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Environmental chemistry of a rare muddy snowfall occurrence on Alpine zone glaciers of Gulmarg, Kashmir Himalaya, India

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ABSTRACT

The Kashmir Himalayan valley witnessed some unique environmental pollution phenomena including black snow and outbreak of red-tide in lacustrine systems during early 1991. The occurrence of a rare muddy snowfall in May 2002 on high altitude (>4300 m.asl) Afarwat glaciers in the alpine zone (near Gulmarg) of Pir Panjal mountainous range of the Kashmir Himalaya indicates changing environmental scenario of the region. The principal hydrochemistry of the snow samples collected from the glacier revealed relatively high pH values (6.2-6.9) as compared to low records (pH;5.6) in snow samples of the valley-floor (alt.1600 m). The ionic composition showed relatively high values (u eq L^{-1}) of chloride (12), carbonates (20), bicarbonates (36) and silicates (19) in the top-most layer of the glacier whilst dissolved oxygen and dissolved organic matter were below detection levels. On the contrary, low levels of nitrate (3.3 u eq L^{-1}) and ammonical-nitrogen (2.8 u eq L^{-1}) were recorded in glacier snow samples compared to valley-floor samples. The comparison with published works from other regions of the world indicates that the ionic concentration is higher in the glacier snow of the Kashmir Himalaya.

Key words: Chemical environment, Muddy snow, Himalayan glacier, Kashmir, Comparison, World-records

INTRODUCTION

Events of substantial aeolian dust deposition on seasonal snow covers and glaciers are a common phenomenon in mid-latitude, (sub-tropical) and even high arctic regions. Such events are emerging as important environmental issues in view of their glacio-chemical and glacio-meteorological aspects. The atmosphere, an integral and huge component of biosphere, receives inputs from myriad anthropogenic activities including expanding industrial establishments. Varied emissions, *inter alia*, noxious gases and particulate pollutants have inherent potential to travel long distances with air/wind currents and get settled depending upon the micro-climatic conditions of the region. Research studies on snow chemistry is a useful tool for assessing the environmental impact of air pollution sources as well as the transport/ deposition of pollutants. Several works have been published on the chemical composition of snow in different parts of the world such as upland site in Mid-Wales (Reynolds 1983), remote Scottish catchment (Tranter *et al.,* 1987), California (Gunz and Hoffmann 1990), Mt. Everest region (Marinoni *et al.,* 2004), high Arctic (Toom-Sauntry and Barrie 2002), and north-eastern European Russia (Walker *et al.,* 2003). However, scanty investigations (Naik *et al.,* 1995, Sarfaraz *et al.,* 2001 and Lone and Khan 2007) have been undertaken on the snow chemistry in India particularly mountainous region of Himalaya .Very recent muddy snow-fall occurrence observed in May 2002 on high altitude. Afarwat glaciers (> 4300 m. asl) on Pir Panjal Range in the Kashmir Himalaya by Lone and Khan (2008) is considered to spell growing environmental pollution in the region.

Kashmir (33°-34° N; 73°-75° E) is a deep elliptical bowl-shaped valley bounded by the lofty mountains of the Pir –Panjal Range in the south and southwest and the Great Himalayan. Range in the north and east. Preponderance of glaciers and patches of snow fields, plateau-like features (thick accumulation of the Pleistocene glacial moraines locally known as Kaerwas) constitute some outstanding physiographic elements of the region. In the recent past, Kashmir valley has witnessed some environmental manifestations. A report about the occurrence of "Black Snow" on the mountain peaks of Gund, Sonamarg (Kashmir) observed during March, 1991 was attributed (Kawosa, 1991) to the burning of oil-fields during Gulf war. Occasional showers of muddy rains were also witnessed in some regions of the Kashmir valley during April 2002. The rare occurrence of muddy snowfall on the Afarwat glaciers in the alpine zone of Kashmir Himalaya in May 2002 evoked considerable environmental concern because of its direct bearing on drinking water supplies, and the ecology of numerous natural snow-fed streams.

The present study deals with environmental aspects of rare environmental phenomenon of muddy snowfall occurrence on the Afarwat glaciers in the alpine zone of the Kashmir Himalaya, and compares the findings with data reported from other regions of the world.

Physical environment and study area

The physical environment of the Kashmir Himalayan Valley, in conjunction with other northern parts of India, is markedly influenced by the western disturbances during spring (March-May). These disturbances can be observed as a low pressure area at the surface, or as a cyclonic circulation in the lower troposphere, or as a trough in the upper westerly, and emanate from the Mediterranean, Caspian and Black Sea.Such disturbances moving across Iran and Turkistan affect the subcontinent north of 30° N. Their frequency of occurrence while passing eastward on an average varies from 2-5 during spring and 7-8 during winter affecting the northern-most parts of India. These disturbances are accompanied by heavy rainfall and rapid drop in temperatures; accentuating snow-formation and ice in these regions as reported in Naik *et al.,* (1995). Sometimes, southwesterly winds also travel from Indian plains during spring-summer and pollutants and natural aerosols. The Kashmir region occupies a strategic position in India (Fig.1) bordering.Afghanistan in the north-west, Pakistan in the west and China and Tibet in the north and east. The study area is the Afarwat glacier in the alpine zone at an altitude of about 4307 m a.s.l in the mountainous Pir Panjal Range of Himalaya. At the foot of the glacier is situated the world famous ice-skiing tourist spot, Gulmarg, renowned for its stupefyingly beautiful surroundings. This place is located at a distance of about 55 km to the north-west of Srinagar city (summer capital of Jammu and Kashmir State). Some of the drainage streams of the glacier include Buniyar Nallah and Ferozpore Nallah, the latter joining river Jehlum which confluences with one of the Asia's largest water body-the Wular Lake.

MATERIAL AND METHODS

The field survey at Afarwat glacier (alt.4307 m.asl) was conducted in May 2002. Snow samples were collected from selected sites; the top-most layer (T_1) and 30 cm depth (T_2). Snow-melt water samples were also collected from the water channels (T_3) at the lower slopes of the glacier. The other sample was collected from the water stream (T_4) flowing at the base of the mountain receiving the entire snow melt (run-off) from the mountain. The Shalimar Campus, Srinagar in the valley-floor (alt.1600 m) was chosen as a control site (C) for the comparison purposes. A glass cylinder (length 40 cm; dia 5 cm) was used for sampling. The snow samples were transported to the laboratory in carefully washed polyethylene bottles, rinsed with deionised water. The snow-melt water was then filtered to separate the muddy suspended particulate matter through Whatman (No.42) filter paper and the filtrate was stored in polyethylene bottles washed and rinsed with deionised water. Standard methods (APHA 1992) were used for various physical and chemical variables. The pH of snow melt water was measured immediately by using electronic digital pH-meter (Systronics 327). The alkalinity forms (CO_3 and HCO_3) were determined against standard solution of H_2SO_4 ; Chloride content was estimated titrimetrically against $AgNO_3$. Phenol-disulphonic acid method was used for obtaining nitrate levels whilst ammonical-nitrogen was analaysed using Nesseler's Reagent. The silicate content was measured by using acid-molybate solution. The estimations were performed on spectrophotometer (Systronics). Dissolved organic matter (DOM) was obtained as oxygen consumed from $KMnO_4$ titration. Analysis of cations (Ca^{2+} and $mg^{2+)}$ was done titrimetrically using Na_2EDTA (disodium dihydrogen ethylene diamine tetra-acetate). Copper content was estimated on AAS (Atomic Absorption Spectrophotometer, GEC 902, Australia).

RESULTS AND DISCUSSION

Chemical Composition of Snow

Field observations of the affected glacier region showed that the upper layer (16-12 cm) of the snow was covered with grayish muddy particulate matter. Data on hydrochemistry of the snow samples collected from the Afarwat glacier and valley-floor (Shalimar campus, Srinagar as a control site) are given in Table 1. The pH value of the glacial snow was close to alkaline range and varied between 6.2 and 6.9. This suggests a strong influence of alkaline dust which might have originated from the Indian plains or arid zones in the west and transported to the region by south-westerly winds. The anions (Cl^- CO_3^{2-} and HCO_3^-) were present in appreciable concentration in all the snow samples (Table 1); higher values were recorded in top-most snow layer (T_1) followed by 30 cm depth sample (T_2), snow-melt channel water (T_3) and stream-flow water at the base of mountain (T_4). The total hardness of the snow samples is correlated with anionic concentration .The lack of dissolved oxygen (DO) and dissolved organic matter (DOM) in the glacier snow samples could be attributed to the oxygen-deficiency and absence of organic wastes respectively at such high altitudes. The concentrations of NO_3^- and $NH^{-4}{}_{-}$N were low in the snow samples collected from the Afarwat glacier as compared to valley plain snow samples (Control site). The higher NO_x concentrations originating from automobiles in the lower plains of

Table 1: Data on ionic composition (averages) on muddy snow of Afarwat glaciers (T_1-T_4 layers) and snow samples of valley plains (C)

Variable	T1	T2	T3	T4	C
pH	6.9	6.4	6.32	6.2	5.66
Cl^- (u eq L^{-1})	12	9.5	8.8	6.3	1.3
$CO3^{2-}$ (u eq L^{-1})	20	18	16	14	9
HCO^{3-} (u eq L^{-1})	36	34	35	30	10
DO (u eq L^{-1})	BDL	BDL	BDL	BDL	5.2
DOM (u eq L^{-1})	BDL	BDL	BDL	BDL	5.4
NO_3^- (u eq L^{1})	3.3	3.6	3.8	4	6.7
NH_4^+- N (u eq L^{-1})	2.8	3	4.5	4.8	15.
Total hardness (u eq L^{-1})	125	120	118	95	68
SiO_3^{2-}	19.	7	6.5	6	2
Ca^{2+} (u eq^{-1})	42.6	24	22	22	13.6
Mg^{2+} (u eq L^{-1})	10.83	8.78	7.5	7	4.8
Cu^{2+} (ug L^{-1})	51.7	17.1	10.8	8.9	6.6

T_1= Top snow layer; T_2 = 30 cm underneath the top snow layer, T_3 = Drainage site of glacier; T_4= Water stream ;C = Samples collected from Shalimar Campus, SKUAST-K

BDL =Below Detection Level

valley accounts for increased levels of nitrogen-forms in snow samples. Under normal atmospheric conditions, HNO_3 can initially form Aitken nuclei which will grow rapidly in to submicron size and react with NH_4^+ to form NH_4NO_3. This reaction is stated (Khemani *et al.,* 1987 a, b) to be reversible and temperature dependent. The formation of NH_4NO_3 in tropical countries is rare due to persistence of higher temperature. However, HNO_3 can react with soil derived or some industrial particulates and become incorporated in snow as the coarse aerosol (Wolff 1984). The data also indicate that concentrations of cations (Ca^{2+}, Mg^{2+}, Cu^{2+}) were higher in the glacier samples covered by muddy particulate layer in the Kashmir Himalaya.

Chemical Composition of the Residue/ Particulate Deposition

The dry residue of the snow melt filtrate appeared grayish cement like dust and showed strong binding and setting ability when mixed with sand (ratio1:2). The hardness was markedly evident after 24 hours suggesting that the particulate matter might be containing a significant proportion of Portland cement. This lends support to our observations that a significantly higher content of Ca^{2+}, Mg^{2+} and SiO_3^{2-} are present in the top most snow layer (T_1) of glacier as all these elements are the important constituents of Portland cement. The chemical composition shows that residue/ particulate deposition approximately contains Lime stone = 78 %, Clay = 20.5 %, Gypsum = 5 % and Iron ore= 1.5 % in which the major constituents are CaO = 61.53 %, SiO_3= 22.75 % and MgO = 4.2 % (courtesy: JK Cements, Srinagar). Such a chemical composition, typical of Portland cement, suggests that these particulates/ aerosols might have origin in the emissions from industries/some cement manufacturing units or stone quarrying activities.

Comparison with other Snow Samples of the World

Table 2 provides a comparison of hydro-chemical features of Afarwat glacier snow in the Kashmir Himalaya with published world records, and wide variations are discernible. The pH of snow at Afarwat glacier is almost neutral (6.9) as compared to low records (4.5-6.2) from other regions. Precipitation acidity is assumed to originate primarily

Table 2: Comparison of the ionic composition of muddy top-most snow layer on Afarwat glacier with other regions of the world. (all values in u eq L^{-1} except pH)

Location	Cl^-	NO_3^-	Ca^{2+}	Mg^{2+}	pH	Reference
Afarwat glacier Kashmir, Himalaya	12	3.3	42.6	10.83	6.9	present study
Valley Plains, Kashmir	1.30	6.7	13.6	4.8	5.66	present study
Gulmarg, Kashmir	9.4	3.4	10.5	1.8	6.2	Naik *et al* (1995)
East Rongbuk Glacier Mt. Everest (Fresh Snow Samples)	1.02	1.14	1.71	0.23	-	Kang *et al* (2004)
Alert, Nunavut, Canada (Upper Barrie (2002) Quartile)	21.81	6.13	37.87	8.43	-	Tom-Sauntry and
Mount Everest Fresh Snow	4	4	38	-	6.2	Mariononi *et al*., (2001)
Mid Wales	21	11	4	-	4.5	Reynolds (1983)
Central and Southern California	16.6	5.1	4	-	5.2	Gung and Hoffmann (1990)

from sulphuric and nitric acids. The atmospheric alkaline ions (e.g. NH_4^- and Ca^{2+}) mostly originate from biogenic sources of NH_4 and other anthropogenic activities and tend to neutralize the acidity in snow samples. In assessing the impact of acid and alkaline species on snow chemistry it is important to know their relative concentration in the snow of Afarwat glacier under study and compare with ionic composition of snow from Gulmarg, North India; Mount Everest, in southern Tibet in the Himalayan region as well as in East Rongbuk Glacier; Alert Nunavut Canada; rural upland site in Mid Wales, UK and in central and southern California, USA (Table 2).

During the present study, the calcium content was observed 4-times and magnesium 6-times higher compared to a decade earlier published record in Naik *et al.,.,* (1995) of Gulmarg snow samples of Kashmir Himalayan region. The calcium content in mid-Wales and California, USA snow samples was extremely low (4 u eq L^{-1}).However fresh snow of Mount Everest and Alert Nonavut, Canada, showed narrow variations with calcium values to Afarwat glaciers. Since nitrates are mainly derived from anthropogenic sources, their concentration in the top most snow layer (T_1) on Afarwat glacier is much lower as compared to Kashmir plains for that reported earlier by Nail *et al.,* (1995) for the region. This justifies the near neutral pH character of snow at Afarwat glacier which may also be due to the presence of higher concentration of alkaline material. The data also indicate that the snow at Afarwat glacier. Kashmir Himalaya, and Mount Everest has high Ca^{2+} contents and nearly neutral pH whilst the Welsh snow is more acidic and characterized by low Ca^{2+} content. The influence of alkaline components on the pH of rain, cloud and fog water in India are well documented in Khemani *et al.,* (1987 a,b). The high concentration of the alkaline components (Ca^{2+} and Mg^{2+}) are responsible for the high pH of precipitation in India and the alkaline pH in the snow samples at Afarwat glacier is consistent with these observations. The presence of appreciably higher concentration of Ca^{2+} reported by Morinoni *et al.,* (2001) in the snow samples of Mt.Everest has been attributed by Wake *et al.,* (1993) to the long transport of Asian dust. Other studies conducted by Parrington *et al.,* (1983) and Goa *et al.,* (1992) have also shown the high ionic concentration of Ca^{2+} in pre-monsoon snow. Such a situation is opined to be as a result of dust deposition during the peak dust storm activity mainly in April and May over Asia. The heavy metal content (Cu^{2+}) in different snow samples during the present study was strikingly higher (51.7 ug L^{-1}) as compared to valley-floor sample (6.6 ug $^{-1}$).

The comparison with snow samples collected from unpolluted areas of Mt. Kitanomine, Houheikyou and Greenland (Table 3) reveals that the Cu^{2+} content is much higher in the top-most snow layer (T_1) on Afarwat glacier and can be attributed to the transportation of Cu^{2+}contaminated particulates from anthropogenic activities. Studies conducted by Sakai *et al.,* (1988) on heavy metal concentration in urban snow as an indicator of air pollution indicates that copper content varied from 0.6-9.7 (Toyohira River basin), 7.2-27.8 (snow dumping station) and 17.7-75.4 ug L^{-1} (urban area of Sapporo City) and attributed it to the accumulation of mixing of various pollutants from industrialization. Very low copper content (0.15 ugL^{-1}) is reported by Weiss et al., (1975) in Greenland glaciers.

Afarwat glacier has a considerable influence on the quality of river and lake water in Kashmir Himalayan region. It is likely that the higher concentration of Ca^{2+} in muddy snow melt after reaching lake basins may result in $CaCO_3$ precipitation (marl formation). Such phenomena have been also reported (Khan and Zutshi 1980, Khan 2000) in Kashmir valley lakes. According to

Table 3: Comparison of copper content (ug L^{-1}) in muddy snow layer samples of Afarwat glacier with other unpolluted areas of the world

Location	Cu^{2+}	Reference
Afarwat glacier, Kashmir Himalaya	51.7	present study
Valley-floor, Kashmir	6.6	present study
Houheikyou	0.6	Sakai *et al.,* (1988)
Greenland glacier	0.15	Weiss *et al.,* (1975)

Moss (1980) the calcium and bicarbonate rich waters have a thick deposit of Ca^{2+} and Mg^{2+} (marl) covering the macrophytes and algal communities. Such precipitations may interfere with aquatic biotic communities of water ecosystems.

The plausible reasons for the rare muddy snowfall occurrence on Afarwat glaciers of the Kashmir Himalaya could be (i) that the clouds loaded with particulate matter might have traveled from some northern state of India with some south-

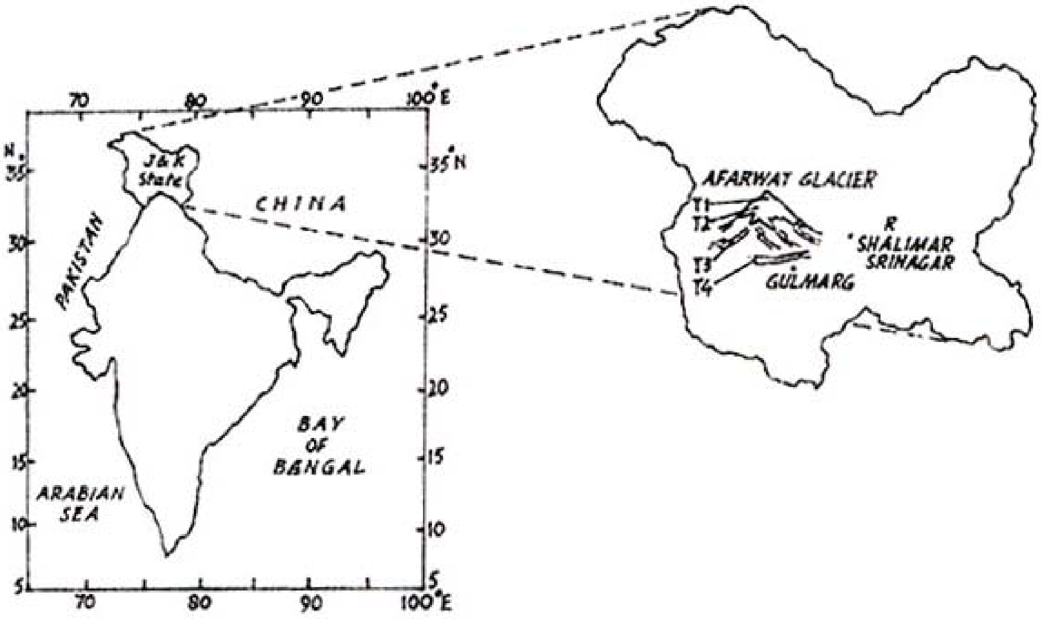

Fig. 1: Map of India (Left) and J&K (Right) shownig the location of afarwat glacier on pripanjal range and the location of sampling sites

westerly monsoon winds or from north-western countries (including Pakistan, Iran, Iraq and Afghanistan etc.) as a result of western disturbances in Mediterranean Sea. However, the former explanation seems more valid in view of the fact that Pir Panjal Range acts as a natural barrier to the south-westerly winds coming over Indian plains. After reaching higher peaks (here Afarwat glaciers) the contaminated cloud droplets (crystals) condense due to the low temperature usually prevailing at high altitude (ii) that the dust emission from cement factories operating in various parts of the valley could be another source of this muddy deposition. Since the Kashmir valley is surrounded by mountains, there are little chances of suspended particulate matter undergoing dispersion to far off places. Such unique physiographic characteristics render Kashmir Himalayan valley more vulnerable to ravages of changing environmental scenario including recent rare muddy snowfall phenomenon.

CONCLUSION

Concluding, the results clearly demonstrate that the muddy snowfall samples of Afarwat glacier in the alpine zone of Kashmir Himalayan region contain higher ionic composition compared to the snow samples from Kashmir valley-floor and other regions of the world. The study calls for an urgent need to undertake inter-disciplinary environmental investigations to assess the changing ecology of mountain ecosystems especially vast glaciers which are important constituents of water resources of the Himalayan regions.

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