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First observations on the saline content of the precipitations in some stations in Sardinia (Italy)*

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Foreword and work objective

During the last few years the problem of the saline contribution from rainfall has been the subject of study of many researchers throughout the world. Many data have in fact been collected to evaluate the polluting effect of the precipitations and numerous studies conducted on their chemical composition in order to individuate the enrichment factors of the various ions.

A knowledge of the chemical composition of these waters has proved useful for evaluating the contribution of nutritional elements to plants and for a better interpretation of the water-rock interaction chemism of the underground water circulations. An accurate interpretation of the latter factor leads to a more precise evaluation of several parameters such as the depth reached underground by these waters, how long they remain there, type of reservoir crossed and the mixing ratio between deep and shallow waters.

The salt content from rainfall and other elements carried through the air to the ground by the winds are sometimes responsible for the anomalous ionic ratios in shallow and deep circulation waters. It is rather difficult to evaluate the chemical composition of these waters without a precise knowledge of the values of these contributions.

Many authors have studied this problem on an international level: SUGAWARA (1954) and KOMABAYASI (1962) found aerosol enrichment factors that area apparently proportional to the atomic weights of the ions (Table 1), while others (SUHAWARA, KOMABAYSI, 1954; 1962; VINOGRADOV, 1959

* Lavoro eseguito nell'ambito del Progetto Finalizzato Energetica del CNR sottoprogetto Geotermia.

Table 1 - *Aerosol enrichment factors relative to chlorine.*

Ion	Enrichment factor	
Ca	2.85	
Mg	1.20	
Na	0.98	Data from KOMABAYASI (1962)
K	3.80°	
Cl	1.00	°Calculated da NEEV and EMERY (1967)
Br	30.00°	
SO_4	1.61	
HCO_3	8.50	

Table 2 - *Ionic ratios in average oceanic water (Salinity 35151)*

Ion	Average content (ppm)	X/Cl	X/Br
Cl	19370	1.000	298.000
Na	10770	0.567	162.477
Mg	1300	0.068	19.569
Ca	409	0.022	6.154
K	388	0.019	5.846
Br	65	0.003	1.000
SO_4	2710	0.143	41.692
HCO_3	139	0.007	2.138

and DUCE et al., 1963) noted that the aerosols deriving from the Ocean have different ionic ratios from those of the Ocean itself (Table 2).

These authors are in disagreement with regard to the factors responsible for this fractionation; there is also considerable disparity in their data, with differences between snow and rainfall, variations with distance from the Ocean, geographic position etc.

Sardinia being an island its circulation waters have peculiar chemical characteristics that are mainly tied to the fact that the precipitations are chloride-enriched (from direct observation of rainfall we deduce that about 180 kg/ha of chlorine ion fall annually).

The uniformity of these saline contents has been evaluated by continuous checks in nine pluviometric stations mainly distributed over the northern sector of Sardinia (Fig. 1). The precipitations were sampled daily and sealed in polythene containers for monthly analysis.

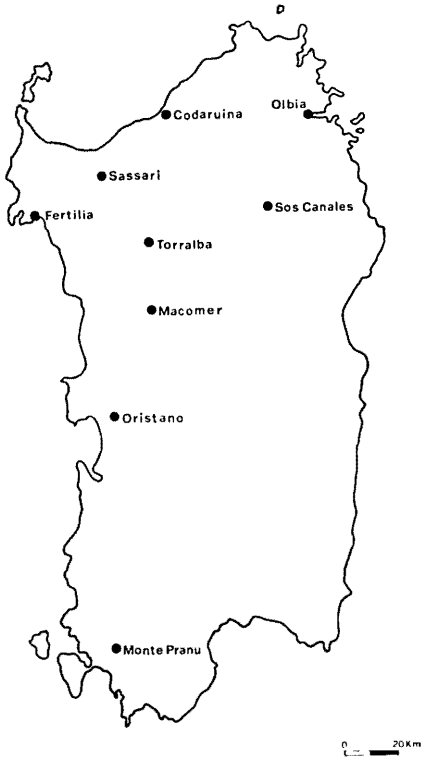


Fig. 1 - Location of pluviometric stations.

The nine stations are listed in Table 3, which also reports the sampling period, elevation above sea-level and coordinates.

Table 3 - *Pluviometric stations*

No.	Station	Sampling period	Elevation m a.s.l.	Coordinates	
1	Codaruina	Dec - June	15	40° 55' 35"	3° 37' 35"
2	Fertilia	Jan - June	9	40° 35' 38"	4° 09' 54"
3	Macomer	Dec - June	572	40° 16' 01"	3° 40' 14"
4	Monte Pranu	Jan - June	47	39° 05' 36"	3° 51' 50"
5	Olbia	Apr - June	15	40° 54' 05"	2° 56' 00"
6	Oristano	Jan - June	12	39° 54' 08"	3° 49' 55"
7	Sassari	Oct - May	224	40° 43' 02"	3° 53' 55"
8	Sos Canales	Nov - May	713	40° 33' 07"	3° 08' 18"
9	Torralba	Jan - May	352	40° 30' 47"	3° 41' 08"

It should be noted that the stations of Sassari, Torralba, Macomer, Fertilia and Codaruina are sited within towns or cities, Sos Canales near the Sos Canales dam near Buddusò, Olbia near the airport, Oristano near the farm of the Istituto di Coltivazioni Arboree of the University of Sassari and, finally, Mt. Pranu near the Pranu dam.

The chemio-physical analyses of pH and conductivity and the chemical analyses of Ca, Mg, Na, K, Cl, SO_4 and HCO_3 were conducted in the laboratory. The methods used for these analyses are those reported in the Standard Methods booklet.

The data are shown in Table 4, along with a weight average of the results for each station.

Table 4 - *Analitical data on waters from the pluviometric stations*

CODARUINA Elevation 15 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
December	83	6.4	105	3.40	1.65	8.65	0.80	18.31	9.70	31.95	65.30
January	28	6.5	60	3.10	0.80	3.90	0.52	18.31	10.37	14.90	42.74
February	85	6.3	135	4.40	2.20	14.60	1.20	18.31	11.50	35.50	78.55
March	50	6.3	78	2.01	0.90	7.20	0.75	18.31	5.30	17.75	43.06
April	45	6.5	220	5.12	3.40	26.35	1.81	18.31	14.00	60.35	120.18
May	98	6.7	125	2.38	2.17	16.60	1.07	12.20	7.40	35.50	71.22
June	19	6.8	108	14.00	0.72	5.60	0.75	12.20	13.87	17.75	58.79
Total mm	408										
Weight aver.		6.47	122	3.85	1.88	13.10	1.03	16.55	9.69	33.05	70.92

FERTILIA Elevation 39 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
January	90	6.2	195	4.60	2.80	17.00	1.20	24.41	15.00	46.15	98.95
February	95	6.1	155	5.40	2.80	18.40	2.20	24.41	19.25	35.50	95.75
March	50	6.1	120	1.60	1.25	10.60	0.52	30.51	6.60	24.85	60.67
April	38	6.3	160	1.64	2.20	17.80	1.00	24.41	11.37	42.60	88.81
May	73	6.9	180	2.24	2.40	22.60	1.28	30.51	14.75	46.15	104.67
June	8	6.9	228	19.40	3.40	16.20	5.60	36.61	14.75	31.95	109.60
Total mm	354										
Weight aver.		6.3	167	3.92	1.71	17.69	1.47	26.81	14.51	39.58	91.94

MACOMER — Elevation 572 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
December	19	6.4	360	6.85	6.95	10.50	2.50	18.31	28.80	95.85	160.60
January	90	5.8	63	2.40	1.20	8.40	0.42	6.10	8.70	21.30	45.47
February	100	6.0	82	2.40	1.40	10.00	0.60	6.10	6.20	24.85	48.50
March	96	5.5	45	0.68	0.60	5.80	0.27	12.20	3.75	14.20	31.40
April	81	5.8	91	1.37	1.40	10.80	0.74	12.20	8.37	28.40	57.18
May	98	5.6	150	1.27	2.92	14.60	0.68	6.10	8.85	31.95	63.32
June	73	6.2	55	2.64	0.59	6.80	0.34	12.20	5.00	14.20	35.67
Total mm	557										
Weight aver.		5.82	92	1.93	1.58	9.54	0.57	9.25	7.57	25.23	51.04

MONTE PRANO — Elevation 47 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
January	60	6.2	140	2.24	1.45	11.40	0.67	12.20	26.30	28.40	76.56
February	42	6.2	190	1.65	1.47	19.80	0.88	24.41	23.00	39.05	98.05
March	57	6.3	145	1.64	1.20	15.20	0.68	24.41	18.70	31.95	81.57
June	32	6.3	110	3.53	0.78	5.60	0.63	24.41	19.00	14.20	55.94
Total mm	191										
Weight aver.		6.25	147	2.14	1.26	13.40	0.71	20.57	22.08	29.42	79.29

OLBIA — Elevation 15 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
Apri-may	100	5.3	48	1.25	0.70	4.80	0.28	6.10	4.60	14.20	28.88
June	32	6.5	48	4.40	0.56	3.80	0.37	12.20	9.85	7.10	32.18
Total mm	132										
Weight aver.		5.59	48	2.01	0.66	4.55	0.30	7.58	5.87	12.47	29.65

ORISTANO — Elevation 12 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
January	50	6.1	150	1.50	2.10	11.10	0.90	18.31	10.50	39.05	74.30
February	35	6.0	125	2.60	2.40	15.00	1.20	12.20	11.25	31.95	70.50
March	37	5.8	65	0.84	0.88	6.80	0.45	12.20	6.20	17.75	39.02
April	83	5.3	145	1.31	2.40	19.40	0.88	6.10	15.00	49.70	91.74
May	16	5.9	65	1.76	0.90	4.60	0.75	12.20	10.12	14.20	38.43
June	10	6.3	85	4.66	1.00	7.60	0.98	12.20	13.62	17.75	51.71
Total mm	231										
Weight aver.		5.74	122	1.64	1.92	13.38	0.85	11.33	10.94	35.74	70.14

SASSARI — Elevation 224 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
October	2	6.2	80	7.35	0.75	4.05	0.90	24.41	23.30	17.75	66.30
November	57	6.4	195	5.95	3.04	10.70	1.25	12.20	19.25	49.70	95.99
December	68	6.0	85	3.50	0.80	9.00	0.38	12.20	10.12	21.30	51.20
January	148	6.2	145	4.40	1.78	14.60	0.81	12.20	19.80	35.50	82.99
February	109	6.1	91	2.43	1.01	9.20	0.50	12.20	9.70	21.30	50.24
March	45	6.4	155	4.83	2.00	15.00	0.93	24.41	24.30	35.50	94.77
April	93	6.4	120	5.02	2.12	14.40	0.70	12.20	16.70	31.95	76.99
May	33	6.5	95	8.80	0.83	5.80	1.19	18.31	8.85	17.75	52.34
Total mm	555										
Weight aver.		6.24	126	4.47	1.68	11.89	0.75	13.60	15.78	30.71	72.08

SOS CANALES — Elevation 713 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
November	60	6.4	98	1.50	1.20	7.35	0.49	12.20	10.37	28.40	55.41
December	60	6.7	150	2.75	3.10	13.80	1.10	18.31	11.37	46.15	87.42
January	95	6.4	89	2.60	1.40	8.20	0.80	12.20	10.00	24.85	53.95
February	89	6.1	98	1.32	1.25	10.40	0.63	12.20	6.60	24.85	51.15
March	59	6.3	185	1.53	3.00	24.10	1.17	24.41	11.25	53.25	106.50
April	158	6.9	85	4.58	1.45	10.40	0.65	24.41	4.25	24.85	58.38
May	27	6.4	62	1.52	0.62	5.00	1.52	18.31	3.30	14.20	35.31
Total mm	548										
Weight aver.		6.51	106	2.96	0.68	11.26	0.80	18.01	7.78	28.95	62.48

TORRALBA Elevation 15 m a.s.l.

Period	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
January	100	6.4	105	5.40	1.80	11.40	1.20	12.20	9.00	24.85	59.75
February	75	6.6	135	9.20	2.00	12.00	1.20	24.41	15.00	31.95	83.55
March	74	6.5	97	5.90	0.93	7.20	0.85	30.51	4.80	17.75	52.69
April	40	6.4	80	3.90	0.85	5.80	0.68	30.51	5.00	17.75	49.24
May	53	7.0	70	3.30	0.66	3.80	0.50	18.31	4.60	14.20	36.21
Total mm	342										
Weight aver.		6.56	101.5	5.84	1.36	8.79	0.95	21.93	8.25	22.38	58.54

RESULTS

The first observation we can make on Table 4 regards the variations in concentration of all the parameters under study; these variations can be noted both within the same station and between different stations, with extreme oscillations of 92% (calcium value at Fertilia, and magnesium at Macomer).

This phenomenon would suggest that a rather long research period is required (at least 3 years) to give a real statistical validity to the data processing and also to individuate, as approximatively as possible, the sources of pollution. The origin of this pollution is not only tied to aerosols but also to the gas and smoke discharged from industries, and the combustion and decay of organic matter.

However, from our first study of the results it would seem that the saline content definitely decreases from west to east; this phenomenon may be explained by the fact that most of the rainfall comes from the west so that the quantity of salts discharged into the atmosphere gradually decreases as the rain moves towards the eastern side of the island.

Figure 2 is a semi-logarithmic diagram of the average trends of the saline contents in all the stations. We can also note the differences and relationships between the different ions under study. The waters are prevalently chloride-alkaline, the percentage of this salt varying between 53 and 70% of the total.

The maximum value for the sulphuric ion is found at Mt. Pranu, probably because this station is near an industrial centre, while the maximum for the bicarbonate ion is at Fertilia (26.81 mg/l).

Determination of the isotopic abundance of the SO_4 ion may, as described in the literature (CORTECCI and LONGINELLI, 1970; CORTECCI, 1976) indicate the contribution of S of industrial origin (oil and coal combustion).

Fig. 2 - Ionic composition of precipitations.

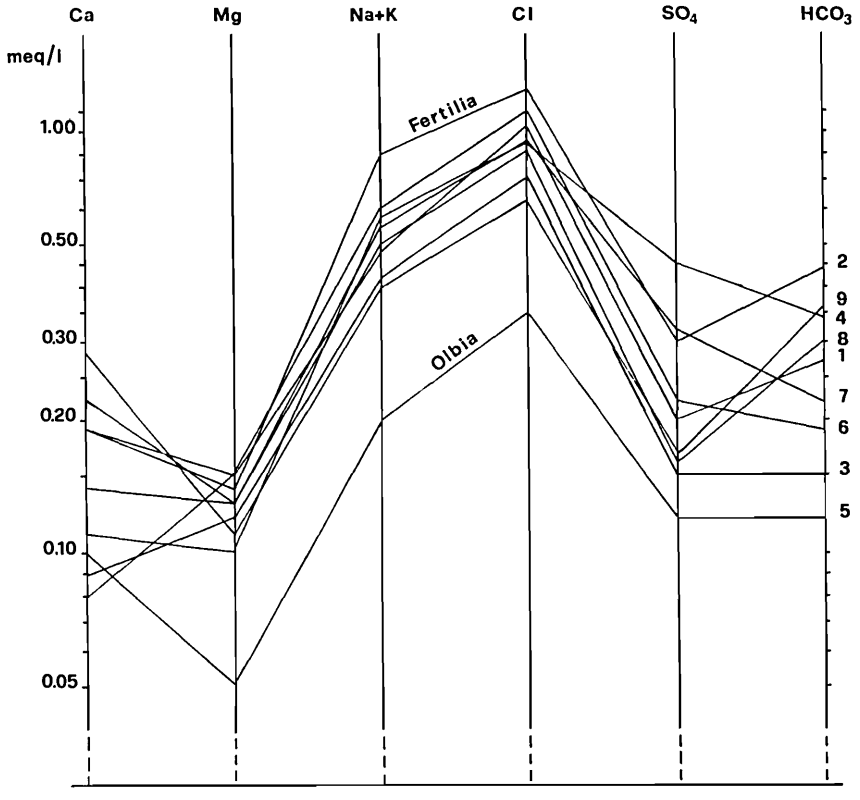
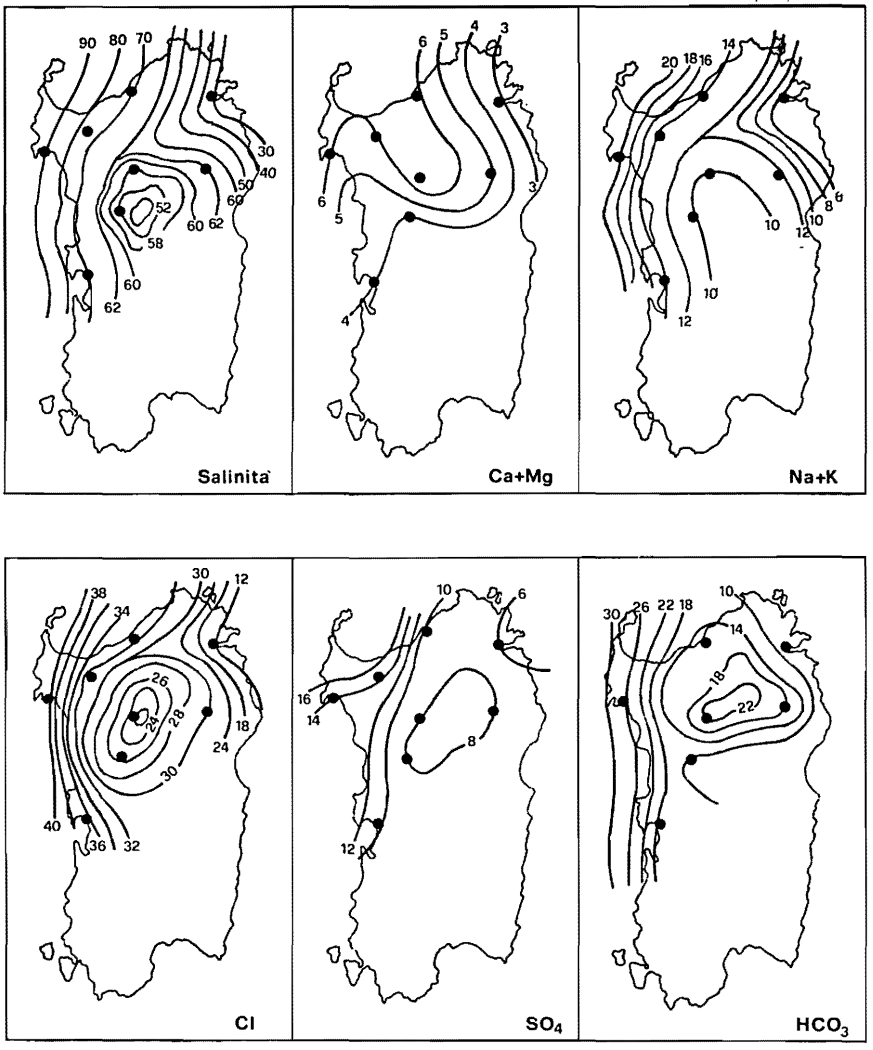


Figure 3 shows the areal distribution (contour lines obtained by interpolation) of the saline contents and ions under study. The isohalines confirm the tendency for the minimum values to lie aroud the Catena del Marghine, as the values follow the preferential directions closely related to the prevailing winds and the trend of the morphological highs.

Taking the results from all the stations month by month (Table 5), we can see that all the ions differ in behaviour, with the exception of the calcium, sodium and chlorine ones.

Fig. 3 - Areal distribution of salinity and the ions (Ca + Mg), (Na + K), Cl, SO_4 and HCO_3 (mg/l) in the precipitations.



In fact, Figure 4 shows that the SO_4 and HCO_3 values tend slightly to decrease from December to June. The potassium value is fairly constant while magnesium, chlorine and sodium are at their maximum in the period with the greatest intensity of precipitations.

Table 5 - *Average monthly results for all stations*

Stat. No.	Month	Rain-fall mm	pH	Cond. a 25°C µs	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	Sali-nity mg/l
1	October	2	6.20	80	7.35	0.75	4.05	0.95	24.41	23.30	17.75	66.30
2	Novem.	117	6.40	145	3.67	2.10	8.98	0.86	12.20	14.70	38.78	75.18
4	Decem.	230	6.40	132	3.54	2.21	10.25	0.89	16.50	11.84	37.78	74.77
8	Jaunary	661	6.21	123	3.58	2.74	11.67	0.85	13.75	14.08	30.63	69.42
8	February	630	6.17	120	3.75	1.76	12.97	1.03	16.16	11.99	29.47	69.06
8	March	468	6.12	107	2.38	1.29	11.10	0.68	21.90	9.32	25.69	61.41
8	April	638	6.13	106	3.11	1.70	12.60	0.74	15.78	9.20	31.01	66.26
7	May	398	6.44	102	2.65	1.93	13.33	0.97	15.80	8.68	29.97	65.42
6	June	174	6.38	79	5.25	0.79	6.37	0.72	15.57	10.38	14.30	45.59

Calcium deserves separate consideration in that it apparently behaves quite the opposite to the Mg, Na and Cl ions.

It is reasonably clear that these elements can be hypothesized of marine origin, although no support can be obtained for this from the correlation of the values from the individual stations and their distance from the sea; the insular nature of this region, in fact, causes microclimatic variations that prevent this type of correlation.

One rather interesting aspect of the problem arises in Table 6; i.e., the Kg/Ha values occur in each station on average each year. These values are very high, especially for sodium and chlorine. The figures relative to these ions are twice or three times the other values found in other stations of Italy.

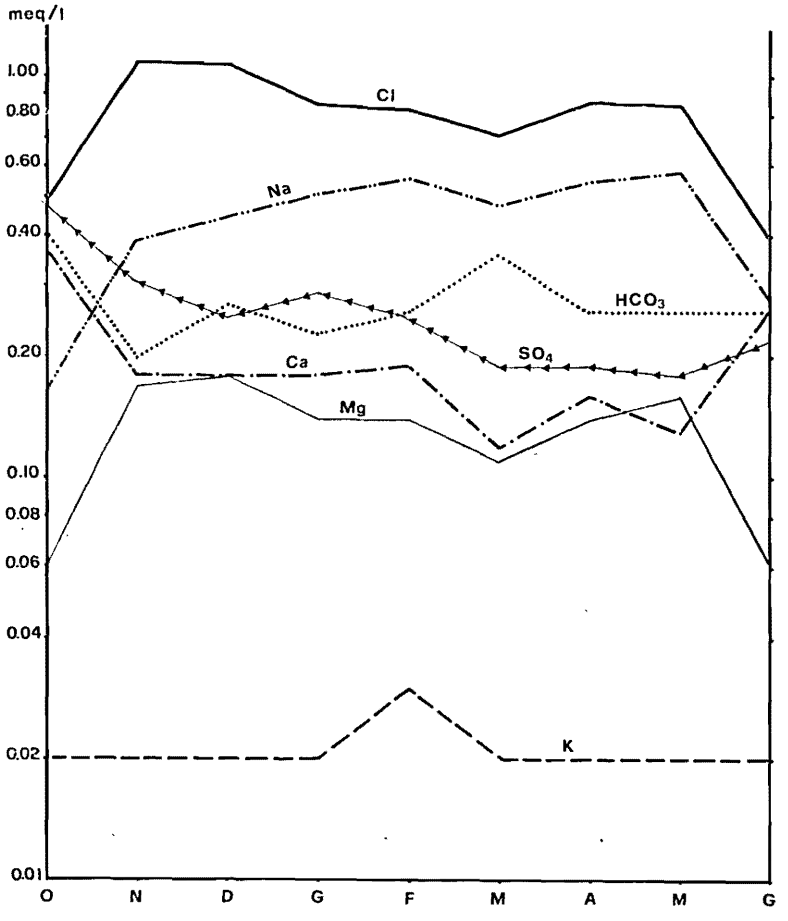


Fig. 4 - Variation of ions during observation period (meq/l).

Table 6 - *Annual contents (Kg/Ha) of the studied ions in all stations*

Stations	Precip. mc/ha	Ca kg/ha	Mg kg/ha	Na kg/ha	K kg/ha	HCO_3 kg/ha	SO_4 kg/ha	Cl kg/ha
Codaruina	4710	18.13	8.85	61.70	4.85	77.95	45.64	155.67
Fertilia	6560	25.72	11.22	116.05	9.64	175.87	95.19	259.64
Macomer	8480	16.37	13.40	80.90	4.83	78.44	64.19	213.95
Monte Prano	6030	12.90	7.60	80.80	4.28	124.04	133.14	177.40
Olbia	6550	13.17	4.32	29.80	1.97	49.65	38.45	81.68
Oristano	5810	9.53	11.16	77.74	4.94	65.83	63.56	207.65
Sassari	5960	26.64	10.01	70.86	4.47	81.06	94.05	183.03
Sos Canales	6010	17.79	4.09	67.67	4.81	108.24	46.76	173.99
Torralba	8040	46.95	10.93	70.67	7.64	176.32	66.33	179.94

Table 7 shows, for each station, the enrichment factors of the ions examined with respect to Mediterranean sea-water. (*)

These values are ratehr high compared to other Italian zones and differ from one zone to the next. This phenomenon could be related to the insular conditions we have already mentioned, to the presence of industrial activities near the pluviometric stations and the combustion products of central heating in the cities.

Table 7 - *Enrichment factors in the precipitations*

	Ca	Mg	Na	K	HCO_3	SO_4	Cl
Codaruina	5.52	0.85	0.71	1.55	71.42	2.09	1.00
Fertilia	4.71	0.64	0.80	1.85	96.71	2.62	1.00
Macomer	8.85	0.61	0.86	1.20	122.71	2.51	1.00
Monte Prano	3.46	0.64	0.82	1.21	99.88	5.36	1.00
Olbia	7.67	0.79	0.66	1.20	86.84	3.36	1.00
Oristano	2.18	0.80	0.67	1.19	45.28	2.19	1.00
Sassari	6.93	0.81	0.70	1.22	63.26	3.67	1.00
Sos Canales	4.87	0.35	0.70	1.38	88.87	1.92	1.00
Torralba	12.42	0.91	0.71	2.12	139.98	2.63	1.00

(*) The analytical values of the Mediterranean sea-water were obtained by multiplying the data given Table 2 by a coefficient of 1.1. The latter is obtained from the ratio between the chlorine value of the Mediterranean Sea and Ocean chlorine (21.220/19.370) (Macchi G. et. al., 1969).

RIASSUNTO

In questa nota vengono esaminati i risultati delle analisi delle acque di precipitazione di 9 stazioni pluviometriche della Sardegna. I campioni sono stati prelevati con periodicità mensile nell'arco di un anno.

I contenuti salini risultanti hanno mediamente valori piuttosto alti variabili tuttavia di mese in mese e di stazione in stazione. Si è potuto notare una variazione decrescente procedendo da Ovest ad Est in relazione ai venti dominanti dell'Isola. Elevata si è rilevata la concentrazione media di Cl e SO_4.

ABSTRACT

The analysis of the saline contents of the precipitations in some stations in Sardinia are given. The waters samples were collected monthly in nine stations for a year. The analysis revealed that all the ions studied have rather high average values and that they vary considerably both in space and time. The values were also noted to decrease from west to east in correlation with the predominating winds on the island (Fig. 3). The average concentration of Cl and SO_4 was very high (180 and 71 kg/ha respectively).

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