INTEGRATION OF GIS AND HYDROLOGICAL DATA BASES FOR WATER BALANCE EVALUATION

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ABSTRACT

This work presents a methodology for integration of INPE geographical information system (SGI) with DNAEE's hydrological data bases for GIS-based water balance (WB) evaluation over Brazilian Amazon. Hydrological data is obtained from DNAEE data bases; the microcomputer-based inventory system MSDHD is used. SGI is used as the basic modelling tool for integration of different sources of data, derivation of WB parameters and product generation.

Topics include a description of the SGI and MSDHD systems, of th methodologies adopted for WB parameters estimation and for GIS organization and modelling. An evaluation test under execution is also described.

RESUMO

Este trabalho apresenta uma metodologia para integração do sistema de informações geográficas do INPE (SGI) com as bases de dados hidrológicos do DNAEE, no propósito de estimar o balanço hídrico sobre a Região Amazonica através do SGI. Dados hidrológicos são obtidos nas bases de dados do DNAEE; o sistema de inventário MSDHD é utilizado para recuperação de dados no ambiente de microcomputadores. O sistema SGI é a ferramenta de base para modelagem, integração de dados de diferentes fontes, cálculo do balanço hídrico e geração de produtos.

O artigo inclui descrições dos sistemas SGI e MSDHD, das metodologias usadas para estimativa dos parâmetros de balanço hídrico e para modelagem de dados no sistema de informações. Um teste de avaliação, atualmente sendo executado, também é descrito.

INTRODUCTION

Estimation of water balance (WB) parameters is a very important element in biogeochemical modelling. It provides critical information for evaluation of plant production, organic matter decay, riverine nutrient flux and trace gas exchanges.

WB modelling estimates runoff, soil moisture and evapotranspiration from land cover, potential evapotranspiration, precipitation, soil and elevation data.

Geographical information systems (GIS) are very useful tools for WB modelling due to their capabilities of integrating data from different sources, WB parameters calculation and generation of maps.

This paper presents a methodology for integration of INPE geographical information system (SGI) with DNAEE's hydrological data bases for GIS-based water balance evaluation over the Brazilian Amazon.

Hydrological data is obtained from DNAEE data bases (DNAEE a,b); the microcomputer-based inventory system MSDHD (DNAEE c) is used for data retrieval. SGI is intended to serve as the basic modelling tool for combination of hydrological and other sources of data, derivation of WB parameters and product generation.

The present work is intended to contribute for a more complex project of studying hydrologic cycles over the Amazon region. This project aims at performing hydrologic modelling under the 1/250,000 scale so that detailed datasets will have to be used. This fact emphasizes the importance of GIS integration to hydrological data bases.

The following topics describe the SGI and MSDHD systems, the methodologies adopted for WB parameters estimation and for GIS organization and modelling. Finally, an evaluation test under execution is described.

THE SGI SYSTEM

To provide computer-based tools for integration of remotely sensed imagery with map and other types of data, INPE's Image Processing Department developed SGI, a geographical information system that runs on IBM-PC compatible microcomputers and on the image processing system SITIM-150, also developed at INPE (de Souza et al, 1990).

SGI can handle cartographic data in both vector and raster formats, digital terrain models (DTM) and satellite imagery. SGI data and formats are shown in table I. Images are geometrically corrected prior to combination with map data. The system is closely linked to SITIM-150 allowing to perform image processing treatments within an integrated environment.

TABLE I: SGI DATA TYPES AND FORMATS

TYPE OF DATA	FORMATS ACCEPTED
Polygonal Data	Vector (arcs, nodes and areas) Raster (incl. classified images)
DTM	Point data Regular grid Raster (DTM images) Contour maps
Image	Geometrically corrected multi-multispectral and classified images

Countour and polygonal maps can be entered via digitizers. It is possible to associate classes and identifiers to polygonal data. (class is the basic information used for most manipulations and identifiers allow to link map features to external data bases). It is also possible to read digital data from ASCII files.

SGI comprehends several functions for data manipulation. Major options are shown in table II.

TABLE II: DATA MANIPULATION BY SGI

Vector to Raster Conversion

Raster to Vector Conversion

Reclassification of Polygonal Data

Logical Operations with Polygons Maps

Weighed Sum of Polygonal Maps

Area Calculation

Distance Map Calculation

Regular Grid Interpolation

DTM Image Interpolation

DTM Level Slicing

Profile Calculation on DTM

Arithmetic Operations on DTM

Slope and Aspect Calculation

Volume Calculation

HYDROLOGICAL DATA

Federal government DNAEE is responsible for maintaining data bases of hydrological data for all Brazilian basins. These data bases contains information about precipitation, flood and other parameters for 8 basic basins (table III) (DNAEE a).

TABLE III - BASINS DEFINED BY DNAEE

Basin 1 - Amazon River Basin

Basin 2 - Tocantins River Basin

Basin 3 - South Atlantic-N/NE Basin

Basin 4 - São Francisco River Basin

Basin 5 - South Atlantic-E Basin

Basin 6 - Paranã River Basin

Basin 7 - Uruguai River Basin

Basin 8 - South Atlantic-SE Basin

Data is collected by DNAEE and several other institutions through pluviometric and river gage stations. Each station can collect different types of data according with its equipment; station types are described in TABLE IV (DNAEE a, DNAEE b).

TABLE IV.a - Pluviometric stations

STATION TYPE	INFORMATION COLLECTED
P	Precipitation (rain gage)
R	Precipitation (pluviographs)
E	Evaporation
C	Climatologic station

TABLE IV.b - River gage stations

ST TYPE	INFORMATION COLLECTED
F	River stage (river gage)
R	River stage (recording river gage)
D	Liquid discharge
S	Solid discharge
Q	Water quality

Data can be acquired from DNAEE in the form of diskettes. Providing for data retrieval and handling the microcomputer inventory system MSDHD was developed at DNAEE (DNAEE c). MSDHD is composed by several modules that allow to formulate different queries about hydrologic, climatic and sedimentary data using different criteria (station name, state, basin and river, geographic location and other). Software libraries are also available for data retrieval from disk, so that special data treatments can be realized by programs that read hydrologic parameters and derive new types of data.

Integration of MSDHD data bases into the SGI system is performed by the following steps:

1) retrieval of precipitation and temperature data from MSDHD data base and creation of SGI point-format files;

2) interpolation of precipitation and temperature data for creation of SGI grid-format files, representing the distribution of these data over the region of study.

Creation of grid-format files is executed according to the basic technique provided by SGI: grid values are calculated from nearest points values.

Interpolated values quality is to be evaluated and there is a possibility that new methodologies for precipitation and temperature interpolation will be required.

EVALUATION OF WATER BALANCE PARAMETERS

The present work adopts the methodology described by Vorosmarthy et al (1989), who executed a water balance and water transport evaluation of South America using GIS, a thirty-minutes grid cell data base and UNESCO-published precipitation and temperature data.

As a result, it is intended to obtain a more refined - up to the 1/250,000 scale - water balance, since more detailed input data is available from DNAEE.

The water balance model input data are precipitation, temperature, potential evapotranspiration, vegetation, soils and elevation. From these data soil moisture, evapotranspiration and runoff are calculated.

Input Data

Temperature and precipitation data are obtained from existing data bases in a monthly basis; vegetation and soils, from corresponding thematic maps.

Temperature and precipitation are treated as digital terrain models. Data is introduced into SGI in the form of point data. Afterwards, DTM interpolation methods procedures are used for generation of SGI grid and image files (temperature is in degrees Celsius, precipitation in mm/month).

Vegetation and soil maps are digitized and rasterized. An overlay of these two maps is created and field capacity, FC, values are associated to the different combinations of vegetation and soil (FC is a function of soil texture and rooting depth), using values from table V.

TABLE V - FIELD CAPACITY (mm)

SOIL	VEGETATION Forest	Grassland & Shrubland
Sand	353	141
Sandy loam	400	200
Silt loam	546	355
Clay loam	563	352
Clay	582	340
Lithosol	27	27

(source: Vorosmarthy et al (1989))

Potential evapotranspiration (PET) is calculated using the Thornthwaite method as described by Rosenberg (1974). PET is defined by the formula:

$$PET = 16\ (10\ t/I)^{a} \qquad (1)$$

where a is defined as

$$a = 6.75\times10^{-7} I^{3} - 7.71\times10^{-5} I^{2} + 1.79\times10^{-2} I + 0.49$$

t is the monthly mean temperature, I is the heat index derived from the sum of 12 monthly index values, i, that is given by the function

$$i = (t/5)^{1.514}$$

Potential evapotranspiration (PET) is calculated from temperature, according to equation (1). The resulting data are of DTM type (values of PET are in mm, of t in degrees Celsius).

Finally, elevation is not considered in the case of the Brazilian Amazon, because it is used basically for calculation of snowmelt water.

Output Data

Soil moisture (SM) can be determined from interactions among precipitation (Pr) and potential evapotranspiration (PET). (Vorosmarthy et al (1989) consider also the influence of snowmelt recharge, which is not the case in the Brazilian Amazon).

During wet months, soil moisture can increase up to a maximum field capacity (FC):

$$dSM/dt = (Pr - PET) \quad \text{when } Pr \geq PET;\ SM < FC \qquad (2.a)$$

$$dSM/dt = 0 \quad \text{when } Pr \geq PET;\ SM = FC \qquad (2.b)$$

During dry periods, soil moisture can be seen as a function of water loss:

$$dSM/dt = -\ a\ (Pr - PET) \quad \text{when } Pr < PET \qquad (2.c)$$

where

$$a = \ln (FC) / (1.1282\ FC)^{1.2756}$$

Calculations starts at the end of the wet season when it is assumed the soil is at field capacity. Soil water stocks are then depleted during the dry season.

Evapotranspiration (ET) is calculated from soil moisture (SM) and potential evapotranpiration (PET) values. For wet months

$$ET = PET \quad \text{when } Pr \geq PET \qquad (3.a)$$

During the dry season,

$$ET = Pr - dSM/dt \quad \text{when } Pr < PET \qquad (3.b)$$

According to Thorntwaite and Mather (1957) only about 50 percent of the surplus water (Pr - PET) actually contributes to **runoff** (RO) for the current month. The rest of the surplus water is detained on the watershed and made available for runoff during the next month. Considering only rain-derived rainfall, the equation

$$RO = 0.5\ (Dr + Pr - PET) \quad \text{when } SM = FC,\ Pr \geq PET \qquad (4.a)$$

can be used on wet months and

$$RO = 0.5\ Dr \quad \text{when } SM < FC \text{ or } Pr < PET \qquad (4.b)$$

can be used for the dry period.

Dr is the rainfall derived detention (storage). Its initial value is determined by the moisture surplus when the soil attains its field capacity. For each next month, Dr is equal to the preceding runoff value.

TEST PROJECT

A test project is being executed at present, designed to help in the development of the GIS-based WB model.

The Alto-Purus basin was selected as test area, comprising a region between 8-12 S latitude and 66-72 W longitude. This area was selected because it comprehends an enough amount of pluviometric and river gage stations maintained by DNAEE.

This area has also suffered from uncontroled deforestation due to antropogenic action, which will help in the study of changes in hydrologic cycle due to that kind of disturbances over the environment.

FINAL CONSIDERATIONS

WB estimation has considerable problems over the Amazon region because of scarce, not up-to-date, information. From this point of view, to make DNAEE datasets available for hydrologic studies is an important contribution to the development of adequate systems for environmental modelling.

Most critical of all data is evapotranspiration - a key, though not available, information. It can be noted, that INPE and DNAEE are working on evapotranspiration estimation with the aid of remotely sensed and hydrological data. Such methods should be helpful for areas with very scarce data, that are very often found in the Amazon.

Finally, it is important to see the present work under the perspective of detailed, 1/250,000 scale, studies of the hydrologic cycle in the Amazon Region. These studies constitute a very important trend in environmental research to be developed at INPE, CENA, DNAEE and the University of Washington (Batista et al, 1988), throughout this decade.

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