PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

# Analysis of changes in crop farming in the Dudh Koshi (Nepal) driven by climate changes

Marco Gianinetto, Francesco Polinelli, Federico Frassy, Martina Aiello, Francesco Rota Nodari, et al.

SPIE.

# Analysis of changes in crop farming in the Dudh Koshi (Nepal) driven by climate changes

Marco Gianinetto*[a], Francesco Polinelli[a], Federico Frassy[a], Martina Aiello[a], Francesco Rota Nodari[a], Andrea Soncini[b], Daniele Bocchiola[b]

[a]Dept. of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via Ponzio 31, Milano, Italy; [b]Dept. of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, Milano, Italy.

## ABSTRACT

Nepal is one of the poorest nations of the world and the Koshi Basin includes some of the poorest regions of this country. It's farming system is subsistence agriculture, mainly rainfed, with crop productivity among the lowest in South Asia. Nepal is also severely impacted by climate changes, such as retreat of glaciers, rise in temperature, erratic rainfalls and increase in frequency of extreme weather. This paper describes the spatio-temporal evolution of cultivated land in Dudh Koshi during the last four decades (1970s-2010s), by mapping the farming of its four main cereals in the districts of Solukhumbu, Okhaldunga and Kothang from space. The analysis of satellite time series showed a 10% of increment in farmland from 1970s to 1990s, and about 60% in the following twenty years. With a shift of cropping to higher altitudes. Data belonging to of the second twenty years are strongly correlated with the population growth observed in the same period ($0.97<R^2<0.99$) and consistent with the average daily caloric intake.

Finding confirms the result of recent studies that agriculture practices once distributed in lowland areas have now spread to higher altitudes and seems to suggest that demographic and socioeconomic pressures are driving the expansion, while climatic and topographic parameters are just channeling the expansion. Apart from any policies that could change the tack, Dudh Koshi should be able to meet the increasing demand of cereals in the near future and climate seems not being a limiting factor for further development as it will be the availability of an irrigation system.

**Keywords:** Nepal, crops, farming, climate change, classification, agriculture, scenarios, satellite time series.

## 1. INTRODUCTION

According to several statistics, Nepal is one of the lowest-income countries of the world. While Nepal is one of the places with the greatest abundance of water in the planet, nevertheless only 72% of people have access to clean water and only the 24% of the cultivated land at lower altitude has an irrigation system. The farming system is subsistence agriculture, mainly rainfed, with crop productivity among the lowest in South Asia.

The Koshi Basin is the largest river basin of Nepal [1] and covers some of the poorest regions of this country [2]. Its economy is based on aid, tourism (trekkers and mountaineers) and self-sufficiency farming of cereals, mainly rice (52% of total production) maize (24% of total production), wheat (20% of total production) and millet (less than 4% of total production) [3]. The basin includes the following eco-zones [4]:

- Terai: flat area with elevation from 0 m to about 1,000 m. It has a hot Monsoon Tropical climate with some irrigation systems;
- Mid-Hills: central region with elevation from 1,000 m to 3,000 m. Its climate changes from warm Temperate Monsoon to cool Temperate Monsoon;
- High mountains: higher mountain areas with elevation >3,000 m and climate from sub-Alpine to Arctic.

*marco.gianinetto@polimi.it

Earth Resources and Environmental Remote Sensing/GIS Applications VIII, edited by Ulrich Michel, Karsten Schulz
Proc. of SPIE Vol. 10428, 104281R · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2278637

With reference to agricultural practice, rice is the main yield of Nepal, sown during the Monsoon season. It can be cultivated up to 1,800 m but most is farmed rainfed below 1,500 m, in Terai and lower Mid-Hills. Rice is very sensitive to temperature fluctuations and, since most of the farming system of Nepal does not has any irrigation/drainage system, it is exposed to sustained droughts. In the few irrigated farmlands of Terai, where water is available also outside the Monsoon season, it is possible to have a second winter crop (sown in February and harvested in June/July).

Maize can be cultivated up to 2,800-3,000 m and is the most water-demanding cereal during the growing stage. For this reason, usually it is sown slightly before the Monsoon season (between April and May).

In Terai and lower Mid-Hills, maize and millet have different growing periods and they are usually cultivated as relay cropping (mixed together in the same piece of land), with millet sown before the harvesting of maize. According to literature, shares are typically 80% maize and 20% millet [5]. In the irrigated farmlands of Terai, maize is double cropped during winter. In higher Mid-Hills and high mountains, above 1,800-2,000 m, the growing periods of maize and millet overlap due to the colder temperature. Thus, they are sown approximately in the same period but in different fields.

Finally, wheat is the less water-demanding cereal. Like maize and millet, wheat can be cultivated up to 3,000 m and is mainly a winter crop.

This paper describes the spatio-temporal of farmlands in Dudh Koshi (Nepal) using satellite images and records of the International Centre for Integrated Mountain Development (ICIMOD). The study tries to draft some first outcomes on how climate change is affecting agricultural practice in one of the poorest places in the world and how cropping has changed in the last 40 years, from 1970s to 2010s, to adapt to a changing environment.

## 2. DATA

### 2.1 Study area

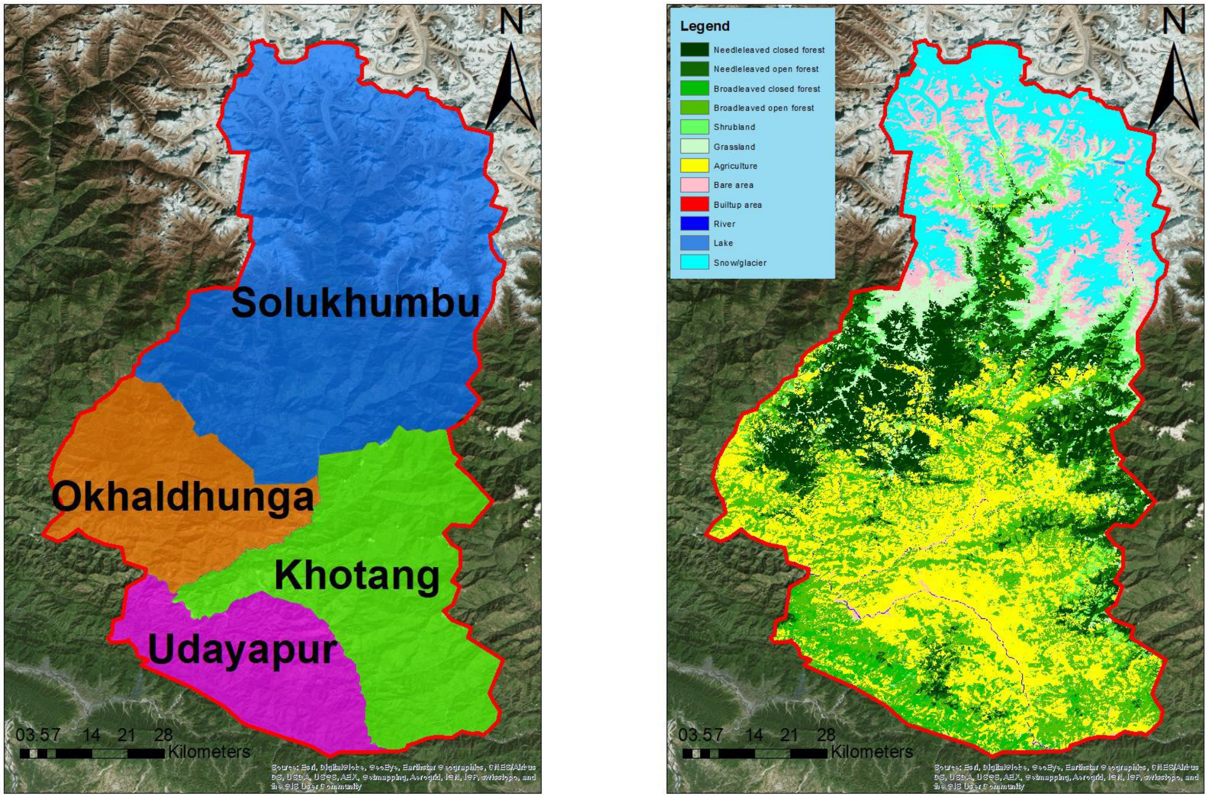
The study area includes three districts of the North-East part of Nepal: Solukumbu, Okhaldunga and Kothang (Figure 1a). Solukhumbu is in the mountainous part of Nepal, has a total area of 3,312 km$^2$ and consists of the Solu and Khumbu regions connected by the Sun Koshi River. It includes Mount Everest (8,848 m) and is well-known for sherpas. Okhaldhunga and Khotang are in the hilly part of Nepal and share a similar topography: Okhaldhunga has a total area of 1075 km$^2$ and an elevation range from 390 m to 3,627 m, while Khotang has a total area of 1,591 km$^2$ and an elevation range from 152 m to 3,620 m.

Besides, a small part of the Udayapur district belonging to Terai (total area of 2,063 km$^2$) was also considered. While the hilly portion of Udayapur included in the study area is not representative of the whole district, nevertheless, it was considered when correlating agricultural changes with topography, being most of the lower-altitude croplands (<500 m) included in Udayapur. Consequently, since Terai is almost excluded from this analysis, the share of the different crops within the study area is different from that of Nepal: maize is the main crop and covers more than the half of the cultivated land, the second spot is taken by rice, and wheat and millet share the remaining part of it. Besides, the average size of plots in Mid-Hills and High mountains is rather small, about half an hectare [5, 6].

### 2.2 Data set

The data set included:

- Satellite time series made of 22 Landsat (-1/MSS, -2/MSS, -5/TM, -7/ETM+ and -8/OLI) images collected from 1973 to 2015;
- Enhanced Shuttle digital elevation model (DEM) generated from NASA's Shuttle Radar Topography Mission (SRTM), at the full resolution of 1 arc-second (approximately 30m) [7];
- 30-meter land-cover/land-use (LCLU) maps produced by ICIMOD for the years 1990 and 2010 (Figure 1b) [8];
- Records of yearly acreage of the main crops aggregated at the district level, made available by ICIMOD [6];
- Meteorological data from 1953 to 2009 made available by the Department of Hydrology and Meteorology (DHM) of Nepal [9].




(a) (b)

Figure 1. (a) Study area. (b) Land-cover/land-use map of the study area produced by ICIMOD (2010). Extracted from the land-cover/land-use map of Nepal [8]

However, this set of data has the limitations and drawbacks listed below:

- No Landsat images were available for 1980s. Thus, this decade wasn’t considered;
- No cloud-free Landsat images were available for summer from 2010 to 2015. Thus, the time series of 2010s had a 5-years gap between the winter (January 2010) and the summer (July 2015) images;
- No ground truth/surveys were available to us. ICIMOD’s LCLU maps had a generic ‘Agriculture’ class, which however did not differentiate between different crop types and also included forests;
- ICIMOD’s records of crops acreage were somehow incomplete, with duplicated values for different years;
- DHM’s records of temperature and precipitation had discontinuities in the time series and a coarse spatial resolution (12 km).

While the data were partially incomplete or inaccurate, to the best of our knowledge these were among the most updated and freely available data for Dudh Koshi at the time of the study.

## 3. METHODOLOGY

The satellite images were grouped in four time spans and assumed representative of the 1970s, 1990s 2000s and 2010s periods. As already mentioned, no satellite data were available for 1980s. The satellite time series was calibrated and corrected for atmospheric and topographic effects with the ATCOR radiative transfer code, thus surface reflectance values were retrieved. Then, the cloudy pixels of each image were merged into a cloud mask and removed from the analysis. Finally, the geocoding of the time series was refined and the study area was clipped.

The limited multispectral capabilities of Landsat satellites, further worsened when using older data (Landsat/MSS), and the small size of typical farmlands included in the study area made the classification of crops very challenging. At the same time, the class ‘Agriculture’ of the LCLU maps provided by ICIMOD largely overestimated the cultivated plots because included forest and vegetated (but not cultivated) areas. Nevertheless, since farmlands were included into this layer, the ‘Agriculture’ class was used as an *a priori* layer to help the search for crops and reduce classification errors of commission (i.e. farmlands mapped outside the croplands).

Thus, two masks were generated for ‘potential croplands’: one for the year 1990 and another for the year 2010. These masks were obtained by removing forests from the ICIMOD’s ‘Agriculture’ classes of 1990 and 2010. Forests were mapped through the classification of NDVI time series with Maximum Likelihood, under the assumption of different patterns of seasonal NDVI for croplands and forests. Then, the ‘potential croplands’ mask for 1990 was used to constrain the classification of 1970s and 1990s satellite time series, while the mask for 2010 was used for the processing of 2000s and 2010s time series. While this assumption may be questionable, however it sounds realistic under the expected outcome of crop expansion in time.

Mapping the four main crops farmed in the study area with a statistical method based on their spectral signature and without any field data would have been extremely difficult. Therefore, we opted for a multi-temporal decision tree approach able to accept as input parameters NDVI, time frame, elevation, clouds, and potential croplands. The four cereals farmed in Dudh Koshi have a similar seasonal NDVI dynamics from sowing to harvesting: a Gaussian shape with the peak almost in the middle of the growing period [10, 11]. Thus, each crop was mapped by thresholding the NDVI values, according to their growing season as described in the introduction.

While this method is very simple if the growing seasons are not overlapped, however this happenes in Dudh Koshi. Especially for millet and rice in Terai (Tropical) and Mid-Hills (Temperate) eco-zones, and for maize and millet in all eco-zones (here the overlap increases with increasing the altitude). Besides, possible time shifts between the period of maximum vigour and the acquisition dates of satellite images can make the mapping more challenging. For this reason, the decision tree also included elevation as input parameter (thus implicitly temperature and precipitation regimes) and maize and millet were grouped in the class “Maize/Millet”. In addition, since maize and millet are cultivated as relay cropping in Terai and in lower Mid-Hills, farmlands classified as “Maize/Millet” were tested for multiple cropping. Thus, all image pixels with autumn (October/November) NDVI values above a fixed threshold were counted twice (x2). Otherwise, they were counted once (x1). Figure 2 outlines the classification scheme.

The decision tree was trained with a trial-and-error approach and thresholds (T1-T10 in Figure 2) were iteratively optimized to find the best matching between the areas of each crop, assumed known from ICIMOD’s database, and the classification outcomes.

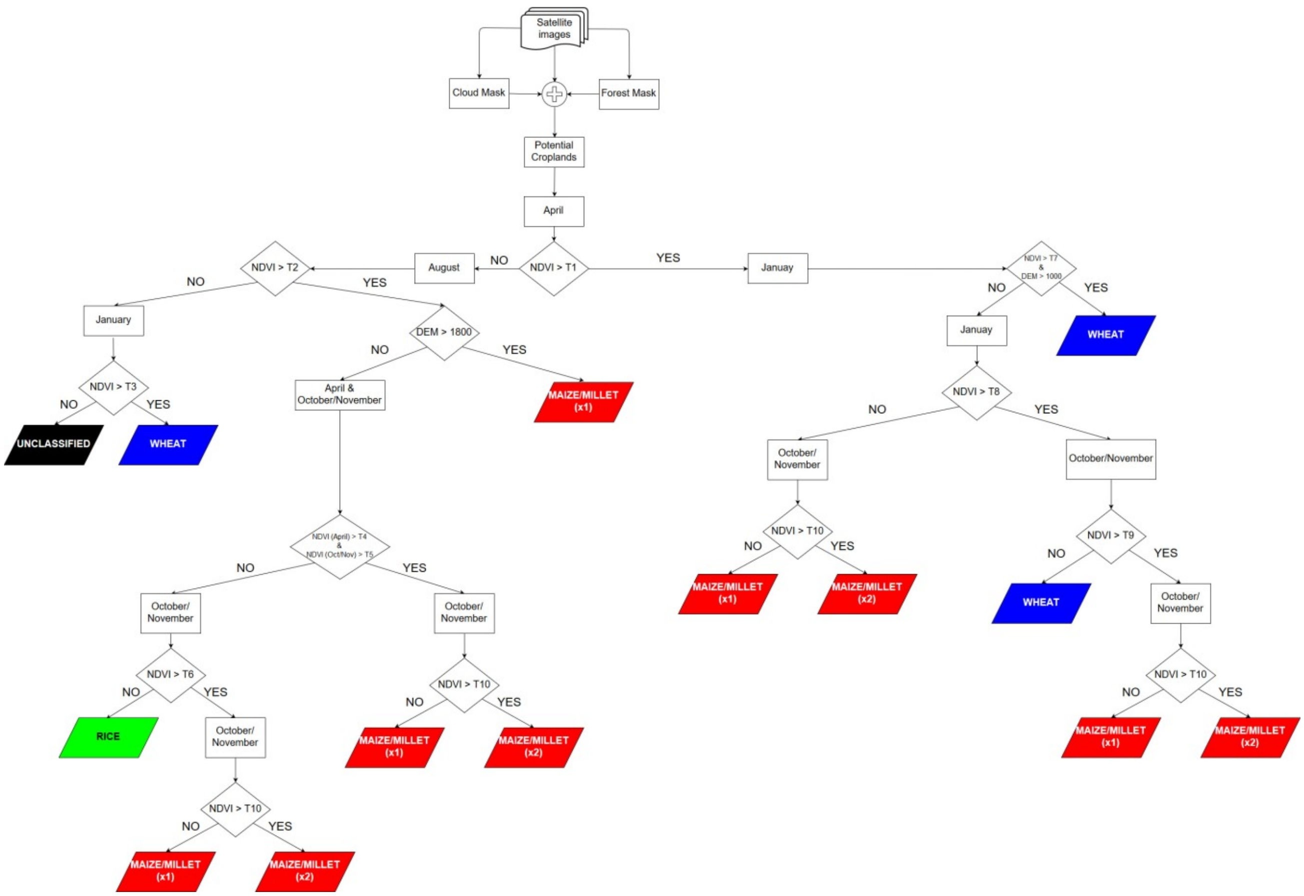


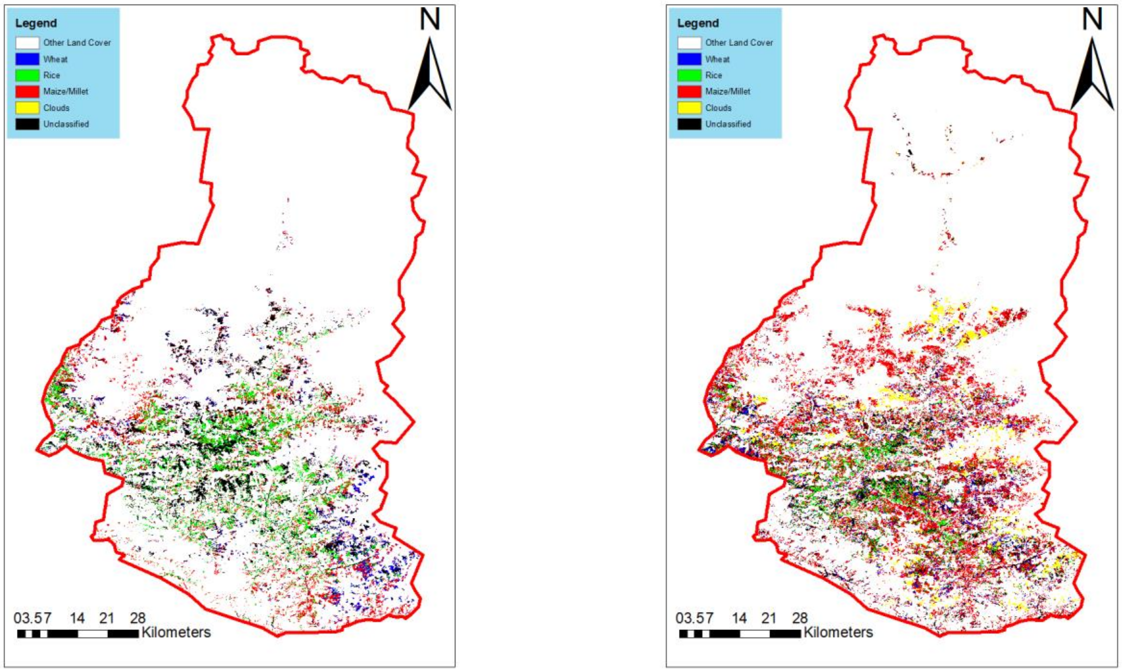

Figure 2. Decision tree classification scheme.

## 4. RESULTS AND DISCUSSION

Overall, results show that agricultural land has increased in both Solukumbu, Okhaldunga and Kothang, with a steeper increase for Kothang in the last two decades. Looking at the different crops, the thematic maps (Figure 3) suggest that maize/millet increased their acreage in Solukumbu from a share of 58% (1970s) to 90% (2010s), while in Okhaldunga and Kothang from about 45% (1970s) to about 70% (2010s). At the same time, the land cultivated for rice decreased and became marginal in Solukumbu (from 26% in 1970s to 4% in 2010s), while in Okhaldunga and Kothang became about half of the land cultivated in 1970s. Finally, the acreage for wheat reduced to about one third in Solukumbu (from 16% in 1970s to 6% in 2010s) but remained almost constant in Okhaldunga and Kothang (about 10-15%).

From 1970s to 1990s we observed an overall increase of farmland in Dudh Koshi of about 10%, while in the following twenty years it was six times (about +60%). Data of the second twenty years are strongly correlated ($0.97<R^2<0.99$) with the population growth observed in the three districts (overall +26%) and consistent with information on average daily caloric intake (+15% computed on data for the whole Nepal).

The mapped changes in crop farming from 1990s to 2010s were then correlated with the environmental constrains and climatic forces through a multiple-linear regression analysis. Elevation, slope, aspect and distance to roads were considered for environmental parameters, while precipitation and temperature were considered for climatic parameters. To handle the different spatial detail of source data and to smooth any local error in the crop maps, all the parameters were rescaled to a spatial resolution of 250 m prior the regression analysis.




(a) (b)

Figure 3. Thematic maps for 1990's (a), and 2010's (b).

Table 1. Multiple-linear regression analysis and statistical significance.

| | | | |
|---|---|---|---|
| | **MAIZE+MILLET** | | |
| | Estimate | Pr(>\|t\|) | |
| Precipitation | 3,56E-05 | <2e-16 | *** |
| Temperature | 5,39E-03 | <2e-16 | *** |
| Slope | -5,55E-04 | <2e-16 | *** |
| Elevation | -2,61E-05 | <2e-16 | *** |
| Distance to roads | 2,56E-01 | <2e-16 | *** |
| Aspect | -1,53E-05 | 5,85E-05 | *** |
| | **WHEAT** | | |
| | Estimate | Pr(>\|t\|) | |
| Precipitation | -1,77E-05 | <2e-16 | *** |
| Temperature | -8,05E-04 | 1,56E-08 | *** |
| Slope | -1,02E-04 | 1,13E-11 | *** |
| Elevation | 4,27E-07 | 0,00019 | *** |
| Distance to roads | -3,61E-02 | 0,00162 | ** |
| Aspect | -2,00E-05 | <2e-16 | *** |
| | **RICE** | | |
| | Estimate | Pr(>\|t\|) | |
| Precipitation | 3,52E-05 | <2e-16 | *** |
| Temperature | 1,94E-03 | <2e-16 | *** |
| Slope | 1,70E-04 | <2e-16 | *** |
| Elevation | -2,84E-06 | <2e-16 | *** |
| Distance to roads | 9,17E-02 | 5,05E-11 | *** |
| Aspect | 8,87E-06 | 6,12E-05 | *** |

Table 1 shows results and their statistical significance. According to the simple linear regression model, both climate-related variables (i.e. mean annual temperature and precipitation) and environmental parameters are strongly correlated with crop land use change. This finding confirms the result of the recent research by Paudel *et al.* (2016) [12]. However, our study on Dudh Koshi did not showed the slight reduction in crop farming during 2010 described for the larger Koshi River Basin [12]. Nevertheless, since our study area focuses on the mountain environment, our outcomes seems to confirm the conclusion of another recent study (2016) that "agriculture practices and patterns that were once intensely distributed in lowland areas have spread to higher altitudes" [13].

Climate change is increasing temperatures and volatility of precipitations in Dudh Koshi. At the same time, the population is growing but the farming system is still mainly rainfed subsistence agriculture and we are also witnessing an expansion of the cropped areas towards higher elevations. This preliminary study seems to suggest that demographic and socioeconomic pressures are driving this expansion, while climatic and topographic parameters are just channeling it. Apart from any policies that could change the tack, Dudh Koshi seems should be able to meet the increasing demand of cereals in the near future and climate seems not being as much a limiting factor as it will be the availability of an irrigation system.

## ACKNOWLEDGEMENTS

The authors thank the International Centre for Integrated Mountain Development for making available through their web site the land-cover/land-use maps of Nepal and the records of yearly acreage, the Department of Hydrology and Meteorology of Nepal for making available through their web site meteorological time series, and NASA for Landsat images and SRTM-DEM.

## REFERENCES

[1] Bharati, L., Gurung, P., Jayakody, P., Smakhtin, V. and Bhattarai, U., "The Projected Impact of Climate Change on Water Availability and Development in the Koshi Basin, Nepal," Mt. Res. Dev. 34(2), 118-130 (2014).

[2] Penton, D. J., Neumann, L. E., Doody, T. M., Foran, T., Grigg, N. J., Zheng, H., Cuddy, S. M., Dolk, M. M., Siddiqui, S., Stratford, D., Boudier, E., Tashi Chua, S. and Fleming, D. A., "Preliminary analysis of hydroclimate and streamflow modelling in the Koshi Basin: Climate, hydrology, ecology and institutional setting," CSIRO, 2016, https://publications.csiro.au/rpr/download?pid=csiro:EP164390&dsid=DS3 (27 July 2017).

[3] Food and Agriculture Organization of the United Nations, "Country briefs: Nepal. Reference date 07 June 2017" GIEWS - Global Information and Early Warning System http://www.fao.org/giews/countrybrief/country.jsp?code=NPL (27 July 2017).

[4] Singh, B. K., Shrestha, T. B., Upadhaya, S., Bhandari, H. M., Shrestha, M. and Steele, A., "Tropical Forestry and Biodiversity (FAA 118 & 119) Assessment Report Nepal" United States Agency for International Development, 17 May 2010, 1-69, http://pdf.usaid.gov/pdf_docs/pnadz033.pdf (27 July 2017).

[5] Subedi, K., "Maize and finger millet relay intercropping system in the hills of Nepal issues for sustainability. Sustainable maize production systems for Nepal," Proc. of a Maize Symposium, 170-174 (2002).

[6] International Centre for Integrated Mountain Development, "Agriculture Atlas of Nepal", http://apps.geoportal.icimod.org/agricultureatlas/atlas/index.html (15 February 2017).

[7] Jet Propulsion Laboratory, "Enhanced Shuttle Land Elevation Data," https://www2.jpl.nasa.gov/srtm/ (27 July 2017).

[8] Uddin, K., Shrestha, H. L., Murthy, M. S. R., Bajracharya, B., Shrestha, B., Gilani, H., Pradhan, S. and Dangol, B., "Development of 2010 national land cover database for the Nepal," J. Environ. Manage. 248, 82-90 (2015).

[9] Department of Hydrology and Meteorology of Nepal, "Climate Portal," http://www.dhm.gov.np/dpc/ (15 February 2017).

[10] Hao, P., Wang, L., Zhan, Y. and Niu, Z., "Using Moderate-Resolution Temporal NDVI Profiles for High-Resolution Crop Mapping in Years of Absent Ground Reference Data: A Case Study of Bole and Manas Counties in Xinkiang, China," ISPRS Int. J. Geo-Inf 5, 67, (2016).

[11] Siyal, A. A., Dempewolf, J. and Becker-Reshef, I., "Rice yield estimation using Landsat ETM+ Data," J. Appl. Remote Sens. 9(1), 095986, (2015).
[12] Paudel, B., Gao, J., Zhang, Y., Wu, X., Li, S. and Yan, J., "Changes in Cropland Status and Their Driving Factors in the Koshi River Basin of the Central Himalayas, Nepal," Sustainability 8(9), 933 (2016).
[13] Paudel, B., Zhang, Y., Li, S., Liu, L., Wu, X. and Khanal, N. R., "Review of studies on land use and land cover change in Nepal," J. Mt. Sci. 13, 643-660 (2016).