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EMPIRICAL DETERMINATION OF THE AVERAGE ANNUAL RUNOFF COEFFICIENT IN THE MEDITERRANEAN AREA

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ABSTRACT

Runoff estimation in ungauged basin is a challenge for the hydrological engineers and planners. For any hydrological study on an ungauged basin, a methodology has to be appropriately selected for the determination of runoff at its outlet. Several methods have been used to estimate the basin runoff production. In this study the empirical Kennessey method to determine average annual runoff coefficient, RC, is tested on 61 Sicilian basins characterized by different climate conditions, surface permeability, mean slope and vegetation cover. A comparison between observed and calculated RC showed that a calibration of the Kennessey model could be necessary. The slight and not satisfying improvement of the calibrated model suggested that the main factors accounted for the Kennessey method could not be enough to describe mean runoff production. So the analysis has been focused on researching empirical relations between RC and other variables which could play a significant role on RC estimation. Finally, the best result on RC estimate was obtained by a simple linear regression for two Sicilian sub-zones, by considering only two main climatic parameters, average annual rainfall depth and average annual temperature.

Keywords: Runoff Coefficient, Kennessey Model, Empirical Models

1. INTRODUCTION

One of the central problem in hydrology deals with the estimation of average annual runoff production at basin scale. Runoff estimation in ungauged basin is a challenge for the hydrological engineers and planners. The problem becomes much more essential in arid and semiarid regions (D'Asaro and Grillone, 2012) as population increases and land use have continues to change, furthermore, in all those regions, such as Sicily, where the problem of water scarcity is particularly nearby so to be arduous water resources planning.

Several methods are available for estimation of runoff (SCS, 1972). Most of them are based on the estimate of the average annual runoff coefficient, RC. RC can be defined as the fraction of the average annual precipitation that does not infiltrate into the soil and is not transferred back to the atmosphere through evapotranspiration. Thus, runoff coefficient represents the fraction of the precipitation, in excess of the deep percolation and evapotranspiration, which becomes surface flow and ends up in either perennial or intermittent surface water bodies.

Because of difficulties on modeling spatial variability of topography, geology, soil type and vegetation, as well in climate fluxes such as rainfall, infiltration and evapotranspiration, simple empirical approaches to determine average annual Runoff Coefficient (RC) have been widely applied (Barazzuoli *et al*., 1988; Santos and Hawkins, 2011). Between the simple empirical models the Kennessey method (Kennessey, 1930) provides RC values by accounting for the main factors wherefrom RC is influenced: Climate characteristic, surface permeability, mean slope and vegetation cover. After computing a climatic aridity index which, the method involves calculating RC as simple addition of three partial runoff coefficients related to the same components, according to empirical tabled values proposed by Kennessey (1930).

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This study, after applying Kennessey model for 61 Sicilian basins and after a not satisfying attempt to calibrate it on the base of rainfall and runoff data, aims to provide an empirical and reliable tool to determine average annual runoff coefficient in Sicily.

2. MATERIALS AND METHODS

2.1. Study Area

The study has been carried out in Sicily, the greatest island of the Mediterranean sea, covering 25,700 km^2 (**Fig. 1**). Sicily is 62% hilly, principally in the inner areas of the island, 24% mountainous, mainly in the north and 14% plain in the coastal areas.

The 1.64 million hectares of agricultural lands are mainly made up of sown lands (50%), olive groves (15%), orchards (10%, with prevalence of citrus orchards), vineyards (10%) (Tudisca *et al*., 2013).

The mean annual rainfall P varies in the mountain ranges from 600 to 1,600 mm, whereas in the rest of island P goes from 300 to 800 mm.

The mean annual temperature T is approximately 14-15°C, with lower T in the mountain ranges (8-13°C and even 4-5°C at Mt. Etna) and higher T in the costal and urban areas (18-19°C) (Agnese *et al*., 2008; Grillone *et al*., 2009; 2012).

The study here presented has been carried out for 61 Sicilian gauged basins, quite uniformly distributed all over the region (**Fig. 1**). **Table 1** reports main characteristics of the considered basins (D'Asaro and Grillone, 2012). Firstly, each basin has been characterized in terms of climate, morphology, land use; same indications of soil permeability were also available from previous study (Fierotti *et al*., 1988).

2.2. Observed Average Annual Runoff Coefficient

For the 61 considered basins, daily measurements rainfall data and discharge data about in the period 1940 -1997 are available (D'Asaro and Grillone, 2012). Spatial variability of rainfall into the basins has also considered for evaluating annual rainfall depth, by using data collected in 130 pluviometric stations. Observed average runoff coefficient, RC_{obs}, were computed as the ratio between average annual runoff volume, Q and average annual rainfall depth, P (**Table 1**).

2.3. Kennessey Method

The Kennessey method let to estimate the average runoff coefficient as a function of three main basin components: slope component, Ca, Permeability component, Cp and vegetation component, Cv. For each of the three components, partial runoff coefficients have to be evaluated, according to their description reported in **Table 2**. Partial runoff coefficient is assigned to the basin, once the basin De Martonne aridity index, Ia, is evaluated.

According to the physical meaning of each component, partial runoff coefficient increases with increasing of slope, with decreasing of soil permeability and by passing from forest land use to bare rock.

Furthermore, partial runoff coefficient increases with increasing Ia, i.e., by passing from dry to wet climate basin conditions. Once the partial runoff coefficients are identified, the basin RC is evaluated by their simple addition, after weighting with the basin homogeneous area fractions, where homogeneity has to be intended for each of the 39 classes of **Table 2** (13×3).

To determine the De Martonne aridity index, Ia, for the 61 considered Sicilian basins, Ia map of the Sicilian Region has been extracted from the "Atlante Climatologico della Sicilia" (SIAS, 2002). Ia map has been developed on rainfall data and temperature data from 1965 to 1994, collected for 55 thermo-pluviometric stations e 124 pluviometric stations distributed all over the region.

To determine basins area fractions, for slope component and particularly for the corresponding area fractions associated to the four slope classes of **Table 2**, 100 m resolution Digital Elevation Model (DEM) of Sicily has been used.

With reference to the permeability component, it has to be observed that soils of Sicily are characterized by a large variety, going from less to more developed pedologic types (Fierotti *et al*., 1988). This is due to the different geolithological formations, sedimentary to volcanic to metamorphic, which characterizes the Sicilian Region, as a consequence soil permeability can be considered the most arduous component to determine. For the purpose of this study, in view of the very small spatial scale of this investigation, soil permeability has been roughly estimated by the pedological map mentioned above, by considering a mixed of the qualitative indications there reported (soil depth, soil structure and texture).

Differences in land cover were accounted by the average Normalized Difference Vegetation Index (NDVI) obtained in a previous study for the Sicily, by using NOAA satellite images, for the period 1988-2005 (Bono *et al*., 2007). Thus, in this study seasonal variability of the vegetation component was not taken into account for the estimation of the average runoff coefficient. **Figure 2** reports the four classes of NDVI considered in this study and associated to the vegetation components of the Kennessey method.

Table 1. Main characteristics of the 61 Sicilian basins

ID Station	Station	Watershed	Area (Km^2)	River length (Km)	Versant	Station altitude (m)	Max basin altitude (m)	Mean basin altitude (m)	Mean annual rainfall P (mm)	Mean annual runoff Q (mm)	Mean annual temperature (°C)
1	Falcone	Elicona	54	22.2	1	30	1344	705	987	400	15.17
2	Aculeia	Pollina	52	15.4	1	330	1979	1040	923	246	13.30
3	Ponte Vecchio	Castelbuono	99	24.8	1	200	1979	929	831	227	13.89
4	Bivio Cerda	Torto	414	60.8	1	25	1326	505	588	85	16.04
5	Monumentale	S. Leonardo	522	56.0	1	2	1613	580	676	192	15.62
6	Lupo	Eleuterio	10	5.4	1	524	1613	776	791	289	14.86
7	Rossella	Eleuterio	10	4.5	1	484	1029	647	1103	405	15.38
8	Serena	Valle dell'Acqua	22	9.0	1	285	1029	652	893	216	15.33
9	Risalaimi	Eleuterio	53	10.5	1	198	1029	624	715	209	15.46
10	Parco	Oreto	76	13.0	1	113	1333	632	1007	432	15.41
11	Zucco	Nocella	57	13.8	1	80	1194	552	990	177	15.88
12	Fellamonica	Iato	49	15.0	1	210	1333	594	802	337	15.58
13	Taurro	Iato	164	33.5	1	124	1333	408	656	244	16.54
14	Alcamo Scalo	Fiumefreddo	273	37.0	1	60	825	242	544	115	17.33
15	Lentina	Forgia	46	14.0	1	88	1008	307	587	115	17.01
16	La Chinea	Fastaia	23	8.0	1	210	751	341	544	121	16.98
17	Chinisia	Birgi	293	43.5	1	4	751	178	504	85	17.72
18	Pozzillo	Delia	139	21.4	2	93	713	273	728	150	17.20
19	Sparacia	Belice destro	116	32.5	2	251	1233	437	800	233	16.32
20	Casebalate	Belice sinistro	342	42.5	2	179	1613	568	626	211	15.72
21	Finocchiara	Senore	77	26.5	2	126	1180	411	609	145	16.57
22	Ponte Belice	Belice	807	94.2	2	58	1613	452	650	159	16.30
23	Bruciato	Belici	131	23.0	2	363	1081	618	564	105	15.42
24	Passofonduto	Platani	1186	76.1	2	136	1580	519	621	109	15.96
25	Mandorleto	S. Biagio	74	20.0	2	92	607	356	506	81	16.79
26	Petralia	Imera Merid.	28	8.5	2	760	1912	1237	805	602	12.50
27	Cinquearchi	Imera Merid.	545	45.0	2	340	1912	730	681	151	14.95
28	Capodarso	Imera Merid.	631	62.0	2	270	1912	691	632	122	15.19
29	Donna Paola	Gibbesi	63	15.6	2	260	652	437	503	82	16.36
30	Drasi	Imera Merid.	1782	125.0	2	56	1912	529	534	106	15.95
31	Castello	Castello	26	7.7	2	460	1007	647	542	50	15.37
32	Castelluccio	Tellaro	102	22.5	2	160	770	444	611	59	16.32
33	Biscari	Simeto	696	60.5	2	211	3274	1075	681	267	13.19
34	Ponte Gagliano	Salso	499	46.7	2	375	1558	790	661	156	14.61
35	Giarretta	Simeto	1832	120.0	2	17	3274	811	633	300	14.52
36	Casecelso	Girgia	25	10.7	2	340	920	507	733	205	16.18
37	Bozzetta	Dittaino	79	15.2	2	330	1192	551	808	233	15.84
38	Case Carella	Crisà	47	15.6	2	331	1025	611	643	180	15.59
39	Chiusitta	Saraceno	19	6.1	2	1170	1754	1480	1117	828	11.20
40	Moio	Alcantara	342	34.0	2	510	3274	1153	822	228	12.74
41	Alcantara	Alcantara	570	58.0	2	20	3274	949	937	408	13.78
42	S. Giacomo	Alcantara	25	7.0	2	1100	1611	1228	1005	679	12.38
43	Ponte Grande	Isnello	33	10.7	1	566	1979	1220	841	267	12.40
44	Scillato	Imera Settent.	105	15.7	1	236	1869	841	733	235	14.38
45	Roccapal. Scalo	Torto	173	31.7	1	335	999	572	514	78	15.73
46	Vicari	S. Leonardo	253	27.0	1	250	1615	675	654	179	15.20
47	Milicia	Milicia	112	22.7	1	130	1257	496	658	137	16.13
48	Sapone	Baiata	29	9.8	1	44	330	112	478	66	18.20
49	Rinazzo	Chitarra	37	17.8	1	50	368	166	460	68	17.74
50	Re Giovanni	Gangi	61	11.8	2	540	1333	866	648	171	14.28
51	Besero	Imera Merid.	995	74.0	2	230	1912	636	616	123	15.42
52	Monzanaro	Salso	184	24.9	2	389	1660	787	608	123	14.64
53	Raffo	Salso	21	8.6	2	685	1660	1038	706	378	13.41
54	S. Pietro	Ficuzza	128	27.0	2	130	692	395	544	41	16.65
55	Noto	Asinaro	55	14.5	2	70	590	362	621	180	16.68
56	S. Nicola	Anapo	82	20.8	2	356	986	627	675	275	15.45
57	Rappis	Trigona	72	23.4	2	88	747	466	599	169	16.16
58	Serravalle	Troina di Sopra	157	32.0	2	545	1566	965	671	212	13.75
59	Torricchia	Sciaguana	67	19.6	2	200	824	426	437	45	16.38
60	Petrosino	Martello	43	11.0	2	800	1800	1319	866	562	11.93
61	Zarbata	Flascio	31	10.4	2	970	1611	1292	926	637	12.09

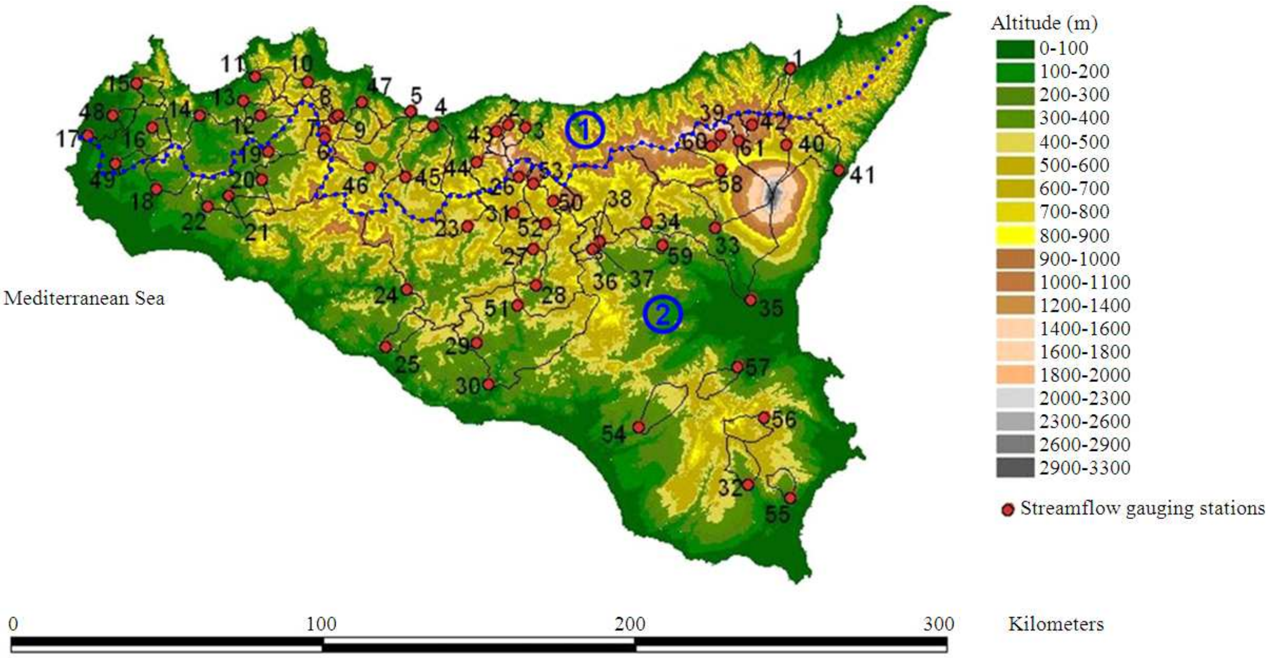

Fig. 1. Sicily region and location of the 61 considered basins. North and south sub-zones, 1 and 2, finally used for the RC linear regression are also indicated

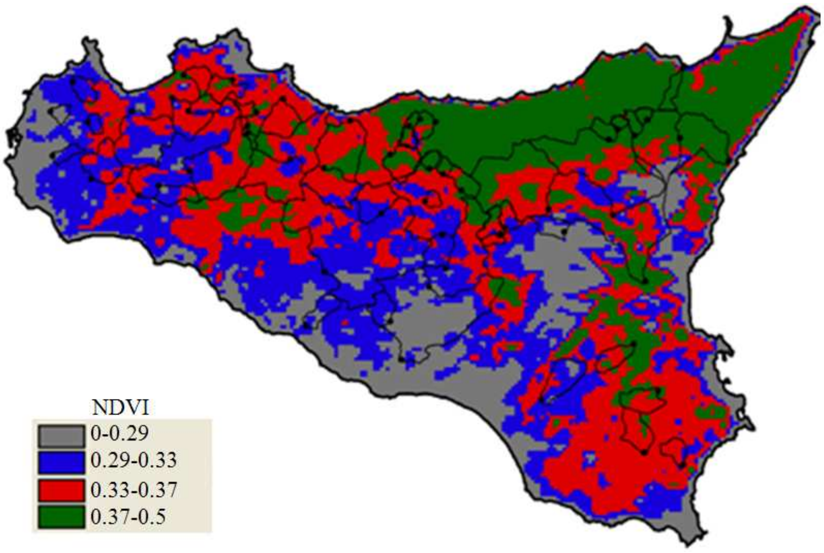

Fig. 2. Classes of NDVI associated to the four vegetation components of the Kennessey method

The determination of the average runoff coefficient of each basin, according to Kennessey method, RC_K, is therefore obtained by adding the partial runoff components of **Table 2**, weighted with the homogeneous area fractions derived by intersecting the four different thematic maps: Acclivity (Ca), permeability (Cp), vegetation (Cv) and climate condition (Ia).

Table 2. Partial runoff coefficients of each basin component accounted for the Kennessey method

		Ia<25	25<Ia<40	Ia>40
Slope	>35%	0.22	0.26	0.30
component	10-35%	0.12	0.16	0.20
Ca	3.5-10%	0.01	0.03	0.05
	<3.5%	0	0.01	0.03
Permeability	Very poor	0.21	0.26	0.30
component	Poor	0.17	0.21	0.25
Cp	Moderate	0.12	0.16	0.20
	Good	0.06	0.08	0.10
	Very good	0.03	0.04	0.05
Vegetation	Bare rock	0.26	0.28	0.30
component	Grass land	0.17	0.21	0.25
Cv	Farm land	0.07	0.11	0.15
	Forest land	0.03	0.04	0.05

Table 3. Calibrated runoff coefficients of each component accounted for Kennessey method

		Ia<25	25<Ia<40	Ia>40
Slope	>35%	0.20	0.20	0.20
component	10-35%	0.11	0.20	0.20
Ca	3.5-10%	0.03	0.03	0.20
	<3.5%	0.03	0.03	0.20
Permeability	Very poor	0.08	0.46	0.46
component	Poor	0.08	0.46	0.46
Cp	Moderate	0.08	0.13	0.38
	Good	0.04	0.04	0.04
	Very good	0.04	0.04	0.04
Vegetation	Bare rock	0.05	0.05	0.05
component	Grass land	0.05	0.05	0.05
Cv	Farm land	0.05	0.05	0.05
	Forest land	0.05	0.05	0.05

2.4. Calibration of the Kennessey Method

Partial runoff coefficients of the Kennessey method (**Table 2**) were also calibrated by minimizing the Root Mean Square Error (RMSE) between observed, RC_{obs} and calculated RC_K, setting up the above discussed expected trend of partial RC by varying with the classes of each component. **Table 3**, analogously to **Table 2**, reports the partial runoff coefficients obtained by calibrating the Kennessey method based on the observed RC values.

Firstly, **Table 3** shows that partial RC is completely unaffected by vegetation component and it is generally weakly influenced by the other components.

Particularly, slope and permeability components result weakly influenced in the down-left side of the table (low Ia and slope values and low Ia and high permeability values), while RC is completely unaffected in the up-right side of the table (high Ia and slope values and high Ia and low permeability values). Calibration results highlights that at basin scale, for Sicily, a spatial averaging effect could probably obscures the important roles of the considered Kennessey components.

3. RESULTS AND DISCUSSION

Results of the comparison between observed runoff coefficients RC_{obs} and estimated ones by the Kennessey method are presented in **Fig. 3**. The pairs (RC_{obs}, RC_K) are almost dispersed around the line of perfect agreement, indicating a clear overestimating/ underestimating of the Kennessey method for the Sicilian environment for small/high RC values.

Figure 3 also reports a comparison between observed RC, RC_{obs} and calculated RC with the calibrated Kennessey method, $RC_{K,c}$, obtained by using partial runoff coefficients of **Table 3**. As expected, calibration strongly improves RC estimation (see R and RMSE in **Fig. 3**), but showed that results are still slights and not at all satisfactory, so to suggest that the components accounted for the RC in the Kennessey method could not be enough to describe mean runoff production. Thus, the analysis has been focused on researching empirical relationships between RC_{obs} and other variables which could play a significant role on RC estimation. In particular, average annual rainfall, average annual temperature, average annual evapotranspiration, vegetation indexes, surface basin, main aspect and distance from coast line, mean altitude and height, distance from basin outlet to cost, as regression variables were also considered.

Finally, the best result on RC estimate was carried out by a stepwise regression. In the final relationship, that follows, RC is a function of only the two main climate parameters, average annual rainfall depth, P (mm) and average annual temperature, T (°C) **Fig. 1**:

$$RC = -0.06+0.000411P+0.0012\,T \quad (1a)$$

for the north sub-zone 1 of Sicily

$$RC = 1.09+0.000411P-0.0707\,T \quad (1b)$$

for the south sub-zone 2 of Sicily

The relationships (1), which show a good fitting of the data with a multiple regression coefficient equal to 0.846 and RMSE = 0.086 (**Fig. 3**), can be usefully used in Sicilian ungauged watersheds. Using the maps of average annual rainfall depth, P (mm) and average annual temperature, T (°C) furnished by SIAS (2002), the Equations (1) were applied to figure out the RC map for Sicily (**Fig. 4**). RC values are higher in the north-east part of the island (0.3÷0.5), with values higher than 0.6 in areas with higher elevation, whereas lower values are in the south part of the island (**Fig. 1 and 4**).

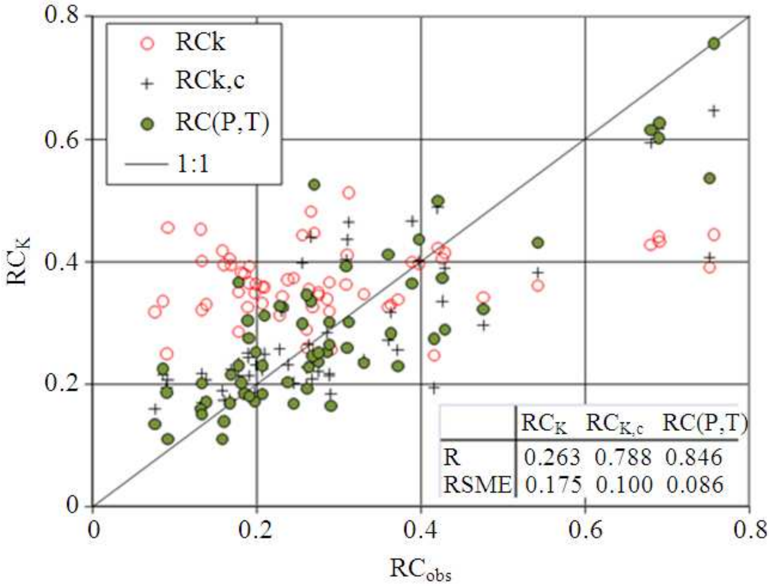

Fig. 3. Comparison between observed RC, RCobs and RC cal-culated by Kennessey method, RCK, by calibrated Kennessey method, RCk,c and by using simple linear regressions (1) as a function of P and T, RC(P,T), for the considered 61 Sicilian basins. Figure also report the corresponding correlation coefficient, R and the root mean square error, RMSE

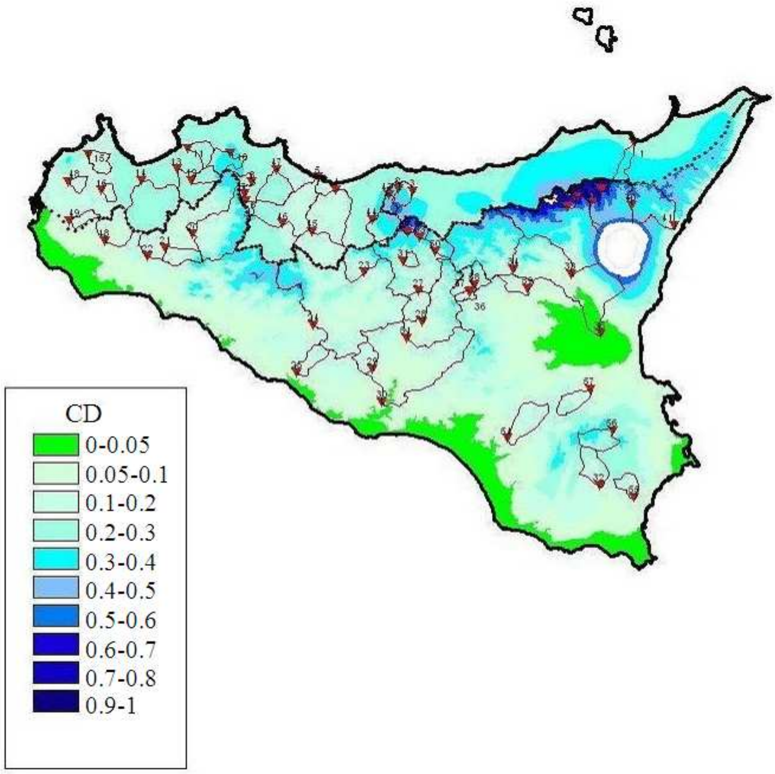

Fig. 4. RC map obtained by Equation (1)

Future work could improve Equations (1) inserting watersheds' morpho-climatic and hydrologic characteristics here not considered.

4. CONCLUSION

After applying Kennessey method to 61 Sicilian basins, a comparison between observed and calculated RC showed that a calibration of the model was necessary. The slight and not satisfying improvement of the calibrated model suggested that the components accounted for the RC estimation could not well explain mean runoff production. So the analysis has been focused on researching empirical relationships between RC_{obs} and other variables which could play a significant role on RC estimation. In particular, mean annual precipitation, mean altitude and height, mean potential evapotranspiration, surface, main aspect and distance from coast line, were also considered. Finally, a regional relationship to estimate mean annual runoff production, involving only the two main climate parameters, the average annual rainfall depth and the average annual temperature, is proposed for Sicily Region.

The collecting of watersheds' morpho-climatic and hydrologic characteristics here not considered could improve the RC estimation.

5. ACKNOWLEDGEMENT

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