Introduction

In a present report procedures, data and results for vulnerability map elaboration are presented. Procedures are based on SINTACS methodology that takes 7 into account parameters. Estimation of these parameters in the study area – Lessini Montains is described in following pages.

Effective infiltration action (I)

Meteorological data

All meteorological data originate from ARPAV Centro Meteorologico di Teolo.

For the purposes of the study, data from 13 meteorological stations in the study area (fig. 1) were used. The meteorological stations have the time series of monthly data for the period from January 1992 to December 2005. For the elaboration, monthly values of precipitation and temperature were used. For the precipitation monthly sum and for temperature average monthly values were used.

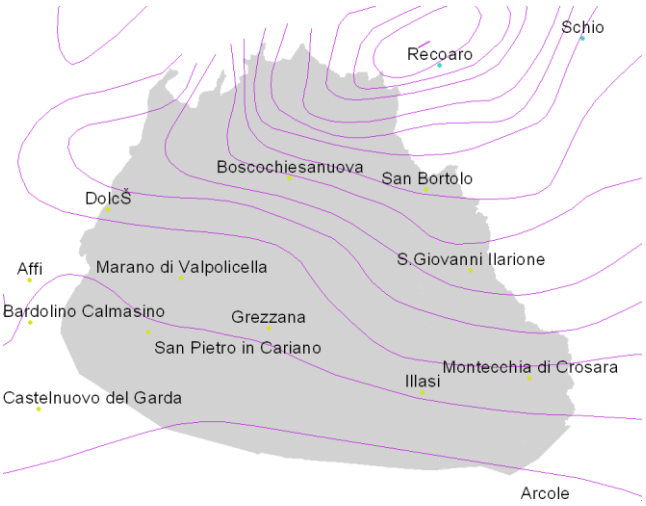

Figure 1: Meteorological stations in study area.

Some of the meteorological stations did not have the complete record for the used period. The missing data (Table 1) were processed in the following way: Time series of m. stations were compared and the correlations among the time series were defined. The missing data were calculated with the equation that defines the linear relationship between the two time series with the highest correlation (Table 2).

Table 1: Missing meteorological data.

P	**Boscochiesanuova**	jan.92 - avg.99
T	**Boscochiesanuova**	jan.92 - avg.99
P	**Grezzana**	jan.92
T	**Grezzana**	jan.92
P	**Marano di Valpolicella**	jan. - apr. 92
T	**Marano di Valpolicella**	jan., feb., apr. 92
P	**S.Giovanni Ilarione**	jan. 92, sep. 97 - feb. 98
T	**S.Giovanni Ilarione**	jan. 92, sep. 97 - feb. 98
T	**Crespadoro**	jan. 92 - oct. 92
P	**Crespadoro**	jan. 92 - oct. 92

Table 2: Correlation of precipitation time series

	Bardolino Calmasino	Bosco chiesanuova	Castelnuovo del Garda	Dolcè	Grezzana	Illasi	Marano di Valpolicella	Montecchia di Crosara	S.Giovanni Ilarione	San Bortolo	S. Pietro in Cariano	Crespa doro	Affi
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	0.84	0.92	0.87	0.87	0.81	0.86	0.77	0.82	0.81	0.90	0.81	0.95
2	0.84	1.00	0.82	0.87	0.85	0.77	0.88	0.68	0.82	0.82	0.86	0.80	
3	0.92	0.82	1.00	0.83	0.81	0.82	0.84	0.77	0.81	0.78	0.88	0.77	0.88
4	0.87	0.87	0.83	1.00	0.85	0.79	0.87	0.78	0.84	0.82	0.86	0.82	0.89
5	0.87	0.85	0.81	0.85	1.00	0.88	0.90	0.82	0.80	0.75	0.91	0.78	0.86
6	0.81	0.77	0.82	0.79	0.88	1.00	0.81	0.91	0.82	0.75	0.87	0.76	0.85
7	0.86	0.88	0.84	0.87	0.90	0.81	1.00	0.78	0.83	0.80	0.91	0.80	0.85
8	0.77	0.68	0.77	0.78	0.82	0.91	0.78	1.00	0.85	0.78	0.82	0.80	0.80
9	0.82	0.82	0.81	0.84	0.80	0.82	0.83	0.85	1.00	0.90	0.84	0.92	0.84
10	0.81	0.82	0.78	0.82	0.75	0.75	0.80	0.78	0.90	1.00	0.80	0.92	0.84
11	0.90	0.86	0.88	0.86	0.91	0.87	0.91	0.82	0.84	0.80	1.00	0.80	0.90
12	0.81	0.80	0.77	0.82	0.78	0.76	0.80	0.80	0.92	0.92	0.80	1.00	0.81
13	0.95		0.88	0.89	0.86	0.85	0.85	0.80	0.84	0.84	0.90	0.81	1.00

Precipitation

Boscochiesanuova = 1.1838 * Dolcè
Grezzana = 1.0223 * San Pietro in Cariano
Marano di Valpolicella = 1.077 * San Pietro in Cariano
S.Giovanni Ilarione = 0.8186 * San Bortolo
Crespadoro = 1.0155 * San Bortolo

Temperature

Boscochiesanuova = 0.9295 * San Bortolo + 0.1791
Grezzana = 0.9855 * San Pietro in Cariano + 0.1284
Marano di Valpolicella = 0.9514 * San Pietro in Cariano + 0.521
S.Giovanni Ilarione = 0.9498 * Bardolino Calmasino – 0.9876
Crespadoro = 0.9379 * Dolcè – 1.7174

Average yearly values of temperature and precipitation (P) were used in the study.

In order to use Turc's (1954) formula for evapotranspiration (Er) calculation, corrected temperature (Tc) that is function of average monthly precipitation (Pi) and temperature (Ti) was estimated with the expression:

$$Tc = \frac{\sum \bar{P}i\bar{T}}{\sum \bar{P}i}$$

Table 3: Meteorological stations used for spatial distribution of meteorological data.

Meteorological station	x	y	type	z(m)	Tc (^{o}C)	P (mm/year)
Bardolino Calmasino	1637929	5042074	Agrometeo	165	14.60	843.0143
Boscochiesanuova	1658971	5053801	Meteo	1050	10.30	1201.479
Castelnuovo del Garda	1638607	5035006	Agrometeo	120	13.87	839.9714
DolcŐ	1644210	5051242	Agrometeo	105	14.40	1019.043
Grezzana	1657307	5041581	Agrometeo	156	14.66	871.389
Illasi	1669803	5036390	Agrometeo	146	14.47	914.8286
Marano di Valpolicella	1650168	5045646	Agrometeo	296	14.34	918.3699
Montecchia di Crosara	1678503	5037502	Agrometeo	50	13.99	1000.943
S.Giovanni Ilarione	1673701	5046287	Meteo	320	12.30	1227.51
San Bortolo	1670129	5052884	Meteo	936	10.02	1400.629
San Pietro in Cariano	1647514	5041286	Agrometeo	130	14.37	825.8143

For the spatial distribution of the precipitation and corrected temperature the relationship between average yearly precipitation (1992 – 2005) and altitude in eleven meteorological stations was used (Table 3). The same approach was used for spatial distribution of corrected temperature. In the figures 2 and 3 are showed defined relationships.

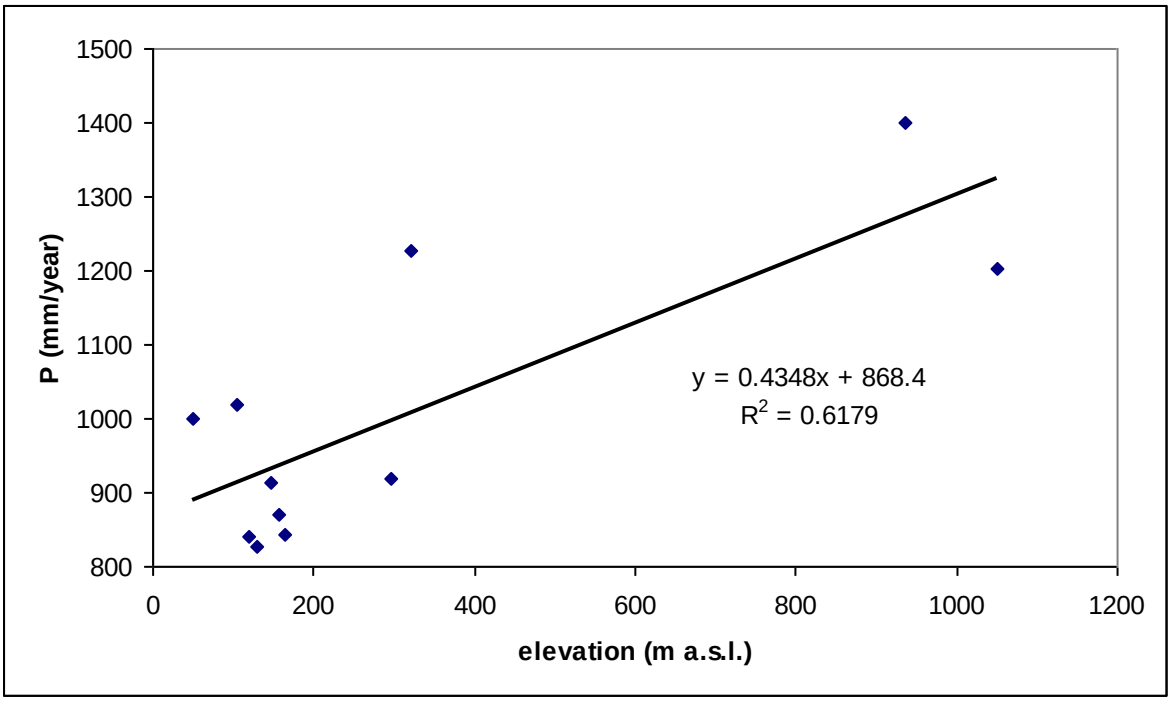

Figure 1: Relationship for spatial distribution of precipitation.

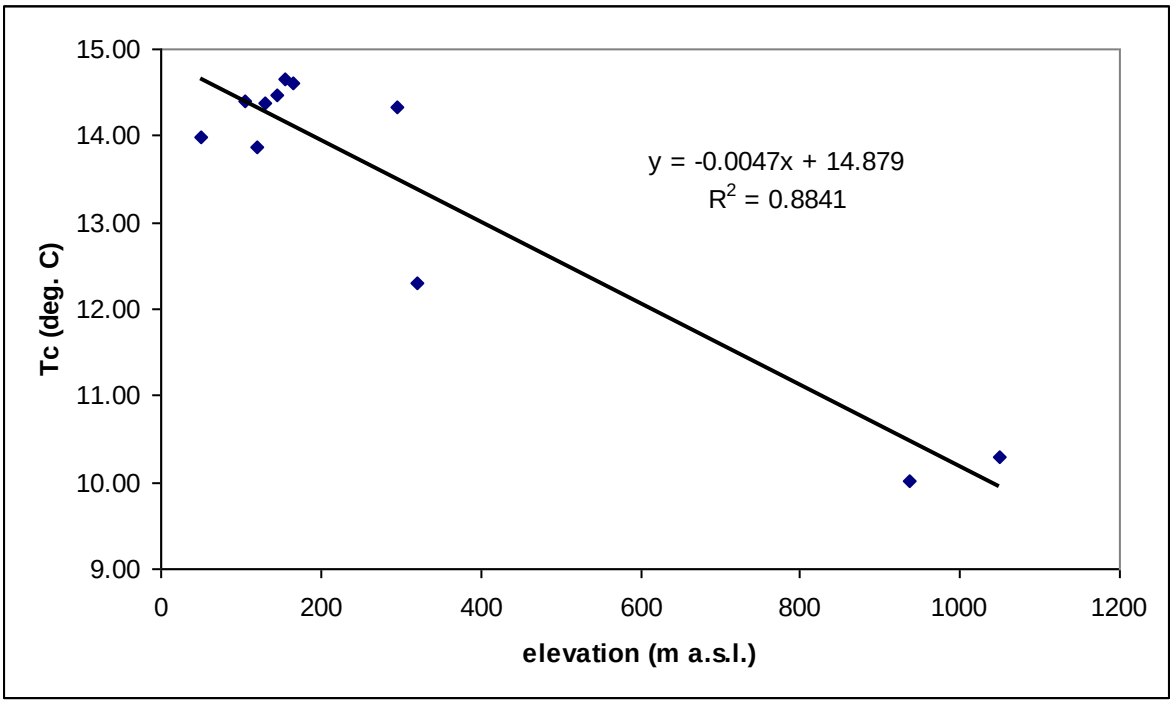

Figure 2: Relationship for spatial distribution of corrected temperature.

For the further calculation of evapotranspiration and effective precipitation (Q) the spatially distributed values of average yearly precipitation and corrected temperature presented in raster information layers were used.

The average yearly evapotranspiration was calculated in the following way:

$$Er = \frac{\bar{P}}{\sqrt{0.9 + \left(\frac{\bar{P}^2}{L^2}\right)}}$$

$$L = 300 + 25T + 0.05T^3$$

$$\bar{Q} = \bar{P} - \bar{Er}$$

Effective infiltration was calculated as Q*infiltration index (Table 4).

Soil/overburden attenuation capacity

SINTACS ratings for parameter soil/overburden attenuation capacity were defined on the basis of pedological map of Lessini area. The map is polygon information layer, consisting of 157 polygons. The ratings are based on texture data and range from 1 to 8.5 (figure 4).

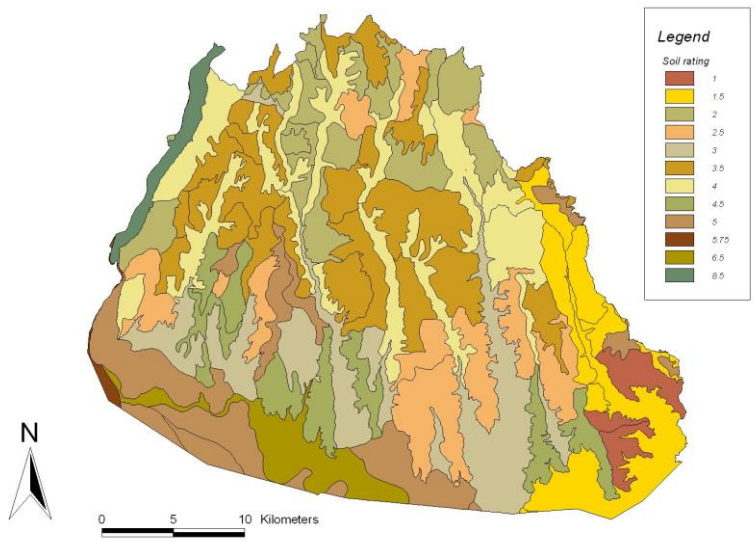

Figure 4: Pedological map with SINTACS ratings

Depth to ground water

Depth to ground water is difference between topographic surface and groundwater table. Topographic surface was described by digital elevation model (DTM) with resolution 5 m.

For the purposes of map elaboration, resolution of DTM was changed to 25 m that is the same resolution as other information layers of parameters have. 25 m DTM in averaged 5 m DTM.

Groundwater level was defined on the basis of measured data in 146 wells. Additionally elevations of permanent springs in area of principal dolomite (defined on lithological map) were used. 54 springs fulfilled mentioned criteria. It was assumed that in the places where those springs occur, groundwater table reaches the surface.

Interpolation of these 200 point data was done with inverse distance weighting (IDW) method. Due to the non-unique distribution of data, in some parts with lack of data, interpolated groundwater table was above the ground surface. Mostly this was the case in valleys and depressions with steep slopes. In described cases with negative values of groundwater depth was assumed that the groundwater table is close to the surface (less then 2.5 m) which gives the highest Sintacs rating. In the rest of the area depth to groundwater was classified according to the recommended SINTACS rating.

Unsaturated zone attenuation capacity

Unsaturated zone was defined on the basis of geological map and lithological well logs which were used for three-dimensional interpretation of geological layers. Thickness of geological layers calcareo_marnosa, marnoso-argillosa and scaglia was estimated from geological map and topograpy of the ground surface. Along the borders between the geological layers points with topography elevation were extracted. These points were used for interpolation of 2 dimensional layers – borders between geological layers. In the next step thickness of geological layers was calculated and limited to the polygon area of each geological unit.

Table 4: Defined values of infiltration index and unsaturated zone attenuation capacity ratings

Geological units	***Infiltration index***	***non_saturo***
calcarea	0.7	9
calcareo_dolomitica	0.8	10
calcareo_marnosa	0.5	7
depositi_alluvionali_limo-argillosi	0.1	4
depositi_colluviali_e_glaciali	0.2	4
depositi_detritici_e_alluvionali	0.5	7
depositi_eluviali_e_colluviali	0.1	3
marnosa	0.1	4
marnoso-argillosa	0.1	2
scaglia	0.5	7
vulcanica	0.1	3

In the area of calcarea the thicknes of calcareo_numulitico and scaglia layers is based on well logs data. In areas where more than one geological layer exist, sintacs ratigs for each geological unit were weigted with its thickness.

Hydrogeologic characteristics of the aquifer and hydraulic conductivity range of the aquifer

Because vulnerability assessment was made for lowest aquifer, it was assumed that only two geological units are relevant for estimation of aquifer properties. For estimation of parameters hydrogeologic characteristics of the aquifer (A) and hydraulic conductivity range of the aquifer (C) area was divided in two parts, area of:

- principle dolomite (A=8, C=7),
- vulcanic rocks (A=4, C=3).

Hydrologic role of the topographic slope

The topographic slope was derived from digital elevation model with the grid size of 25 m. Sintacs ratings were assigned to the slope intervals according to the recommended classification.

Weight strings

In the study area two weight strings were used:

- area of principle dolomite – weight strings for karst area;
- area of vulcanic rocks– weight strings for fisured area

Vulnerability map

Result of described procedures is vulnerability map presented in figure 5.

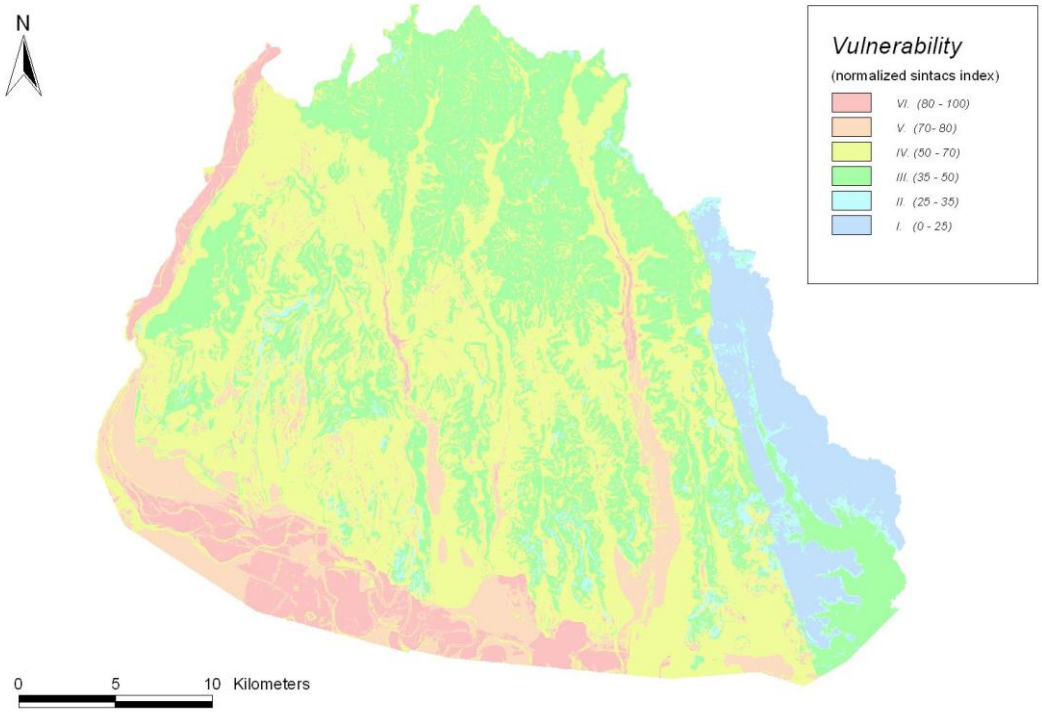

Figure 5: Vulnerability map