# Hydrochemical Characteristics of Headwater Streams in the Middle Hills and High Mountains of the Himalayas, Nepal

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**Abstract**

Water chemistry data from seven regions of the Himalayas of Nepal are reported. The data were collected during regional surveys of water chemistry in February 1992 and in October 1994. All samples were collected during low flow conditions. Streams are characteristically well buffered against acidity, with pH around 7.0 and bicarbonate the dominant anion. Bedrock geology exerts the greatest influence on major ion chemistry, and surface water ion relationships may be used to confirm mapped geology. Local geological differences, not currently mapped, promote differences in concentrations of heavy metals and fluoride. Acid anions, sulphate and nitrate, are apparently unrelated to streamwater pH. Sulphate concentrations are positively correlated with calcium and pH, indicating a geological rather than anthropogenic origin. Nevertheless, in some streams, pH was below 6.5, mostly clustered in the eastern regions, and these were characterised by the lowest base cation concentrations. These streams are likely to be sensitive to increased input of acid anions from atmospheric deposition.

**Introduction**

The impact of anthropogenic pollution from industrial and agricultural sources on water chemistry has concerned environmentalists and scientists for the past two decades. This concern has focused on quantification of the impacts of atmospheric deposition of acidic oxides resulting from fossil fuel combustion. Such pollution is known to travel long distances and across international boundaries. As a consequence, the chemistry of headwater streams, lakes, and lowland rivers has been monitored widely in Europe and North America in an effort to define and quantify the impacts on terrestrial and aquatic ecosystems. In the Himalayas, nitrate and sulphate concentrations of similar magnitude to those observed in NW Europe have been reported in snow samples (Mayewski et al. 1986). The deposition of acidic oxides is predicted to increase in the future in Asia in line with an expected increase in emissions as industrial development continues (Galloway 1989).

An understanding of how anthropogenic pollutants affect water chemistry, and thereby the ability to predict the location and severity of potential impacts, can be achieved only through knowledge of hydrochemical processes in pristine waters of similar physico-chemical characteristics (Bruns et al. 1991). If a sufficiently detailed knowledge of pristine, or baseline, water chemistry is available, the effects of local pollution, stemming from land use and land management, and of regional pollution, from atmospheric deposition of acidic oxides for example, can be quantified. This paper presents data from the first wide-scale surveys of the chemistry of medium-to-high-altitude first-order streams, draining relatively undisturbed and apparently unpolluted catchments, in the Himalayas of Nepal. The data are used to determine the major controls on surface water chemistry in this largely unpolluted region and to determine the areas most susceptible to acidification from future increased deposition of acidic oxides.

## Study Area and Sampling Methodology

The regional water chemistry surveys were conducted as part of an ongoing research programme on Himalayan biodiversity funded by the UK Department of the Environment under the Darwin Initiative. Data reported are from seven regions of the Himalayas of Nepal based around significant river basins (Fig. 1); the Everest region (Region A - Dudh Kosi); the Annapurna region (Region B - Modi *Khola*); the Langtang region (Region C - Langtang *Khola*); the Makalu region (Region F - Arun and Barun *Khola*); the Simikot region (Region E - Mugu and Humla Karnali); the Dunai region (Region G - Churto *Khola*); and the Nuwakot region (Region D - Likhu *Khola*). Sampling was undertaken during February and March 1992 in the Everest, Annapurna, Langtang, and Nuwakot regions and during November and December 1994 in the Dunai, Simikot, and Makalu regions. A repeat survey of the Langtang region was also carried out in 1994, and the hydrochemical data are consistent between the two surveys. At both times, flows were low at all elevations. Sampling at low flows during a prolonged dry season was chosen primarily to reduce the variance in stream chemistry due to high flow events; this would produce regionally comparable data sets, but ease of access during this period was an important consideration.

Detailed geology of these individual areas is unknown, although the national scale geological survey (ICIMOD, unpublished) indicates the broad regional characteristics (Fig. 2). The dominant bedrock geology consists of Pre-Cambrian gneiss with large areas of low-grade metamorphic green schist noted in the field in all sampling regions. The Central Himalayan Thrust fault is associated with a calcareous formation and outcrops in many of the regions. Natural vegetation in all regions is strongly zoned by altitude and so reflects a north (high mountains characterised above the tree line but below the zone of permanent snow cover by juniper, rhododendron shrubs, and grassland) to south (middle hills dominated by terraced cultivation and grazing land) gradient.

## Results and Discussion

Stream chemistry in mid-high-altitude Himalayan mountain streams is well buffered, with pH generally in the range of from 7.0 - 8.5. Bicarbonate is the dominant anion and calcium and magnesium the dominant cations, and these represent the main weathering products, but significant hydrochemical differences between the seven regions (Fig. 3) associated with bedrock geology exist.

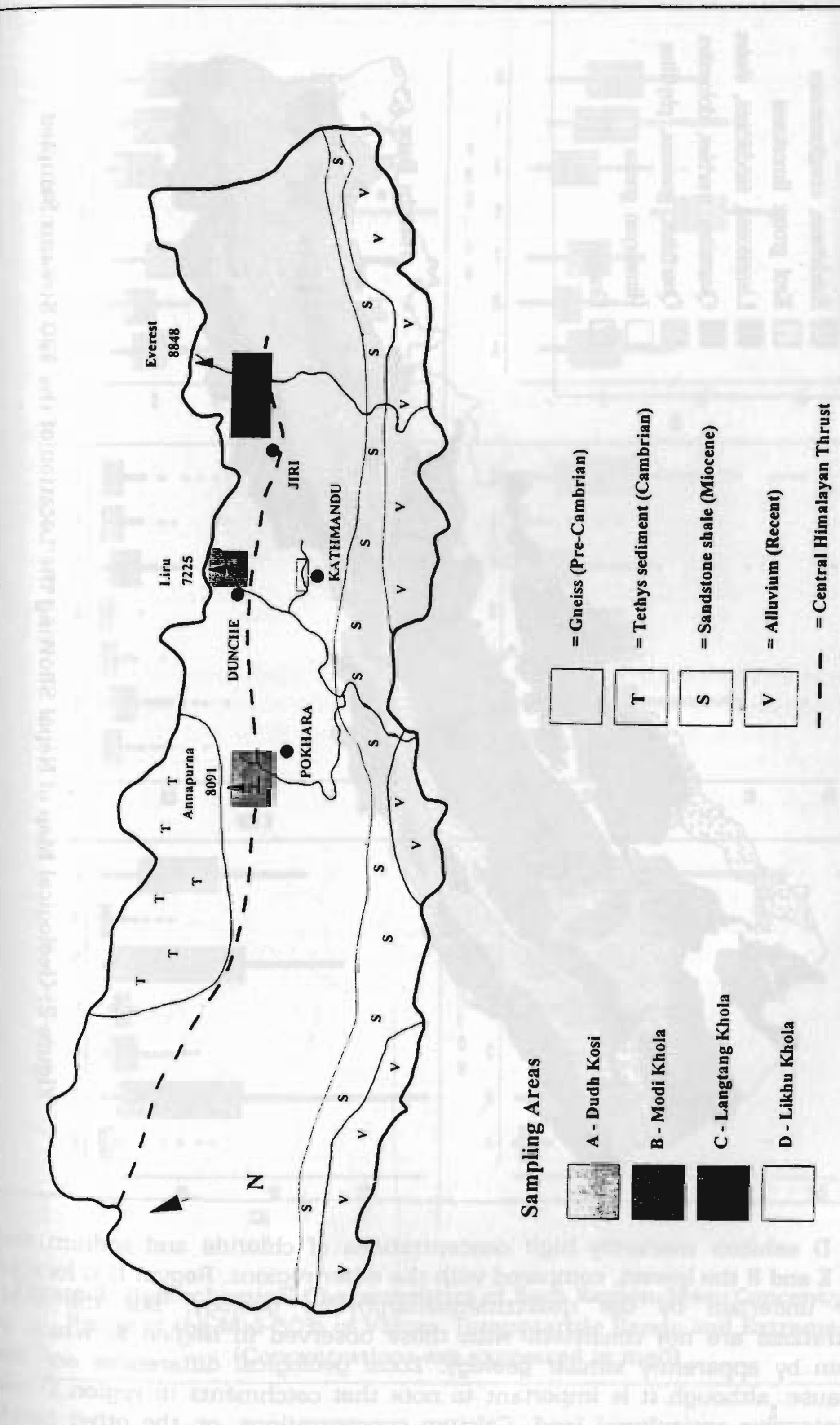


Figure 1: Location of the Seven Sampling Regions

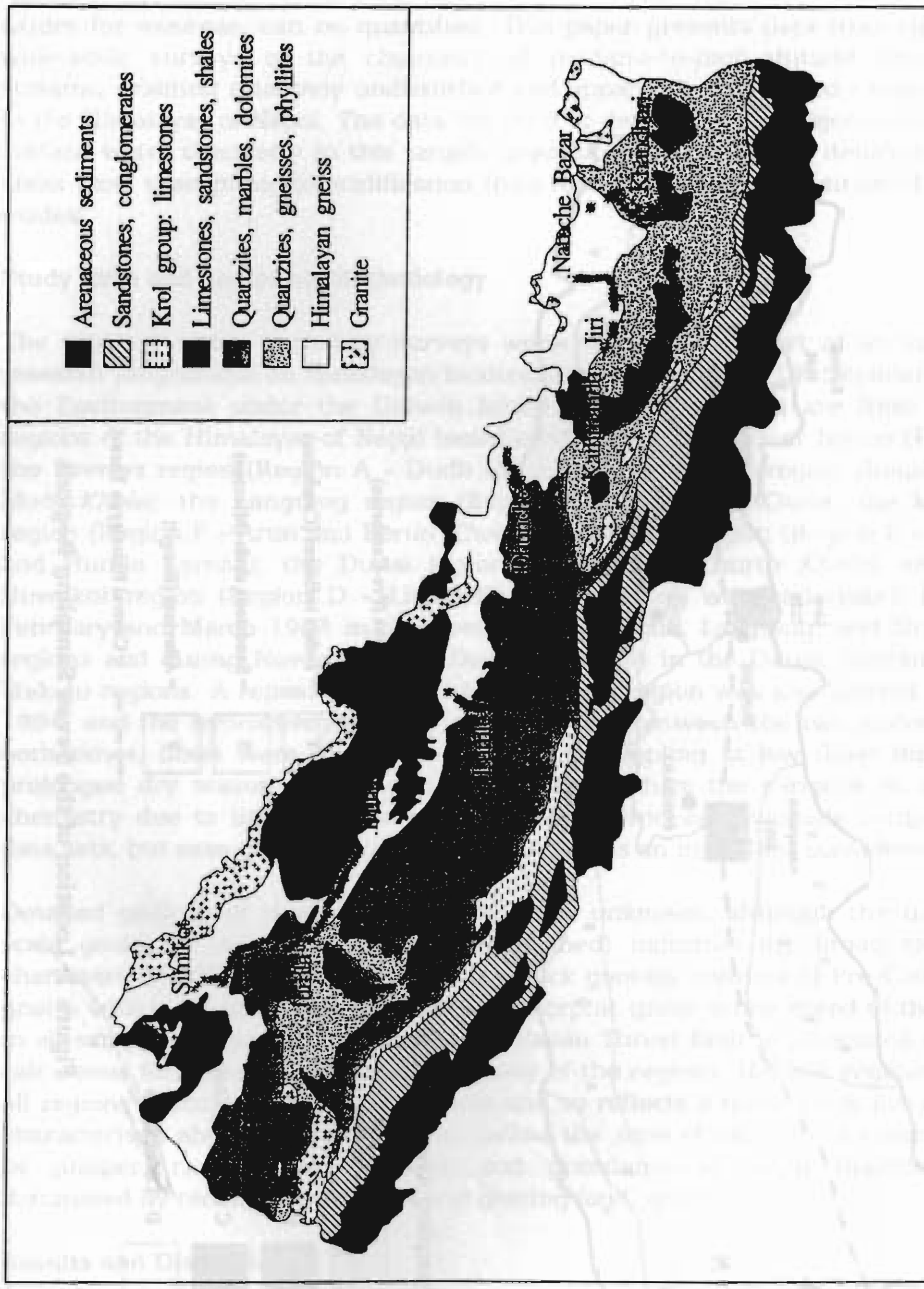


Figure 2: Geological Map of Nepal Showing the Location of the 420 Streams Sampled

Region D exhibits markedly high concentrations of chloride and sodium and regions E and B the lowest, compared with the other regions. Region D is located entirely underlain by the quartzite/gneiss/phyllite geology, but the high concentrations are not consistent with those observed in Region F, which is underlain by apparently similar geology. Local geological differences are the likely cause, although it is important to note that catchments in region D are under intensive agricultural land. Calcium concentrations, on the other hand, demonstrate the opposite regional behaviour, being markedly high in regions G,

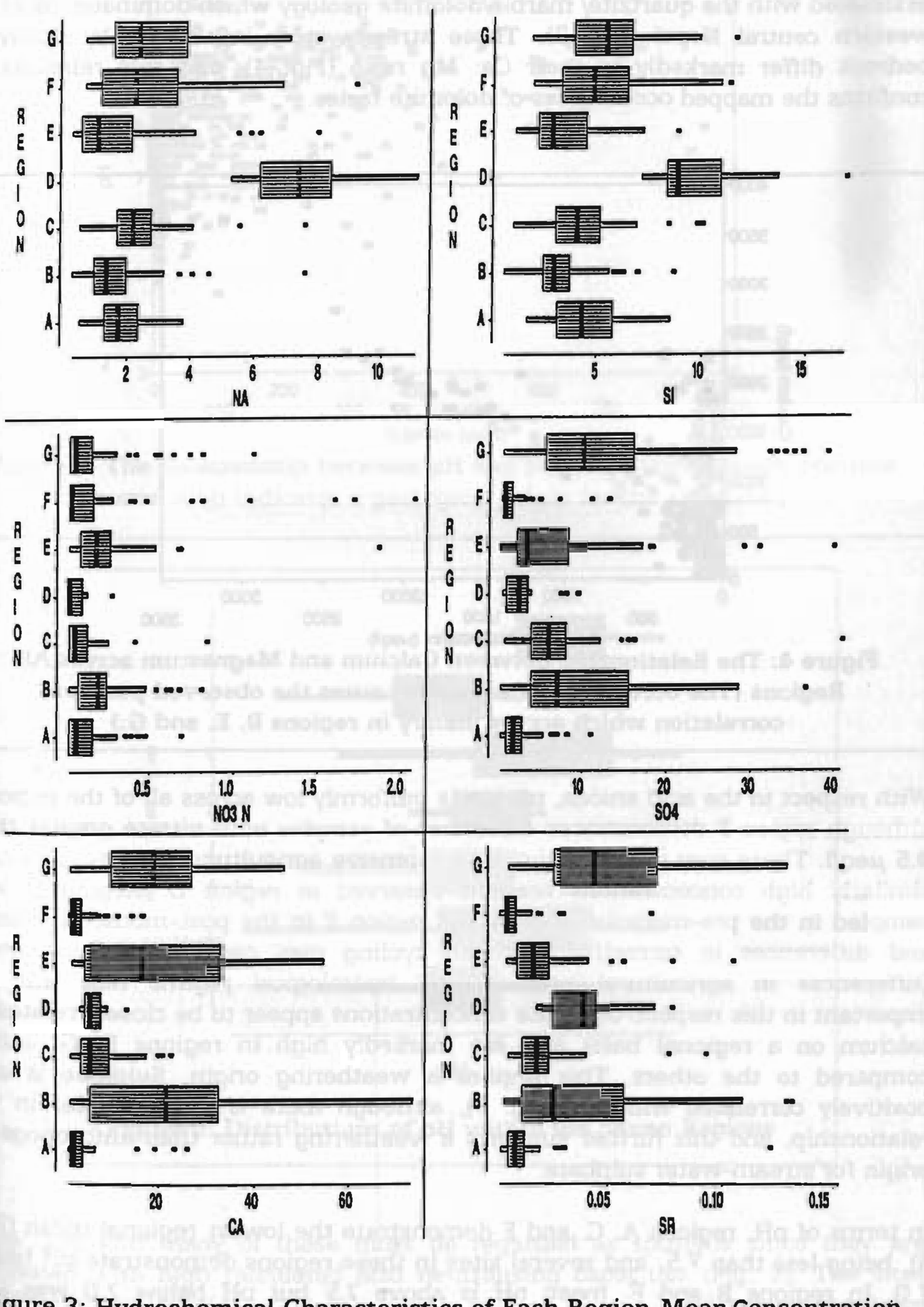


**Figure 3: Hydrochemical Characteristics of Each Region-Mean Concentration, Range of the Mid-50% of Values, Interquartile Range and Extremes (Concentrations are expressed in mg/l)**

B, and E compared to all of the other regions. These high concentrations are associated with the quartzite/ marble/dolomite geology which dominates much of western central Nepal (Fig. 2). Those streamwaters influenced by dolomite bedrock differ markedly in their Ca: Mg ratio (Fig. 4), and this relationship confirms the mapped occurrences of dolomite facies.

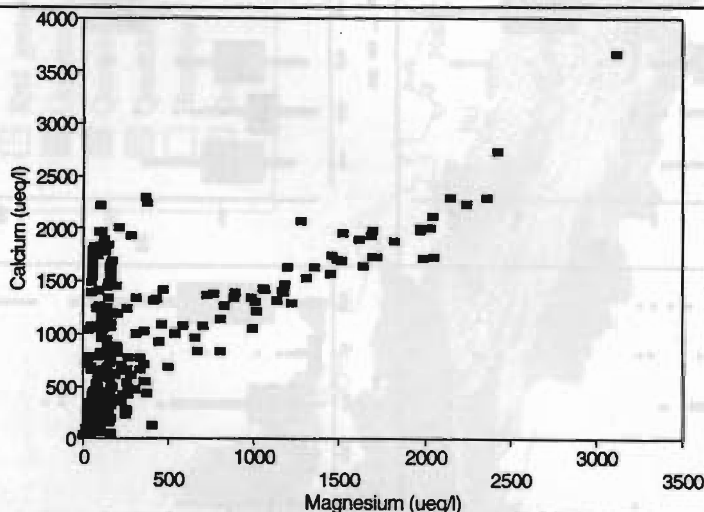


**Figure 4: The Relationship between Calcium and Magnesium across All Regions (The occurrence of dolomite causes the observed positive correlation which occurs mainly in regions B, E, and G.)**

With respect to the acid anions, nitrate is uniformly low across all of the regions, although region F demonstrates a number of samples with nitrate greater than 0.5 $\mu$eq/l. These may well be related to intensive agricultural activity, although similarly high concentrations are not observed in region D. Region D was sampled in the pre-monsoon season and region F in the post-monsoon season, and differences in terrestrial nitrogen cycling may cause this discrepancy. Differences in agricultural practice and hydrological regime may also be important in this respect. Sulphate concentrations appear to be closely related to calcium on a regional basis and are markedly high in regions B, G, and E compared to the others. This implies a weathering origin. Sulphate is also positively correlated with pH (Fig. 5), although there is much scatter in the relationship, and this further supports a weathering rather than anthropogenic origin for stream-water sulphate.

In terms of pH, regions A, C, and F demonstrate the lowest regional mean (Fig. 6), being less than 7.5, and several sites in these regions demonstrate pH below 7.0. In regions B and E, mean pH is above 7.5 but pH below 7.0 was also observed at some sites. Region D has mean pH above 7.5, but all sites have pH above 7.0, region G has mean pH greater than 8.0, and all sites greater than 7.0. Clearly, regions D and G are unlikely to be sensitive to increased input of anthropogenic sulphate, as acidic deposition, or nitrate, as fertilizer. It is also clear that of the 420 streams sampled, only approximately 10 per cent have pH

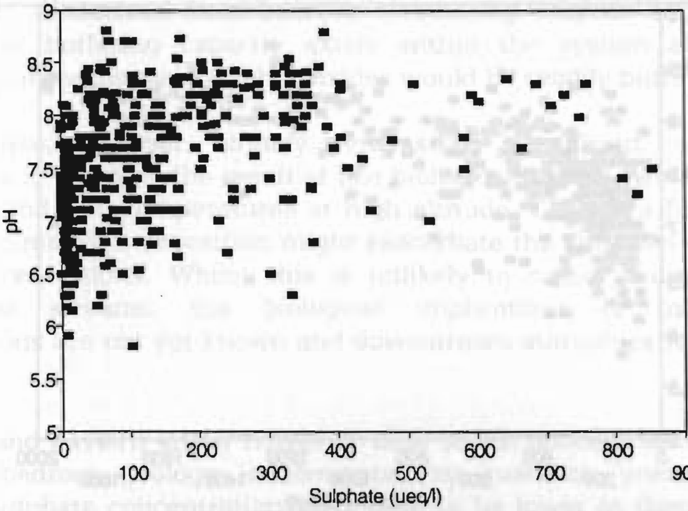


**Figure 5: The Relationship between pH and Sulphate (The broadly positive correlation indicates a geological origin for the sulphate.)**

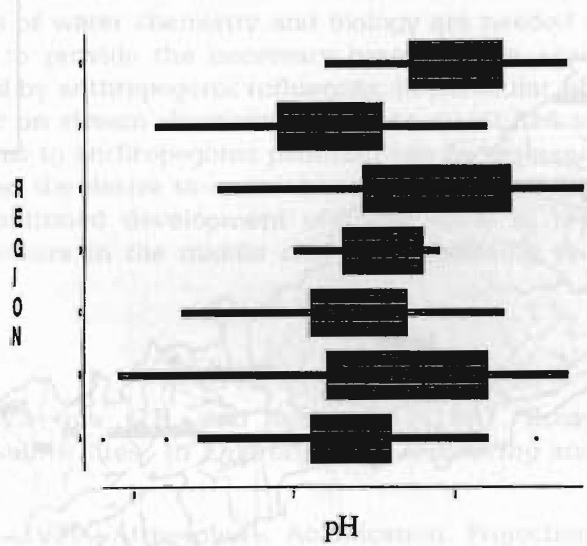


**Figure 6: Distributions of pH within the Seven Regions**

below 7.0, and many of these must be regarded as spurious since they are associated with high calculated acid neutralising capacities (Fig. 7). The sites which might be considered sensitive to increased input of acid anions are those with a pH less than 6.5, especially where these also exhibit markedly low base cation concentrations. These all occur in the central and eastern areas of Nepal (Fig. 8).

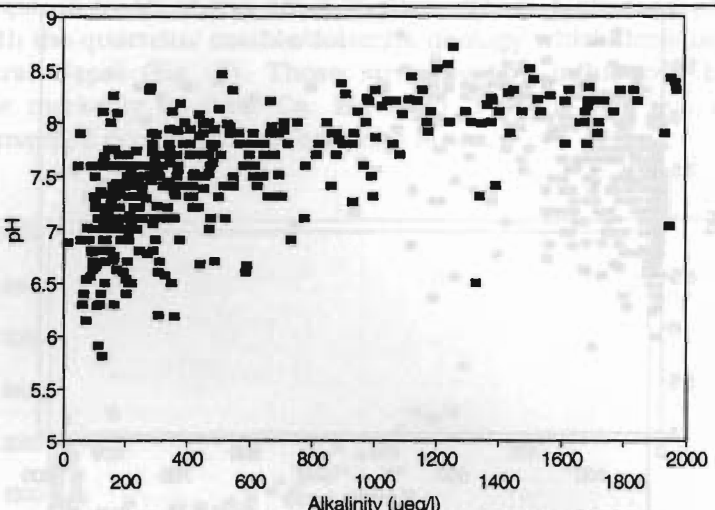


**Figure 7: The Relationship between pH and Calculated Alkalinity (acid neutralising capacity)**

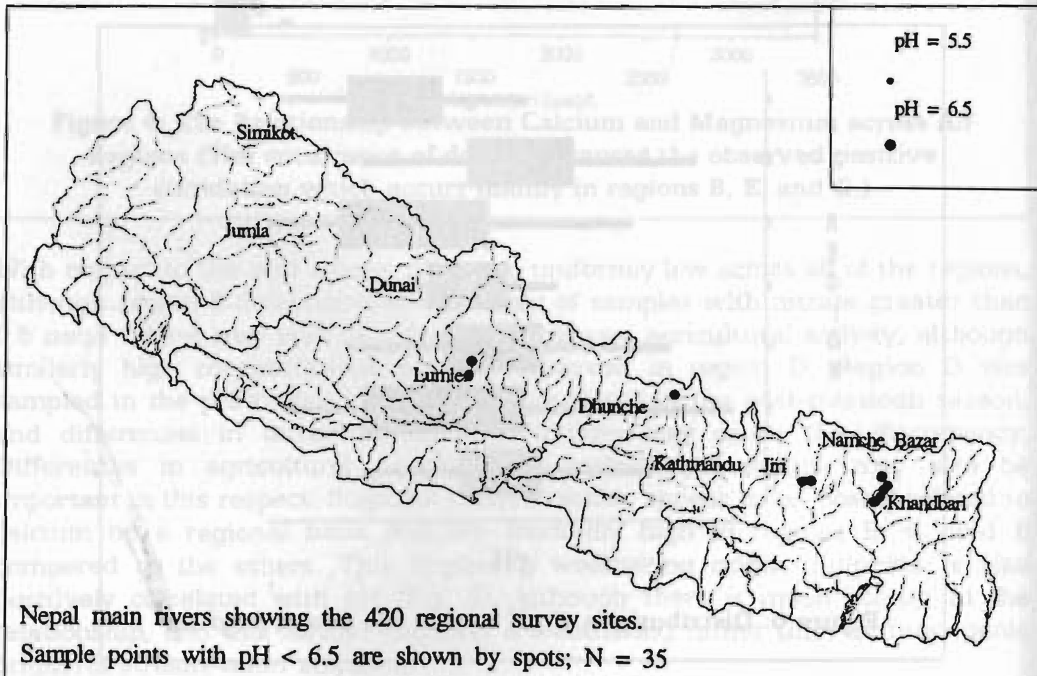


**Figure 8: Regional Location of Streams with a pH of Less than 6.5 and Likely to be Sensitive to Increased Input of Acid Anions**

## Conclusions

The high-altitude forest and alpine scrub-covered catchments in the Himalayas are generally unlikely to be sensitive to atmospheric deposition of acidic pollutants or to increased fertilizer input. In general, the waters from these catchments have high background concentrations of sulphate, calcium, and bicarbonate, all derived from bedrock weathering sources. High pH indicates that a large buffering capacity exists within the system and that further additions of anthropogenic sulphur oxides would be readily buffered.

Many streams, however, already demonstrate significant concentrations of nitrate. This is probably the result of low biological requirements, given the poor vegetation and cold temperatures at high altitude. Clearly, a future increase in atmospheric nitrogen deposition might exacerbate the situation and promote yet higher concentrations. Whilst this is unlikely to cause acidification of these upland-most streams, the biological implications of increased nitrate concentrations are not yet known and downstream eutrophication problems may occur.

In central and eastern areas, however, base cation concentrations are generally lower, as bedrock geology is dominated by quartzite, gneiss, and phyllite. Although sulphate concentrations also tend to be lower in these areas, low pH indicates that streams in these areas are likely to be sensitive to increased input of acid anions. It is in these areas that changes in surface water chemistry and biological impacts should be adequately monitored into the future.

Future surveys of water chemistry and biology are needed in similar Himalayan environments to provide the necessary baseline data against which to assess damage caused by anthropogenic influences; in particular, the impact of land use and land cover on stream chemistry should be quantified so that the sensitivity of these systems to anthropogenic pollution can be assessed. This is particularly important given the desire to maintain ecosystemic stability and biodiversity in the face of continued development of these areas in response to increasing population pressure in the middle hills and increasing tourist pressure in the high hills.

**References**

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