Runoff modelling in northern Algeria using a distributed physically-based model integrating remote sensing data

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Abstract This paper describes the possibility of using remote sensing data in order to obtain the information necessary to apply a distributed physically-based runoff model. Many of the classical hydrological models are based on transfer functions or lumping techniques due to limitations of the available ground data. Remote sensing techniques have rapidly developed these last years and offer a practicable way of limiting ground work to previously identified classes with the same physical properties. The established classification does not correspond to a usual pedological soil map but reflects the physical soil properties instead. These soil properties are first of all the infiltration patterns (or runoff generation) and the vulnerability towards erosion which can be determined by rainfall simulation. It is possible, furthermore, to obtain information about the antecedent soil moisture distribution by applying a principle component analysis to the satellite images. These detailed information is coherent for the whole coverage of the satellite image which allows the modelling of even large basins in a detailed way. No traditional field method is capable of furnishing a similar amount of detailed simultaneous data. This modelling technique was used in a project of the Algerian–German technical cooperation dealing with the introduction of new technologies to the Algerian Hydraulic Resources Administration. On an example in northern Algeria the application of this combined modelling technique is shown.

INTRODUCTION

Data disposability is often one of the major limiting factors to hydrological modelling in semiarid countries. Remote sensing techniques can help considerably to reduce the amount of field work necessary in order to obtain a reliable data basis for modelling purposes. Linking the different kinds of data with GIS techniques enables the modeller to precisely identify the sites for field investigations. This is especially useful for larger basins, where classical approaches would take a long time. One of the main tasks of the Algerian National Agency for Hydraulic Resources—ANRH (Agence Nationale de Ressources Hydrauliques, Algiers) is the nationwide inventory of the natural resources soil and water in Algeria.

Within the context of the technical cooperation between Algeria and Germany, a project between the ANRH and the German technical cooperation office (Deutsche

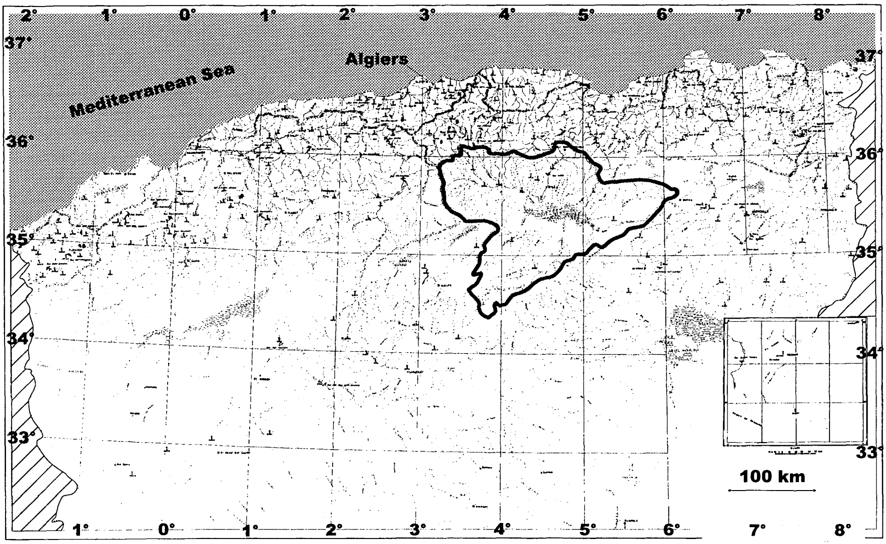

Fig. 1 Map of the location of the Chott el Hodna drainage basin in Algeria (Source: ANRH, 1989, modified).

Gesellschaft für Technische Zusammenarbeit, GTZ, GmbH) was initiated in 1995, and aimed to ameliorate the performances of the ANRH through the introduction of modern modelling techniques.

SITUATION OF THE STUDY AREA

The chosen study area, the basin of the Chott el Hodna, is situated about 300 km south of Algiers between the peaks of the Tell Atlas (up to 1800 m a.m.s.l) in the north and those of the Sahara Atlas (up to 1600 m a.m.s.l) in the south (Fig. 1). It occupies a surface of about 25 000 km^2 and its climate is semiarid. Annual precipitation ranges between 150 and 400 mm (ANRH, 1993). For modelling purposes, a drainage basin of about 460 km^2 has been identified, located in the northwestern part of the basin, controlled by the gauging station of Ain Nessissa (Fig. 2).

DATA

Topography

Based on topographic maps at a scale of 1:50 000 contour lines have been digitized and then transformed to a Digital Terrain Model (DTM) based on a regular grid with a grid size of 100 m. The DTM then allows the determination of other derived parameters as the slope angle, the exposition angle, the flow direction and the drainage size for every grid cell.

Climate data

Within the drainage basin there are about 20 raingauging stations providing daily rainfall recordings but only two rain recorders. On the runoff measurement side there is only one gauging station at the basin outlet, the station of Ain Nessissa whose recordings end with the year 1978. Therefore, only a reduced number of events was available with both precipitation and runoff data. There is no evapotranspiration data available and for further balancing purposes at least an approximation via values from the literature will have to be integrated.

Soils

Usually information on soil and land use is hard to obtain or inaccurate in quality for modelling purposes. A classical pedological soil map is based on genetic criteria which are difficult to relate to hydrological data. Therefore we used Landsat TM5 data to derive a classification based on the physical properties of the soils. The method adopted is based on an inverse classification approach (Vogt, 1991). Instead of applying a supervised classification with previously identified soil types (which are then introduced as training samples), principal component analyses is used. As a result a classification is obtained regrouping soils with similar physical properties—of course these soil classes do not correspond directly to traditional soil classifications as the FAO system. Then there is field work to be done in order to determine the analytical characteristics of content of the classes. This means on precisely spotted locations two to three pits have to be excavated to identify the

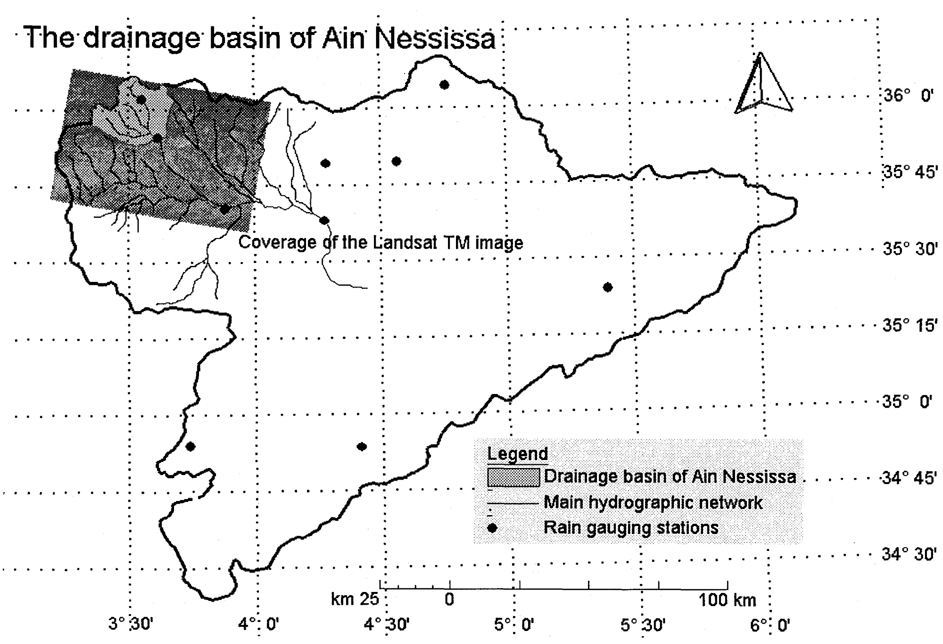

Fig. 2 The drainage basin controlled by the gauging station of Ain Nessissa.

nature of the soils. Then a final classification can be performed which is applicable to the totality of the satellite image, combining the local precision (1 Landsat TM pixel = 900 m²) with the coverage of a large surface (185 km × 185 km for a Landsat TM scene). For the Chott el Hodna a first classification has been established containing 21 soil classes (Fig. 3, Table 1).

Soil moisture

Crist & Cicone (1984) showed the possibility of obtaining information on the spatial distribution of soil humidity by interpreting satellite data. They determined that the third component of the Tasseled Cap Transformation, (a variant of the principle component analysis) performed as an indicator of soil wetness. Rimbert & Vogt (1991) showed that the normalized PCA revealed identical structures for the third factor as the Tasseled Cap Transformation but in the case of poor vegetation cover it passed on second place for the explained variance. We therefore applied the normalized PCA on the channels TM1–TM5 and TM7 (TM6 being very sensitive to shadows) of the Landsat TM5 quarter scene and derived a spatial distribution from the third factor of the PCA. Integrated in a georeferenced form, this gives an idea of the spatial distribution but of course does not reflect the actual volumetric values of the soil moisture. As there are two satellite images chosen for the study, one from a wetter period (March 1988) and one from a dryer period (August 1986) we can qualitatively identify zones that are wet most of the time and others that are nearly always dry (Fig. 4). This information is extremely useful as covering a surface of about 460 km² with simultaneous measurements is either expensive or nearly impossible.

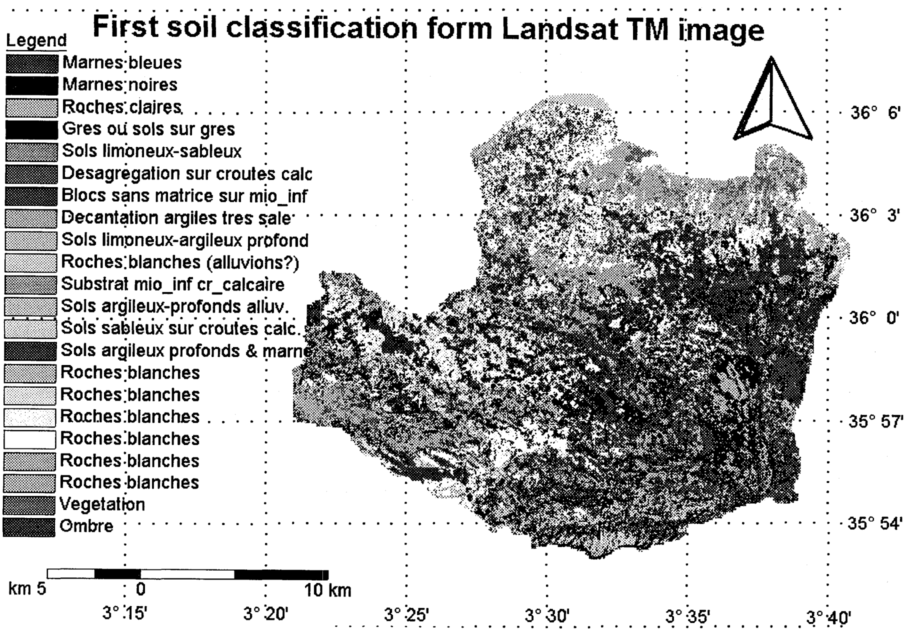

Fig. 3 First soil classification derived from a Landsat TM5 image.

Table 1 Analysis of the first soil classification for the drainage basin of Ain Nessissa.

Class	Legend	Area (%)	Cumm area	Area (km^2)
1	Blue marls	10.51	10.51	48.631
2	Black marls	8.22	18.73	38.016
3	Light rocks	2.82	21.55	13.049
4	Sandstone or soils on sandstone	5.61	27.16	25.963
5	Loamy sandy soils	0.78	27.94	3.597
6	Soils on calcretes	0	27.94	0.001
7	Disaggregation on calcretes	0	27.95	0.02
8	Boulders	0.53	28.47	2.435
9	Decantation of dirty clays	2.45	30.92	11.319
10	Thick loamy clayey soils	0.32	31.24	1.47
11	Light rock (alluvium?)	0.2	31.44	0.922
12	Substratum on calcretes	0.02	31.46	0.092
13	Deep clayey soils on alluv.	2.89	34.34	13.348
14	Sandy soils on calcretes	0.05	34.39	0.223
15	Thick clayey soils and marls	17.78	52.17	82.236
16	Light rocks	1.92	54.09	8.896
17	Light rocks	2.35	56.45	10.89
18	Light rocks	7.32	63.77	33.875
19	Light rocks	15.09	78.86	69.79
20	Light rocks	5.98	84.84	27.66
21	Light rocks	5.92	90.76	27.389
22	Vegetation	2.97	93.73	13.749
23	Shadow	6.27	100	29.008

APPROACH

Traditional modelling techniques in Algeria generally rely on system functions to describe the hydrological behaviour of a drainage basin. These models often require long series of observed field data in order to be properly calibrated. Furthermore, once the calibration is done any application of the model to another site demands a new calibration.

The application of a distributed physically-based model integrating remote sensing data allows the calibration of the model for a given drainage basin but also grants the usage throughout the area covered by the satellite without further calibration. The number of equations is reduced to the main physical processes relevant for the runoff generation. In the case of this study, a cell size of 100 m has been chosen for the regular grid to be applied. For each given cell we have to supply information on the topography, the climate and the soils. When this information is supplied, the model will allow the calculation of the infiltration and the runoff for each cell using a kinematic wave approach (Bronstert, 1994; Schramm, 1994) based on the second equation of St Venant to route the runoff to the basin outlet. Gomer (1994) gave a detailed description of the model theory.

RESULTS

An essential step towards the detailed modelling is the necessary field work. Due to

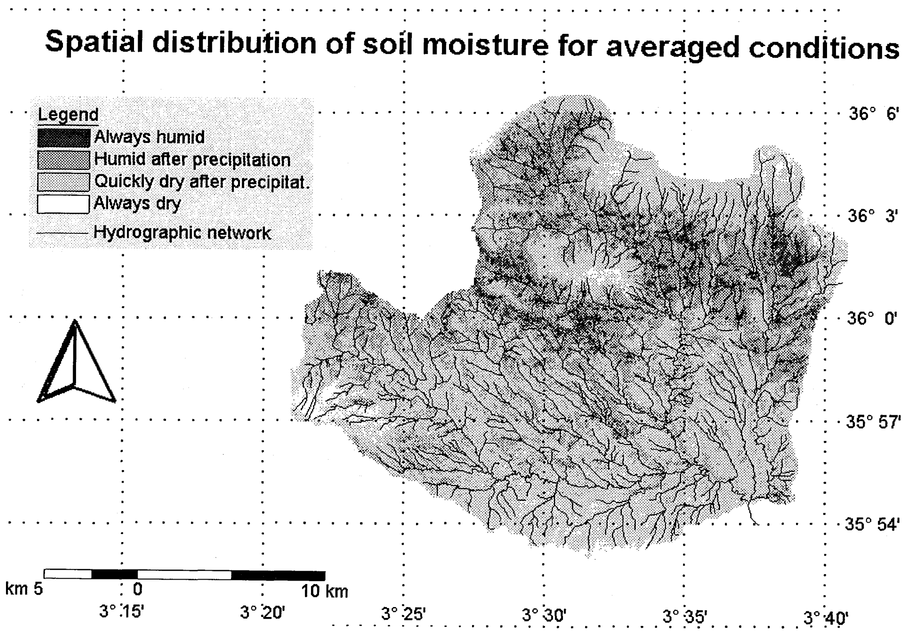

Fig. 4 Spatial distribution of soil wetness for averaged conditions.

the actual conditions in Algeria, only a part of the field work has been undertaken so far. The location of the field study was downstream in the drainage basin to be modelled which means not all the classes identified by the remote sensing classification have been verified. As a consequence, the infiltration measurements do not cover all the existing soil classes, leaving the uncertainty of hypothetical data for the rest of the classes.

As the aim of the project itself is the introduction of new modelling techniques we decided to take over the soil parameters of another project carried out in Algeria, in the Oued Mina basin (Gomer, 1994), in order to allow first modelling runs. Although the results of the modelling itself do not reflect the hydrological reality (therefore no comparison between observed and modelled values is shown here) as soon as the necessary field work is done the hypothetical data will be replaced by more realistic measurements. So far the results obtained are as follows:

- Construction of a DTM and an analysis of the topography resulting in thematic maps, as the sense of overland flow.
- First soil classification with 21 classes.
- Spatial distribution of soil wetness for averaged conditions

Unfortunately, the values obtained so far have not allowed a realistic modelling of the runoff processes in the drainage basin of Ain Nessissa to be carried out. It has to be pointed out, that the missing data could be achieved within one or two months of field work, as soon as the conditions in Algeria allow field work to be done.

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