

Extracting NDVI temporal profiles of vegetation types in the Rižana spring catchment area from NOAA-AVHRR data using linear mixture model

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Abstract

This paper presents methodology that was used to derive NDVI temporal profiles of the vegetation types in the Rižana spring catchment area. In the methodology the Landsat TM image was used for the classification of the area into vegetation cover classes and to determine proportions of classes within AVHRR pixels. According to the influence of the vegetation types on the water cycling process in the catchment area, six vegetation classes were defined (deciduous forest, grass, agricultural areas, shrub, coniferous forest and areas with no/sparse vegetation). This data and the NDVI data derived from AVHRR satellite images was then used in the linear mixture modelling that was applied to estimate the mean NDVI value of each vegetation class. The resulting temporal NDVI profiles of vegetation cover classes, with exception of class with no/sparse vegetation, are in general in agreement with the observed vegetation characteristics area.

Introduction

Recharge of the aquifer is a dynamic process that depends on many factors. For accurate modelling of this process data is required that is distributed in time and space. One of the very important data are vegetation characteristics. Remote sensing data is a potentially very useful source of information on the state and development of a long range of vegetation and hydrological parameters (Sandholt et al., 1999). For vegetation monitoring from satellite platforms are common used vegetation indices. One of the most widely used is normalized difference vegetation index $NDVI = (NIR - IR) / (NIR + R)$ (Rouse et al., 1973).

For describing spatial variability of vegetation in the catchment areas Landsat TM

(30 m nominal spatial resolution) provides in general adequate data. But to monitor temporal dynamic of vegetation development Landsat TM, with its temporal resolution of 16 days, is often not sufficient. Especially if we have in mind that atmospheric conditions (cloudiness) at the time of the satellite overpass can make interpretation of satellite images impossible. On the other hand NOAA-AVHRR satellite system provides fine temporal resolution (daily frequency). But its coarse spatial resolution (nominal 1,1 km at nadir) is a huge limitation in many applications.

An ideal satellite system for observation of vegetation changes in catchment area would have spatial resolution of Landsat TM and temporal resolution of NOAA-AVHRR satellite system.

An approach towards this kind of system is a linear mixture model.

This paper presents methodology that was used to derive NDVI temporal profiles of vegetation types in the Rižana spring catchment area from Landsat TM and AVHRR images. Landsat TM image was used for classification of the area into vegetation classes and to determine proportions of the classes within AVHRR pixels. Linear mixture model based on multiple linear regression was then applied on the set of 21 AVHRR images to estimate the mean NDVI value of each vegetation class.

Study area: The Rižana spring catchment area

Rižana spring is the most important water resource for water supply of the coastal area of Slovenia. Its catchment area covers nearly 240 km² (Figure 1). The terrain is mainly hilly, with altitude ranging from 70 m to 1028 m. Very complex karst aquifer system was developed in limestones that cover most of the catchment area. Minor part of the area consists of flish sediments. According to the used classification most of the area is covered by deciduous forest, following by grass, agricultural areas, shrub, coniferous forest and areas with no or sparse vegetation (Table 1).

Table 1. Vegetation cover classes and their cover portions in the study area

vegetation class	cover portion (%)
R1 no/sparse vegetation	2
R2 grass	19
R3 agricultural areas	18
R4 deciduous forest	32
R5 coniferous forest	10
R6 shrub	19

Satellite data

In the study one Landsat-5 TM image ((c) ESA, Eurimage, ZRC SAZU, 1992) taken on 18.8. 1992 and set of 21 images AVHRR (Advanced Very High Resolution Radiometers) - LAC images (NOAA Satellite Active Archive, <http://www.saa.noaa.gov>) were used. This set of images was selected from all available images for the studied period of two years (1992, 1993). Cloud contaminated images were rejected and in order to minimize scan angles effects only images where the study area is within 30° scan angle were selected.

On the AVHRR images only Sun angle correction and correction of panoramic distortion were applied. Neither atmospheric nor topographic corrections were performed on the used AVHRR and Landsat TM satellite images. Radiometric calibration was performed on all images and for the first two bands of NOAA 11-AVHRR images

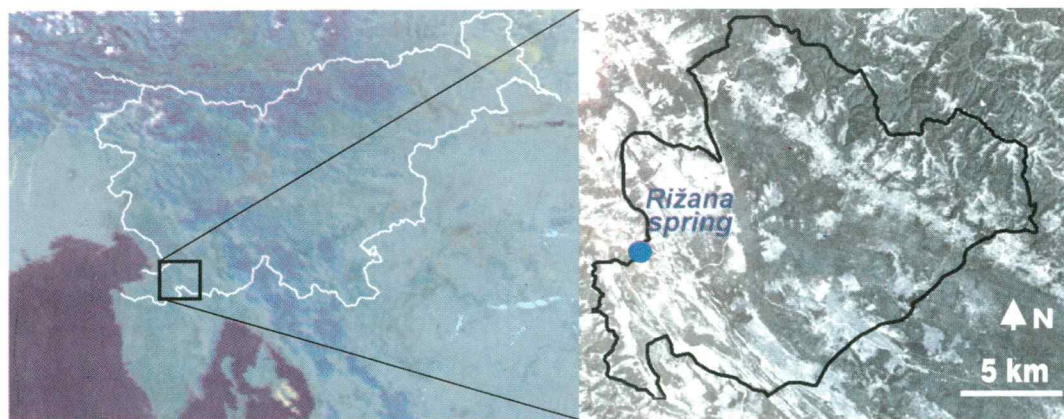


Figure 1. Position of the study area, NOAA-11 AVHRR image, colour composition – RGB: Bands 1,2,4 (left) and Landsat TM image, colour composition – RGB: Bands 1,2,3 (right). Both images were taken on 18.8.1992

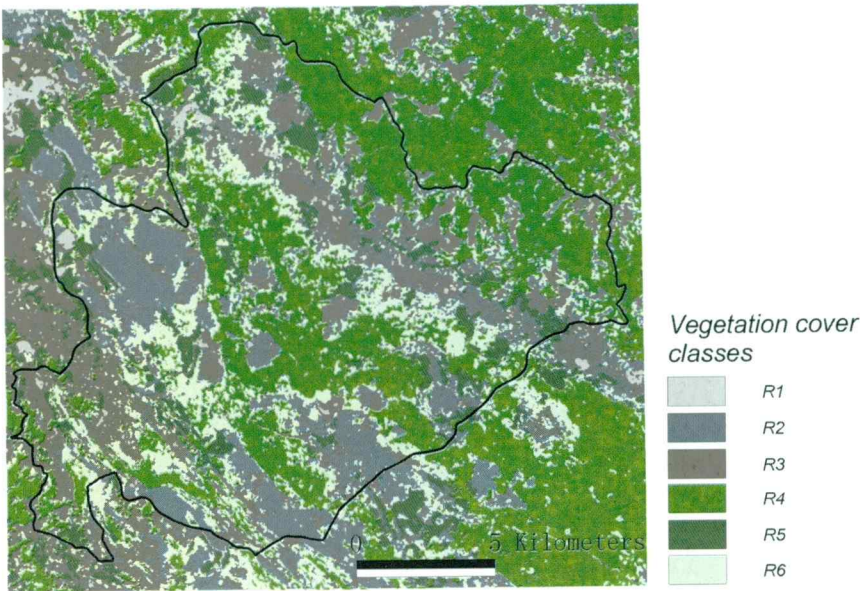


Figure 2. Classified study area

non-linear correction that accounts for sensor degradation was applied (Rao & Chen, 1994).

All AVHRR images were coregistered to a Transverse Mercator projection (as the Landsat-TM image). Second order polynomial transformation and nearest neighbor resampling method were used. A georeferencing of AVHRR image was based mainly on the referenced points selected along the coastline.

Vegetation cover classification

Vegetation cover classification was carried out by supervised classification based on maximum likelihood classifier. For the reference data CORINE Land Cover (Hočevár et al., 2001) was used that covers part of the study area. According to the influence of the vegetation types on the water cycling process in the catchment area, six vegetation classes were defined. For each class more training areas (spectral classes) were selected (altogether 62) in order to incorporate variability within the class. After the classification smoothing with majority filter (3x3) was applied. The distribution of vegetation classes is shown in Figure 2.

Spatial degradation of the fine resolution image

Used methodology of preparation of data for linear mixture model is based on the procedures presented by Oleson et al. (1995).

From the classified map a set of single class maps was determined. For each single-class map, a digital number (DN) 1 was assigned to each pixel that contains corresponding cover type. All other pixels were assigned a DN of 0.

Each single class map was then degraded to a spatial resolution approximating that of the AVHRR. With regards on the AVHRR point spread function (PTF), which defines the characteristics of the image of a point source formed by an optical system, convolution with a Gaussian filter was applied. This is similar approach to that used by Moreno & Melia, (1994), who modeled AVHRR PTF at nadir with two-dimensional Gaussian distribution. The standard deviation (σ) of the Gaussian distribution was defined with the expression (Oleson et al., 1995):

$$\frac{AVHRR\_pixel}{TM\_pixel} = 2.8\sigma$$

A series of new (filtered) class maps was created this way. Value of each pixel on these maps corresponds to the vegetation cover class proportion within an AVHRR spatial resolution pixel. These portions have been used in linear mixture model (as independent variables).

Linear mixture model

Linear mixture modelling considers that the pixel's radiance results from the linear combination of the radiances of the elements composing the pixel multiplied by their respective proportion within the pixel. These base elements of the landscape are named endmembers (Kerdiles & Grondona, 1995). This assumption should be strictly true only for the original bands. However, studies of Kardiles and Gordona (1995) showed that linear combination of NDVI values implies only very minor inaccuracies. The linear mixture model in this study was formulated as:

$$\begin{aligned} NDVI_1 &= f_{11} \cdot NDVI_{11} + \dots + f_{1k} \cdot NDVI_{1k} + \varepsilon_1 \\ &\vdots \\ NDVI_n &= f_{n1} \cdot NDVI_{n1} + \dots + f_{nk} \cdot NDVI_{nk} + \varepsilon_n \end{aligned}$$

The system of n equations corresponds to the number of pixels and k (independent or regressor variables) to the number of vegetation cover classes.

Using more general symbology, this set of equation can be expressed in matrix notation as $Y = X\beta + \varepsilon$ and

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1k} \\ x_{21} & x_{22} & \dots & x_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nk} \end{bmatrix}, \beta = \begin{bmatrix} \beta_1 \\ \vdots \\ \beta_k \end{bmatrix} \text{ and } \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix}$$

Where Y is a $(n \times 1)$ vector of observation, X is a $(n \times k)$ matrix of the levels of the independent variables, β is a $(k \times 1)$ vector of regression coefficients and ε is a $(n \times 1)$ vector of random errors.

Multiple linear regression model was used to solve the set of equations. The least squares estimate of β is (Montgomery & Runger, 1994):

$$\hat{\beta} = (X'X)^{-1}X'y$$

and the fitted model in the matrix notation is

$$\hat{y} = X\hat{\beta}$$

Results

The mean NDVI temporal profiles of vegetation cover classes derived from AVHRR images are presented in Figure 3. Temporal profiles for two years show phases of vegetation cycle that are in agreement with known vegetation characteristics in the study area. In general low values of NDVI at the beginning and at the end of the year in the winter are shown. In the spring a green-up is observed. Very fast increase of NDVI values, that starts to increase in the middle of April and reaches the climax at the end of May and beginning of June. In the next phase in the summer period NDVI profile is relatively flat with gentle decrease until the end of August or beginning of September. After that phase in the autumn period NDVI profile drops fast and reaches low value, characteristic for the winter period, around the middle of November.

Extracted NDVI profiles for individual vegetation cover type show evidently separated profile of R4 (deciduous forest) that has far highest NDVI values in the spring and summer. Les evident characteristics of the others NDVI vegetation cover type profiles are:

- R5 (coniferous forest) profile has the lowest amplitude and relatively the highest value in the winter period,
- R2 (grass) profile has in average the lowest value.

• R6 (shrub) profile has relatively high amplitude similar to the R4 profile.

Exception is the profile of R1 (no/sparse vegetation) vegetation type that doesn't follow the characteristics of the other profiles. In general it has the lowest value, but very high amplitude, which makes it very difficult for interpretation. The reason for this is most probable low cover portion (2%) of that vegetation cover type in the study area.

Conclusion

The study confirmed the potential of using linear mixture model for extraction of NDVI temporal profiles of vegetation cover types in Rižana catchment area and pointed out some characteristics of the used method.

Results are in general in agreement with the observed vegetation development cycle in study area. Study shows the ability of extracting NDVI temporal profiles for vegetation cover types that are spectrally separated and well represented in the mean of cover portion, which confirmed conclusions of Oleason et al. (1995). In this study it is the vegetation cover type R4 that satisfied

mentioned criteria. Other vegetation classes' temporal profiles, with the exception of R1 profile, are of mixed quality and less separable but still in general in agreement with observation. Temporal profile of R1 that covers a very small part (2 %) of the study area is difficult to interpret and doesn't agree with expected results. This fact shows inability of linear mixture model to extract subpixel information for the vegetation classes that are not well represented in terms of cover portion within the study area.

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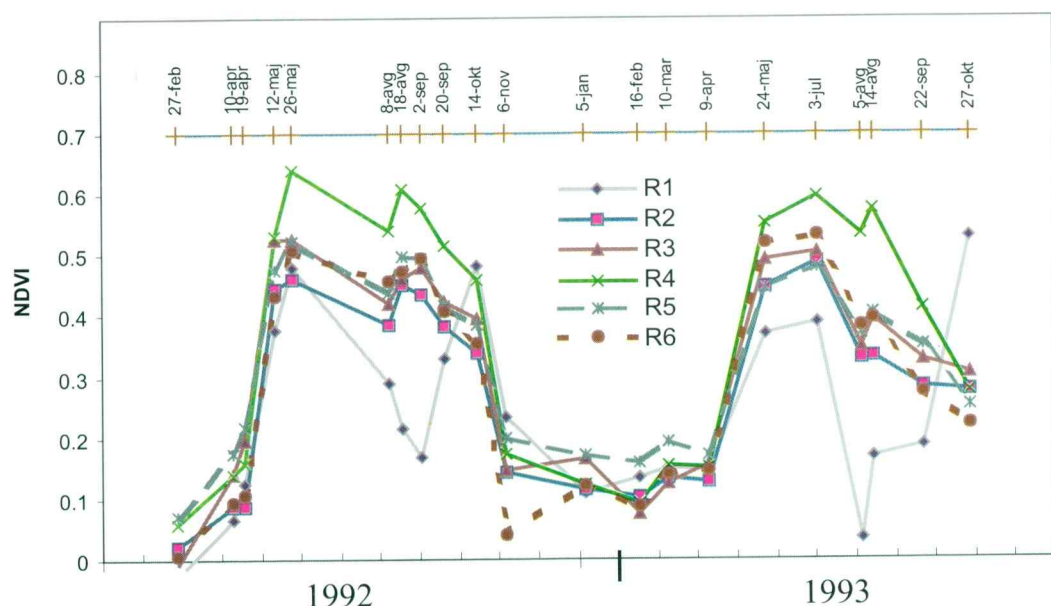


Figure 3. The mean NDVI temporal profiles of vegetation cover classes

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