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SPATIO-TEMPORAL ASSESSMENT OF VEGETATION COVERS IN THE UPPER CATCHMENT OF KOSI RIVER BASIN USING MODIS DATA

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Abstract:

The major natural and anthropogenic factors for degradation of forest are shifting cultivation, illegal lopping, encroachment, and gradual degradation etc. To monitor these changes and their impact on land cover dynamics is of major interest for biospheric studies, mainly carbon budget, land degradation and consequent impact. The objective of this study is to assess the variations found in the vegetation over the years in space and time in the Kosi sub-catchments. MODIS NDVI 16 day's composite datasets for eight year (2001 to 2008) have been used for the assessment of variations in vegetation cover. Composite datasets of these eight years have been used to analyze the Spatio-Temporal assessment of vegetation in the upper catchment of Kosi river basin. The study using MODIS 16 day's composite NDVI data clearly shows that half of the entire sub-catchments, i.e. in the central and northern portion, there is a dominance of open scrub land and ever green broad leaves forest. But in the other half of the study area i.e. in the south, ever green needle forest, grassland and mixed forest, there appears to be a great deal of variation in NDVI in spatial profile value among the different river basins because of latitudinal and altitudinal differences. There are also some anthropogenic factors responsible for these dynamics. It is finally evident that MODIS NDVI data could be used to provide timely and detailed vegetation status and an input to biophysical, geochemical and climate models that require timely estimation of the forest area.

Key words: *Spatio-Temporal, Multispectral, MODIS, NDVI, River Basin*

1. Introduction

Obtaining empirical vegetation data over large Spatio-temporal scale is highly expensive and time-consuming (Santin Janin et al., 2009). Normalized Difference Vegetation Index (NDVI) from remote sensors, most often onboard satellites, is now commonly used by the ecologists as a proxy for vegetation productivity (Pettorelli et al. 2005). In sub-Antarctic area, this has so far been limited both by logistical constraints and by extreme climatic conditions often leading to short and local time series. As a consequence, numerous studies are now using NDVI as a proxy of vegetation productivity instead of performing direct vegetation assessments (Ryan et al., 2007). Normalized Difference Vegetation Index (NDVI) may also be incorporated in the classification process to enhance the quality of land cover information from remote sensing data in mountainous regions (Eiumnoh and Shrestha, 2000). Traditional methods of vegetation density analysis mapping are based on ground surveys and aerial observations, but when the phenomenon is widespread, such methods are time consuming and expensive. Furthermore, timely aerial observations may be impossible due to prohibitive weather conditions. Due to synoptic view, map like format and repetitive coverage, satellite remote sensing imagery is a viable source of gathering quality land cover information at local, regional and global scales (Csaplovics, 1998; Foody, 2002).

Various ecological studies, including that of the polar environment, are now using the remotely sensed NDVI, e.g. PAL-NDVI (Pathfinder AVHRR Land-NDVI) It is a data set of NOAA satellite, or MODIS-NDVI) as a proxy of vegetation productivity rather than performing direct vegetation (Santin Janin et. al., 2009). The knowledge of spatial land cover information is essential for proper management, planning and monitoring of natural resources (Zhu, 1997) especially natural vegetation. Remote sensing data are, in particular, useful for vegetation cover mapping in inaccessible regions such as the Himalayas, Tibet and upper catchment of Kosi river basin. These areas are generally inaccessible due to high altitudes and ruggedness of the terrain. Due to changes in environmental conditions, spectral characteristics also change from one region to the other (Arora et. al., 2003).

In an effort to monitor major fluctuations in vegetation and understand how they affect the environment, 20 years ago Earth scientists began using satellite remote sensors to measure and map the density of green vegetation cover over the Earth. Using NOAA's Advanced Very High Resolution Radiometer (AVHRR), scientists have been collecting images of our planet's surface. By carefully measuring the wavelengths and intensity of visible and near-infrared light reflected by the land surface back into space, scientists use an algorithm called a "Vegetation Index" to quantify the concentrations of green leaf vegetation around the globe. Then the daily Vegetation Indices combined into 8, 16, or 30-days composites, scientists create detailed maps of the Earth's green vegetation density that identify where plants are thriving and where they are under stress (i.e., due to lack of water).

To determine the density of green on a patch of land, researchers must observe the distinct colours (wavelengths) of visible and near-infrared sunlight reflected by the plants. As can be seen through a prism, many different wavelengths make up the spectrum of sunlight. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The NDVI formula in particular was originally termed the VI (Vegetation Index) and devised by (Rouse et al. 1974) and applied to Landsat MSS data (Tucker, 1979).

In this study, we have attempted to explore the Spatio-temporal changes during 2001 to 2008 in vegetation cover in the upper catchment of Kosi River Basin using MODIS NDVI 16 day's composite data. We have two-fold objectives: (1) to evaluate the potential of MODIS data in identifying the vegetation cover status and its dynamics in Kosi River Basin. (2) To document the current status of vegetation cover types and respective area measurements in Kosi River Basin using LANDSAT TM data acquired in 2008. Kosi River basin area is rich in biodiversity with a wide range of landforms which includes major mountain ranges, open scrubland, rich agricultural plains, and hilly forest regions. The vegetation covers have abundant tree species and a variety of types including evergreen, semi-evergreen, deciduous and mixed forest. Human activities and natural disturbances have caused havoc and resulted in a substantial loss of the natural forests and the landscapes turned fragmented. The result of this study of vegetation cover status and its temporal changes as derived from MODIS data provides a real picture to monitor vegetation status and dynamics during a very small span of time at a regional scale together with that of the understanding of the landscape fragmentation process and environmental vulnerability.

2. The Study Area

The catchment of upper Kosi River Basin comprises of Sun Kosi, Arun and Tamur and is bounded by 26º 48' 34"N to 29º 07'48"N latitude and 85º 22'19"E to 88º 55' 44"E longitude (figure 1). The catchment cuts across 25659 sq km area in Nepal and 32135 sq km across China. The area under sub-catchment of Arun is highest (32397 sq km) followed by that of Sunkosi (17623 sq km) and Tamur (5850 sq km). The sub-catchments are given in Figure 1. It covers an area of 55, 870 sq km. The study area is highly rugged with elevations varying from 880 m to 4785 m above mean sea level. There is a large variation in the climatic condition i.e. in the Arun sub-catchment, the average temperature is subzero and winter lasts from October up to May or June. Rainfall is mostly recoded in the rainy season from June to September. Whereas in the other two sub-catchment i.e. Sunkosi and Tamur the average annual rainfall is less than 75 cm. Most part of the sub-catchment falls under rain shadow region. The annual average temperature is 2.8-1.7 ºC. The summer average temperature varies between 1 to 12 ºC and the winter average temperature is -7 to -9 ºC.

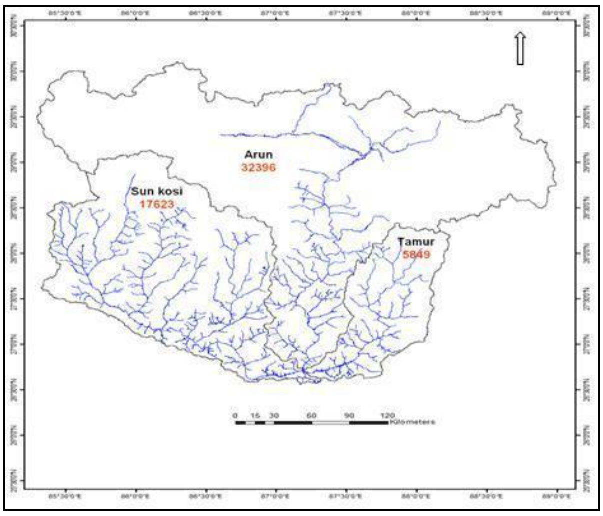

Figure 1

3. Data and Methods

3.1 Data Source

The satellite data sets that has been used for this study is given in table 1.

3.2 Methods

The methodology adopted for this study is shown as Figure 2. The different stages are elaborated below.

Table 1 Satellite data sets used

Satellites Sensor	TERRA MODIS	Landsat ETM+	SRTM Radar
Year	2001 to 2008	2008	2008
Resolution	500 m	30 m	90 m
Extractable data	NDVI	LU/LC	DEM
No. spectral bands	Multi-Spectral 6	1,2,3,4,5, 7	C-band
Spectral region (um)	0.459-2.155	0.4-12.5	

3.2.1 Radiometric corrections

Unwanted artefact pixels like additive effects due to atmospheric scattering were removed through a set of pre-processing or cleaning up routines using image processing software. First-order radiometric corrections have been applied using dark pixel subtraction technique (Lillesand and Kiefer, 1999). This process assumes that there is a high probability that at least a few pixels within an image should be black (0% spectral reflectance). However, because of atmospheric scattering, the imaging system records a non-zero Digital Number (DN) value at the supposedly dark-shadowed pixel location. Therefore the DN value must be subtracted from the data to remove the first-order scattering component.

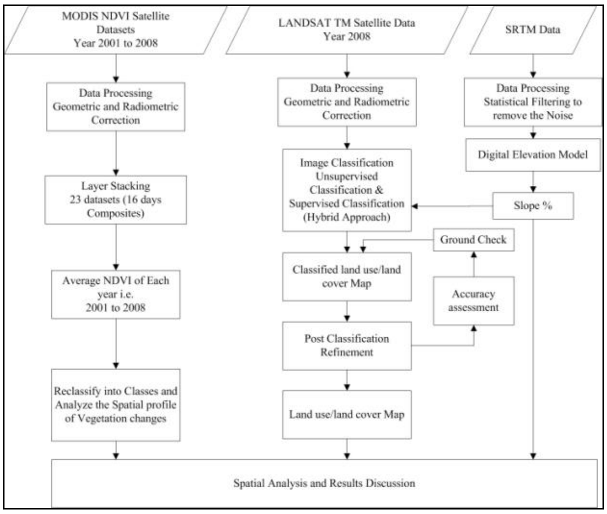

Fig.2 Flow Chart Showing the Methodology adopted

3.2.2 Geometric corrections

Images were registered geometrically using toposheets of Survey of India (SOI). Uniformly distributed Ground Control Points (GCPs) were marked with Root Mean Square Error (RMSE) of less than one pixel and the image was resampled by the nearest neighbourhood method. All the 8 years (2001 to 2008) of data (23 datasets in one year) were then co-registered for further analysis. The study area was extracted using digital boundary data provided by SOI and SRTM data.

3.2.3 Vegetative indices

NDVI is a band ratio calculated using (Infrared−Red) / (Infrared+Red) (Rouse et al., 1974; Eiumnoh and Shrestha, 2000). It is highly correlated with vegetation parameters such as green leaf biomass and green leaf area and hence is of considerable value for vegetation segmentation (Curran & Franquin, 1980; Tucker et al., 1981; Roy 1993; Joshi et.al., 2006). Moreover, it also to reduce the shadow effect due to variations in topography (Holben and Frasher, 1984) and compensates for variation in radiance as a function of Sun elevation for different parts of the scene, which is highly valuable in continental studies. The pixel values of the NDVI data layer range from -1 to +1 and are scaled from 0 to 255 respectively in 8 bit satellite data. The higher NDVI values indicate increase in biomass per unit area and vice versa. The positive values represent different types of vegetation classes, very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, water or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). To demonstrate the applicability of MODIS data for monitoring vegetation status at a regional scale, random temporal plots were selected and analyzed for the NDVI values

3.2.4 Vegetation mapping

Analysis of MODIS NDVI data has been carried out using various digital and analytical procedures. MODIS NDVI 16 day's composite data set was downloaded from GLCF for each year i.e. 2001, 2002, 2003, 2004, 2005, 2006, 2007and 2008. For the classification a stack of NDVI of MODIS dataset was taken. In one year there were 23 data sets (16 days composite) and these data was layer staked and the resultant comes as one composite data i.e. average NDVI for one year.

3.2.5 Land use/land cover mapping

The aim of this study is to find out spatial pattern of land use/land cover of 2008 using LANDSAT TM satellite imagery. A classification scheme for vegetation categories was prepared based on phenological variations, composition, and the type of climate in which they thrive and location. For non-vegetation classes a descriptive level I classification scheme was adopted. Cloud classes were masked out using a supervised classification technique. The mapping step involves using unsupervised classification based on the K-means algorithm. Vegetation cover type classification based on phenology (evergreen and deciduous), and leaf life form (broad leaf and needle leaf) was followed with the ground truth knowledge. For each category, identification of land use and land cover has been done through extensive fieldwork. Each cluster was assigned a preliminary cover type considering the spatial pattern and spectral or multi-temporal statistics using ancillary and extensive ground data. Ancillary data included descriptive land cover information (NATMO, 1982). The unsupervised classification was followed by post-classification refinement for a coherent set of classes. Some shadow areas were put to the relevant classes on the basis of extensive field knowledge. On the final output, majority filtering (3×3 kernel) was carried out for image smoothing.

3.2.6 Accuracy estimation

A set of land cover information collected during the fieldwork for accuracy assessment. The cover type information of these locations (GPS points) was compared with classified maps. The field sample locations were overlaid on classified maps to assess corresponding classes. Statistically valid sampling strategy was adopted to assess commission, omission and overall accuracy (Rosenfield and Fitzpatrick-Lins, 1986; Stehman, 1996). Finally, the contingency table was tested using Kappa Statistics (Khat coefficient) (Lillesand and Kiefer, 1999).

4. Result and discussion

4.1 Land Use/Land Cover Analysis

LANDSAT TM data has been used to prepare land use/land cover in sub-catchments of Kosi of 2008. The figure 3 shows that the half of the entire sub-catchments i.e. in the central and northern portion there is dominance of open scrub land and ever green broad leave forest. But in the other half of the study area i.e. in the south ever green needle forest, grass land and mixed forest.

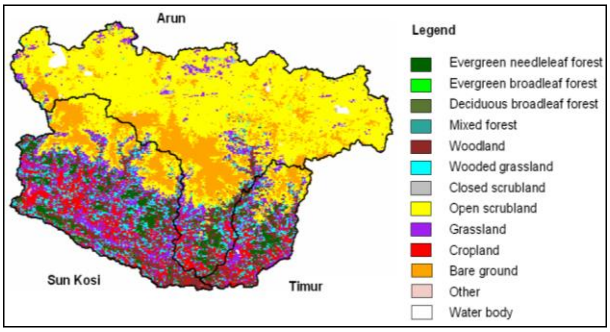

Fig. 3 Land use/land cove in Sub-Catchment of Kosi

The table 1 shows the area wise comparison between the Arun, Sunkosi and Tamur. The study shows that the Arun sub-catchment has 65.38 per cent of its area under the open scrubland where as in Sunkosi and Tamur sub-catchments there is no dominant class rather about 1/5 of the total area in both the sub-catchments is covered by the Mixed forest, Grassland, Woodland and the Crop land (table 2). For assessment of topography SRTM DEM data (figure 4) has been used and then slope percentage has been calculated. It is seen that there is large variation in the topography of the study area, which covers the three rivers Arun, Sunkosi and Tamur. The slope has been classified into seven classes (table 3). The steepest slope is found in the Sunkosi in the west and Tamur sub-catchment in the east whereas relatively flat or nearly levelled slopes are found at Arun sub-catchment in the north of the study area (figure 5). Figures in parenthesis indicate percent of total area

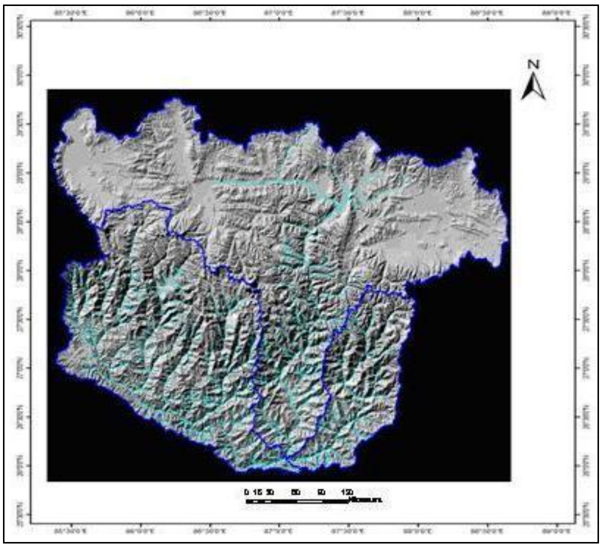

Fig. 4 Digital Elevation Model

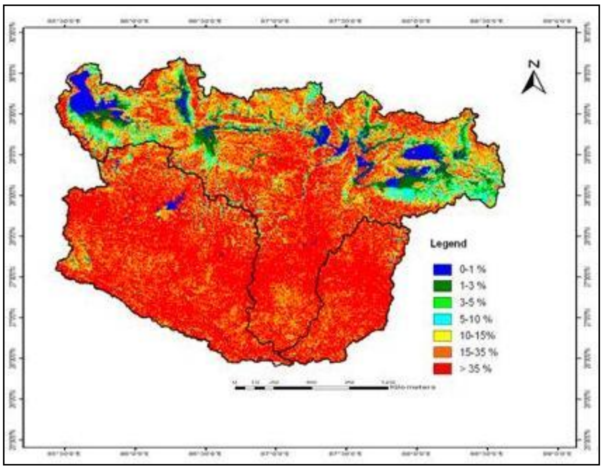

Fig. 5 Slope in the upper catchment of Kosi river basin

Table 2 Land use/land cover in sub-catchments of Kosi

Land use/land cover classes	**Arun**		**Sunkosi**		**Tamur**	
	Area (sq. km.)	**Area** (in %)	**Area** (sq. km.)	**Area** (in %)	**Area** (sq. km.)	**Area** (in %)
Evergreen needle leaf forest	400.51	1.24	1303.67	7.40	479.69	8.20
Evergreen broad leaf forest	30.94	0.10	61.35	0.35	16.83	0.29
Deciduous needle leaf forest	0.00	0.00	0.00	0.00	0.00	0.00
Deciduous broad leaf forest	25.78	0.08	52.83	0.30	10.94	0.19
Mixed forest	12.03	0.04	34.08	0.19	9.26	0.16
Woodland	1227.31	3.79	3368.23	19.11	1233.72	21.09
Wooded grassland	990.96	3.06	2494.01	14.15	879.43	15.03
Closed scrubland	372.15	1.15	176.38	1.00	67.32	1.15
Open scrubland	21179.75	65.38	2543.43	14.43	812.94	13.90
Grassland	1897.69	5.86	2882.55	16.36	869.33	14.86
Crop land	695.31	2.15	2638.86	14.97	970.31	16.59
Bare ground	5564.17	17.18	2053.49	11.65	499.88	8.55
Others	0	0	14.49	0.08	0	0
Total	**32396.61**	**100**	**17623.36**	**100**	**5849.65**	**100**

Table 3 Slope distribution of the study area

Slope (%)	Description	Arun(Area) (in sq. km.)	Sunkosi(Area) (in sq. km.)	Tamur(Area) (in sq. km.)
0-1	Level I	1731.20 (5.34)	159.63 (0.91)	4.56 (0.08)
1-3	Level II	1963.38 (6.06)	29.41 (0.17)	1.69 (0.03)
3-5	Level III	1024.64 (3.16)	29.75 (0.17)	2.61 (0.04)
5-10	Level IV	2803.72 (8.65)	246.54 (1.40)	46.22 (0.79)
10-15	Level V	2117.03 (6.53)	232.53 (1.32)	47.15 (0.81)
15-35	Level VI	10249.78 (31.64)	4092.86 (23.22)	1145.08(19.58)
> 35	Level VII	12506.88 (38.61)	12832.64 (72.82)	4602.33 (78.68)

4.2 Vegetation cover (NDVI) in upper catchment of Kosi river basin

The study using MODIS NDVI average data of eight year i.e. 2001 to 2008 shows that there are significant changes in vegetation cover in the entire Kosi sub-catchment. It is seen that there are some similarities between Sun Kosi and Tamur where NDVI value ranges 0.32 to 0.6 but in Arun sub-catchment it is quite low 0.12 to 0.25 (figure 6). If we look at the sub-catchment of Arun River which is situated on the world's highest plateau Tibet is a barren land but on the other side of it approximately in the middle part of the sub-catchment, it is covered by snow and ice most of the year.

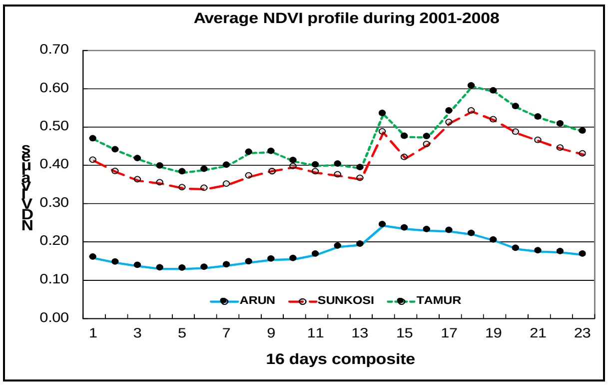

Fig. 6 Average NDVI Profile during 2001-2008

We compared the NDVI values by taking the annual average NDVI values of these three sub-catchments separately. From figure 7 it can be seen that there are some similarities between Sun Kosi and Tamur where NDVI value ranges from 0.38 to 0.46 but in Arun sub-catchment it is quite low 0.12 to 0.13 running almost parallel to base line. In the first two catchments we see that there is very less variation between the years. On the other hand the NDVI value range is very less due to its semi-arid region. In this region the density of vegetation is very sparse due to its rocky structure and paucity of rainfall.

The analysis of the MODIS NDVI 16 day's composites of the sub-catchments across the year (2001-2008) shows some variations in vegetation cover in the study area. Figure 8 shows the annual variation in vegetation cover in the study area i.e. Upper Catchment of Kosi River Basin (Arun, Sun Kosi and Timor). The figure shows that the central part in NDVI value is of <0 because it's a hilly area which is covered by snow and ice most of the year. Hence there is no vegetation. Little lower to this a patch runs from west to east which has NDVI value of 0.4 – 0.6. In 2003 and 2004 most of the area comes with the NDVI value of 0.4 to 0.6 showing healthy vegetation but in other years it is lesser areas are under this class. This is due to the good rainfall in these two years.

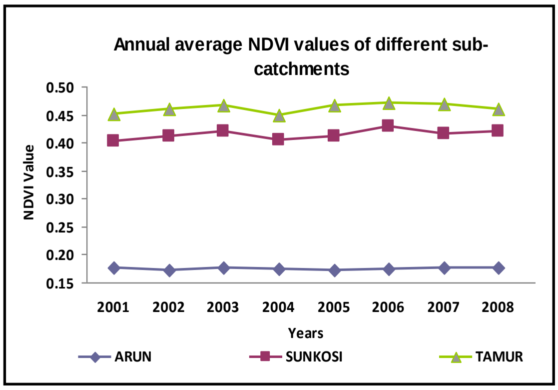

Fig 7 Annual mean NDVI values

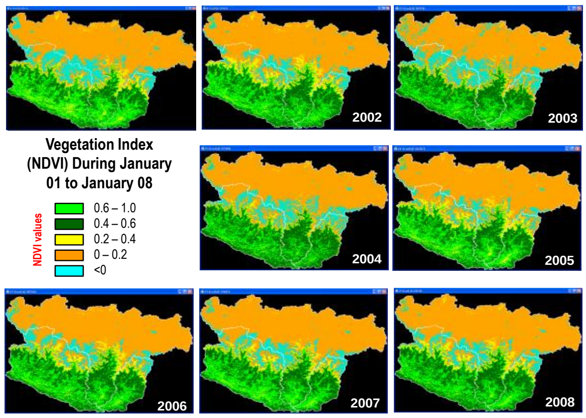

Fig 8 Vegetation Index (NDVI) during 2001-2008

In 2001 the average NDVI value of Arun sub-catchment is 0.176 and the highest value (0.25) is recorded in first half of August, whereas the lowest value 0.13 is observed in the month of March (figure 9). There is variation in NDVI in sun-kosi and Tamur sub-catchment. Although both the sub-catchment have healthy vegetation due to steeped slope and being situated in high rainfall region. Sunkosi sub-catchment is relatively near to Equator and at a less height. In this sub catchment the average value lies in the middle of the positive NDVI scale.

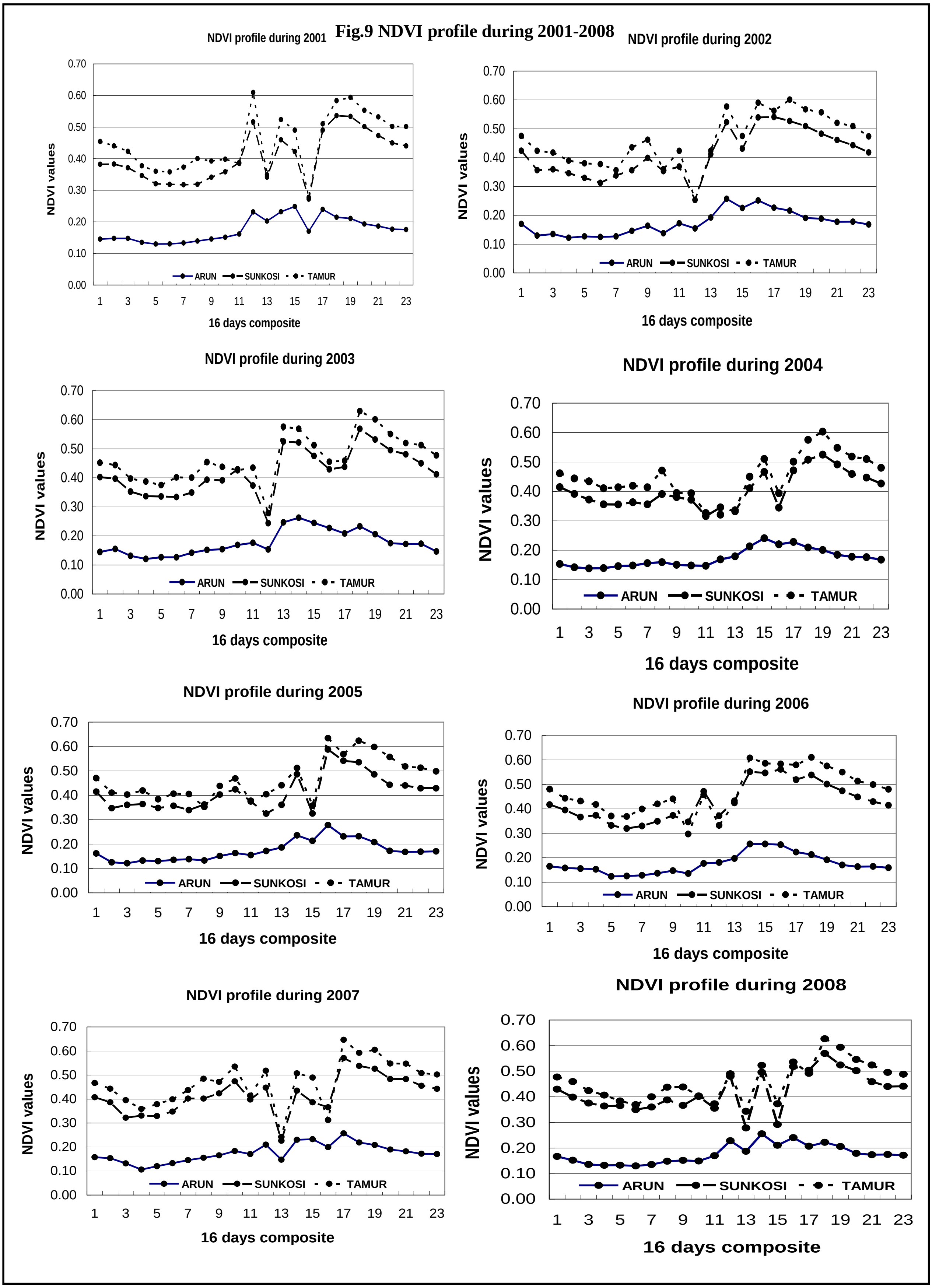

Fig.9 NDVI profile during 2001-2008

In the year of 2001 the lowest value 0.317 is found in the first half of April and the highest value is found in the second half of September whereas the average value is 0.404. After analysing the graph of 2001 we find that there are similarities between Sunkosi and Tamur sub-catchment because both the sub-catchment is situated side by side. In the year 2002 the lowest value observed in Sunkosi and Tamur is 0.312 and 0.356 respectively. The highest NDVI value is 0.541 and 0.601 in Sunkosi and Tamur respectively in the month of July and August due to relatively high rainfall at this time. It can be seen that after the month of September the NDVI values decline. On the other hand Arun sub-catchment is reported to have low variation in NDVI value for all the months. More or less similar type of situation is observed in 2003 for all the sub-catchments. However, if we analyse the graph and NDVI data for the year of 2004 the variation between Sunkosi and Tamur sub-catchment remains proportionally equal for all the month across the year. Although, Tamur has relatively higher vegetation cover than the Sunkosi this is due to its location in eastern Himalayas and steepness in the slope. More than 78 per cent area of Tamur sub-catchment is covered by very steep slope and it can be seen from the digital elevation model (figure 4). The NDVI data of 2005 (figure 9) shows very less patches of snow cover in the entire study area and variation in NDVI values in Arun sub-catchment is negligible round the year except in the middle of August due to the monsoon season. There are lots of variations that have been observed in 2007 and 2008. Sometime values go up very high but after a very short span of time duration it comes down as can be seen in the graph of 2007 and 2008, which it has not been observed in the previous years. The healthy season for the vegetation is monsoon but if we analyse the graph we can see that in both the years the month June, July and August are having low values whereas after September its values go high. It has happened due to late onset and breaking of monsoon in 2007 and 2008 respectively.

5. Conclusion

The objective of this study is to use multi-spectral-temporal satellite data to generate a vegetation assessment particularly in the high mountainous region, where most of the areas are inaccessible due to the rugged terrain. However, classification just on the basis of the reflectance characteristics of remote sensing data may not be appropriate due the presence of shadows in these areas. Therefore, the use of ancillary datasets in addition to remote sensing data is important for vegetation assessment. The multi-spectral-temporal dataset has helped to capture phenological variability and define vegetation status with climatic variations representing physiognomic and physiographic community characteristics and geographical distribution pattern i.e. temperature and local specific parameters. The database that resulted from the approach has advantages over earlier databases. First, it is modified to the information content of remotely sensed satellite earth observations. Second, it provides relatively stable and unambiguous vegetation status for the purpose of global biophysical, geochemical or climatic modelling. Most importantly, it not only uses the plant attribute but also climatic variables for the landscape class definition. The present data is best suited to monitor vegetation status and dynamics in a very small interval of time at a regional scale (RF 1:1000000) comparable with available LISS or ASTER or LANDSAT MSS datasets.

The study using MODIS 16 day's composite NDVI data clearly shows that the half of the entire sub-catchments i.e. in the central and northern portion there is dominance of open scrub land and ever green broad leaved forest. But in the other half of the study area i.e. in the south ever green needle forest, grass land and mixed forest, the study further shows some similarities in NDVI between Sun Kosi and Tamur sub-catchment and large difference in NDVI value is found in Arun River. In Arun sub-catchment NDVI range is very less due to its semi-arid region. Comparatively healthy vegetation in Sunkosi and Tamur sub-catchment is observed compared to Arun. The vegetative cover increases in almost all the year 2001 to 2008 beginning with the end of June and till the end of Sept. and thereafter, it begins to decline. The result of this study could form the basis for stratified random sampling strategy, understanding the landscape fragmentation process, rapid growing stock assessment, and for suggesting management plans and policies. It shall also be used for environmental vulnerability studies.

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Biographies

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