Journal of Nepal Geological Society, 2005, Vol. 31, pp. 11–18

Arsenic and other heavy metals in the rivers of central Nepal

Steven H. Emerman
Department of Biology and Environmental Science, Simpson College,
Indianola, Iowa 50125, U.S.A
(Email: emerman@simpson.edu)

ABSTRACT

The objective of this study was to measure fluvial As, Co, Cu, Fe, and Zn in order to determine whether central Nepal has a geographically-limited source of As. Seventeen rivers in central Nepal outside and eight rivers inside the heavily polluted Kathmandu valley were sampled monthly for six months. Outside the Kathmandu valley, fluvial As (11 ± 1 μg/l), Co (110 ± 30 μg/l), Cu (93 ± 4 μg/l), Fe (550 ± 80 μg/l), and Ni (50 ± 3 μg/l) were over 5, 550, 13, and 13 times the global averages for each respective element, while Zn (27 ± 4 μg/l) was very close to the global average. The only statistically significant differences between inside and outside the Kathmandu valley were pH (inside: 7.13 ± 0.06, outside: 8.13 ± 0.06), Fe (inside: 1060 ± 90 μg/l) and Cu (inside: 70 ± 10 μg/l) so that Co, Cu, Ni, and Zn levels inside the Kathmandu valley were all naturally occurring. Fluvial As was correlated both in space and time with pH. Outside the Kathmandu valley, fluvial As decreased when pH decreased, due to the increase in the number of positively-charged sorption sites on river bed sediment. Inside the polluted Kathmandu valley, fluvial As increased when pH decreased, due to the organic complexation of As and the negative correlation between organic matter and pH. Central Nepal has multiple sources of As associated with mineralisation of Co, Cu, Fe, and Ni, but not Pb-Zn.

INTRODUCTION

Much attention has focused recently on the problem of As contamination of groundwater in West Bengal and Bangladesh (Bhattacharaya et al. 1997; Dhar et al. 1997; Nickson et al. 1998). It is generally agreed that As contamination is too widespread to be due to human activities such as smelting or use of As-based pesticides (Aswathanarayana 1997). Nickson et al. (1998) and Acharyya et al. (1999, 2000) have discussed possible natural sources of As in As-bearing rock units of India and Bangladesh (Bhattacharyya 1972; Das 1977; Ghosh and De 1995). Acharyya et al. (2000) suggested also that the ultimate bedrock source of As may lie in the upper reaches of the Ganges River system. Most workers have investigated not the ultimate source of As, but the mechanism by which As is released from soil or sediment into groundwater (Badal et al. 1996; Mallick and Rajgopal 1996; Acharyya et al. 1999, 2000; Nickson et al. 2000; McArthur et al. 2001; Shanker et al. 2001; Appelo et al. 2002; Bose and Sharma 2002; Harvey et al. 2002; Emerman 2004). In a comprehensive review of the occurrence of As in natural waters, Smedley and Kinniburgh (2002) wrote with regard to the As-bearing sediments in south Asia, "These sediments are derived from the drainage systems of 3 major rivers (Ganges, Brahmaputra, and Meghna) which are themselves sourced from a wide area of the Himalaya. Therefore, while it could be argued that the source of much of the As in the Bengal Basin sediments is derived from specific mineralised areas in the source region, these are likely to be so widespread as to be academic and of little practical relevance."

Arsenic contamination in groundwater is also known to occur in the Terai region of Nepal (Fig. 1a), although it has not been so well documented as in the other parts of south Asia. As of March 2002, nearly 27% of tested wells exceeded the World Health Organisation (WHO) guideline value of 10 μg/l , while 5% exceeded the Interim Nepal Standard of 50 μg/l. The most affected districts were Rautahat, Nawalparasi, Parsa and Bara in the central Terai (Neku and Tandukar 2002). The Terai region is much closer to possible Himalayan As-bearing source rocks than are West Bengal and Bangladesh. Therefore, it is much more likely that it is possible to identify the sources of As mineralisation that affects the Terai region than other parts of south Asia.

The first objective of this study was to measure As concentrations in rivers that drain through central Nepal into the Terai region. If there were one or more As-rich watersheds, then it might be possible to roughly locate the sources of As and to describe the transport of As through surface and groundwater into and through the Terai. The second objective was to measure in the same rivers the concentrations of Co, Cu, Fe, Ni, and Zn, the elements most commonly associated with As (Boyle and Jonasson 1973). If there were correlations between As and one or more heavy metals, then it might be possible to locate sources of As more precisely based on knowledge of mineral deposits of

Table 1a: Rivers sampled in central Nepal outside the Kathmandu valley

No.	Name[a]	Latitude (N)	Longitude (E)	Description and Sampling Dates
1	Aruba[b]	27°36′56.4″	83°57′13.2″	Bridge on Mahendra E-W Highway 2/13, 3/10, 4/23, 5/21, 6/23, 7/14
2	Aruwa[c]	27°10′49.9″	85°10′15.8″	Bridge on Mahendra E-W Highway 2/20, 3/19, 4/23, 5/22, 6/24, 7/15
3	Bagmati	27°07′58.2″	85°28′54.9″	Bridge on Mahendra E-W Highway 2/20, 3/19, 4/23, 5/22, 6/24, 7/15
4	Betara	27°34′15.7″	84°13′03.4″	Confluence with Rapti River 2/13, 3/10, 4/24, 5/21, 6/23, 7/14
5	Binai	27°35′02.8″	83°52′28.9″	Bridge on Mahendra E-W Highway 2/13, 3/10, 4/23, 5/21, 6/23, 7/14
6	Budhigandaki	27°48′53.3″	84°46′55.4″	Confluence with Trishuli River 2/12, 3/11, 4/22, 5/20, 6/22, 7/13
7	Hardinath[d]	27°00′49.8″	85°44′29.9″	Bridge on Mahendra E-W Highway 5/22, 6/24, 7/15
8	Jhim[e]	27°02′10.0″	85°40′22.4″	Bridge on Mahendra E-W Highway 5/22, 6/24, 7/15
9	Kaligandaki	27°44′44.2″	84°25′29.4″	Confluence with Trishuli River 2/12, 3/11, 4/22, 5/20, 6/25, 7/13
10	Kamala	26°52′38.8″	86°08′13.3″	Bridge on Mahendra E-W Highway 2/20, 3/19, 4/23, 5/22, 6/24, 7/15
11	Macha[f]	27°00′17.1″	85°47′45.2″	Bridge on Mahendra E-W Highway 5/22, 6/24, 7/15
12	Malekhu	27°48′24.0″	84°50′00.5″	Confluence with Trishuli River 2/12, 3/11, 4/22, 5/20, 6/22, 7/13
13	Marsyandi	84°51′55.2″	84°32′53.4″	Confluence with Trishuli River 2/12, 3/11, 4/22, 5/20, 6/22, 7/13
14	Narayani	27°41′54.9″	84°25′11.3″	Bridge on Mahendra E-W Highway 2/13, 3/11, 4/23, 5/20, 6/23, 7/14
15	Rapti	27°34′02.1″	84°12′54.9″	Near Meghauli 3/10, 4/24, 5/21, 6/23, 7/14
16	Seti	27°49′16.8″	84°27′15.9″	Confluence with Trishuli River 2/14, 3/11, 4/22, 5/20, 6/22, 7/13
17	Trishuli	27°48′06.6″	84°52′17.7″	Gajuritar, upstream from Malekhu 2/12, 3/11, 4/22, 5/20, 6/22, 7/13

[a]River names are according to DS (2002a,b) and may differ from local names (see below).

[b]Local name is Arun. [c]Local name is Bakeya. [d]Local name is Bankhe. [e]Local name is Phuljor. [f]Local name is Marha.

Table 1b: Rivers sampled in central Nepal inside the Kathmandu valley

No.	Name	Latitude (N)	Longitude (E)	Description
18	Bagmati	27°41′11.7″	85°20′39.7″	Min Bhawan bridge
19	Bagmati	27°41′23.0″	85°18′56.2″	Thapathali bridge
20	Balkhu	27°41′05.2″	85°18′00.2″	Balkhu bridge
21	Bisnumati	27°41′54.3″	85°18′08.2″	Teku Masan bridge
22	Dhobi	27°41′24.6″	85°19′42.2″	Thapagaon bridge
23	Manahara	27°40′24.2″	85°20′28.8″	Balkumari bridge
24	Nakhu	27°39′45.3″	85°18′22.5″	Nakhu Bazar bridge
25	Teta	27°39′57.6″	85°20′01.0″	Ashok Stupa bridge

heavy metals (Sharma 1995a). The third objective was to compare concentrations of As and other heavy metals inside and outside the heavily polluted Kathmandu valley in order to determine which heavy metal concentrations are naturally occurring and which are due to human activities.

MATERIALS AND METHODS

Seventeen rivers in central Nepal outside the Kathmandu valley and eight rivers inside the Kathmandu valley were sampled monthly over six months from February to July 2003 (Tables 1a, b and Fig. 1a, b). Rivers inside the Kathmandu valley were sampled on February 6, March 5, March 30, May 4, June 1, and July 1. Rivers outside the Kathmandu valley were sampled within nine days of one another in February and March and within three days of one another thereafter (see Table 1a for dates). The Hardinath (No. 7, Table 1a and Fig. 1a), Jhim (No. 8), and Macha Rivers (No. 11) were dry until the pre-monsoon rains of May and were sampled only three times. The Rapti River (No. 15) was not sampled in February due to the author's mistaking the Betara River (No. 4), a tributary of the Rapti River, for the Rapti River itself. Thereafter, both the Betara and Rapti Rivers were sampled monthly. The two sampling locations are indistinguishable on the scale of Fig. 1a.

River samples were collected in duplicate 250-ml Nalgene bottles and 2M HNO_3 was added until pH < 2 (Sanders 1998). The river pH was measured on-site with the Oakton pH Tester with ATC (precise to 0.1 pH units) until June and with the Hanna HI 9025 pH meter (precise to 0.01 pH units) in July. Duplicate testing in July verified that the two pH meters gave the same result. The river samples were not filtered, but were allowed to stand for at least 5 days to allow the suspended matter to settle (Salbu et al. 1979). Just prior to analysis, 2M KOH was added until pH > 4 (Sanders 1998). Arsenic was measured with the Hach Arsenic Test Kit, Co and Ni with the Hach Nickel / Cobalt Pocket Colorimeter, Cu with the Hach Copper Pocket Colorimeter, Fe with the Hach Total Iron FerroVer Method Pocket Colorimeter, and Zn with

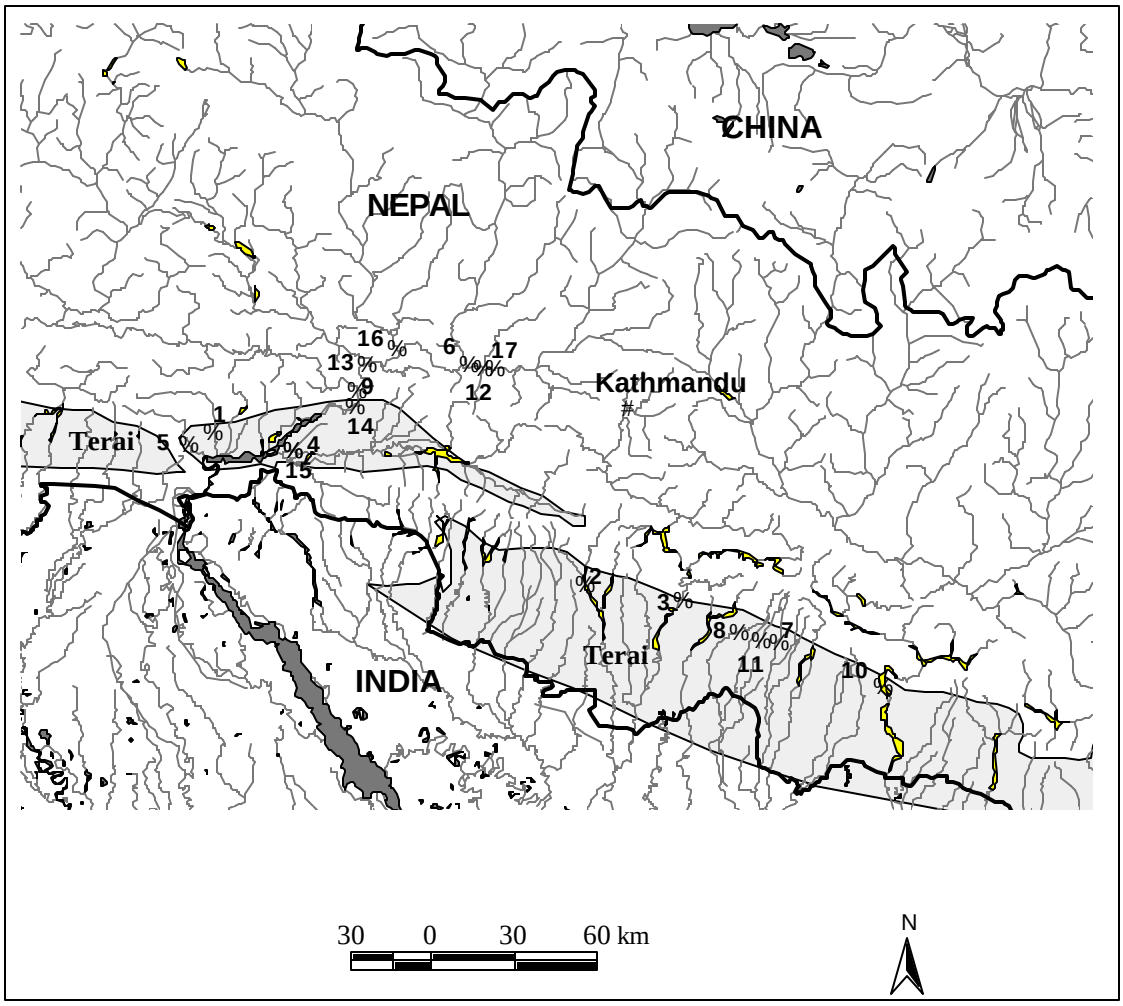

Fig. 1a: Sampling locations for rivers outside of the Kathmandu valley. See Table 1a for river names. Locations nos. 4 and 15 are indistinguishable at map scale. Drainage system and boundaries of Terai are based on Hearn et al. (2001).

the Hach DR/2010 Portable Datalogging Spectrophotometer. The Hach Arsenic Test Kit could be read reliably at 0, 5, 10, 20, 30, 40, 50, 60, and 70 µg/l. The other instruments all had precision and minimum detection value of 10 µg/l. Outliers were re-measured with the duplicate sample. Elemental concentrations were corrected for the dilution with acid and base.

RESULTS

Tables 2a and 2b show pH and As, Co, Cu, Fe, Ni, and Zn concentrations averaged over the six-month period for rivers outside and inside the Kathmandu valley. Other workers (e.g., Lenvik et al. 1978; Salbu et al. 1979) have computed geometric means for fluvial chemical data under the assumption that geochemical data follow a log normal distribution. However, recently Reimann and Filzmoser (2000) have criticised this assumption and argued that log-transformed data rarely are a better fit to a normal distribution than the untransformed data. Moreover, a logarithmic transformation requires an additional assumption about how to handle values that fall below the detection limit. A standard test for a normal distribution is that the cumulative frequency data should lie on a straight line when plotted against a probability scale (Reimann and Filzmoser 2000). The above test was applied to each of the 14 data sets for pH, As, Cu, Co, Fe, Ni, and Zn, outside and inside the Kathmandu valley (results not shown). In no case was it found that log-transformed data more closely followed a normal distribution than untransformed data. Therefore, arithmetic, rather than geometric means, were calculated (Tables 2a, b). Statistical significance was determined by $P < 0.05$ using the T-test (Tables 2b, 3), which assumes that data follow a normal distribution.

Table 2a shows that there is not a small set of As-rich rivers, but that almost all rivers in central Nepal show elevated levels of As. In central Nepal outside the Kathmandu valley the average fluvial As concentration (11 ± 1 µg/l) was over five times the global average (2 µg/l) (Drever 1997). Only the Kaligandaki River (No. 9) and the ephemeral Macha

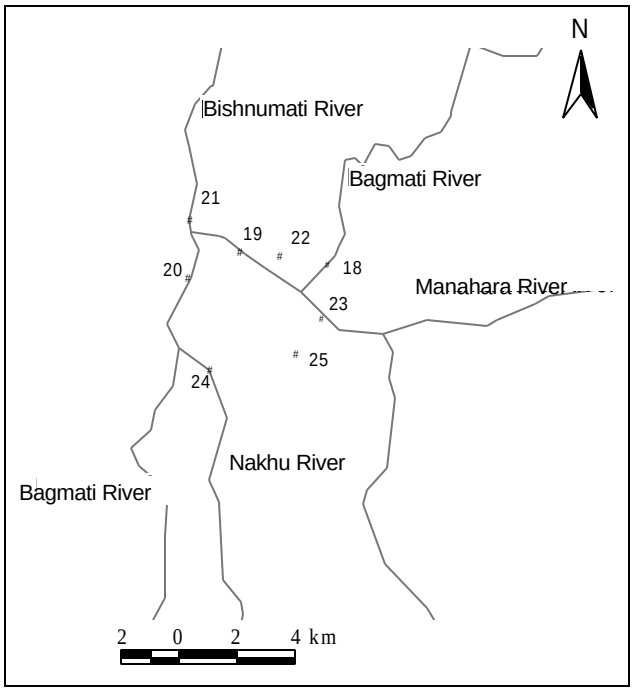

Fig. 1b: Sampling locations for rivers inside of the Kathmandu valley. See Table 1b for river names. Drainage system based on Hearn et al. (2001)

River (No. 11) did not show elevated As levels. Moreover, nearly all rivers outside the Kathmandu valley showed elevated levels of Co, Cu, Fe, and Ni. The average Co concentration (110 ± 30 μg/l) was over 550 times the global average (0.2 μg/l), the average Cu concentration (93 ± 4 μg/l) was over 13 times the global average (7 μg/l), the average Fe concentration (550 ± 80 μg/l) was over 13 times the global average (40 μg/l), and the average Ni concentration (50 ± 3 μg/l) was 25 times the global average (2 μg/l) (Drever 1997). On the other hand, the average Zn concentration (27 ± 4 μg/l) was very close to the global average (30 μg/l).

Table 2b compares pH and As, Co, Cu, Fe, Ni and Zn concentrations inside and outside the Kathmandu valley. The difference between the average pH inside the Kathmandu valley (7.31 ± 0.06) and outside the Kathmandu valley (8.13 ± 0.04) is statistically significant. This difference is probably due to the decomposition of large amounts of organic matter in the rivers of the Kathmandu valley (Sharma 1988, 1995b, 1997). The difference between the average Fe concentration inside the Kathmandu valley (1060 ± 90 μg/l) and outside the Kathmandu valley (550 ± 80 μg/l) is also statistically significant, probably due to the many rusted pipes that empty into the rivers of the Kathmandu valley (Sharma 1988, 1995b, 1997). Inside the Kathmandu valley the As (15 ± 2 μg/l), Co (170 ± 30 μg/l), Ni (80 ± 10 μg/l), and Zn (40 ± 10 μg/l) concentrations are not statistically different from the concentrations outside the Kathmandu valley, indicating that elevated levels of fluvial As, Co, and Ni are naturally occurring in the Kathmandu valley, while the Zn level is simply the global background. It is interesting that the Cu concentration

Table 2a: Average pH, As, Co, Cu, Fe, Ni, and Zn concentrations (μg/l) for rivers in central Nepal outside the Kathmandu valley, sampled monthly (February–July, 2003)

No.	pH	As	Co	Cu	Fe	Ni	Zn
1	8.16(0.09)[a]	13(5)	60(60)	100(20)	180(70)	30(20)	30(10)
2	8.3(0.1)	9(4)	70(40)	90(10)	600(200)	30(20)	40(10)
3	8.2(0.1)	11(5)	90(60)	90(10)	600(300)	50(30)	40(20)
4	7.99(0.06)	16(5)	20(10)	100(10)	180(10)	8(5)	5(2)
5	8.06(0.07)	13(4)	200(100)	80(10)	600(300)	70(50)	20(10)
6	8.26(0.07)	13(4)	30(10)	90(20)	900(500)	30(20)	30(10)
7	7.8(0.6)	8(4)	400(100)	60(50)	1300(500)	180(70)	0(0)
8	8.3(0.3)	13(5)	1000(500)	50(50)	2900(900)	400(300)	20(10)
9	8.1(0.1)	4(2)	40(20)	130(10)	300(200)	10(10)	40(30)
10	8.0(0.2)	8(3)	50(40)	100(20)	500(300)	20(20)	10(10)
11	7.9(0.3)	2(1)	260(60)	80(60)	1200(400)	110(40)	30(20)
12	8.4(0.1)	9(4)	10(10)	100(20)	200(100)	10(10)	7(4)
13	8.20(0.06)	12(5)	20(10)	80(10)	150(70)	10(10)	30(20)
14	7.9(0.1)	13(5)	60(20)	110(10)	140(30)	30(10)	30(20)
15	8.2(0.1)	14(3)	60(20)	80(10)	400(200)	30(10)	40(20)
16	8.26(0.07)	13(4)	80(80)	90(10)	200(100)	90(90)	20(10)
17	8.0(0.2)	13(3)	50(20)	100(10)	700(400)	20(10)	40(10)
Average	8.13(0.04)	11(1)	110(30)	93(4)	550(80)	50(3)	27(4)
Global Average[b]		2	0.2	7	40	2	30

[a]Value with standard error in parentheses; [b]Drever (1997)

Table 2b: Average pH, As, Co, Cu, Fe, Ni, and Zn concentrations (µg/l) for rivers in central Nepal inside the Kathmandu valley, sampled monthly (February–July, 2003)

No.	pH	As	Co	Cu	Fe	Ni	Zn
18	7.1(0.1)[a]	12(4)	300(100)	40(20)	1200(200)	130(40)	50(30)
19	7.2(0.1)	12(4)	180(60)	50(10)	1300(100)	70(30)	70(30)
20	7.2(0.1)	15(4)	60(30)	80(10)	1400(400)	20(10)	7(4)
21	7.11(0.05)	18(5)	210(90)	80(30)	900(200)	80(40)	40(20)
22	7.01(0.06)	30(10)	400(100)	70(20)	1200(400)	160(40)	90(40)
23	7.26(0.08)	18(4)	80(30)	80(10)	1400(200)	40(20)	15(4)
24	8.0(0.2)	6(3)	50(20)	90(10)	410(80)	30(10)	40(40)
25	7.7(0.2)	10(4)	50(20)	70(10)	800(200)	80(60)	20(10)
Avg.	7.31(0.06)***	15(2)	170(30)	70(10)**	1060(90)***	80(10)	40(10)

[a]Value with standard error in parentheses
*, **, *** indicates difference between value inside and outside the Kathmandu valley is statistically significant at the 95%, 99% and 99.9% confidence levels

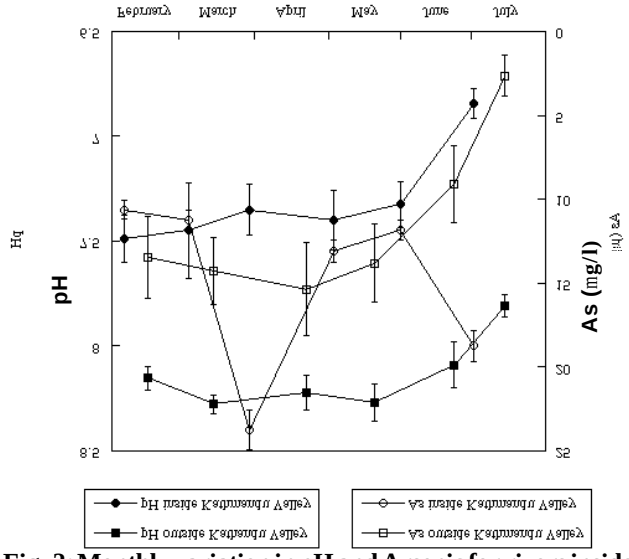

Fig. 2: Monthly variation in pH and Arsenic for rivers inside and outside of the Kathmandu valley. Arsenic outside of Kathmandu valley and pH inside and outside of the Kathmandu valley show similar trends. The onset of monsoon season causes both pH and As to decrease. Arsenic inside the Kathmandu valley increases with the onset of monsoon due to the increase in fluvial organic matter and the organic complexation of As. The early spring spike in As inside the Kathmandu valley is anomalous

is higher outside the Kathmandu valley (93 ± 4 µg/l) than inside (70 ± 10 µg/l) and the difference is statistically significant. The difference is probably due to the relative lack of copper deposits inside of the Kathmandu valley aside from Phulchauki and Chobhar (Sharma 1995a) and emphasises that fluvial Cu in the Kathmandu valley is naturally occurring.

The important question is what distinguishes a relatively low-As river from a relatively high-As river in central Nepal. Table 3 compares the four rivers outside the Kathmandu valley with relatively low As concentration (Hardinath (No. 7) (8 ± 4 µg/l), Kaligandaki (No. 9) (4 ± 2 µg/l), Kamala (No. 10) (8 ± 3 µg/l) and Macha (No. 11) (2 ± 1 µg/l)) with the remaining rivers with As > 9 µg/l. The Co, Cu, Fe, Ni, and Zn concentrations of the two sets of rivers are very similar. The only statistically significant difference is the pH, which is lower for the low-As rivers (7.97 ± 0.07) than the high-As rivers (8.16 ± 0.04). Since As occurs in aqueous form as an oxyanion, it is expected that it would be desorbed from sediment when pH increases. Normally sediment has more negatively charged sorption sites at high pH and more positively charged sorption sites at low pH (Drever 1997). Attempts to correlate As with either Co, Cu, Fe, Ni or Zn, or combinations of the above elements, were uniformly unsuccessful for rivers either outside or inside the Kathmandu valley.

Table 3: Comparison of average pH and Co, Cu, Fe, Ni, and Zn concentrations for low-As (£ 8 µg /l) and high-As (> 9 µg/l) rivers in central Nepal outside of the Kathmandu valley

	Low-As Rivers	High-As Rivers
As (µg/l)	6 ± 2[a]	12 ± 1*
pH	7.97 ± 0.07	8.16 ± 0.04*
Co (µg/l)	190 ± 90	130 ± 70
Cu (µg/l)	90 ± 20	90 ± 4
Fe (µg/l)	800 ± 200	600 ± 200
Ni (µg/l)	80 ± 40	60 ± 30
Zn (µg/l)	20 ± 10	27 ± 3

[a]Value ± standard error
*indicates difference between value for low-As and high-As river is statistically significant at the 95% confidence level

Fig. 2 shows the monthly variation in pH and As inside and outside the Kathmandu valley. Points inside and outside of the Kathmandu valley are offset in time, since they were not measured on the same day of the month. Points outside the Kathmandu valley are plotted on the average day of sampling for each month. The average pH inside and outside the Kathmandu valley showed remarkably similar trends with a roughly constant pH until the onset of the monsoon in June introduced relatively acidic rainwater into all rivers.

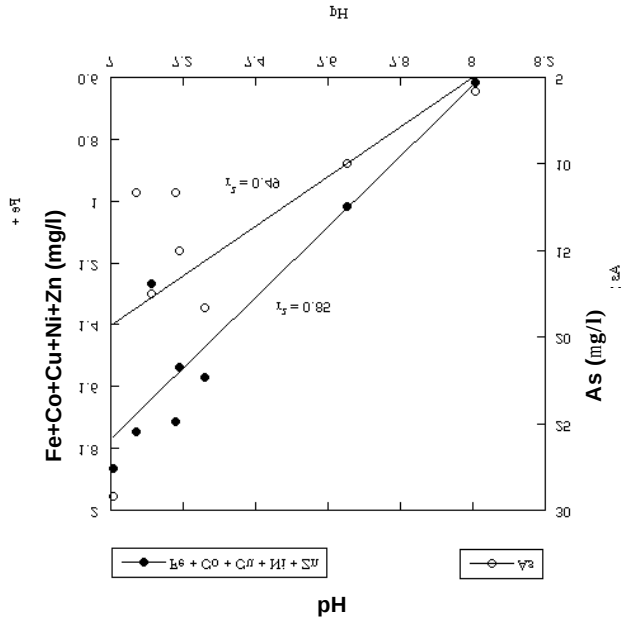

Fig. 3: Dependence of sum of measured cations (Fe + Co + Cu + Ni + Zn) and measured anion (As) upon pH for rivers inside of the Kathmandu valley. The negative correlation of both cations and anions with pH implies that ions are mobilised by organic complexation

Outside the Kathmandu valley, the As level also had a similar trend. Arsenic was roughly constant until the decrease in pH caused sorption of As onto sediment and a drop in fluvial As. The monthly variation in As inside of the Kathmandu valley was more complicated. The increase in fluvial organic matter at the beginning of the monsoon (Sharma 1988, 1995b, 1997) could have resulted in increased fluvial As due to complexation by organic matter (Waslenchuk 1979). It is unclear what could have caused the spike in As inside the Kathmandu valley on March 30.

Fig. 3 shows the dependence of the sum of all measured cations (Fe + Co + Cu + Ni + Zn) and the measured anion As on pH for rivers inside the Kathmandu valley. Each point represents a sampling location averaged over all 6 months (Table 2b). Both cations and anions were negatively correlated with pH. Such similar behaviour is inconsistent with sorption and desorption of ions from charged sites on sediment. Such behaviour would be expected if the dominant process for removing both cations and anions from sediment was organic complexation since the addition of organic matter will decrease pH (Waslenchuk 1979).

DISCUSSION

Related studies include fluvial As in India (Pandey et al. 2002), fluvial pH and Fe in rivers in Nepal inside the Kathmandu valley (Sharma 1997), and As in river bed sediment in Bangladesh (Datta and Subramanian 1997) and Pakistan (Halfpenny and Mazzucchelli 1999). Pandey et al. (2002) investigated high levels of groundwater As in Rajnandgaon District, Chhattisgarh State, India, outside the Bengal Delta Plain, and measured fluvial As in the Shivnath River whose catchment lies in the region with high groundwater As. Pandey at al. (2002) found that fluvial As was undetectable until it began to rise with the onset of the monsoon in June, reached a maximum in July at 60 μg/l, and returned to undetectable by October. As discussed above, elevated fluvial As during the monsoon may be related to elevated levels of fluvial organic matter and organic complexation of As. Aside from the present study, there do not appear to be any published studies of fluvial As in the rivers that drain into West Bengal or Bangladesh.

Sharma (1997) reported measurements of pH in the Kathmandu valley carried out in 1988, 1993, and 1995. Taking only those measurements that match the same sampling locations as the present study, average pH was 7.55 (N = 4) in 1988, 7.15 (N = 4) in 1993, and 7.21 (N = 8) in 1995. This small data set and the present study (average pH = 7.31, see Table 2b) do not show any decrease in river pH over the past 10 years, despite the increase in pollution. Sharma (1997) also reported Fe concentrations measured in 1993 and 1995. Again taking only the measurements that match the sampling locations of this study, average Fe was 900 μg/l (N = 5) in 1995, which again shows no long-term change compared with the present Fe = 1060 μg/l (Table 2b). On the other hand, it is curious that Sharma (1997) reported no detectable fluvial Fe at detection limit 100 μg/l anywhere in the Kathmandu valley in 1993. There do not appear to be any studies of fluvial As, Co, Cu, Ni, or Zn in Nepal.

The chief result of this paper is that central Nepal does not contain one geographically-limited source of As in that nearly all rivers showed elevated levels of As. Nearly all rivers also showed elevated levels of Cu, Co, Fe, and Ni, while fluvial Zn was very close to the global background level. Therefore, As mineralisation may be associated with mineralisation of Cu, Co, Fe, or Ni, but probably not with Pb-Zn mineralisation (Pb and Zn are almost always associated). In central Nepal the best predictor of fluvial As appears to be pH. Outside the Kathmandu valley, fluvial As decreased when pH decreased, due to the increase in the number of positively-charged sorption sites on river bed sediment. Inside the polluted Kathmandu valley, fluvial As increased when pH decreased, due to the organic complexation of As and the negative correlation between organic matter and pH.

The important question now is how the level of groundwater As in a region is related to the level of fluvial As in the rivers that drain into that region. Neku and Tandukar (2002) have shown that groundwater As is high in the Terai region of central Nepal, but not eastern or western Nepal. The next step will be to study the concentrations of As and other heavy metals in the tributaries of the Karnali River, which drains into the western Terai, and the Sapta Koshi River, which drains into the eastern Terai.

ACKNOWLEDGEMENTS

The author is grateful to Professor B. N. Upreti for inviting him to teach and carry out research at Tri-Chandra Campus, Kathmandu, Nepal during 2003. Dr D. P. Adhikari, Dr D. Pathak, Mr. G. Neupane, Mr. S. Shah, and Dr L. Smith assisted with collection of samples. This work was partially funded by a Fulbright Lecturer / Researcher Award through USEF (United States Educational Foundation) Nepal.

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