Canopy arthropods of *Vateria indica* L. and *Dipterocarpus indicus* Bedd. in the rainforests of Western Ghats, South India

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This study aimed at quantifying the total arthropod diversity by fogging the rainforest canopies at Makuta, Western Ghats. Emergent canopies of *Vateria indica* and *Dipterocarpus indicus* were fogged with short-lived pyrethroid and arthropods collected. Arthropod samples thus obtained were comparable with those from other tropical parts of the world for species richness and diversity. In general, arthropods from *D. indicus* were more diverse than those from *V. indica*. Coleoptera tended to be more dominant and hence less diverse in canopies of both trees. The most diverse group in *D. indicus* was Diptera, while Areneae was the most diverse group in *V. indica* canopy. The proportion of singletons was extremely high for all the groups, often exceeding 75%. Our results suggest that the arthropod composition of the most dominant tree species in the forest could significantly influence the composition of the samples drawn from other tree species in the same forest.

FOREST canopies, defined as 'the aggregate of all crowns in a forest stand'[1], are known to be the heart of terrestrial biological diversity[2,3] and guide several crucial ecosystem processes. The rich variety of life, range of adaptations and complex interactions make the canopy a world in itself[4]. Although early investigators began the process of documenting organisms that live up there, it was not until Erwin[5] that canopy studies drew global attention. Erwin's estimates based on fogging of canopies of *Luehea seemannii* Triana and Planch (Tiliaceae) in the rainforests of Panama, raised the global species richness to 30–100 million from 3 to 5 million[6]. Since then, there has been a flurry of canopy studies across the world, so much so that the rate of publications on canopy surpassed those from the general fields of biology[7].

In India, canopy studies can be traced back to the times when specimens were collected (viz. vegetative and reproductive parts of the canopy species, orchids and other epiphytes) for taxonomic descriptions[8]. However, there have been no studies from India quantifying the biological diversity in these rooftops despite its significance for conservation[9]. Recognizing the need to quantify this biological diversity in India, we initiated studies on the diversity of canopy arthropods by sampling two emergent canopies in the Western Ghats through insecticide-fogging. In this communication, we compare arthropod diversity in canopies of two dipterocarp (Dipterocarpaceae) species (*Vateria indica* L. and *Dipterocarpus indicus* Bedd.) and across four major groups of arthropods – Coleoptera (beetles), Diptera (flies), Hymenoptera (wasps) and Areneae (spiders). In addition to the above-mentioned groups, the samples obtained through fogging included scorpions, mites and other groups of insects (Heteroptera, Orthoptera, Thysanoptera, Lepidoptera, Psocoptera, Blattodea, Mantodea, etc.). However, due to poor representation (in terms of number of species) and/or difficulties in identification, data from the latter-mentioned groups have not been considered for analysis. As there are difficulties in comparing the abundances of social arthropods (like ants) with non-social arthropods, data from the former have also not been considered for analysis.

The emergent rainforest canopies of *V. indica* and *D. indicus* at Bannadapaare, Makuta (N 12°04′39.2″; E 75°43′33.6″) were sampled during the last week of June 2003. The canopies, located at an altitude of 128 and 87 m amsl for *V. indica* and *D. indicus* respectively, are a part of the linear tree increment plot that lay undisturbed since the 1920s. In terms of abundance, *V. indica* dominates the forest followed by *D. indicus*. Both trees have a moderately dense canopy and are ~40 m tall with the lowermost branch at ~22 m from the ground. At the time of sampling, *V. indica* was in fruiting while *D. indicus* was in its vegetative phase. Three other canopies of *V. indica* surrounded the target canopy of *V. indica*, while two canopies of *V. indica* and a canopy of *D. indicus* surrounded the target *D. indicus* canopy.

Among the many canopy arthropod sampling techniques that have evolved[10], insecticide fogging is widely practised[11]. In the present study samples were obtained using an insecticide fog (Kingfog® @ of 0.34% a.i.)[12] generated from a thermal fogger (Vanfog®). A rope was hoisted from a neighbouring tree as an access to the target canopy; to this access rope, a climbing rope was attached, pulled over and firmly anchored. The climber 'jummared up' to the canopy using ascenders (Figure 1) and fixed a pulley to a branch for hoisting the fogging machine on a separate rope. The fogging machine was then hoisted up to the target canopy. Since the monsoons had already set in at the study site, fogging (Figure 2) was carried out at 09.00 am, allowing for 3 h of sunlight to dry the foliage. A collection system to intercept the 'raining' arthropods was established below the fogging area, well ahead of fogging. The collection system comprised plastic sheets tied to each other making up a total area of 25 m^2. The ends of the sheets were tied to the nearby trees and poles at a height of about 1 m from the ground. The knocked-down arthropods were handpicked and transferred to 70% ethyl alcohol. Arthropods were

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collected up to 1 h after 20 min of fogging. The collections were later sorted into recognizable taxonomic units (RTUs). Only beetles were sorted to families before classifying them into RTUs or 'species'.

A total of 1168 and 1467 arthropods grouped into 219 and 372 'species' were collected from the canopies of *V. indica* and *D. indicus* respectively. The species richness of arthropods from the canopy of *D. indicus* was higher than that of *V. indica* [Margalef's index[13] (D_{Mg}) = 29.60 and 49.33 for *V. indica* and *D. indicus* respectively]. Although Coleoptera represented ~ 40% of the total number of arthropods collected, only ~ 20% of the total arthropod species belonged to Coleoptera. A total of 1074 coleopterans were sorted to 104 species representing 30 families (see Table 1 for details). Formicidae (ants) alone accounted for ~ 32% of the total arthropods collected from the canopies. The overall diversity of arthropods from the canopies at Makuta was comparable with the canopy arthropod diversity in other parts of the world. Eight trees of *Castanopsis acuminatissima* in New Guinea[14], on fogging, yielded an average of 497 individuals of coleopterans grouped to 117 species, which is comparable with the present study, which yielded 537 individuals and 104 species of Coleoptera from two trees. Although ants were the secondmost dominant group among the arthropods sampled in the present study, with a single canopy of *D. indicus* yielding 482 individuals comprising 15 genera and 31 species, they still compare favourably with several studies from Amazon where ants were the most dominant group[15,16].

Figure 1. Accessing the canopy of *Vateria indica* using single-rope technique.

Figure 2. Insecticide (pyrethroids) fogging of the canopy of *V. indica*.

A total of 30 families of Coleoptera were collected from two canopies, with 27 families coming from *D. indicus* and 19 families from *V. indica*. Buprestidae, Cicindelidae, Colydiidae, Corylophidae, Helodidae, Lampyridae, Languriidae, Nitidulidae, Phalacridae, Ptinidae and Scolytidae were represented exclusively in the canopy of *D. indicus*, while Eucnemidae, Elmidae and Scarabaeidae were exclusive to *V. indica*. Interestingly, 72 out of 104 RTUs of Coleoptera belonged to only eight families. *D. indicus* had a higher proportion of species in six of these eight families (Figure 3). A comparison of the two canopies considering the overall beetle species composition showed that two species of Curculionidae (RTUs 2 and 3) and one species of Elateridae (RTU 1) dominated the beetle abundance in both the canopies, whereas one species of Anthicidae (RTU 3) was abundant in *V. indica* alone (Figure 4). Each of the remaining species in both the canopies accounted for less than 3% of the total abundance. A high degree of similarity in species composition was observed between the two trees (Morista–Horn similarity measure[13] = 0.93) in spite of only 12 out of 104 species being shared by them. This high similarity is a result of the 12 species, common in the samples of both trees, accounting for 78.9% of the total coleopteran individuals sampled.

The fruits of *V. indica*, the most dominant emergent tree species at Makuta, were infested with curculionids (RTUs 2 and 3) that dominated the samples. Not surprisingly, these curculionids were also abundant in the samples drawn from *D. indicus*, which was surrounded by two individuals of *V. indica*. We believe that the community composition of the most abundant and spatially well-distributed tree species (as *V. indica* in the present study) would greatly influence the composition of arthropod samples drawn from any other tree species through fog-

Table 1. Number of species and individuals belonging to each of the 30 families of Coleoptera in arthropod samples collected by canopy-fogging from the canopy of *Vateria indica* and *Dipterocarpus indicus* trees at Makuta

	V. indica		*D. indicus*		Total	
Family	Species	Individuals	Species	Individuals	Species	Individuals
Aderidae	1	2	1	1	2	3
Anobiidae	1	1	1	1	2	2
Anthicidae	3	43	2	3	3	46
Anthribidae	2	2	4	4	6	6
Buprestidae	0	0	1	1	1	1
Carabidae	1	6	4	6	4	12
Cerambycidae	1	9	2	5	2	14
Chrysomelidae	4	5	13	17	16	22
Cicindelidae	0	0	2	2	2	2
Cleridae	2	2	2	11	4	13
Coccinellidae	1	1	4	4	5	5
Colydiidae	0	0	1	2	1	2
Corylophidae	0	0	1	1	1	1
Curculionidae	12	370	15	345	21	715
Elateridae	1	36	1	104	1	140
Elmidae	1	1	0	0	1	1
Eucnemidae	1	1	0	0	1	1
Helodidae	0	0	1	1	1	1
Lampyridae	0	0	2	3	2	3
Languriidae	0	0	1	1	1	1
Mordellidae	1	3	1	10	1	13
Nitidulidae	0	0	1	8	1	8
Phalacridae	0	0	1	1	1	1
Ptilodactylidae	2	6	2	5	4	11
Ptinidae	0	0	1	1	1	1
Scarabaeidae	1	1	0	0	1	1
Scolytidae	0	0	1	1	1	1
Silvanidae	1	2	1	10	2	12
Staphylinidae	3	3	10	18	12	21
Tenebrionidae	1	1	2	3	3	4

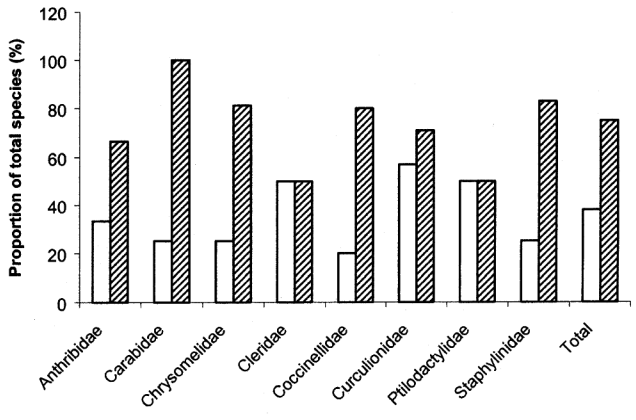

Figure 3. Proportion of species (%) shared between *V. indica* (empty bars) and *Dipterocarpus indicus* (hatched bars) in eight families of Coleoptera represented by most number of species in the collection.

ging, especially if the dominant tree happens to be flowering or fruiting.

Different groups of arthropods collected from the two tree canopies were compared using various measures of richness and diversity[13] (Table 2). Among the different groups sampled from *D. indicus*, Diptera was found to be extremely species-rich ($D_{Mg} = 22.91$) followed by Coleoptera ($D_{Mg} = 12.13$), Areneae ($D_{Mg} = 9.82$) and Hymenoptera ($D_{Mg} = 9.16$). The high species richness of Diptera was, however, not represented in the canopy of *V. indica*, where its species richness ($D_{Mg} = 7.78$) was comparable with that of Areneae ($D_{Mg} = 8.00$). However, the species richness of Coleoptera tended to be lower ($D_{Mg} = 6.29$) and comparable with that of Hymenoptera ($D_{Mg} = 6.23$). Shannon's diversity index (H') also showed a similar trend with the diversity of Coleoptera, Diptera and Areneae being significantly higher (t-test; $P < 0.01$) in *D. indicus* than in *V. indica*. Interestingly, H' was not different between wasps of the two canopy species (t-test; $P > 0.05$). Among the different arthropod groups tested, H' was lowest for beetles (t-test; $P < 0.05$) in both samples. Although H' differed significantly between all the four groups in *D. indica* (t-test; $P < 0.01$), these differences were non-significant across Diptera and Hymenoptera; and Diptera and Areneae in *V. indica* ($P > 0.05$). Fisher's index of diveristy (α) also reflects a similar trend. Even-

Table 2. Diversity measures for different groups of arthropods collected by canopy-fogging from the canopy of *V. indica* and *D. indicus* trees at Makuta. Estimates are based only on 1522 individuals classified into four groups (total number of individuals sampled was 2635)

	Coleoptera		Diptera		Hymenoptera		Areneae	
	V. indica	*D. indicus*	*V. indica*	*D. indicus*	*V. indica*	*D. indicus*	*V. indica*	*D. indicus*
S	40	78	33	118	24	42	32	40
N	495	572	61	165	40	88	48	53
D_{Mg}	6.29	12.13	7.78	22.91	6.23	9.16	8.00	9.82
α	10.27	24.88	29.35	185.29	25.33	31.50	41.96	74.25
H'	1.87	2.51	3.12	4.54	2.76	3.12	3.15	3.52
E	0.51	0.57	0.89	0.95	0.87	0.84	0.91	0.96

S, Species; *N*, Individuals; α, Fisher's alpha index of diversity; D_{Mg}, Margalef's index of species richness; H', Shannon's index of diversity; *E*, Shannon's index of evenness.

Table 3. Number of species and their proportion represented by one (singletons) and two (doubletons) individuals in arthropod samples collected by canopy-fogging from the canopy of *V. indica* and *D. indicus* trees at Makuta

	V. indica				*D. indicus*			
	Singletons		Doubletons		Singletons		Doubletons	
Group	Species	Percentage	Species	Percentage	Species	Percentage	Species	Percentage
Coleoptera	25	62.50	3	7.50	45	57.69	17	21.79
Diptera	22	67.00	5	15.15	99	83.90	8	6.78
Hymenoptera	20	79.17	3	12.50	33	78.57	3	7.14
Areneae	27	84.38	3	9.38	40	85.00	3	7.50

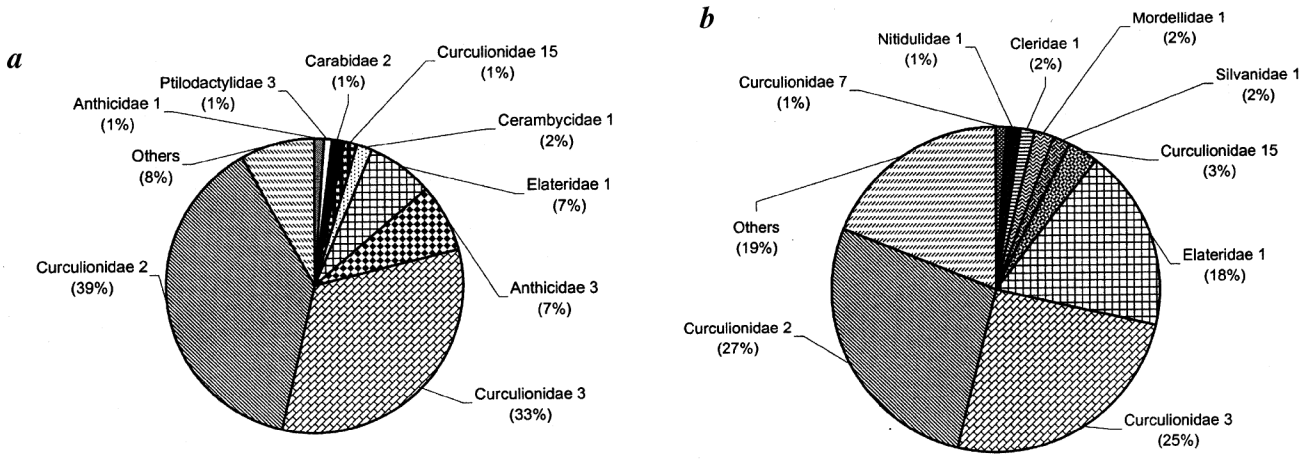

Figure 4. Proportion of individuals representing nine most abundant species of Coleoptera in (***a***) *V. indica* and (***b***) *D. indicus*. Name of the family followed by a number represents a particular morphospecies. Abundance of the remaining species (31 and 69 species in ***a*** and ***b*** respectively) is represented under 'others'.

ness index (Table 3) shows that all the groups except Coleoptera (owing to the large abundances of seed-infesting curculionids), were evenly distributed to a considerable extent. Although the species richness (D_{Mg}) of Coleoptera was greater than that of Hymenoptera and Areneae in *D. indicus*, diversity (H', α) of the latter two was higher owing to greater evenness (*E*) among them.

A comparison of the dominance pattern (through *K*-dominance curves)[17] across different groups within each of the tree species showed high domination of Coleoptera in both trees, suggesting a lower diversity for the group (Figure 5). Although Diptera was clearly the least dominant in *D. indicus*, its dominance is comparable with those of Areneae and Hymenoptera in *V. indica*. *K*-dominance

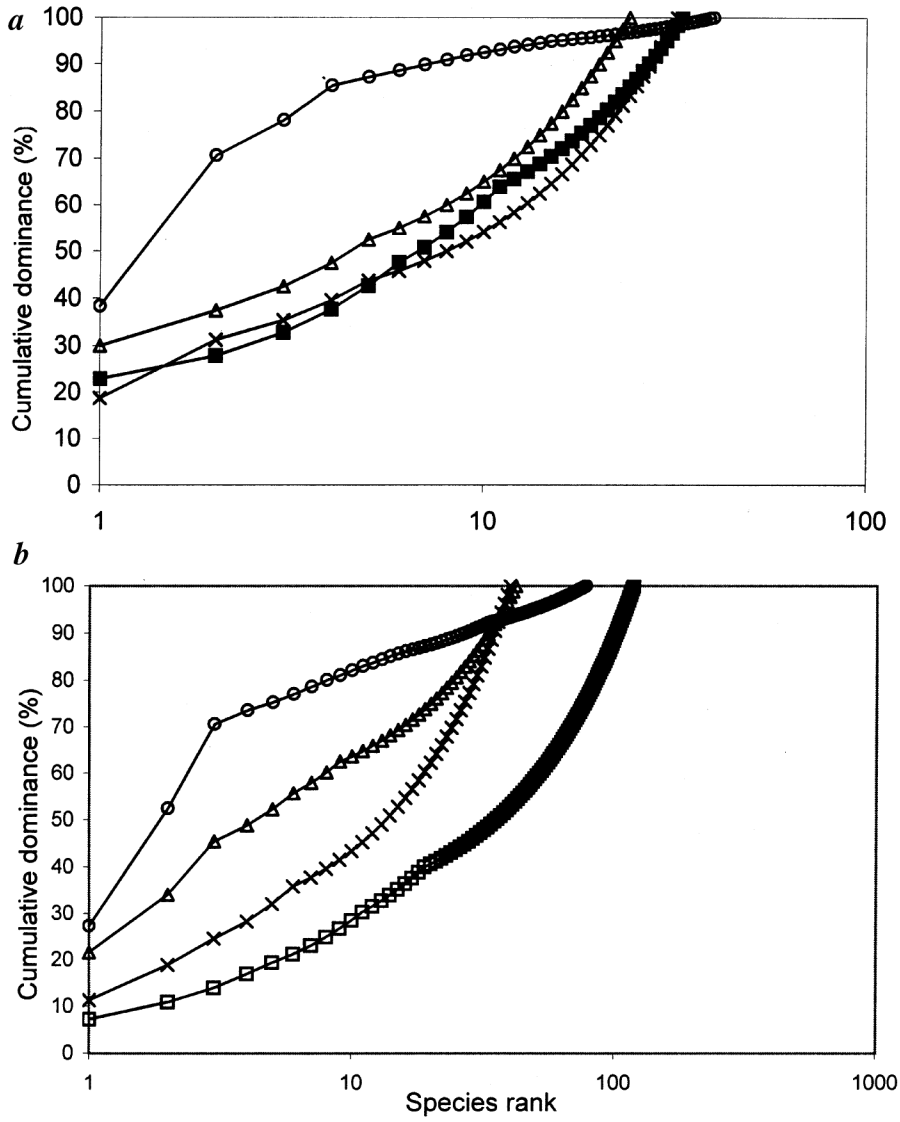

Figure 5. *K*-dominance curves illustrating the diversity of Coleoptera (○), Diptera (□), Hymenoptera (×) (excluding Formicidae) and Araneae (Δ) in (***a***) *V. indica* and (***b***) *D. indicus*.

curves comparing different groups across the two trees (Figure 6) clearly indicated lower dominance for Coleoptera, Diptera and Areneae in *D. indicus* and hence higher diversity over those from *V. indica*. However, overlap of the curves (Figure 6 *c*) in Hymenoptera, although indicates shift in dominance pattern, is difficult to interpret.

An interesting result of this study was the exceedingly high proportion of species represented by one individual (singleton) in the samples (Table 3). An overwhelming majority of Coleoptera (62.50 and 57.69% respectively, in *V. indica* and *D. indicus*) were singletons and comparable with other similar studies[18]. The proportion of singletons for the remaining groups in both trees was exceptionally high and not reported from any study so far. Singletons represented more than 75% of the species of Diptera in *D. indicus*, and Hymenoptera and Areneae in both the tree species. This high proportion of singletons makes it difficult to fit the species-abundance distribution curves and does not permit species-abundance comparison through *Q*-statistics. Results also show that the number of singletons common to both trees is low (only coleopterans were compared here), which suggests that a large proportion of these singletons are true tree-crown specialists[3].

There were two major limitations in the present study. First, as the sampling was done during the monsoons, time available for carrying out the entire operation was highly limited; also, wet leaf condition was not particularly suitable for sampling arthropods through the fogging method. Secondly, the raining arthropods were hand-picked from simple sheets tied below the fogged area due to which most micro-arthropods would have been missed

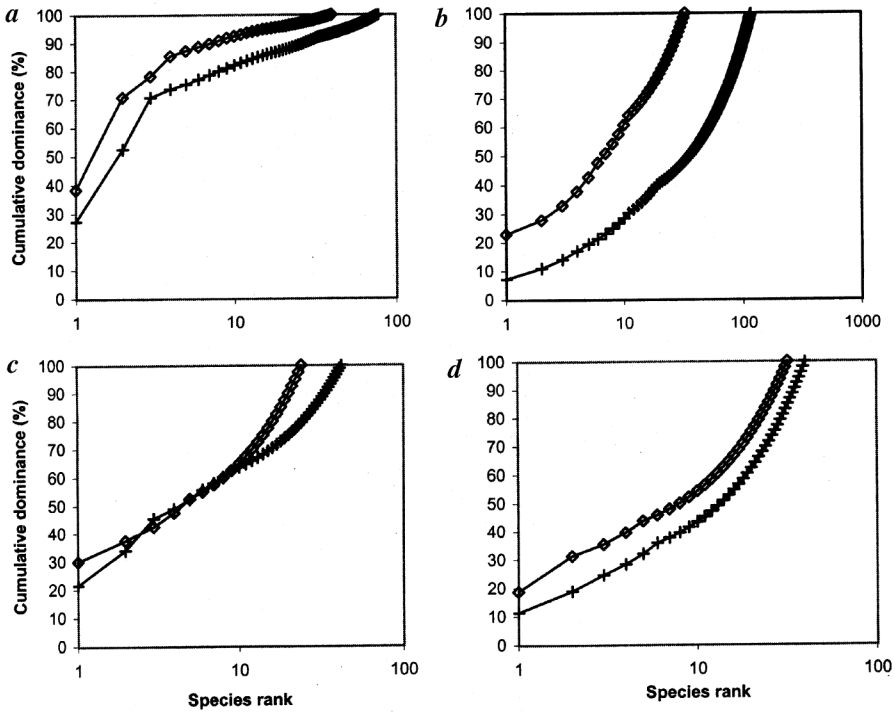

Figure 6. *K*-dominance curves for comparing the dominance among (*a*) Coleoptera, (*b*) Diptera, (*c*) Hymenoptera (excluding Formicidae) and (*d*) Araneae across canopies of *V. indica* (◇) and *D. indicus* (+).

from the samples. However, we would like to emphasize that pyrethroid-fogging is a reliable sampling method in the present circumstances. This method results in an unselective, yet large collection of arthropods particularly useful for taxonomic studies and preparing inventories. With the exception of sedentary forms (like some Homoptera) and those living inside tree trunks (like grubs of cerambycids), most other groups are exceptionally well-sampled through this technique. In spite of the many advantages and a few disadvantages of this technique[11], we would draw your attention to the prominent and inexplicable absence of cicadas (Cicadidae) from our samples when the forest was, at that time, reverberating with their sounds.

Arthropods, particularly insects, play a crucial role in the interaction of plants with their environment and form an important link in most terrestrial food webs. Documentation of their diversity in the forest canopies forms an important step in understanding the functioning of a forest system mediated through their interactions with the 'last biotic frontier'.

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Sampling and preservation artifacts in arsenic analysis: Implications for public health issues in developing countries

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This communication presents the probable sampling and preservation artifacts in arsenic analysis of natural groundwater. It has particularly scrutinized the standard method of sampling and preservation of arsenic, where the sample is to be acidified with concentrated HNO_3 until a pH of less than 2. It has also ascertained the efficacy of sample container material in preserving the original arsenic concentration. Arsenic losses due to preservation imperfections will adversely affect the results and their interpretation from the public health point of view. The communication also discusses that proper sampling and preservation could be the most neglected part of the whole regulation and could be the cause of under-reporting of arsenic contrasted with a higher incidence of arsenic ailments in the population, particularly in the Third World.

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THE analysis of toxic elements in natural water samples is a complicated task, as they are present in a low concentration and are subject to a variety of chemical modifications after sampling. The regulatory limits of most of the toxic elements in drinking water are getting gradually lowered worldwide, as our knowledge about the health effects of trace elements is increasing. Arsenic contamination has been acknowledged as a major public health issue by the World Health Organisation (WHO) based on its international prevalence; WHO has proclaimed that it requires to be dealt with on an emergency basis[1].

As most of the trace elements cannot be determined on-site due to technical limitations, it is a general practice to collect a representative sample and preserve it until analyses in a laboratory. The preservation steps aim to maintain the original concentration of the analytes and their chemical nature. A proper estimation of the concentration and speciation is important from the health point of view, where the dose and its chemical species govern the likely effects. However, many factors contribute to the water chemistry results obtained from groundwater samples. Laboratory analytical methods for most analytes and sample types are well established and carefully documented. Errors associated with the collection and handling of a sample generally exceed those associated with the analysis[2].

Preservation of groundwater samples aims to retard the biodegradation reactions, hydrolysis reactions, precipitation and co-precipitation reactions, sorption reactions and any other physico-chemical reactions, which may occur in a natural sample. Sample preservation usually involves reducing or increasing pH by adding an acid or base preservative and the samples to be analysed for organics are generally preserved by cooling them to 4°C.

The total concentration of the distribution of inorganic arsenic species must be preserved in the field to eliminate changes caused by metal oxyhydroxide precipitation, photochemical oxidation, and redox reactions. Arsenic species sorbs to iron and manganese oxyhydroxide precipitates, and arsenite can be oxidized to arsenate by photolytically produced free radicals in many sample matrices[3]. Several preservatives were evaluated to minimize metal oxyhydroxide precipitation, such as inorganic acids and ethylenediaminetetraacetic acid (EDTA). Aqueous nitric, perchloric, hydrochloric, and acetic acids have been used to help stabilize As (III) and As (V) species, and stabilization was improved by storing samples at temperatures below 15°C. Different storage temperatures and the addition of hydro-