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POTENTIAL RECHARGE ESTIMATION OF THE SIBARI PLAIN AQUIFERS (SOUTHERN ITALY) THROUGH A NEW GIS PROCEDURE

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ABSTRACT:
This paper suggests a method for the estimation of the potential aquifers recharge based on an innovative GIS procedure. The spatial arrangement of thermo-pluviometric parameters (rainfall and temperature) is performed starting from the data of thermo-pluviometric stations and the definition of the relative linear regression functions depending on altitude. The punctual altitude values, obtained through the DTM transformation in a point shapefile, are used to calculate rainfall and temperature starting from the linear regression functions. These calculated values are useful to estimate the real evapotranspiration and the effective rainfall. The coefficient of potential infiltration and its correction factor, depending on slope and soil use, are mapped through the elaboration of bibliographic data. All created maps are intersected in a single shapefile and the investigated area is subdivided in hexagonal cells. The centroids of these cells are obtained and for them are extracted all information previously elaborated. The values of effective infiltration and surface runoff are calculated for each centroid and the relative maps are obtained by points interpolation. The method is applied to estimate the potential recharge of the Sibari Plain aquifers (southernItaly) considering the whole potential recharge area. The estimated data has a good agreement with the climatic and geological knowledge.

Key-words: *Aquifer recharge; GIS; Thermo-pluviometric data; Hydrogeological parameters.*

1. INTRODUCTION

In the potential recharge area of the Sibari Plain aquifers, water balance has been calculated. In detail, all drainage basins present in recharge area (**Fig. 1**) are considered assuming the correspondence between watersheds and hydrogeological limits. The study area includes 27 drainage basins with a global area of 3466.6 km^2.

The Sibari Plain is located in the northeastern sector of the Calabria Region (southernItaly) in correspondence of the boundary between the Calabrian Arc and the Southern Apennine. This plain is characterized by two well-defined aquifers; the shallower one (from soil surface to -20/-30 m a.s.l.) is separated by clayey and silty-clayey layer from a deeper one (from -50/-60 m a.s.l.) (Polemio & Luise, 2007).

A new method inspired to the Inverse Hydrogeological Balance (Civita, 2005) are used trough the integration of a correction coefficient of the potential infiltration coefficient (c.i.p.) based on the *Progetto di Bacino del fiume Arno – Stralcio Bilancio Idrico* (AdBArno, 2008). Inverse Hydrogeological Balance method is an indirect method and consists of a numerical model with parameters arranged with a GIS software. This method allows to obtain an estimation of the infiltration rate starting from climate (rain and temperature), topographic (altitude and slope) and hydrogeological (soil permeability) data. The investigated area must be divided in square cells to which are assigned all the

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parameters necessary for the water balance estimation. Furthermore, a new GIS procedure for the rainfall and temperature distribution has been created.

2. STUDY AREA

The investigated area is located in the northern Calabrian Arc. The latter represents a fault-bounded continental fragment within the western Mediterranean orogen, located at the intersection of the E–W trending Sicilian Maghrebides on the South and NW–SE trending Southern Apennines on the North (Bonardi et al., 2004).

Toward southeast, the area is made by metamorphic, intrusive rocks and their mesozoic sedimentary cover (Sila Units) overlaid by a Cenozoic stratigraphic sequence (Messina et al., 1994; Barone et al., 2008)

Westward, this massif is bounded by the CratyValley which represents a N-S oriented graben delimited toward west by the CoastalRange. The latter is an elongate N-S mountain chain mainly made by metamorphic rocks.

The northwestern sector of the study area is occupied by the Pollino Massif, a mountain chain mainly built by carbonate rocks with local association of “flyschioid” terranes. The latter are overlaid by a sedimentary Plio-Pleistocene succession (Caruso et al., 2013). The northwestern sector is instead occupied by the Sibari Plain which represents a complex Holocene fault-bounded coastal plain characterized by strong subsidence in historical (Ferranti et al., 2011) and present (Cianflone et al., 2015 in press) time.

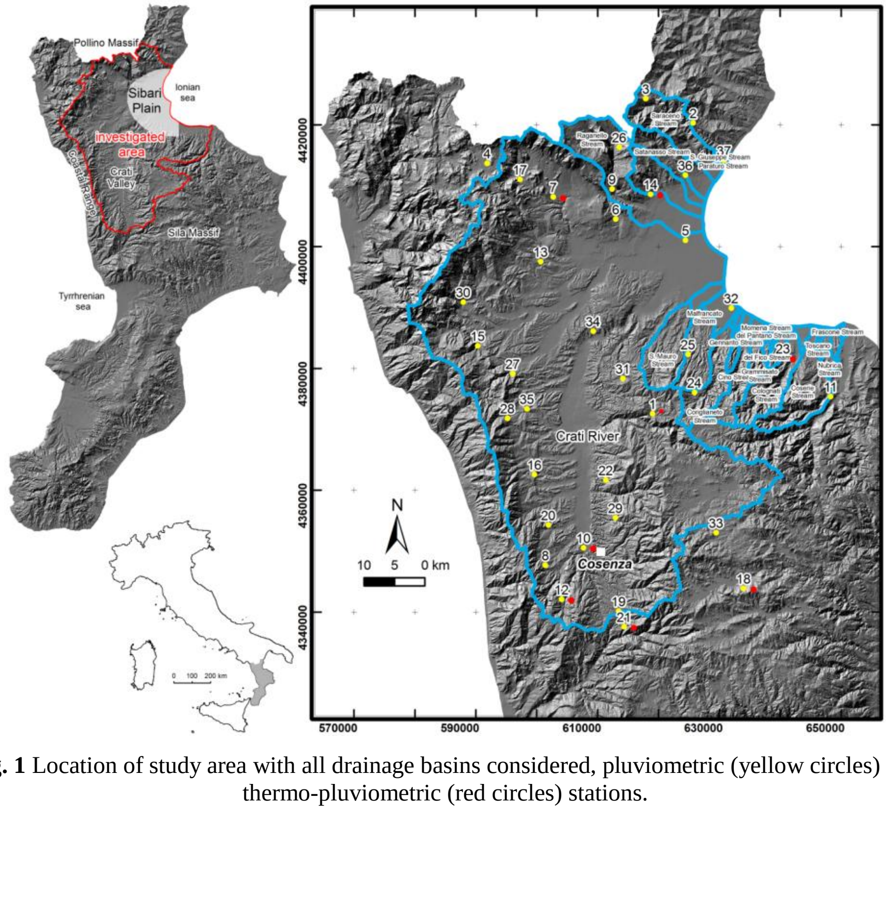

Fig. 1 Location of study area with all drainage basins considered, pluviometric (yellow circles) and thermo-pluviometric (red circles) stations.

3. METHOD DESCRIPTION

In this work a new method is proposed for the potential recharge estimation based on climatic, topographic, geological and hydrogeological data, elaborated with an innovative GIS procedure.

3.1 Stage 1- Thermo-pluviometric parameters estimation

In the first stage, the meteo-climatic parameters (rain and temperature) of the investigated area are estimated.

The Average Pluviometric Modulus are estimated starting from the thermo-pluviometric data of Regional database (ARPACAL) relative to a period of thirty years (1970-2000). In detail 29 pluviometric and 8 thermo-pluviometric stations are analyzed (**Fig. 1**, **Table 1**).

Table 1. List of the pluviometric and thermo-pluviometric stations used (for their location see Fig. 1).

n.	station	n.	station	n.	station	n.	station
1	Acri	11	Cropalati	21	Rogliano	31	S.Sofia d'Epiro
2	Albidona	12	Domanico	22	Rose	32	Schiavonea
3	Alessandria del Carretto	13	Firmo	23	Rossano	33	Sculca
4	Campotenese	14	Francavilla Marittima	24	S.Giacomo d'Acri	34	Tarsia
5	Caselle	15	Malvito	25	S.Giorgio Alb.	35	Torano
6	Cassano all'Ionio	16	Montalto Uffugo	26	S.Lorenzo Bellizzi	36	Trebisacce
7	Castrovillari	17	Morano calabro	27	S.Marco Argent.	37	Villapiana
8	Cerisano	18	Nocelle	28	S.Marino di Finita		
9	Civita	19	Piane Crati	29	S.Pietro in Guarano		
10	Cosenza	20	Rende	30	S.Sosti		

The study area was divided in 5 sectors depending on their homogeneous morphology and climate. This subdivision is necessary because the orography of the area is complex and influences the rain distribution.

In each sectors, using the data of the relative pluviometric stations, rainfalls are determined by a linear regression as function of altitude R=f(q).

- sector 1, northern Ionian side: 0.3427808341 * q + 538.9498608 R^2=0.80
- sector 2, southern Ionian side: 0.7342542095 * q + 563.9783327 R^2=0.80
- sector 3, Pollino massif: 0.98877983079 * q + 396.9676075 R^2=0.83
- sector 4, Sila massif: 0.2865014086 * q + 824.0390339 R^2=0.70
- sector 5, CoastalRange : 1.131366381 * q + 905.7756799 R^2=0.56

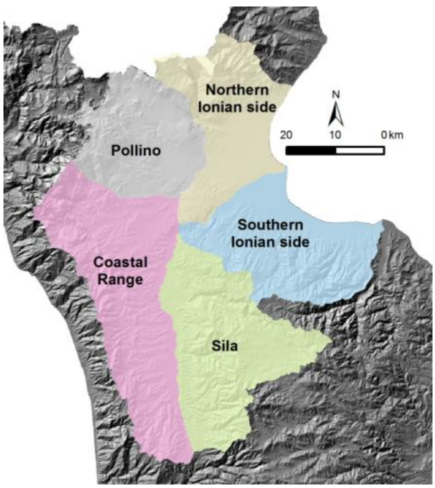

Fig. 2 Climatic sectors present in the investigated area.

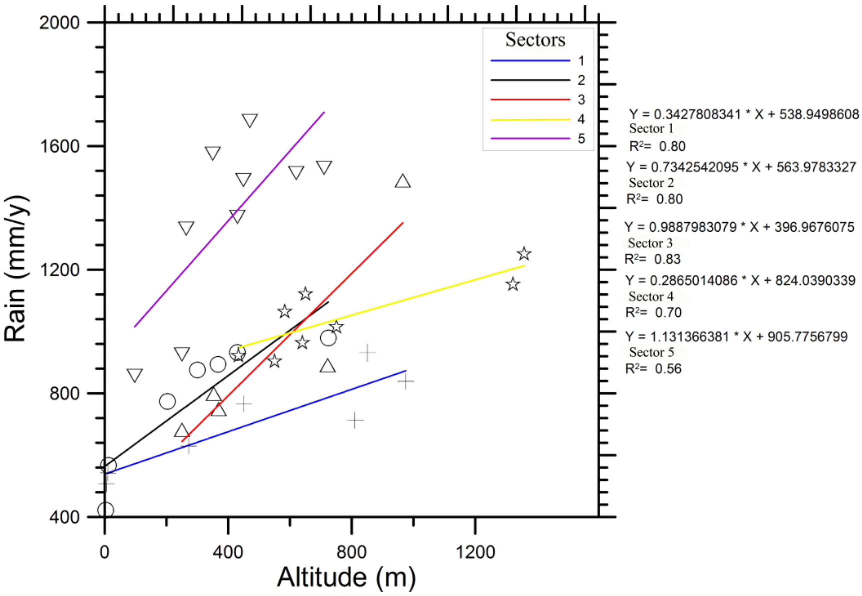

Fig. 3. Functions of linear regression of the 5 sectors.

The distribution of the Average Annual Pluviometric Modulus are determined by the previous described functions and altitude data. The raster format of a DTM 20X20m (GN) was resampled with a 50X50m cell and converted from raster to a point shapefile (one point for each cell) with associated altitude data. The altitude value of each point was used in the function R=f(q) (according to the relative sector) to obtain the average annual pluviometric modulus.

The analysis of the 8 thermo-pluviometric available stations allows to investigate the temperature spatial variations in the study area. In detail, we analyzed the correct temperature (Tc) depending on the rainfall. The choice of the Tc depends on the application of the simplified Turc formula (Turc, 1954) in the evapotranspiration calculation.

Tc was calculated for each thermo-pluviometric station by the formula:

$$Tc = \sum_{i=0}^{n} R_i T_i / R$$

R_i and T_i represent respectively the average monthly rainfall (mm/yr) and temperature (°C) of the *i*-th month. *R* is the average annual rainfall (mm/yr) from 1970 to 2000.

Later, the linear regression function Tc=f(q) was defined for the whole study area and not for single sector because Tc values are corrected depending on the rainfall values.

The defined function is Tc= -0.00678224841*q +14.44436976 with R^2=0.89 which testifies the good correlation between temperature and altitude.

Using the function Tc=f(q), the Tc was calculated for all points obtained by the resampled DTM.

Known the average annual pluviometric modulus (P) and the correct temperature the Real Evotranspiration (RET) was calculated by means of the simplified Turc formula:

$$RET = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}}$$

L represents the atmospheric power of evaporation and was calculated with the formula $L=300+25Tc+0.05Tc^3$.

The values of the average annual pluviometric modulus (P) and the Real Evotranspiration (RET), obtained for all points derived from the transformation of the resampled DTM, allow to calculate the Effective Rainfall (Reff) for each point:

$$Reff = P - RET$$

The map of Reff(**Fig. 5**) was generated by the interpolation of all its punctual values.

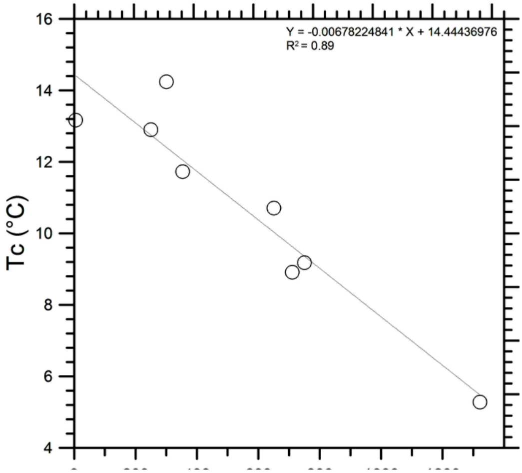

Fig. 4. Linear regression line Tc-altitude.

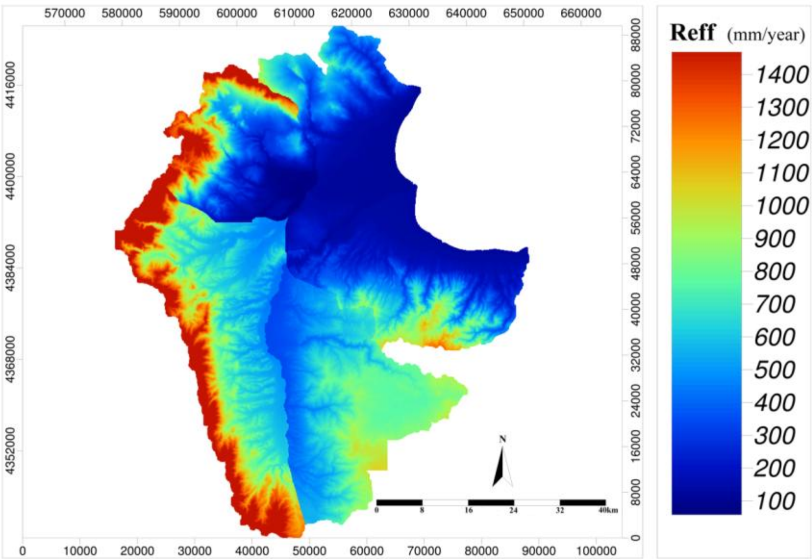

Fig. 5 Map of the effective rainfall.

3.2 Stage 2 –Computation of the potential infiltration coefficientandcorrection factorarrangement

During the second stage, the spatial variability of the potential infiltration coefficient (c.i.p.g) was investigated. Furthermore, a correction factor (*c.i.p.ss*) based on slope and soil use was calculated and mapped.

The*c.i.p.g* values are strictly connected with the outcropping lithology. A simplified lithological map was created to estimate *c.i.p.g* values. In detail, we used the Official Geological Map of Calabria (Casmez, 1967-1969) and defined different lithological complexes based on genesis and compositional features of the mapped rocks.An average *c.i.p.g* value was assigned to each complex using the range values proposed by Celico (1988) (**Table 2**).

Table 2. Potential infiltration coefficient (c.i.p.ss. values) proposed by Celico(1988).

Lithological complex	c.i.p.g %	Lithological complex	c.i.p.g %
Limestone	90-100	Lava	90-100
Dolomitic limestone	70-90	Pyroclastic deposits	50-70
Dolostone	50-70	Pyroclastite and lava	70-90
Marly limestone	30-50	Intrusive rocks	15-35
Coarse detritus	80-90	Metamorphic rocks	5-20
Alluvial deposits	80-100	Sands	80-90
Clayey-marly-sandy deposits	5-25	Clayey sands	30-50

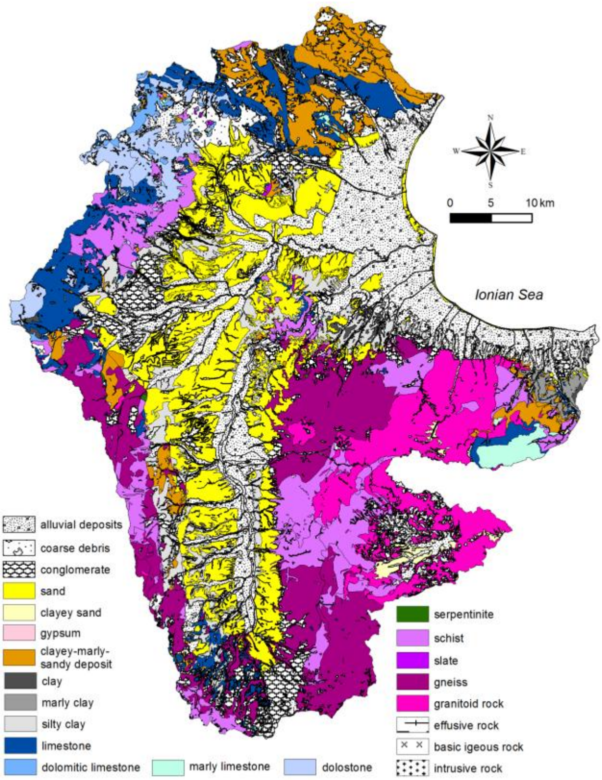

Fig. 6 Simplified lithological map obtained by the elaboration of Casmez (1967-1969).

The estimation of the *c.i.p.*$_{ss}$ was based on the matrix developed in the *Bacino del fiume Arno – Stralcio Bilancio Idrico* (AdBArno, 2008).

The slope map was obtained starting from a 20X20m DTM (GN) and later reclassified in four classes (**Fig.7a**) depending on the influence of slope on the infiltration (AdBArno, 2008).

Soil use analysis of the investigated area was based on the maps of the CORINE Land Cover 2000 (ISPRA, 2006). In detail we used the third level of these maps which includes 31 soil use classes; the classes were reclassified in the four categories (**Table 3**) suggested by AdBArno (2008): urbanized areas and uncovered rocks, grazing land, cultivated and wood land and forest.

Table 3. Reclassification of CORINE Land Cover2000-level 3 proposed by AdBArno (2008).

CORINE Land Cover, level 3	Reclassification (AdBArno, 2008)
Sparse vegetation areas	urbanized areas and uncovered rocks
Quarries and mines	
Industrial and commercial areas	
Harbours	
Ponds	
Building sites	
Dumps	
Inland swamps	
Highways and railways	
Uncovered rocks, cliffs, outrops	
Continuous urban fabric	
Discontinuous urban fabric	
Natural grazings and high altitude pastures	grazing land
Fired areas	
Sport and recreational areas	
Stable grasslands	
Woodlands and shrublands in evolution	cultivated and wood land
Agricultural land with natural areas	
Annual cultivations associated with permanent cultivations	
Orchads	
Rice fields	
Arable lands in irrigation areas	
Arable lands in non-irrigation areas	
Permanent cultivation systems	
Beaches, dunes, sands	
Olive tree groves	
Vineyards	
Sclerophyllous vegetation areas	forest
Conifer woods	
Broad-leaved woods	
Mixedwoods	

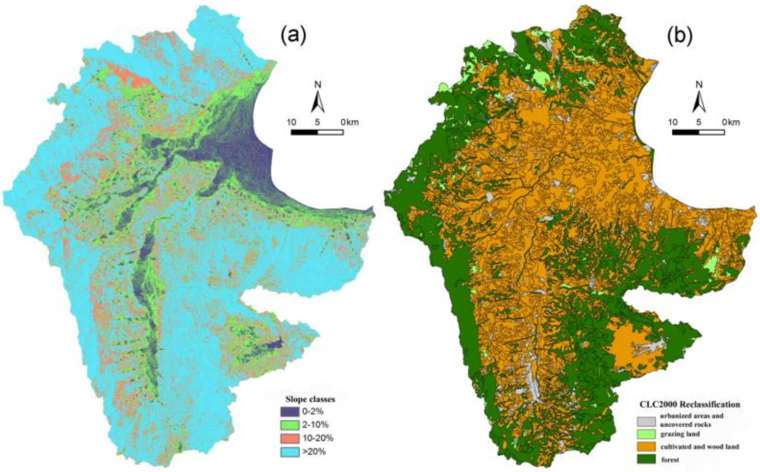

Fig. 7 (**a**) Slope classes map and (**b**) reclassification map of CORINE Land Cover 2000-level 3.

The slope and simplified soil use maps was "intersected" to obtain a single shapefile containing both information. These data combination allowed to assign the $c.i.p._{ss}$ values.

Table 4. Matrix depending on slope and soil us proposed by AdB Arno (2008) to assign c.i.p.ss values.

		Soil use			
		10	20	30	40
slope	0-2%	B	A	E	E
	2-10%	B	M	A	E
	10-20%	B	M	M	A
	>20%	B	B	M	A

class	*c.i.p.ss*
B	50
M	65
A	85
E	100

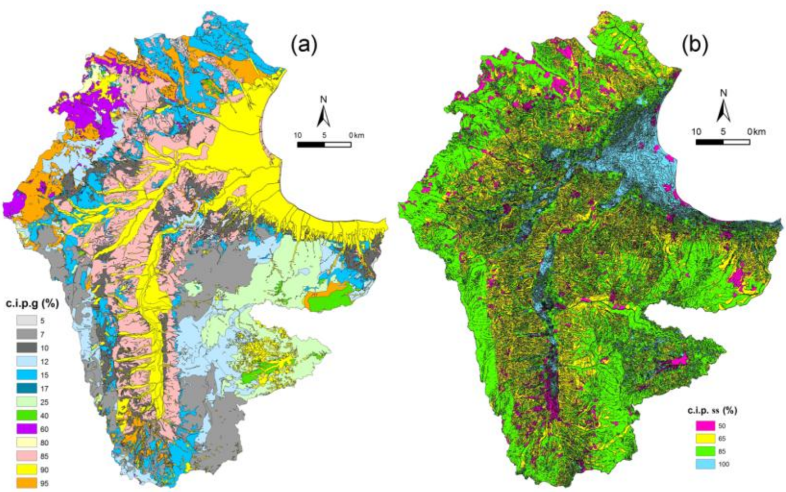

Fig. 8 (**a**) Map of c.i.p.g. based on geological simplified map (**Fig.6**). (**b**) Map of c.i.p.ss created starting from slope (**Fig.7a**) and soil use (**Fig.7b**) maps.

3.3 Stage 3 – Effective infiltration estimation

The effective infiltration (*I*) was calculated based on effective rainfall (Reff) values, *c.i.p.*g and *c.i.p.ss*, using the formula:

$$I = Reff \times c.i.p.g \times c.i.p.ss$$

The study area was divided in hexagonal cell with a diameter of 200 m and the Reff, $c.i.p._g$ and $c.i.p._{ss}$ were "intersected" to produce a single shapefile. The geometrical centroid of each cell was extracted obtaining a point shapefile. Reff, $c.i.p._g$ and $c.i.p._{ss}$ values, now present in a single shapefile, are extracted for each point. Using the previous formula, the I values of all points were calculated.

The interpolation of punctual I values allowed to obtain the effective infiltration map (**Fig.9a**). Later, the surface runoff (R) was calculated and mapped using the formula:

$$R = Reff - 1$$

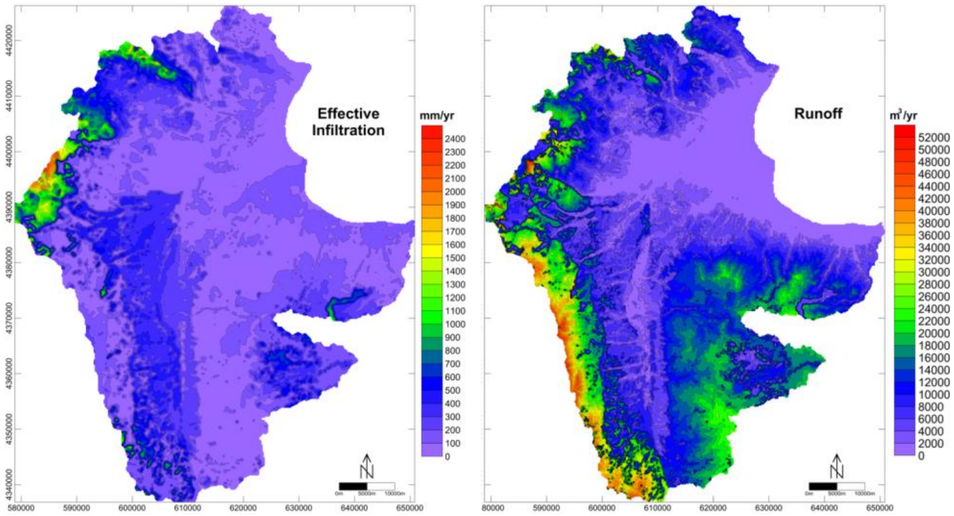

Fig. 9 (**a**) Effective infltration map. (**b**)Surface runoff map.

4. DISCUSSION

The analysis of the potential recharge of the Sibari Plain aquifers allowed to identify the main recharge areas and to estimate the effective infiltration rate.

The direct recharge, due to the effective infiltration close to the Sibari Plain area, is poor (I≤ 200 mm/yr). The main aquifers recharge is due to the outflows coming from others aquifers present in the recharge area. In detail, the main recharge happens in the northwestern sector of the study area characterized by the limestones of the Pollino Massif and the "flyschioid" terranes of the Saraceno and Albidona Formation (Selli, 1962).The highest infiltration values (>2000 mm/yr) are recorded in the westernmost sector, where the high limestones permeability is combined with the high rainfall rate due to the presence of

Coastal Range. The latter represents a NNW-SSE oriented mountain chain which acts as a barrier for the winds coming from East producing high rainfall rate.

In the middle and southern sectors of the Coastal Range, lower I values (I ≤ 500 mm/yr, with isolated peak up to 1000 mm/yr) are observed. In these areas, despite high rainfall rate, the effective infiltration is not helped by the low permeability of the prevailing metamorphic rocks, the high slopes and the diffuse presence of forests.

In the Sila Massif area, the low I values (I ≤ 500 mm/yr) is due to a different meteo-climatic regime and the presence of low permeable granitoid and metamorphic rocks. High I value (1000/1100 mm/yr) are observed in the eastern side of the Sila Massif, where the carbonatic rocks of the Longobucco Group (Santantonio & Teale, 1987) are present.

In the high and middle Crati Valley average I value of 700 mm/yr are estimated and can be correlated with the high permeability of the alluvial deposits which fill the valley.

The spatial distribution of the effective infiltration, obtained with our innovative procedure, shows a good correlation with the meteo-climatic features of the Calabria Region and the lithological pattern of the investigated area.

5. CONCLUSION

The method proposed in this paper is based on easily available data (geological, metereological, land use) and introduces an innovative GIS procedure to elaborate them. This procedure, relatively simple to apply, allows to create and elaborate large datasets.

Considering the reliability of the proposed method in the investigated area, we consider it very useful in the potential recharge estimation of the aquifers.

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