Applied remote sensing for parameterizing solute transport and sediment models in the ARSGISIP project

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Abstract The EU project ARSGISIP applies remote sensing techniques and GIS analyses to parameterize hydrological, erosion, and solute transport models. Activities of the first project stage are presented, emphasizing the common environmental problem of nutrient leaching within three representative European drainage basins located in Italy, Germany, and Sweden. Physically-based simulation models used by project partners are briefly described and the contribution of optical and radar remote sensing techniques for model parameterization is discussed. The scientific approach concentrates on deriving physical parameters characterizing soil and vegetation by means of land use/land cover classifications using Landsat TM, IRS-1C LISS, and ERS-2 SAR data. First results are quite promising: (a) agricultural crops and Mediterranean vegetation could be classified with optical and radar data, and (b) model parameters describing the distributed features of the test basins vegetation-soil-topography interface (VSTI) could be derived.

INTRODUCTION

The EU project, "Applied Remote Sensing and GIS Integration for Model Parameterization" (ARSGISIP) applies and evaluates the potential of Earth Observations (EO) to identify source areas generating runoff, erosion, and nutrient leaching for the parameterization of physically-based dynamic models. This paper focuses on the aspect of nutrient leaching into reservoirs, lakes, and the sea and consequent eutrophication. Flügel (1995) and Bende (1997) have shown that runoff, erosion, and nutrient leaching are generated from different source areas distributed over a heterogeneous vegetation-soil-topography interface (VSTI) within the drainage basin. Factors controlling their transport dynamics are represented in physically-based simulation models by process algorithms and parameterizations related to the VSTI. However, at present, spatial information from larger catchments is scarce, and parameterizations describing the VSTI consequently often have a low spatial and time resolution. The latter can be improved by exploiting the potential of classification techniques offered by remote sensing integrated into a GIS.
OBJECTIVES

The objectives of the ARSGISIP project are addressing the following research subjects: (a) exploit the synergetic potential of remote sensing and GIS integration for model parameterization; (b) developing and applying such techniques in modelling studies of test catchments in different European climates (mediterranean, humid moderate, cold boreal); (c) evaluate the cost benefit analyses in comparison to standard field methods applied so far.

METHOD

Three drainage basins from major European climatic regions were selected to demonstrate this approach: (a) the Weida-Zeulenroda Reservoir in Thuringia, Germany (humid–temperate), (b) the Flumendosa Reservoir in Italy (mediterranean) and (c) the basin of the Lagan River in Sweden (cold boreal).

The physically-based simulation models WASMOD (Reiche, 1991), PRMS (Leavesley et al., 1983), SOIL-N (Johansson & Hoffmann, 1997), and HBV-N (Naturvårdsverket, 1997) were selected for the German, Italian, and Swedish drainage basins respectively. They parameterize common physiographic basin properties comprising their VSTIs such as land use/land cover, slope gradient, aspect, soil moisture, surface roughness, or leaf area index (LAI). A hydrological systems analysis carried out within the three river basins revealed key model parameters and variables directly related to the VSTI. They were classified by standard remote sensing techniques and integrated GIS analyses to derive source areas for nutrient leaching within the basins. The classifications included canopy development, forestry types, land degradation by erosion, chlorophyll, and sediment distribution of reservoirs and lakes.

DESCRIPTION OF DRAINAGE BASINS

Three river basins of the ARSGISIP project are presented: (a) The Weida-Zeulenroda Reservoir ($A = 163\ km^2; V = 40\times10^6\ m^3$) in Thuringia, Germany; (b) the Flumendosa ($A = 1826\ km^2; V = 347\times10^6\ m^3$) and the Mulargia reservoirs ($A = 178\ km^2; V = 316\times10^6\ m^3$) in Sardinia, Italy, and (c) the Lagan River drainage basin ($A = 6454\ km^2; V = 316\times10^6\ m^3$) located in Sweden. They differ in climate and scale but have in common to experience eutrophication by nutrients leaching from diffuse sources (agriculture, grazing land), point sources (sewerage) and erosion during floods. The respective water authorities are aware of this problem and are involved as end users in ARSGISIP.

DESCRIPTION OF MODELS

The WASMOD model developed by the University of Kiel, Germany (Reiche, 1991) is applied at the Weida-Zeulenroda basin. It is a distributed model simulating water balance and nitrate leaching from soils on a basin scale. The model uses physically-
based process algorithms and the spatial distribution is represented by modelling entities of “smallest geometry” corresponding to the HRU- and CHRU-approach described by Flügel (1995) and Bende (1997). Routing of water and nutrient transport between the modelling entities is carried out using GIS analyses.

The Precipitation-Runoff Modelling System (PRMS) will be applied at the drainage basin of the Flumendosa River in Sardinia. It is a modular designed, physically-based, distributed modelling system developed by the US Geological Survey, Denver, USA (Leavesley et al., 1983). Spatially distributed Hydrological Response Units (HRUs) are used to simulate the hydrological basin’s response to rainfall. Based on a thorough hydrological systems analyses HRUs are derived by GIS overlay analyses using data layers characterizing the VSTI (Flügel, 1995).

The two models SOIL-N developed at the Swedish Agricultural University and HBV-N developed at the Swedish Meteorological and Hydrological Institute are applied in the Swedish basin. SOIL-N simulates nitrate leaching into lakes during harvest and data input comprises crop type, climatic data, and the use of manure and chemical fertilizers (Johansson & Hoffmann, 1997). The HBV-N model simulates the retention of nitrogen (immobilization and transformation) during its transport through the basin towards the sea (Naturvårdsverket, 1997).

DERIVATION OF MODEL INPUT PARAMETERS BY REMOTE SENSING

Standard remote sensing techniques are used to identify source areas for runoff generation, nutrient leaching and sediment input by classifying agriculture, forest types, canopy development, land degradation by erosion, bare soils and chlorophyll within the basin. A multitemporal, multispectral, and multisensoral approach is applied to improve the classification accuracy by enhancing the discrimination capabilities. Data obtained from optical and microwave sensors such as Landsat TM, IRS-1C LISS, ERS-1/2 SAR, and JERS-1 SAR are processed and evaluated, using e.g. colour composites of optical and microwave data.

Optical data are used to classify vegetation types (crop, grassland, forest), water bodies, and settlements. Vegetation indices such as the NDVI (normalized difference vegetation index) are derived to characterize crop health and growth stages using red and near infrared bands. Agricultural crop types are discriminated by multitemporal classification. High resolution optical data are processed to classify different growth stages and biomass conditions (well developed, damaged, severely damaged) of forest canopies. Nitrate leaching into the reservoirs causing algae growth is indirectly assessed by identifying chlorophyll distribution. Erosion features and land degradation within the drainage basins were classified using standard methods described by Canuti et al. (1996).

Microwave data obtained by the Synthetic Aperture Radar (SAR) data are sensitive to the geometric surface structure controlled by vegetation type, biomass, soil water content, roughness, soil texture, field tillage or row direction (Fellah et al., 1996). SAR’s sensitivity to surface roughness data can e.g. be used to monitor different growth stages of forest stands by combining ERS-2 and JERS-1 data with different frequencies.
LAND USE CLASSIFICATIONS: PRELIMINARY RESULTS

For the Weida-Zeulenroda basin, optical data from Landsat TM (30 m) acquired in July 1995 and September 1997 and ERS-1/2 SAR (25 m) data acquired in July 1995, April 1996, and July 1998 have been processed. Three field campaigns were carried out in the summer of 1998 to map crop types and to collect soil samples. They revealed that gravimetric topsoil moisture is correlated with corresponding radar backscatter. For the Flumendosa River basin, one IRS-1C LISS image (23 m) acquired in July 1997 has been processed so far, and optical data from the Indian LISS and WiFS (180 m) instruments from May 1998 and ERS-2 data from four dates between March and July 1998 are under evaluation for the Lagan River basin. For all test basins, additional optical and radar data for the growing seasons 1998 and 1999 will be analysed, and further field campaigns for ground truth are scheduled.

Classification Except for the adaptive filtering, the processing of microwave data is similar to methods used for optical data. Both data were processed as follows: (a) adaptive filtering to reduce speckle (only microwave images), (b) registration of the individual satellite images to the national coordinate system, (c) visual assessment of land use, crops, regional patterns and specific features, (d) unsupervised and (e) supervised classification, and (f) post processing of classification results. Further processing will focus on the correction of atmospheric disturbance, radiometric topographic affects using a DEM.

Preliminary results For the Weida-Zeulenroda drainage basin, five major land cover classes: water, settlement, forest (with two sub-classes), grassland, and farmland (with six sub-classes) could be classified using a Landsat TM image (Fig. 1; this figure can be seen in colour at http://geogr.uni-jena.de/~arsgisip/annual_report1.html). The separation of different agricultural crops is still under research, but multitemporal and multisensoral classifications are expected to improve the present classification accuracy significantly. Due to the pixel size (30 m x 30 m) of Landsat TM images, rural sewage ponds which are important point sources for phosphorus discharge can only be identified if they are sufficiently large.

As LISS was acquired after harvest, vegetation in the Flumendosa River basin was very poorly developed. Altogether six main land cover classes were distinguished: water, settlements, farmland, grassland (with two sub-classes), mediterranean vegetation (with six sub-classes), exposed bedrock and soils (Fig. 2; this figure can be seen in colour at http://geogr.uni-jena.de/~arsgisip/annual_report1.html). Due to illumination and shadow effects, the spectral appearance of the different vegetation types in mountainous regions is strongly influenced by the elevation of the sun and its zenith angle.

In the Lagan River basin remote sensing data show significant local and regional differences in land use patterns and field sizes, crop development, and growing conditions. However, four major land cover classes (water, forest, settlements, agriculture) were classified using optical and multitemporal radar data. Research is ongoing to separate specific agricultural crops, e.g. certain types of cereals and pasture. Further ground truth during the growing season 1999 is expected to improve the classification accuracy significantly. Figure 3 from the Swedish test basin demonstrates
Fig. 1 Land use classification of georeferenced Landsat-5 TM scene acquired 22 September 1997, test-site Weida-Zeulenroda, Germany; the black line marks the basin border.
Fig. 2 Land use classification of georeferenced IRS-1C LISS scene acquired 25 July 1997, test-site Flumendosa, Sardinia, Italy.
the different information content of optical and radar data: (a) at the left-hand side, the shore line with dunes and the mouth of the Lagan River appear as a bright line in the red band of LISS data; (b) at the lower right-hand corner the city of Laholm appears as scattered small bright objects; (c) large forests are near the shore and agricultural areas with pastures, small cereal fields, sugar beet and oil seeds can be classified in the centre and the north.

**CONCLUSION AND FUTURE RESEARCH**

In respect to the potential of remote sensing and GIS integration for model parameterization first results obtained in the ARSGISIP project are quite promising: (a) agricultural crops and mediterranean vegetation could be classified with optical and radar data, and (b) model parameters describing the distributed features of the test basins VSTIs could be derived. For future research local and regional differences in the spectral characteristics of crops and forests require further attention. The radar data also show differences in brightness not related to land use and crop types. Only in some areas are agricultural fields large enough to be identified in the WiFS data which has a 180 m resolution. Common agricultural management practices e.g. in Sweden sugar beet, or potatoes in the central part of the field are surrounded by a 10 m strip of cereals, or very small and irregular fields in the hilly areas are causing additional problems for the land use/land cover classifications.

Future research in ARSGISIP therefore will also focus on the combination of optical and radar data to improve the obtained classifications. Their synergetic potential will be evaluated by using selected classification results and compared with such obtained from radar images alone. The results obtained from such comparisons will be the base of a cost–benefit evaluation demanded by the end users of ARSGISIP.
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