

INAA at the top of the world: Elemental characterization and analysis of airborne particulate matter collected in the Himalayas at 5,100 m high

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In 1990, following an agreement with the Royal Nepal Academy of Science, the Italian National Research Council (CNR) installed a scientific laboratory (Pyramid) at 5,050 m (s.l.) in the Himalayan region. Among the environmental related researches, the task project RATEAP (Remote Areas Trace Elements Atmospheric Pollution), started in 2001, aims at obtaining information about the chemical composition of the high altitude airborne particulate matter. During the period of March–April 2002 series of samplings have been carried out by pump aspiration. Samples of total suspended particles (TSP) as well as of the particles size fraction PM10 and PM2.5 have been collected and submitted to INAA for the determination of more than 30 elements present at nanogram levels, in few micrograms of air dust. Data quality assurance has been performed by the analysis of different NIST SRMs and, in particular, the SRM 2783 Air Particulate on Filter Media.

Introduction

Knowledge of the concentrations of potentially toxic substances in the airborne particulate is fundamental for assessing the air pollution levels and provides important information for evaluating the long term low level exposure of the population. Current studies take into account the analysis of the PM10 (air particulate matter with an aerodynamic equivalent diameter AED of less than 10 μm) as well as the fraction of 2.5 μm of AED, since it contains the finest particulate which can be more deeply inhaled into the lungs. These fine particles can be subjected to long transportation phenomena that may be responsible of the distribution of the pollutants far from the emission sources. In 1990, following an agreement with the Royal Nepal Academy of Science, the Italian National Research Council (CNR) installed a scientific laboratory (Pyramid Laboratory-Observatory) at 5,050 m (s.l.) in the Himalayan region. The laboratory is located in one of the highest inhabited places in the world: the Khumbu valley (Nepal), at the foot of Mount Everest (see Fig. 1). Since that moment, several multidisciplinary research activities have been initiated in the framework of the CNR scientific program Ev-K²-CNR. Among the environmental related researches, the task project RATEAP (Remote Areas Trace Elements Atmospheric Pollution), started in 2001, aims at obtaining information about the elemental composition of the airborne particulate matter of high altitude remote areas such as those of the Himalayan region, free of any industrial and anthropogenic sources. Furthermore, this research can provide additional information to the

studies of the so-called “Asian Brown Cloud” (ABC) that is the haze hovering the Indo-Asian-Pacific region as documented by INDOEX (Indian Ocean Experiment).^{1,2}

In the year 2001 feasibility studies and experiments have been carried out to prepare the mission in the Himalayas. Sampling equipment, filters, pre-analytical as well as analytical procedures have been tested and controlled. A series of airborne particulate samplings have been experimented in the Alps region (Plateau Rosa-Cervino) at 3450 m s.l. to simulate the Himalayan conditions. In March 2002 the mission at the CNR Pyramid laboratory started. Two researchers of the CNR of Pavia initiated the airborne particulate samplings. The samples were collected from March to May. The filters have been submitted to neutron activation analysis (INAA) for the determination of more than 30 elements. All lead, cadmium, chromium, nickel and copper analysis have been carried out by electrothermal atomic absorption spectroscopy (ET-AAS). Data quality control on the analytical procedures was accomplished by means of the certified standard reference materials SRM 2783 Air Particulate on Filter Media, SRM 1632a Trace Element in Coal and SRM 1547 Peach Leaves of NIST (Institute of Standard and Technology, USA).

Experimental

Airborne particulate sampling

Three different air particles size fractions were sampled, i.e., (1) total suspended particles (TSP), (2) particles with an equivalent aerodynamic diameter below 10 μm (PM10) and (3) below 2.5 μm (PM2.5).

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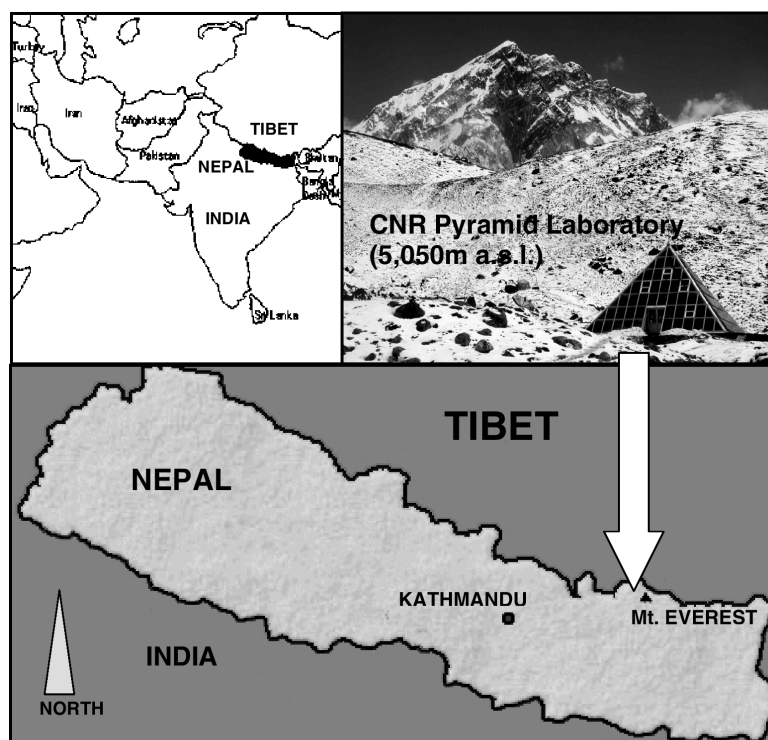


Fig. 1. CNR Pyramid Laboratory-Observatory and air particulate sampling site location

The air particulate matter was collected onto 0.5 μm high purity Teflon[®] filters of 47 mm diameter (Zefluor[™], PALL, USA) using aspiration sampling systems expressly developed to operate at low atmospheric pressure (Zambelli s.r.l., Bareggio-Milano, Italy). The following conditions were applied.

TSP were collected at a flow rate of 24–26 l/min, while the PM₁₀ and PM_{2.5} fractions were sampled by inertial particle size impactors at a flow rate of 16.6 l/min. For each fraction, eight independent samples for a total of 24 filters have been collected. Sampling times between 80 and 120 hours have been adopted in order to collect an amount of air dust suitable for the analysis. A minimum of 120 m³ (about 67.1 Nm³) of air was collected for each sample. All samplings were carried out in similar weather conditions (excluding raining and snowing times) and the flow rates and pump functioning were continuously followed. The overall sampling period was of 50 days. All filter handling procedures were carried out inside of the Pyramid laboratory in clean conditions and using gloves and plastic tweezers to avoid possible contamination. At the end of the sampling the filters were sealed in individual plastic containers. Field-blanks consisting of filters handled in the same manner of the samples (including loading and dismantling from the filter-holders) have been also collected and stored.

Weather condition

During the sampling period temperature ($^{\circ}\text{C}$), pressure (hPa), relative humidity (%), wind velocity ($\text{m}\cdot\text{s}^{-1}$) and precipitation (mm) were recorded hourly by the Automatic Weather Station (LSI-Lastem, Italy) located near the Pyramid Laboratory-Observatory at 5050 m a.s.l. The daily minimum, mean, maximum temperature, mean and maximum wind speed, mean humidity and pressure and total rain were considered to characterize the climatic condition. The sampling period is representative of a pre-monsoon season with a weather and climate conditions characterized by a median of daily mean temperature ranging between -7.7°C and $+1.6^{\circ}\text{C}$, and a daily mean minimum of -14.2°C and a maximum of 8.3°C , a median of daily mean relative humidity of 69% and a total precipitation of 53 mm.

Analyses

The filters samples were divided in two groups of 12 filters each for the analysis by INAA and ET-AAS, respectively. INAA was employed for the determination of the major part of the trace elements while ET-AAS was used for the analysis of Pb, Cd, Cu, Ni and Cr. Apart for Pb, this last technique was chosen because its better sensitivity in Cd and Cu determination. In the case of Cr, instrumental neutron activation analysis (INAA)

were affected by the high content of Cr from the blank of the filter (see below). In the analyses carried out by INAA, the filter samples and standard reference materials (NIST SRM 1632a Coal, NIST SRM 1547 Peach Leaves, NIST SRM 2783 Air Particulate on Filter Media) were sealed in polyethylene plastic containers while the multielement primary standard solutions were sealed in quartz vials (Suprasil AM, Heraeus, Germany). The samples were then neutron irradiated in the TRIGA Mark II (General Atomic, USA) research nuclear reactor of the University of Pavia. According to the type of the analysis two different irradiation procedures have been adopted. The pneumatic irradiation facility "Rabbit" (samples transfer time 3.5 s) was used for short irradiations (between 30 s and 5 min), at a neutron flux of $5 \cdot 10^{12} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$. Long term irradiations (40–50 h) were performed in the reactor central thimble facility, at a neutron flux of $10^{13} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$. For the gamma-spectra analysis HPGe (gamma-X) detectors (Ortec, USA) coupled to computerized multichannel analyzers (Ortec DSPEC, USA) were used. The relative efficiencies of the detectors were ranging between 25 and 45% with resolutions of 1.75–1.85 keV on the 1332.4 keV gamma line of the ^{60}Co . For medium and long countings, automatic sample changers were coupled to the systems and the counting times were ranging between 3000 and 50000 seconds.

The ET-AAS analyses were carried out by a Shimadzu AA 660. The filters with the air particulate matter were leached by conc. HNO_3 and conc. HF (3:1) using high pressure Teflon[®] lined bombs in a microwave oven (Milestone 1200, USA). In this conditions all the air particulate matter was solubilized. The undissolved Teflon[®] filters were discarded and the resulting solutions were evaporated near dryness at about 80 °C, re-dissolved with 0.1M HNO_3 and Milli-Q water (Millipore[®], Italy) and submitted to analysis. Blanks of the filters and of the reagents have been determined in the same way.

Blanks

The blanks arising from the filters may constitute a severe analytical problem since many trace elements are contained at levels which may be close to the concentrations present in the collected mass of the air particulate.^{3–5} This is of great importance in collecting airborne particulate matter in very low polluted areas where the ratio air dust mass/filter blank could be very critical.⁶ To prevent and control this interference, an accurate analysis of both filters and field-blank filters was performed. Table 1 reports the values of 28 elements determined by INAA in the analysis of 8 new filters taken from four different batches and 5 field-blank filters. The high blank contents of Cr and Ni did

not allow their determination in the finest air particulate matter (PM_{2.5}) being the filter blank contribution >100%. Nevertheless, Cr and Ni have been determined by ET-AAS. In fact, in the analysis by ET-AAS the leaching procedure (see above) solubilizes only the air particulate matter while the filters remain undissolved retaining the major part of Cr and Ni contained as blank impurities (probably included in the filter fibers). The blanks arising from the ET-AAS procedure (blanks leached from the filters and reagents blanks) were sensibly lower in comparison to those determined by INAA allowing the determination of these two elements. This fact was further investigated by leaching experiments on blank filters and subsequent analysis by INAA of the leached filters and leaching solutions. The amount of Cr and Ni left in the leached filters was constantly found in the range of 70% and 80%, respectively. Table 2 shows the blanks values measured in the ET-AAS analyses. The data refer to the mean values obtained in the analysis of 6 new filters collected from four different batches and 5 field-blank filters.

Table 1. Elemental content (in ng) in filters blank and filters field-blank (0.5 μm , 47 mm diameter Zefluor[™], PALL-USA) determined by INAA

Element	Blank filter ng/filter \pm SD	Field-blank filter, ng/filter \pm SD	Field-blank contribution in PM 2.5 analysis, rel. %
As	0.5 \pm 0.2	0.5 \pm 0.3	18
Br	14 \pm 5	27 \pm 18	34
Ca	2260 \pm 900	2625 \pm 1400	60
Ce	<0.8	<0.8	11 max.
Cl	890 \pm 350	1100 \pm 240	74
Co	4.3 \pm 2	4.5 \pm 3	34
Cr	136 \pm 47	153 \pm 60	>100
Cs	0.2 \pm 0.05	0.2 \pm 0.05	19
Fe	1970 \pm 592	2120 \pm 510	50
Hf	0.18 \pm 0.07	0.18 \pm 0.07	34
Hg	<0.5	<0.5	n.d.
I	<10	<10	38 max.
K	1000 \pm 300	1000 \pm 300	22
La	1.5 \pm 0.5	1.7 \pm 0.5	25
Mg	1240 \pm 230	1300 \pm 265	44
Ni	130 \pm 47	153 \pm 51	>100
Mn	43 \pm 8	40 \pm 9	54
Mo	11 \pm 8	12 \pm 9	>100
Rb	<0.6	<0.5	3.7 max.
Sb	2.8 \pm 0.8	2.8 \pm 1.0	19
Se	<0.8	<0.8	40 max.
Sc	0.21 \pm 0.07	0.17 \pm 0.10	11
Ta	<0.1	<0.1	n.d.
Ti	200 \pm 70	180 \pm 95	36
Th	0.14 \pm 0.09	0.17 \pm 0.11	12
U	<0.3	<0.3	n.d.
V	2.1 \pm 1.4	2.7 \pm 1.8	16
Zn	109 \pm 39	131 \pm 43	34

Mean values and relative SD (1 σ) obtained from the analysis of 8 blank filters and 5 field-blank filters.
n.d.: Not detected.

Table 2. Blank content of Cd, Cr, Cu, Ni and Pb in leaching solutions of blank filters and field-blank filters (0.5 μm , 47 mm diameter Zefluor™, PALL-USA) determined by ET-AAS

Element	Reagents and analytical procedure (without filter), ng/filter \pm SD	Leaching of blank filter, ng/filter \pm SD	Leaching of field-blank filter, ng/filter \pm SD
Cd	<0.3	0.5 \pm 0.2	0.5 \pm 0.3
Cr	12 \pm 5	46 \pm 25	63 \pm 34
Cu	51 \pm 23	61 \pm 26	70 \pm 32
Ni	16 \pm 6	38 \pm 23	42 \pm 18
Pb	<5	<5	<5

Leaching with the same solution mixture used for airborne particulate dissolution (HNO_3/HF ; 3:1); mean values and relative SD (1 σ) obtained from 6 blank filters, 5 field-blank filters and 5 procedures with reagents alone.

Data quality control

The accurate determination of very low amounts (in the range of 10^{-9} g) of trace elements constitutes the main analytical difficulty in the analysis of air particulate matter collected onto filters. Correct measurements can be achieved by keeping under control every single uncertainty associated to each step of the analytical procedure adopted (from sample collection to the final measurements). In this case, the major sources of uncertainty associated to the analyses were: yields of the chemical steps and blanks of the reagents (for the measurements carried out by ET-AAS), mass of the primary standards, nuclear and gamma-spectroscopy parameters (neutron irradiation geometry and flux, counting geometry, counting efficiency and statistics, peak integration, etc.). The total uncertainties evaluated in the analysis of the filters samples were ranging as follows: (1) measurements by INAA: from 2% to 4% for Co, Cs, Fe, Sc, Th, Zn; from 4% to 7% for As, Br, Ce, La, K, Mn, V; from 7% to 10% for Ca, Cl, Cr, Hf, Rb, Sb, Se; from 10% to 25% for I, Mg, Ni, Ta, Ti, U; (2) measurements by ET-AAS: from 8% to 12% for Cd and Pb, from 12% to 20% for Cu, Ni and Cr. Counting statistics was the main source of uncertainty in INAA analyses and prolonged counting times with a very close counting geometry were required. For long-lived radionuclide counting times of more than 13 hours were adopted. In the ET-AAS measurements, great attention was paid to the reproducibility of chemical steps and to the reagent blank analysis.

Finally, the internal quality control of the overall analytical procedures adopted was carried out by the control material NIST SRM 2783 Air Particulate on Filter Media.⁷ The results obtained in the determination of As, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, Sb, Ti, V and Zn were in good agreement (within 5–6%) with those certified and the results Ce, Rb, Sc, Th, U (within 5–6%) with those given in the certificate as “reference values”.

Results and discussion

The concentration values in ng/Nm^3 of 31 elements determined in the total suspended air particulate (TSP) collected at the CNR Pyramid are presented in Table 3. The values are compared with those obtained in previous sampling campaigns in rural areas and in an urban area (Milan downtown) of north Italy.^{8–10} As expected, the values found in the Himalayas are comparable only with those of Ispra being of one or more orders of magnitude lower in comparison to those of Milan. Many elements such as As, Br, Cd, Ni, Pb, Sb, Se and Zn, some of which may be considered associated to atmospheric pollution processes, are sensibly lower also in comparison to those of Ispra. Only few elements such as Ce, Rb, Sc and Th show values that are slightly higher than those found in Ispra. The same 31 elements have been also determined in the PM10 fraction. The results are shown in Table 4 and are compared with the range values found in Ispra and Milan during a monitoring campaign carried out in winter 1999. Again, the comparison with the Milan values shows, unless for some elements such as Mg, Ce, La, Rb and Ti, values of one or more orders of magnitude lower. The concentrations of elements such as As, Br, Cd, Cl, Cu, Ni, Pb, Sb, Se, V and Zn are significantly lower also in comparison with those of Ispra. Table 5 reports the distribution of the concentration in ng/Nm^3 of the same elements in the different size particles fractions, i.e., TSP, PM10 and PM2.5. The relative percentages are also indicated. Almost all elements are present with high percentage in the fine particles. Twenty-three elements are contained with a percentage higher than 70% in the PM10 fraction. In this last, 10 elements are present in the PM2.5 fraction with a percentage of 50% or higher, i.e., Zn, Sb, Pb, Ni and Cu. These elements, that can be considered of anthropic origin, are mainly contained in the finest air particulate fractions and may be associated to long distance transport from far pollution sources.

This finding, even if obtained from few measurements carried out in a short sampling period, suggested to follow these elements as possible markers for our incoming future studies. To this purpose, series of

sampling in different periods (seasonal variation and wind directions) and the evaluation of the enrichment factors¹¹ calculated on the basis of local soil compositions are envisaged.

Table 3. Elemental content determined by INAA in airborne particulate matter TSP (total suspended particulate) collected at 5100 m s.l. in Himalayas (Khumbu valley – CNR Pyramid, March–May 2002) compared to those of Ispra and Milan (Italy)

Element	Himalayas (March–May 2002), ng/Nm ³			Ispra (1996–99), ng/Nm ³	Milan (1996–99), ng/Nm ³
	Min	Max	Mean ± SD	range	range
As	0.06	0.17	0.14 ± 0.04	0.5–1.6	0.5–12.5
Br	1.11	3.06	2.12 ± 0.75	7.5–16.9	43–908
Ca	347	694	483 ± 121	–	–
Cd*	0.01	0.09	0.04 ± 0.03	0.35–0.84	1.7–6.3
Ce	0.51	1.26	1.1 ± 0.5	0.2–0.6	0.3–3.1
Cl	40	357	175 ± 110	185–421	150–2600
Co	0.25	0.59	0.43 ± 0.12	0.4–1.2	0.8–19
Cr*	1.3	5.6	3.6 ± 1.7	4.1–10.3	2–298
Cs	0.15	0.34	0.22 ± 0.07	0.1–0.3	0.1–3.8
Cu*	1.5	4.9	3.6 ± 1.4	6.5–15.8	6–153
Fe	269	733	500 ± 185	312–834	300–4067
Hf	0.03	0.04	0.036 ± 0.006	0.02–0.08	0.05–0.56
Hg	<0.01	<0.01	<0.01	0.03–0.15	0.1–1.8
I	0.4	1.5	1.1 ± 0.4	1.6–4.3	5–18
K	228	539	392 ± 123	270–578	690–1650
La	0.31	0.62	0.43 ± 0.13	0.18–0.76	0.4–2.4
Mg	234	833	490 ± 220	120–730	1900–3870
Mn	6.3	18.7	11.4 ± 4.3	9–28	16–330
Mo	<0.2	<0.2	<0.2	0.2–0.7	7.5–14
Ni*	0.7	2.2	1.5 ± 0.7	6.7–15	3.9–167
Pb*	0.6	6.9	4.4 ± 2.4	61–154	75–3200
Rb	1.4	3.0	1.9 ± 0.6	0.3–1.1	3.2–8.9
Sb	0.13	0.91	0.42 ± 0.28	3.2–6.9	14–156
Se	0.11	0.26	0.17 ± 0.05	0.8–1.6	0.3–1.9
Sc	0.08	0.21	0.16 ± 0.05	0.03–0.07	0.5–3.7
Ta	0.02	0.11	0.05 ± 0.03	n.d.	n.d.
Ti	29	128	73 ± 39	12–35	40–132
Th	0.15	0.31	0.21 ± 0.05	0.02–0.1	0.02–1.1
U	0.01	0.07	0.026 ± 0.02	0.03–0.09	n.d.
V	0.9	1.6	1.3 ± 0.2	2.3–6.3	9.1–75
Zn	4.8	20.4	11.2 ± 5.4	125–198	31–329

Mean values and relative SD (1σ) obtained from 4 individual samplings.

* Determined by ET-AAS.

n.d.: Not detected.

Table 4. Elemental content determined by INAA in the PM10 fraction of air particulate matter collected at 5100 m.s.l. in Himalayas (Khumbu valley-CNR Pyramid, March–May 2002) and compared to those found in Ispra and Milan.

Element	Himalayas (March–May 2002), ng/Nm ³			Ispra (1999), ng/Nm ³	Milan (1999), ng/Nm ³
	Min	Max	mean ± SD	range	range
As	0.05	0.21	0.13 ± 0.05	0.8–1.8	6.0–11
Br	1.0	3.1	1.9 ± 0.7	8–14	280–758
Ca	329	451	380 ± 77	–	–
Cd*	0.01	0.05	0.03 ± 0.01	0.3–0.7	4.5–6.8
Ce	0.5	1.16	0.78 ± 0.20	0.3–0.4	1.0–1.9
Cl	28	69	40 ± 22	270–364	1700–2400
Co	0.15	0.63	0.40 ± 0.15	0.5–1.0	3.5–15
Cr*	1.4	5.9	3.1 ± 2.0	5.5–9.1	52–250
Cs	0.14	0.25	0.18 ± 0.04	0.2–0.3	0.5–1.9
Cu*	1.5	4.5	2.8 ± 1.1	7.7–12.2	52–120
Fe	333	644	435 ± 108	510–638	1600–2870
Hf	0.013	0.033	0.024 ± 0.007	n.d.	0.2–0.4
Hg	<0.01	<0.01	<0.01	0.07	0.9–1.6
I	0.45	1.50	0.8 ± 0.6	2.1–4.1	11–17
K	218	408	300 ± 61	312–422	750–1188
La	0.31	0.52	0.40 ± 0.08	0.3–0.6	0.8–1.3
Mg	283	654	452 ± 130	290–449	500–1900
Mn	6.6	10.4	8.3 ± 2.3	11–19	45–210
Mo	<0.2	<0.2	<0.2	0.3–0.6	6.1–11.5
Ni*	0.9	2.1	1.2 ± 0.7	6.8–12.5	30–110
Pb*	0.9	5.3	3.7 ± 2.6	68–112	512–1900
Rb	1.2	2.3	1.7 ± 0.5	0.4–0.6	1.6–2.6
Sb	0.08	0.65	0.36 ± 0.26	4.0–6.1	55–125
Se	0.06	0.21	0.09 ± 0.06	0.5–1.3	0.9–1.3
Sc	0.13	0.18	0.12 ± 0.03	0.03–0.05	0.7–1.8
Ta	0.009	0.042	0.016 ± 0.012	n.d.	n.d.
Ti	38	69	53 ± 13	18–28	55–89
Th	0.14	0.22	0.18 ± 0.02	0.03–0.04	n.d.
U	0.015	0.023	0.018 ± 0.01	n.d.	n.d.
V	0.76	1.34	1.12 ± 0.19	3.6–5.6	28–61
Zn	3.9	11.8	6.5 ± 3.0	110–170	209–250

Mean values and relative SD (1σ) obtained from 4 individual samplings.

* Determined by ET-AAS.

n.d.: Not detected.

Table 5. Trace elements distribution in the different particles size fractions of air particulate matter collected at 5100 m s.l. in Himalayas (Khumbu valley – CNR Pyramid, March-May 2002)

Element	TSP, ng/Nm ³	PM10, ng/Nm ³		PM2.5, ng/Nm ³	
	mean ± SD	Mean ± SD	% of TSP	Mean ± SD	% of PM10
As	0.14 ± 0.04	0.13 ± 0.05	93	0.04 ± 0.02	31
Br	2.12 ± 0.75	1.98 ± 0.70	93	1.17 ± 0.67	59
Ca	483 ± 121	380 ± 77	79	65 ± 20	17
Cd*	0.04 ± 0.03	0.03 ± 0.01	75	0.015 ± 0.006	50
Ce	1.1 ± 0.5	0.78 ± 0.20	71	0.11 ± 0.07	14
Cl	175 ± 110	40 ± 22	23	22 ± 8	55
Co	0.43 ± 0.12	0.40 ± 0.15	93	0.20 ± 0.09	50
Cr*	3.6 ± 1.7	3.1 ± 2.0	86	1.7 ± 0.9	55
Cs	0.22 ± 0.07	0.18 ± 0.04	82	0.016 ± 0.006	9
Cu*	3.6 ± 1.4	2.8 ± 1.1	78	1.9 ± 0.7	68
Fe	500 ± 185	435 ± 108	87	63 ± 30	15
Hf	0.036 ± 0.006	0.024 ± 0.007	67	0.008 ± 0.003	33
Hg	<0.01	<0.01	–	<0.01	–
I	1.1 ± 0.4	0.8 ± 0.6	73	0.37 ± 0.23	46
K	392 ± 123	300 ± 61	77	69 ± 36	23
La	0.43 ± 0.13	0.40 ± 0.08	93	0.10 ± 0.03	25
Mg	490 ± 220	452 ± 130	92	44 ± 24	10
Mn	11.4 ± 4.3	8.3 ± 2.3	73	1.1 ± 0.3	13
Mo	<0.2	<0.2	–	<0.2	–
Ni*	1.5 ± 0.7	1.2 ± 0.7	80	0.8 ± 0.4	67
Pb*	4.4 ± 2.4	3.7 ± 2.6	84	2.6 ± 2.0	70
Rb	1.9 ± 0.6	1.7 ± 0.5	89	0.20 ± 0.11	12
Sb	0.42 ± 0.28	0.36 ± 0.26	86	0.22 ± 0.14	61
Se	0.17 ± 0.05	0.09 ± 0.06	53	0.03 ± 0.008	33
Sc	0.16 ± 0.05	0.12 ± 0.03	75	0.022 ± 0.009	18
Ta	0.05 ± 0.03	0.016 ± 0.012	32	<0.01	–
Ti	73 ± 39	53 ± 13	73	7.4 ± 2.9	14
Th	0.21 ± 0.05	0.18 ± 0.02	86	0.02 ± 0.01	11
U	0.026 ± 0.020	0.018 ± 0.010	69	<0.01	–
V	1.30 ± 0.2	1.12 ± 0.19	86	0.25 ± 0.05	22
Zn	11.2 ± 5.4	6.5 ± 3.0	58	5.8 ± 2.1	89

Mean values and relative SD (1σ) obtained from 4 individual samplings.

* Determined by ET-AAS.

Conclusions

The elemental characterization of the airborne particulate matter collected in the Himalayas region at 5100 m s.l. during the period of March–April 2002 has been accomplished. The concentration in ng/Nm³ of more than 30 elements has been measured in the different particles size fractions (total suspended particles-TSP, PM10 and PM2.5). To our knowledge, these data constitute, at present, the first series of values obtained in this region of the world and must be considered preliminary. Nevertheless, the results furnish information about the local ranges of concentrations experimentally measured that can be used to set up and plan further investigation in this area. The major part of

the elements has been determined by INAA that has demonstrated its great capability in performing multielemental analyses on few micrograms of air dust collected onto filters.¹² Furthermore, a very accurate evaluation of blanks arising from filters, field-blanks and the overall pre-analytical procedures was carried out. The results of this work refer to the pre-monsoon and additional sampling campaigns in the post-monsoon period of September–October are envisaged to obtain a more comprehensive set of data. The new results will give important information either in assessing these preliminary data or to evaluate possible long distance transport phenomena related to seasonal variations. This may be monitored by following those elements present in the finest airborne particulate fraction.

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