Evaluating the Available Regional Groundwater Resources Using the Distributed Hydrogeological Budget

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Abstract In this study, several hydrogeological catchments of Central Italy have been characterized focusing the attention on the presence of areas in which, over the last two decades, the hydrological equilibrium between recharge and discharge (phenomena of marked reduction of spring discharge and progressive drawdown of groundwater levels) has been compromised by overexploitation of groundwater resources. A GIS system has been used in order to develop the study and the homogenous distribution of the hydrological knowledge and of the existing imbalances has been performed. Characterizing elements of the research are: a) the definition of the hydrogeological units; b) the hydrogeological survey of around a thousand water-points; c) the monthly analysis of climatic data of numerous survey stations; d) the census and the recording of water concessions; e) the evaluation of agriculture hydro-exigency derived from the analysis of the use of soil; f) the withdrawals defined by a statistic analysis of data. These elements have allowed to define the Distributed Hydrogeological Budget which is a useful instrument to evaluate critical areas.

Keywords Groundwater recharge/water budget · Groundwater management · Geographic information systems · Groundwater statistics

1 Introduction

Growing urban areas are forced to increase their clean water supply in order to meet the demand from households and industries. When possible, increasing local pumping is an

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economically viable option (Calderhead et al. 2012). However, a direct consequence of heavy groundwater pumping in the aquifers is often the effect on the total balance in terms of changing in stream and springs' discharge amount.

Traditional hydrological balance calculation are based on measurement of some of the components of the water balance (always involving errors). The only components of the water balance that are regionally observed from a number of stations are precipitation, streamflow, and to a lesser extent the withdrawals. Soil moisture, evaporation and transpiration, water storage and infiltration are usually estimated from empirical formulae. Here, the accuracy of the model depends on the input requirements and the degree to which the structure of the model approximates the physical process (Arnold and Allen 1996).

Rapid advances in the development of the Geographical Information System (GIS) which provides spatial data integration and tools for natural resource management have enabled integrating the data in an environment which has been proved to be an efficient and successful tool for groundwater studies (Meijerink 1996; Nour 1996; Jaiswal et al. 2003; Krishnamurthy et al. 1996; Smith et al. 1997; Rao and Jugran 2003; Edet et al. 1998; Jasrotia et al. 2009; Casta et al. 2010; Chen et al. 2005; Manghi et al. 2009; Yihdego and Webb 2013).

In view of the strategic importance of groundwater resources in Latium Region (Central Italy), and the conflicting evidence of potential impacts of groundwater overexploitation (Custodio 2002; Sidiropoulos et al. 2013), this study aims to establish a management instrument for the sustainable development and management of the aquifers. The Distributed Hydrogeological Budget (DHB) model (Capelli et al. 2005) has been developed according to a multi-layer GIS to that end, and in order to achieve the following objectives:

- A better understanding of flow processes of the analysed catchments of Volcanic areas of Latium Region and Lepini Mountains and Pontina Plain (Fig. 1)

- The evaluation of the hydrologic balance of these regional catchments

2 Geological and Hydrogeological Setting of the Study Area

The study area is located in the Central Appenines Tyrrhenian margin of the Latium Region which is characterized by Volcanic districts to the North, and by the carbonates outcrops of Lepini Mountains and the Pontina Plain to the South. For simplicity, the geological and hydrogeological setting of these two sectors are distinctly and briefly described as follow (Fig. 1).

2.1 Volcanic Sector

The volcanic activity in the Latium Region stated during the late Pliocene, as part of the Tuscany-Latium Volcanic Province (De Rita 1993; De Rita et al. 1993), in a extensional sector westward to the Apennine chain. The volcanic area is located between the Apennine reliefs to the east and the Tyrrhenian sea to the west. This volcanic activity originated several volcanic districts mainly characterized by explosive activity: the Vulsino district, the Cimino-Vicano district, the Sabatino and Tolfetano-Ceriti-Manziate districts and finally the Colli Albani district (Fig. 1).
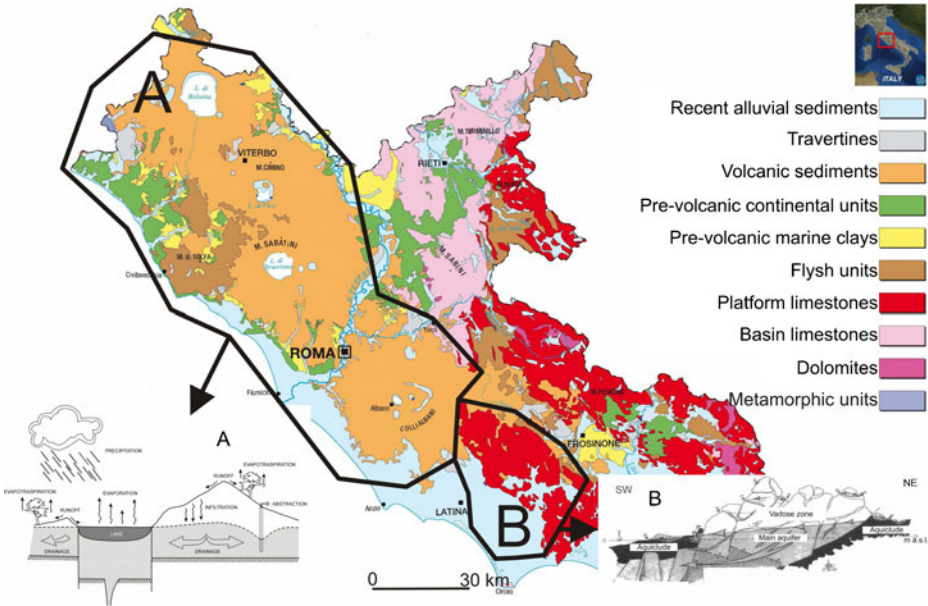
Fig. 1 Location of the study areas (1 – Volcanic sector; 2- Lepini Mountains and Pontina Plain) and general hydrogeological setting of the Latium Region (Capelli et al. 2012) with the simplified conceptual models of the: *A*- volcanic sector (modified from Mazza et al. 2014); *B* - of the Lepini Mountains and Pontina Plain sector (from VV. AA 2010)

The pre-volcanic lithologies are continental and marine Pliocene and Pleistocene deposits overlapping the limestone Mesozoic bedrock and flisch sequences.

By an hydrogeological point of view, the groundwater circulation mainly reflects the volcanic structures flowing radially from the higher sector of each volcano (Baiocchi et al. 2006; Capelli et al. 2005). The groundwater circulation in these aquifers depends on the typology of volcanic products. Because of the explosive nature of these volcanic complexes, basalts' fractured aquifers are just located in lava flows bodies while the majority of groundwater flows thorough porous aquifers of tuffs, pozzolans and ignimbrites. Even if volcanic products are so inhomogeneous in term of geometry and hydraulic properties, at regional scale all the volcanic sector can be considered as a large continuous phreatic aquifer, sustained by the generally less permeable pre-volcanic deposits. Deep circulation in the existing subsided limestone bedrock (La Vigna et al. 2013) is not considered in this work.

In this sector the main discharge of groundwater occurs as baseflow of the superficial drainage network rather than important point sources.

2.2 Lepini Mountains Group and Pontina Plain Sector

The Lepini Mountains, together with the Ausoni and Aurunci, form the pre-appenninic Volsci range (southern Latium). The Monti Lepini ridge extends in NW-SE direction for about 20 Km, its width ranges from 25 to 30 Km and heigth from 1,000 m to 1,536 m of Monte Semprevisa. The ridge, made of series of stratified carbonate karst rocks (limestones, dolomitic limestone and dolostones) mostly Mesozoic, is cut into large monoclines dislocated at different depths with mainly a North-East dip (Accordi 1964; Cosentino et al. 1993; Cosentino et al. 2002).

By an hydrogeological point of view, the Lepini Mountains can be divided into two big reservoirs(VV. AA 2010). The main component is the Lepini Massif that represents the

recharge system of the studied aquifer. It is mostly made of carbonatic outcropping formations that can reach high altitudes and are widely karstified (1,600–1,700 m s.l.m.). The second component is the Pontina Plain. This is made of carbonate deposits underlying to volcanic or alluvial deposits which confine the basal limestone aquifer. Hydraulic connection between the two aquifers occurs at the base of the limestone massif, where several important overflow karst springs discharge a large quantity of water, and under the plain in places where the confining of the subsided limestone aquifer is locally interrupted contributing to the lateral recharge of the plain sediments (Fig. 1).

3 Data and Methods

In the aim of a territorial planning and preservation of the water resources, hydrologic analysis must let an objective comparison between available water resources and withdrawals and the human and natural demands for each portion of a territory according to the following equation:

$$\Delta S = I_{eff} + Underground\ Inflows - Withdrawals - Natural\ Outflows \tag{1}$$

Where ΔS is the variation of the groundwater volume stored and $Ieff$ is the effective infiltration that can be calculated as:

$$I_{eff} = \alpha P_{eff} (Direct\ Method) \tag{2}$$

$$I_{eff} = P_{eff} - R (Inverse\ Method) \tag{3}$$

Where $Peff$ is the Effective Precipitation (E.I.) the portion of rainfall not used by vegetation or evaporated, α a proportionality coefficient that varies based on the different methods, R Runoff that is the amount of water that runs on the ground not infiltrating in it.

For evaluating the terms of the hydrological balance for the study area a specific procedure has been developed. This procedure is based on a "distributed parameter" approach which considers: physical characteristics of the aquifers determining their effective recharge; anthropic effect on hydrology and hydrogeology due to withdrawals and watercourse diversions; variation of the catchments' boundaries (potential divide) during time, due to variation of the recharge or the withdrawal amount.

All collected data were analyzed, validated and spatially distributed on the study areas which are divided in homogenous territorial units (raster cells) of 250 m on each side. By means of GIS tools every point data has been interpolated and transformed in raster data in order to obtain a value in every cell of the considered areas (normalized in mm/y); the raster dataset has been thus used in the calculation to evaluate first the effective recharge and then the withdrawals in each cell. In this way the hydrological budget is always known cell by cell.

Temperature and rainfall data were collected from the Regional Hydrographic Survey, Land use information correspond to the Corine Land Cover (European Commission 1994) dataset, industrial, domestic and aqueducts' withdrawals available data were furnished by the Latium Region Authority database, physical characteristics of the areas derived from digital elevation model of the region and hydrogeological data were collected by field survey.

Collected data for the period 1997–2001 for the volcanic area and for the period 2005–2010 for the Lepini Mountains sector have been analyzed and presented as follow layer by layer.

3.1 Rainfall and Temperature

Climatic data spatial distribution was obtained using geostatistical methods (Fig. 2).
The algoritm used for the interpolation of these value is the *Kriging in FAI-k*.

3.2 W.D.T.U. (Water Demand Territorial Units)

The land use was analyzed as function of the water demand of the anthropic activities and the vegetation typology. The distinction of every class was determined considering the water use necessary to maintain the current usage condition in each territorial unit. The minimal dimensions of the map unit was defined considering every specific condition of high water demand. For example, anthropic areas were grouped in units as function of the water demand associated to the typology of each anthropic activity. For the portion of the studied areas with predominant vegetation cover (spontaneous or agricultural) the water demand was calculated by means of different crop coefficients (Kc) of each plant species; the water demand was evaluated as the water needs of the specific crop, with respect to the reference species (*Festuca arundinacea*). It was therefore possible to classify the urban texture, the farms, the different industrial plants, the bush zones, all types of crops and orchards etc.

WDTU map (Fig. 3) was realized by means of the analysis of aerial photos (1:10.000 scale) and field survey.

3.3 A.W.C. (Available Water Capacity of Soils)

This information is a fundamental parameter in the hydrogeological budget and water demand evaluation. As detailed soil data were still not available at that stage of the study, the AWC was evaluated by the following dataset:

The regional geological map (1:25.000 scale); The Slope data of the land surface (from the regional DEM); The previously presented WDTU map
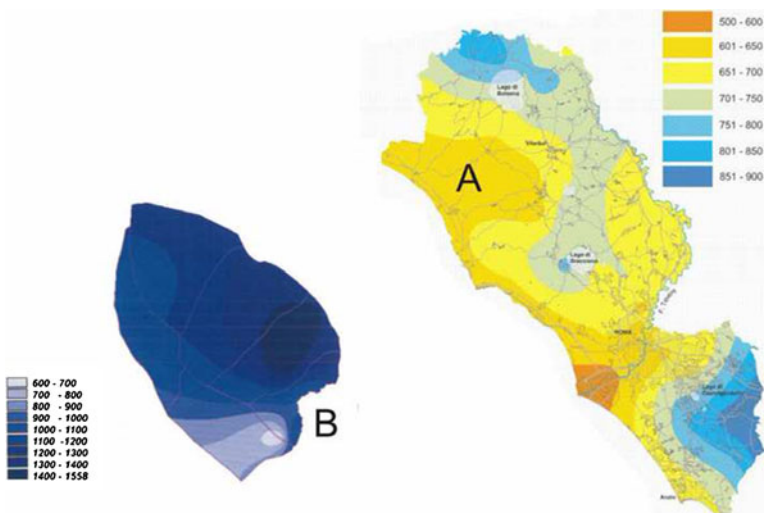
Fig. 2 Geostatistical evaluation of the rainfall on the two considered study areas (mm/y). **a** The volcanic sector (Capelli et al. 2005); **b** the Lepini Mountains and Pontina Plain sector (from VV. AA 2010)
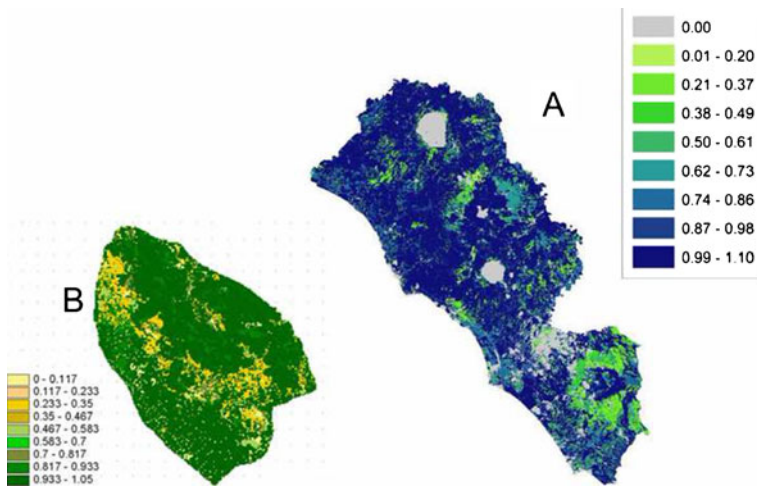
Fig. 3 Kc (crop coefficient) of the two considered study areas in different seasons (adimensional). **a** The volcanic sector (Capelli et al. 2005); **b** the Lepini Mountains and Pontina Plain sector (VV. AA 2010)

Several simplifications were applied to the calculation and they are:

- In the volcanic area the soils generally present a medium or medium-fine texture
- Medium-coarse texture soils are generally less prevalent
- The contribution of the soil below the roots to the AWC was considered negligible
- Depth and stoniness of the soil constitute a proportional limit to the AWC and are in relation with the bedrock typology, the slope of the land surface and the real depth of the roots.

All outcropping lithologies were classified in lithological complexes with group formations that can generate similar soil types. Then by the comparison of this data with the slope of the land surface the thickness of soils was estimated.

The available water capacity (AWC) of soils is obtained (Fig. 4) by the function:

$$AWC = H(1-P)120F \qquad (4)$$

Where :
H is the soil thickness (m)
P is the stoniness (%)
120 is the average reference AWC value for the considered soils (mm/m)
F is a correction factor for the soils deriving from volcanic units

3.4 Withdrawals Evaluation

Generally, the comparison between the water supplied from water services and the estimated water demand allows to detect areas where the "water deficit" makes groundwater withdrawals more probable. This is valid considering the assumption that the withdrawals amount in a certain area is function of the unsatisfied water demand to water services. The withdrawals can therefore be estimated in each territorial unit as the difference between the water needs and the supplied water.
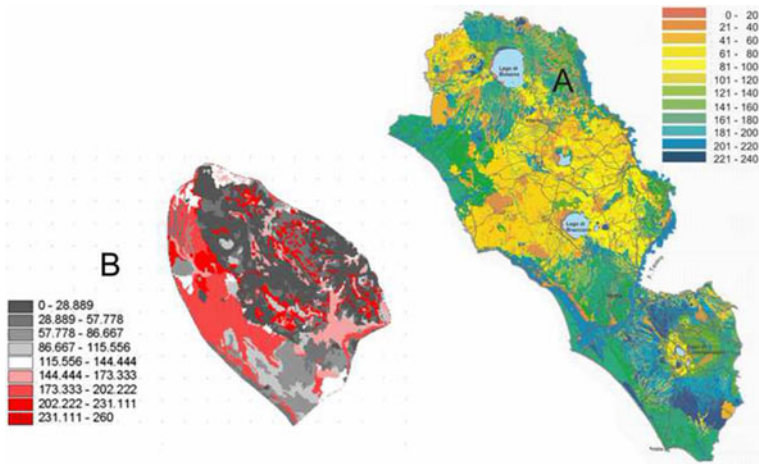
Fig. 4 Available Water Capacity of soils of the two considered study areas (mm/y). **a** The volcanic sector (Capelli et al. 2005); **b** the Lepini Mountains and Pontina Plain sector (VV. AA 2010)

Supplied water can be evaluated in each territorial unit by means of information given by water services and available data about the users. Three important steps are necessary in order to obtain this evaluation:

- Evaluation of the amount and distribution of the water demand
- Evaluation of the amount and distribution of the supplied water from water services and known withdrawals
- Evaluation of the amount and distribution of the unknown withdrawals which should exist to satisfy the local water needs

3.5 Evapotranspiration

Evapotranspiration is defined as the amount of water that passes from the lithosphere and biosphere to the atmosphere, by means of the two main processes that are: evaporation (passive loss of water by moist of rain plants or by wet or moist soil) and transpiration (active release by plants of water absorbed by their roots) (Fig. 5).

In the aforementioned Eq. (3) that defines effective infiltration, the term P_{eff} can be rewritten introducing Real Evapotranspiration ETR i.e.:

$$P_{eff} = P - ETR \qquad (5)$$

Similarly real Evapotranspiration equals the minor between crop Evapotranspiration (ETC.) that symbolizes the water demand from the cultivation during the period and the sum $P+U_i$ where the latter is the volume of water usable by plants (fraction of the AWC):

$$ETR = ETC \quad \text{if } P + U_i \geq ETC \qquad (6)$$

$$ETR = P + U_i \ \text{if } P + U_i \leq ETC \qquad (7)$$

ETC is calculated by introducing Crop Coefficients K_c from the Potential Evapotranspiration (ETP) that represents water that evaporates in a certain period of time from a vast area,
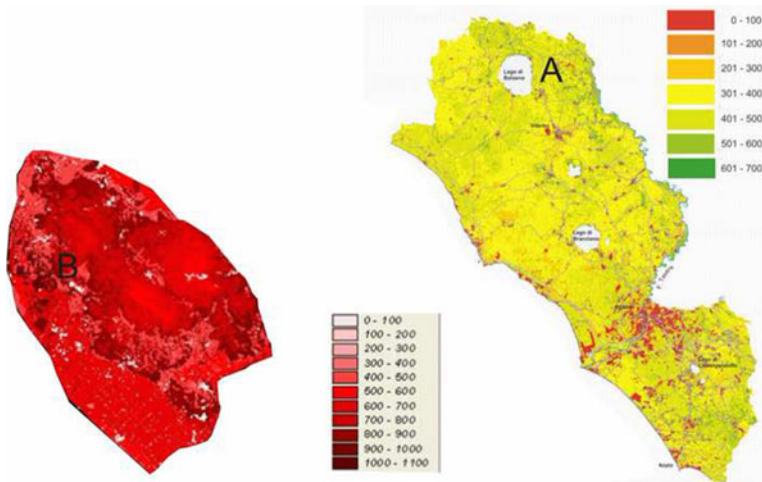
Fig. 5 Potential evapotranspiration of the two considered study areas (mm/y). **a** The volcanic sector (Capelli et al. 2005); **b** the Lepini Mountains and Pontina Plain sector (VV. AA 2010)

covered by a thick, low and homogenous vegetation in full growth, well supplied of water and that completely shades the ground:

$$ETC = K_c ETP \tag{8}$$

3.6 Potential Evapotranspiration Calculation Methods

ETP, according to the aforementioned definition, is a dummy parameter that gives the need of evapotranspiration of the environment freed from the single cultivation demands which depend only on:

- solar radiation by about the 80 %;
- wind (16 %);
- relative humidity (4 %).

Many are the methods to estimate both real and potential evapotranspiration, but no method can be applied to all cases.

Anyhow, all methods fall into three general categories:

- air temperature measurement methods;
- solar radiation measure or estimate based methods;
- combined methods.

As the registered data available in the study areas are only the minimum and maximal temperature the H-S method (Hargreaves and Samani 1985) was chosen. Considering that often global solar radiation data are not available, they suggested to estimate the R_g basing on the extraterrestrial solar radiation (i.e. the one that reaches an hypothetic surface outside the atmosphere) and the temperature range in the considered month (difference between maximum mean temperature and minimum mean temperature in the month).

$$ET_{THARG} = 0,0023 \frac{R_a}{\lambda} \sqrt{T_d(T + 17,8)} \tag{9}$$

Where:

T_d: monthly temperature range [°C]

R_a: extraterrestrial radiation received in a day [MJ m-2 d-1]

$$R_a = \left(\frac{24(60)}{\pi}\right) R_{sc} d_r [\omega_s \ \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos \omega_s] \tag{10}$$

ω_s: clock angle at sunset [rad]

$$\omega_s = \cos^{-1}(-\tan \varphi \tan \delta) \tag{11}$$

Once evapotranspiration has been calculated this way, its value is multiplied by the number of days passing since the beginning of the year and the middle day of the specified month (number of the day).

Then recalling that the cultivation evapotraspiration is given by:

$$ETC = K_c ETP \tag{12}$$

3.7 Infiltration and Runoff

In order to calculate the real evapotranspiration some considerations must be made on water stored in the soil St that equals:

$$St = Stl + P - ETC \tag{13}$$

where $St1$ equals the water stored the soil calculated in the month before or AWC if it is the first month of the calculation.

$$ETR = ETC \ \text{if} \ \text{St is positive or} \ = 0 \tag{14}$$

Otherwise if it is negative we force it to zero and consider as evapotranspiration all the rain of the current month:

$$ETR = Stl + P \tag{15}$$

If the water stored in the soil (St) ends up being lower or equal to AWC effective precipitation (P_{eff}) will be null, otherwise:

$$\begin{aligned} P_{eff} &= St - AWC \\ St &= AWC \end{aligned} \tag{16}$$

Runoff is the amount of water that runs on the soil surface, either as laminar flow on a vast area and as concentrated canalized flow.

The estimate of runoff is one of the most complex problems in hydrologic analysis.

The phenomenon shows a big variability, depending on intensity of precipitation, nature of the saturated layer of the soil, morphologic aspects of territory, substrates lithology, etc.

3.8 Kennessey Method For Runoff Evaluation

The method developed by Kennessey (Kennessey 1930), provided its relative ease of implementation and its widespread use, can be applied with some degree of reliability and confidence for the value of the results.

For a definite portion of territory the method calculated the yearly mean outflow coefficient. This coefficient derives from the sum of three components:

- Slope
- Permeability of emerging soils
- Green coverage

To each cell is given a value of the runoff coefficient (CK) according to the indications in Table 1.

To support the choice of a figure, besides the physical characteristics of the territory the "dryness index" must be considered (I_a):

$$I_a = \frac{\dfrac{P}{T + 10} + 12\dfrac{p}{t}}{2} \tag{17}$$

Where:
P: Yearly mean
T: Yearly mean temperature
p: Precipitation during the driest month
t: Temperature during the driest month

To assign to every cell of the discretization of the territory values of the components of the runoff coefficient the following cartographic data have been used:

- Hydrogeological complexes (permeability factor)
- UTI (green coverage factor)
- Slope Map obtained from the DEM (slope)

Table 1 Components of the Kennessey Index

Components of the Kennessey Index	Dryness index		
	<25	25–40	>40
Permeability			
Very low	0.21	0.26	0.30
Low	0.16	0.21	0.25
Medium	0.12	0.16	0.20
High	0.06	0.08	0.10
Very high	0.03	0.04	0.05
Slope			
>35 %	0.22	0.26	0.30
10 %–35 %	0.12	0.16	0.20
3.5 %–10 %	0.01	0.03	0.05
<3.5 %	0.00	0.01	0.03
Green coverage			
Absent (bare rock)	0.26	0.28	0.30
Pastures	0.17	0.21	0.25
Cutlivations-shrubs	0.07	0.11	0.15
High trunk woods	0.03	0.04	0.05

Runoff (R) is calculated on yearly base as sum of the monthly parts, by the relationship:

$$R_{(year)} = \Sigma \left(P_{(month)} - Evr_{(month)} \right) CK \qquad (18)$$

where:

$P_{(mese)}$: Monthly Precipitation
$E_{vr(mese)}$: Monthly Evapotraspiration
CK: Kennessey runoff coefficient

Must be noticed that the runoff coefficient (CK) has validity on yearly base, and for this reason in the water balance one considers the sum and not the single month. However the monthly runoff figures, turn out to be more significant in verifying the results obtained and the errors in the procedure (Fig. 6).

3.9 SCS-CN Method For Runoff Evaluation (USDA 1972)

The Soil Conservation Number (SCS) curve number (CN) Method has been published for the first time by the United States Department of Agricolture in 1956.

It's based on the Aquifers water balance Eq. (1) and on two fundamental hypothesis:

* The runoff/total rainfall ratio and the infiltration/volume of water stored in the aquifer ratio are equal.
* The infiltration before runoff begins is proportional to the volume of water stored in the aquifer, via a regional parameter (λ) dependant on geological and climatic factors.

The SCS-CN method assumes λ equal to 0.2 so for practical application:

$$R \quad = \quad \frac{\left(P_{eff} - 0,25 \right)^2}{P_{eff} + 0,85} \qquad (19)$$
$$\text{if} \quad P_{eff} > 0,2S \quad \text{otherwise} \quad R = 0$$

where:
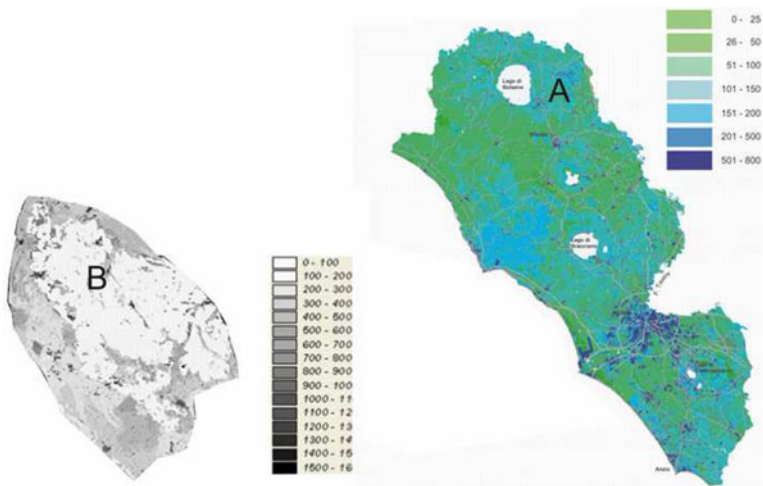
Fig. 6 Runoff of the two considered study areas (mm/y). **a** The volcanic sector (Capelli et al. 2005); **b** the Lepini Mountains and Pontina Plain sector (VV. AA 2010)

S: volume of water stored in the aquifer.

S can be parametrized to an adimensional factor (*CN*, curve number) (ranging from 0 to 100, in practice from 40 to 98) according to:

$$S = \frac{1000}{CN} - 10 \tag{20}$$

The factors that affect the CN are:

- Soil type
- Green cover type
- Soil Usage
- Hydrogeological Conditions
- Climate
- Initial Moisture

So the value of CN can be derived from specific tables (USDA 1972).

In most cases the curve numbers are developed using rainfall-runoff data at daily scale corresponding to the maximum yearly flows deriving from instrumented aquifers.

For aquifers in urban areas the CN should be calculated based on the percentage of impermeable surface of the urban aquifer.

It's then calculated the correction of the CN for slope. This is obtained by calculating the CN for the AWC first:

$$CN = 25400/(AWC + 254) \tag{21}$$

From this is calculated the *CNa*, slope-corrected *CN*, (Huang et al. 2006):

$$CN_a = CN \frac{(322, 79 + 15, 63*SLOPE)}{(SLOPE + 323, 52)} \tag{22}$$

where *SLOPE* is slope in percentage.

According to the value read in the coverage runoff is calculated the following way:

$$\text{Kennessey}: \quad R = CkP_{eff} \quad (COP > 0, \text{ fractured cover}) \tag{23}$$

$$\text{SCS-CN}: \quad R = \frac{P_{eff}^2}{(PE + S)} \quad (COP = 0, \text{ porous cover}) \tag{24}$$

$$\text{Urban}: \quad R = P_{eff} \quad (COP < 0, \text{ impermeable cover}) \tag{25}$$

If the effective precipitation (Fig. 7), or infilration (P_{eff}) is greater than than runoff (*R*) there is infiltration:

$$I = P_{eff} - R$$
$$\text{otherwise} \quad I = 0 \tag{26}$$

Water deficit (*DEF*) is calculated only on porous soils and where the cultivation evapotraspiration (*ETC.*) is greater than the sum of the stored in the month before (St1) plus precipitation during the current month (*P*) and equals:

$$DEF = Stl - ETC + P \tag{27}$$
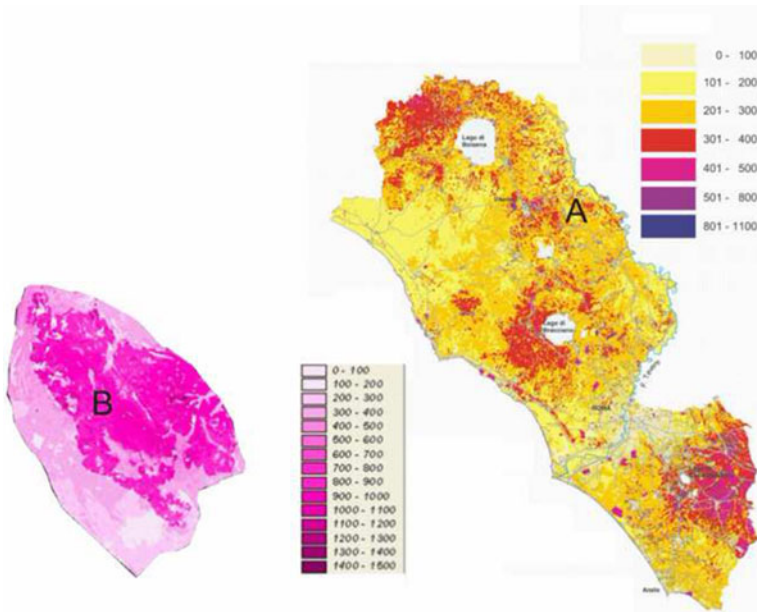
Fig. 7 Effective recharge of the two considered study areas (mm/y). **a** The volcanic sector (Capelli et al. 2005); **b** the Lepini Mountains and Pontina Plain sector (VV. AA 2010)

Otherwise is set to zero.

4 Results

Main results of this study are the distributed hydrological budgets obtained by the GIS overlay and calculation of the previous presented layers for the two study areas (Fig. 8) which are distinctly described as follow.

4.1 Volcanic Sector

The hydrogeological budget of the volcanic sector was calculated on an area about 6,515 km^2. In the Colli Albani volcano area were also considered the aquifers of the coastal terraced deposits, strictly hydraulically in relation with the deep groundwater circulation of the volcanic system.

The budget (Table 2) furnishes an interesting point of view of the water availability of a region where more than 3.600.000 inhabitants live, where several business activities, and relative 924.000 employees, are present, and where there are about 1,490 km^2 of water-demanding crops.

From the point of view of the water supply, excluding the City of Rome (more or less 3.000.000 of inhabitants) mainly supplied by important karst springs out of the volcanic domain, almost all the considered region, which is developing its urban character, day by day, can supply by itself the water needs by means of public and private groundwater withdrawals (wells).

Fig. 8 Flowchart of the DHB
process
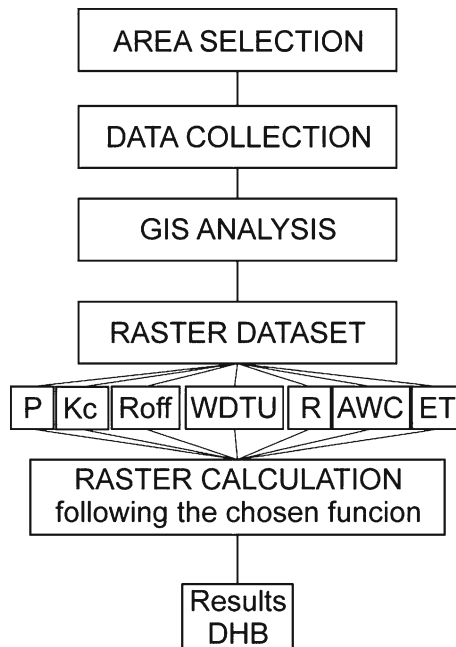
4.2 Lepini Mountains Group and Pontina Plain Sector

The distributed budget evaluated to the Lepini Mountains and the Pontina Plain aimed first to
verify the renewable groundwater resources and second to define the effective recharge areas
for each basal spring of the plain.

The renewable resource corresponds to the effective recharge. The global budget about the
Lepini's massif during the 5 years analyzed shows as average yearly rainfall is equal to
24.1 m^3/s. Evapotranspiration is evaluated equal to 8.6 m^3/s while effective recharge is equal
to 12.5 m^3/s. The ratio between rainfall and recharge is about 52 % as average. The average
yearly basal springs discharge in the Pontina Plain is equal to 10.4 m^3/s, so about 80 % of
recharge are yearly discharged from the springs (Table 3).

Table 2 Hydrogeological distributed balance of the volcanic sector

Area 6,515 km² - withdrawals/recharge 46.6 %	mm/y	l/s	Mm³/y	%P
Rainfall	704	145,370	4,775	100
Evapotranspiration	97	19,485	640	13.4
Runoff	365	73,046	2,400	50.2
Recharge	240	48,012	1,577	33.0
Measured baseflow	74	14,792	486	10.2
Agriculture Withdrawals	30	5,941	195	4.1
Industrial withdrawals	32	6,438	211	4.4
Water services withdrawals	50	10,018	329	6.9
Total withdrawals	112	22,397	736	15.4

5 Discussion and Conclusions

It is known that every hydrogeological budget is affected by heterogeneity in soil hydraulic properties, land use, landscape, topography and geological properties, and soil moisture profile and surface–subsurface interactions, but it has not been quantitatively assessed to what extent. This cannot be explicitly obtained without a small-scale distributed model that is capable of explicitly accounting for these characteristics (Grayson and Blöschl 2000).

In the volcanic sector the groundwater withdrawal exceeds the 45 % of total recharge, while in the Lepini mountains within the five considered years the ratio between withdrawals and recharge is about 20 %. Therefore the latter hydrogeological system seems to be less stressed than the volcanic sector where the budget imbalances cannot be attributed only to a few isolated cases but rather is a general phenomenon. Considering a recharge depletion, also connected to global warming (Di Matteo et al. 2010), and the increasing anthropic water demand, the reduction of spring discharge and stream baseflow is obviously expected in both considered areas.

The Distributed Hydrogeological Budget presented in this work demonstrated its applicability in different geological contexts and scales. It can be applied to management purposes to catchment scale in order to reach:

- The maintenance of springs discharge
- The maintenance of streams baseflow
- The correct distribution of withdrawals in order to guarantee the satisfaction of domestic, agricultural and industrial needs
- The protection of strategic groundwater resources

The distributed hydrogeological budget can moreover be used to locate critical areas of the studied region in which groundwater withdrawal restriction policies can be imposed by the government for a more sustainable use of resources (Mays 2013).

A fully distributed model predicts throughout the catchment (and not only at the outlet of the basin) a larger number of observable processes than traditional lumped models. However, it also requires a corresponding increase in input data and parameters (Rigon et al. 2006). In this sense it has been showed as Geographical Information System (GIS) based studies are efficient and successful tool for groundwater resources planning and management.

Table 3 Hydrogeological distributed balance of the Lepini Mountains and Pontina Plain

Area 598 km^2 - withdrawals/recharge 26.8 %	mm/y	l/s	Mm^3/y	%P
Rainfall	1,160	24,100	760	100
Evapotranspiration	415	8,600	271	35.8
Runoff	145	3,000	95	12.5
Recharge	600	12,500	394	51.7
Measured baseflow	554	10,400	331	47.8
Agriculture withdrawals	43	800	23	3.7
Industrial withdrawals	53	1,000	31	4.6
Water services withdrawals	65	1,200	39	5.6
Total withdrawals	161	3,000	93	13.9

In conclusion the main features of the distributed hydrological budget (DHB) model can be synthesized as follow:

- It allows to analyze the spatial and temporal variability of rain events and climatic conditions, on a monthly basis, and through a discretization of the area into cells of 250 m (for this study) on each side;
- It allows to consider the effects on runoff and evapotranspiration, due to morphology, lithology, soil, vegetation and land use;
- It allows to consider the withdrawal amount and distribution respect to the local effective recharge;
- It allows to quickly upgrade the dataset and to analyze the budget catchment by catchment.

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