grid cell covered by vegetation) (Fritzsche 2010).

Some data coding for constant values include that for ambient CO_2 (398.55), air temperature, R_n (net radiation values), A_{dt} (daytime net photosynthesis (user defined)), λ (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). As a source code, .txt files were defined. The following steps represent the usage of the model:

Step 1: Select a country, district and watershed. The map and the information are updated when you select a country, a district or a watershed.
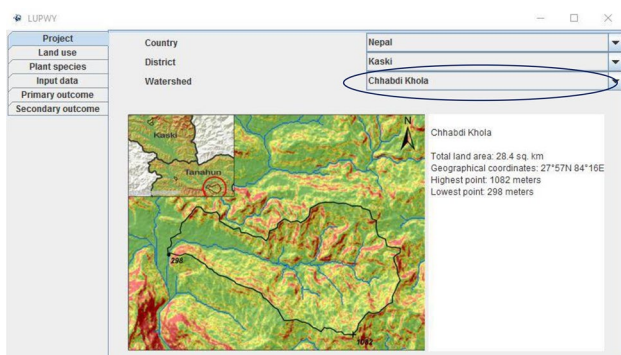

Step 2: Calculate the land use. The percentage of each land cover type depends on the watershed you selected before, and on the selected year.
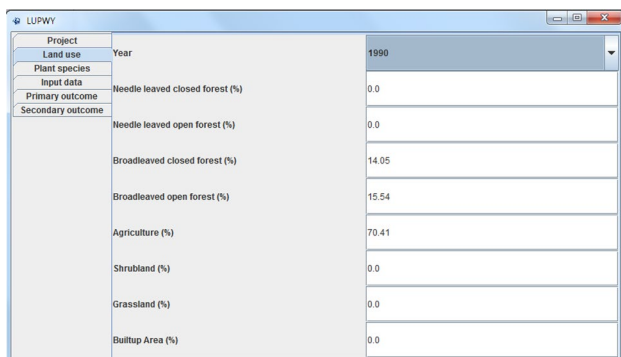
Step 3: Select the plant species. The model allows user to select necessary agro species, tree species and medicinal and non-timber forest species.
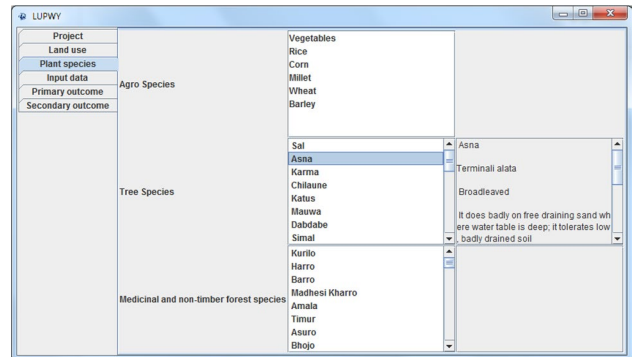

Step 4: Input data. The year should be selected as in the window "Land use". You can change its, the percentages of land use will be updated. Select a month, the values of "Air temperature" and "Daily precipitation" will be updated, but user can change them manually. Here all the parameters needed can be found to calculate the water budget. The values are pre-filled, but you can change the values manually When all the parameters are set, user can calculate the water budget by clicking on the button "Calculate".
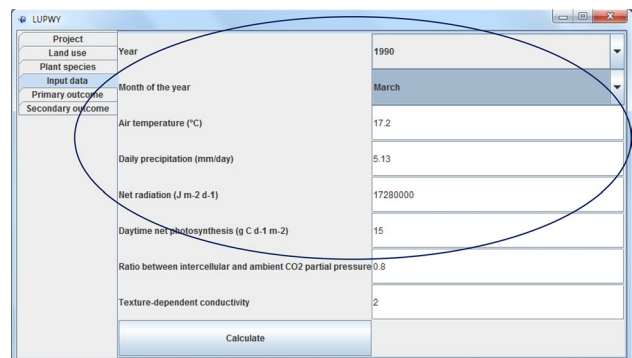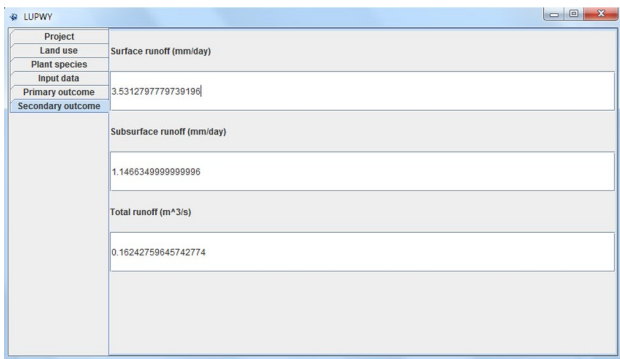

Step 5: Primary outcome.

Here you can find a part of the results of the water budget: interception loss, transpiration, soil evaporation, percolation.
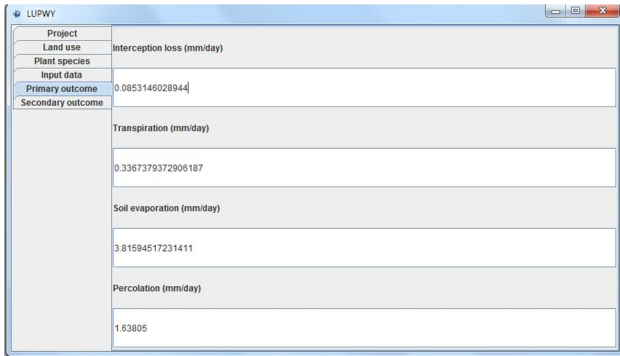
Step 6: Secondary outcome. The results linked with surface runoff and subsurface runoff can be found in the following section.

Calibration and implementation of model in software

In order to assess the effectiveness of the model, the results of the model and the river discharge have been compared (Table 5). The model seems to give accurate results for Guhe and Bhoti Khola. However, the area of Chhabdi Khola watershed represents high error rate.

As for the land use classification, on the basis of finding of the study, it can be concluded that the land cover practice is changing in the areas of study, although there is not a clear trend of change (Houghton et al. 2006). In most of the cases, share of open broadleaved forest is more. In case of closed broadleaved forest, it has improved in the recent years. The trend is first decreasing and then increasing. The causes could be mostly attributed to the improvement in community forest and management practices (Putz et al. 2008). In case of Bhoti Khola watershed, agricultural land proportion is more, which also shows decreasing trend.

Table 5 Calibration

Watershed	Model (m³/s)	River discharge (m³/s)	Error rate
Chhabdi Khola	0.767	0.489	56.85%
Guhe Khola	0.049	0.050	2.00%
Bhoti Khola	0.153	0.152	0.65%

Conclusion

Land use practices play an important role in the conservation of natural resources of the catchment area and its protection from degradation. The unpredictable power of nature can cause a lot of damage if they won`t be observed and prevented. Among the others, land use changes influence the local water and soil balance.

The developed software makes it possible to see how topography, soil characteristics, vegetation and climate 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. The research pilot project was aimed to understand the nature of watershed with respect to changing scenario of land cover as well as climate change trend. The detailed land cover mapping of watersheds was carried out to assess the current status of vegetation cover. In order to assess the properties of soil and other field estimates that play vital role in determining the capacity of the watershed to contribute to the stream flow or to feed up the water supply, representative sampling of the soil was done and the properties were determined through the laboratory analysis.

Different territories with similar characteristics can implement developed software for daily use on the local level. However, for successful applying in a new area the model has to be localized. Further evolvement is necessary in order to make the model applicable to any different location with specific features which can be different from the original example provided. The basic calibration of the model will consist on the similar steps; however, the required data may vary according to specific characteristics of the territory of the research.

The software based on LPJ model is established in order to account for the characteristics of the watershed and study on the nature of changing output with changing inputs to the model. However, the state of art established model is limited in its use for the study area only, because of inbuilt characterization limitations. Along with providing the useful insights of the study area, such research can be useful for establishing the foundation upon which to base the future studies of such kinds.

References

Alexander L, Zhang X et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111(D5):22

Bonan, G. B., S. Levis, et al. (2003). A dynamic global vegetation model for use with climate models: concepts and description of simulated vegetation dynamics. Glob Chang Biol 9(11): 1543–1566.

Bruijnzeel, L. A. (2004). Hydrological functions of tropical forests: not seeing the soil for the trees? Agric, Ecosyst Environ 104(1): 185–228.

Calder, I. (1992). The hydrological impact of land-use change. Proceedings of the conference on priorities for water resources allocation and management, natural resources and engineer advisers conference, Southampton.

Carpenter, C. and R. Zomer (1996). Forest ecology of the Makalu-Barun National Park and Conservation Area, Nepal. Mt Res Dev 16:135–148. Doi:10.2307/3674007

Croke J, Mockler S et al (2005) Sediment concentration changes in runoff pathways from a forest road network and the resultant spatial pattern of catchment connectivity. Geomorphology 68(3):257–268

Eiumnoh, A. and R. P. Shrestha (2000). Application of DEM data to Landsat image classification: evaluation in a tropical wet-dry landscape of Thailand. Photogramm Eng Remote Sens 66(3): 297–304.

Foody GM (2002) Status of land cover classification accuracy assessment. Remote Sens Environ 80:185–201

Fritzsche, P. (2010). Development of a satellite-based dynamic regional vegetation model for the Drâa catchment, Citeseer.

Gerten D, Schaphoff S et al (2004) Terrestrial vegetation and water balance—hydrological evaluation of a dynamic global vegetation model. J Hydrol 286(1):249–270

Houghton R, Lambin E et al (2006) Global land-cover change: recent progress, remaining challenges. Springer, Berlin

Kaly, U. L. (2004). Review of Land-based sources of pollution to the coastal and marine environments in the BOBLME Region. Unpublished report prepared for the BOBLME Programme. Unedited version at http://www.BOBLMME.org.

Lal R (2003) Soil erosion and the global carbon budget. Environ Int 29(4):437–450

Matteo M, Randhir T et al (2006) Watershed-scale impacts of forest buffers on water quality and runoff in urbanizing environment. J Water Resour Plan Manag 132(3):144–152

Mouazen, A., M. Maleki, et al. (2007). On-line measurement of some selected soil properties using a VIS–NIR sensor. Soil Tillage Res 93(1): 13–27.

Nepal W (2013). Chitwan annapurna landscape (CHAL): a rapid assessment. World Wildlife Fund Nepal

Osti R (2005) Indigenous practices for harvesting water from streams in the semi-arid environment of Nepal. Int J Sustain Dev World Ecol 12(1):13–20

Palmer MA, Reidy Liermann CA et al (2008) Climate change and the world's river basins: anticipating management options. Front Ecol Environ 6(2):81–89

Parker DC, Manson SM et al (2003) Multi-agent systems for the simulation of land-use and land-cover change: a review. Ann Assoc Am Geogr 93(2):314–337

Paudel, D., J. K. Thakur, et al. (2015). Soil characterization based on land cover heterogeneity over a tropical landscape: an integrated approach using earth observation data-sets. Geocarto Int 30(2): 218–241.

Putz FE, Zuidema PA et al (2008) Improved tropical forest management for carbon retention. PLoS Biol 6(7):e166

Schwartz, M. R., J. C. Bridger, et al. (2001). A validity assessment of aggregation methods for multiple key informant survey data. Community Dev 32(2): 226–237.

Singh SK, Srivastava PK et al (2014) Appraisal of land use/land cover of mangrove forest ecosystem using support vector machine. Environ. Earth Sci 71(5):2245–2255

Sitch S, Smith B et al (2003). Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Glob Chang Biol 9(2): 161–185.

Tu J (2011). Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. Appl Geogr 31(1): 376–392.

UIZ (2015) Land Use Planner - LUPWY. http://uizentrum.de

Wigmosta MS, Vail LW et al (1994) A distributed hydrology-vegetation model for complex terrain. Water Resour Res 30(6):1665–1679