sistent presence of this behaviour in the samples suggests that there is indeed a bleached signal in the sample. Should this be so, the zero error in the age will be < 50 a. This will be an improvement on the mean SAR age of < 250 a.

We thus conclude that with recently developed component-specific OSL dating techniques[9], it is possible to date tsunami events with reasonable accuracy. It is also possible to use luminescence dating to provide constraints on sediment influx during such events. A set of analysis on drilled cores in tidal region and modelling of the equivalent dose behaviour as a physical mixing of two end-members can help in quantifying the potential transportable sediment volume.

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ACKNOWLEDGEMENTS. A.K.S. thanks the Heidelberg University and the AvHumboldt foundation for support.

Received 13 May 2006; revised accepted 31 October 2006

A season-wise estimation of total dissolved solids from electrical conductance and silica in ground waters of upper Gunjanaeru River basin, Kadapa district, Andhra Pradesh

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In order to establish season-wise relationship between total dissolved solids (TDS), electrical conductance (EC) and silica (SiO_2) in upper Gunjaneru River basin, Kadapa district, Andhra Pradesh, a study has been made by collecting 51 and 46 groundwater samples during post-monsoon and pre-monsoon season, respectively. TDS, EC and silica are some of the groundwater quality parameters measured in a laboratory generally. EC and silica measurements are made quickly and are less costly than TDS measurement. The results indicate that 99.7% and 99.8% of the variability in TDS could be ascribed to the variable EC and SiO_2 concentrations and the rest by some other unaccounted variables in the post-monsoon and pre-monsoon season, respectively. Inclusion of SiO_2 concentration in the regression models produces, for individual samples, a lower per cent difference between measured and estimated TDS for both seasons. However, on the average the inclusion of SiO_2 in regression models reduced the mean difference 0.09% for the post-monsoon season and 0.11% for the pre-monsoon. From regression analysis it is found that the multiple regression model did not improve the predictability of TDS values over the linear regression model for both post-monsoon and pre-monsoon seasons. TDS can be estimated from either EC or EC and SiO_2 by these regression models within the acceptable limit of error. This is due to the low content of SiO_2 in the groundwater samples in shale aquifers of the study area.

Keywords: Electrical conductance, regression equation, silica, total dissolved solids, upper Gunjanaeru River basin.

TOTAL dissolved solid (TDS) measurements are time-consuming. The procedure requires several days for evaporation and drying of a known volume of filtered water under constant and standard laboratory conditions[1]. Different drying temperatures give correspondingly different results because of residue weight changes caused by oxidation, loss of water of crystallization, volatilization of organic matter, mechanically occluded water, and gases from heat-induced chemical composition[2]. These variations can be minimized by the choice of the optimal drying temperature. Electrical conductance (EC) values are useful as an indica-

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tion of the dissolved solids or as a base for extrapolating other chemical data when only partial chemical analysis is known[3]. The EC measurement procedure is simple, rapid, precise and portable instruments are available for field analyses that produce valid data, when the instruments are used and maintained according to the manufacturer's instructions. Silicon (Si) in water is in the form of its oxide, silica (SiO_2) or its hydrated form $Si(OH)_4$. EC measurements have been used to estimate TDS concentrations in mountain streams[4] and rivers[5]. Regression equations which were based on physical properties and analysis of water samples collected from 1995 to 1998 throughout 95% of the Little Arkansas river flow duration, were developed to estimate alkalinity, dissolved solids, total suspended solids, chloride, sulphate, atrazine, and foecal coliform bacteria concentrations[6].

EC could be monitored instead of TDS if a valid relationship between the two can be established, thereby reducing analytical costs. The TDS in water samples is estimated by multiplying EC by an empirical factor. This factor may vary from 0.55 to 0.90 depending upon the nature of soluble ionic components, their concentration and the temperature of water[3]. Rainwater and Thatcher[7] have reported the value of the multiplying factor as 0.65 ± 0.1. Day and Nightingale[8] reported the value as 0.527 to 0.570 for groundwaters of Fresnol Wisalie and Bakersfield in USA. Reddy *et al.*[9] have reported that the multiplying factor ranges from 0.61 to 0.64 for surface and groundwater of Tirupati region, Andhra Pradesh (AP). Kefford *et al.*[10] have expressed salinity in terms of EC and arrived TDS using the formula EC = 0.754 TDS for the Barwon River, Victoria, Australia. These varied values of the multiplying factor reported by various researchers clearly indicate that the multiplying factor depends upon the hydrogeology of the area and is not related on a one-to-one basis.

Many groundwaters contain $Si(OH)_4$ in the un-ionized form because the pH of the waters is less than 9 and therefore, is not included in the EC measurements but is included in the TDS measurements. Thus a regression model to predict TDS from EC measurements can be in error because silica is not considered. As such, it is needed to develop a regression model for a specific hydrogeologic area to predict the TDS quickly from EC measurements. Such a model can conveniently be used as an alternative to the conventional tedious methods for the estimation of TDS, once the electrical conductance and silica measurements are made either in the laboratory or in the field by portable instruments. This communication deals with estimation of TDS with less error from EC and also from silica, once the relationship among the three has been established.

The upper Gunjanaeru River basin (Figure 1) is formed by four small ephemeral streams that drain 390 sq. km area and finally join the Cheyyair River. The area lies between north lat. 13°43′45″ and 14°1′44″ and long. 79°15′16″–79°27′38″. The Nagari quartzites overlie the granites in the hilly tracts of the catchment. These rocks are characterized by bedding joints and master joints which trend vertically. The intermediate portion of the area is occupied by Pullumpet shales which trend N15°–20°W–S15°–20°E and dip at 12–16° due NE (Figure 2). The shales are mainly composed of silt and clay with calcareous and argillaceous cementing material. Recent alluvial sediments consisting of boulders, cobbles, pebbles and gravel mixed with silt and clays occupy the central portion of the catchment. Thickness of these alluvial deposits ranges from 5 to 20 m. Groundwater occurs under unconfined and semi-confined nature. The mean rainfall is 1000 mm. Groundwater flow is basically from south to north direction following the trend of topography.

Fifty-one groundwater samples from post-monsoon season and 46 samples from pre-monsoon season were collected from different parts of the upper Gunjanaeru River basin, Kadapa district, AP, South India. Sample locations are given in Figure 1. These samples were then analysed for different parameters such as silica, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, TDS and EC according to the standard methods[1]. TDS was estimated gravimetrically after evaporation (180°C) to dry residue on a water bath until constant weight is obtained. EC was measured by Elico soil bridge type CM-84B at a

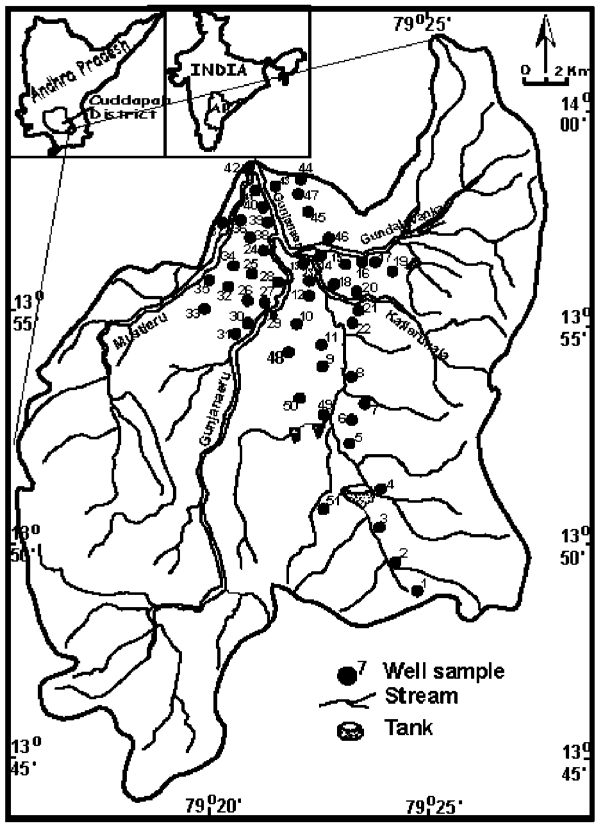

Figure 1. Location map of the upper Gunjanaeru River basin (after N. Janardhana Raju, unpublished).

temperature of 25°C. SiO_2 was estimated by ammonium molybdate blue method. Statistical analysis including correlation and regression was carried out between TDS and EC using the established procedures[11]. The regression equations of TDS as a function of EC and as a function of EC + SiO_2 were determined for post-monsoon and pre-monsoon season for the upper Gunjanaeru River basin.

The results of the analyses of groundwaters indicate that the quality during both seasons is significantly varied due to natural and man-made pollution (N. Janardhana Raju, unpublished). Calculation of total cations and total anions on milliequivalent basis indicates that there is a good correlation during both the seasons. Statistical values for the study area, based on the number of observations considered are presented in Table 1.

In order to estimate TDS for groundwater samples of post-monsoon and pre-monsoon season, linear and multiple regression equations were used. Regression equations for TDS from EC measurements are given in Table 2 for groundwater of both seasons.

The intercepts, namely 4.35 and 12.95 for post-monsoon and pre-monsoon season respectively, can be assigned to un-ionized species of SiO_2 or Si $(OH)_4$. The varied values of slope, namely 0.58 and 0.65 are indicative of the valance of ions in solution, their mobility and relative numbers. The calculated mean value of silica (SiO_2) concentration for the study area was 5.7 and 4.8 mg/l for post-monsoon

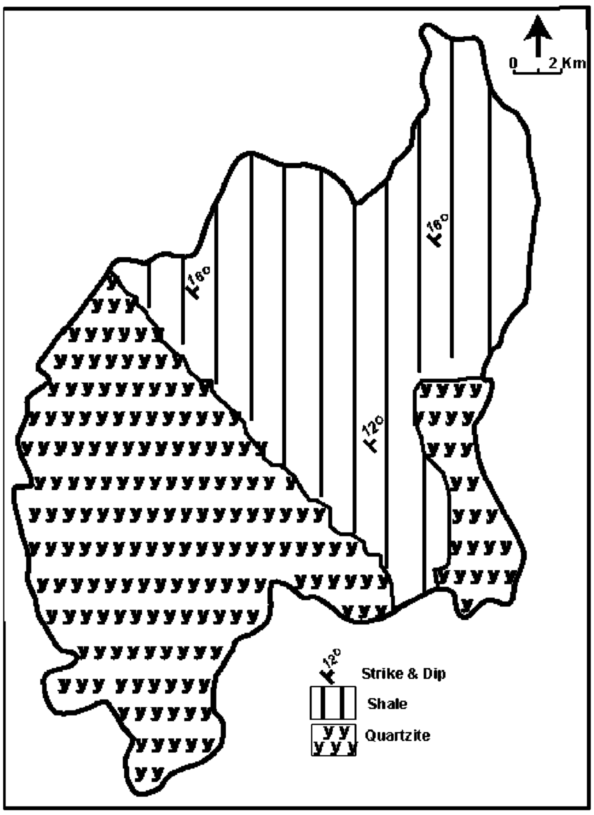

Figure 2. Geology of the upper Gunjanaeru River basin.

and pre-monsoon season respectively. $Si(OH)_4$ is un-ionized at pH 7 to 8 for the upper Gunjaneru River waters. Thus silica may be an additive quantity in the functional relationship between TDS and EC.

Sixty per cent of the earth's crust is composed of silicate minerals. Therefore, silica constitutes the bulk of common rock, soil, clay and sand[12]. Water that drain from deposits high in silicate minerals (T. V. Krishna Reddy, unpublished), particularly feldspar often contain up to 60 mg/l SiO_2. Waters that drain through shale formation[11] often contain less than 10 mg/l of SiO_2. As the pH of the water increases above 9, solubility of the hydrated form increases because of the formation of the silicate ion[13].

$$Si(OH)_4 + H_2O + OH^- = (H_2O)\ Si(OH)^-_5.$$

All the samples collected from the study area possess pH values less than 8 for both seasons. Hence, silica occurs in the unionized state, even though it is present in small quantities. Addition of SiO_2 as another independent variable to form multiple regression equations of post-monsoon and pre-monsoon seasons (Table 3) for estimating TDS did not significantly change the regression coefficient for the EC variable because of low values of silica. Whereas in areas where the silica concentrations ranged from 45 to 60 mg/l, an improvement in the prediction of TDS values was observed[8]. Multiple regression analyses carried out for TDS as a function of EC and SiO_2 for ground-waters for both seasons are presented in Table 3.

The coefficient of determination for both seasons, r^2 shows the fraction of variability in TDS accounted for by EC. Thus, 99.7 and 99.8% of the variability in TDS could be ascribed to the variable EC, and 0.3 and 0.2% by some other unaccounted variables in post-monsoon season and pre-monsoon season respectively. The standard errors of estimate are 12.30 and 12.08 for linear and multiple regression equations respectively, for post-monsoon season, whereas in the pre-monsoon season, the standard errors of estimate are 8.83 and 8.74 for linear and multiple regression equations respectively. Examination of the coefficient of determination (r^2) and standard error of the estimated values (Tables 2 and 3) for both seasons indicated that inclusion of SiO_2 in the regression analysis has not much improved the predictability of TDS for the study area. Figure 3 *a* and *b* shows the linear relationship between TDS and EC for post-monsoon and pre-monsoon season respectively. Lines that intercept the *Y*-axis at 4.35 for post-monsoon, and 12.95 for pre-monsoon season are not significantly different from zero, because of the low values of SiO_2.

Table 4 presents a comparison of measured and estimated TDS using simple linear regression equation with EC as the only independent variable and multiple regression equation with EC and SiO_2 as independent variables for both post-monsoon and pre-monsoon season. Data for these comparison illustrations were obtained by random selection of results for ten groundwater samples from the

Table 1. Statistical values for groundwater TDS, EC and SiO_2 for the upper Gunjanaeru River basin

Parameter	No. of samples	Range: Low	Range: High	Range: Mean	Standard error of mean	Standard deviation
Post-monsoon season						
TDS (mg/l)	51	87	1126	440.8	33	227.8
EC (μS/cm)	51	150	1850	751.60	56	391.7
SiO_2 (mg/l)	51	2.5	10	5.7	0.3	2
Pre-monsoon season						
TDS (mg/l)	46	95	1009	375.2	25	198.5
EC (μS/cm)	46	140	1515	550.08	47	290.33
SiO_2 (mg/l)	46	2.5	10	4.8	0.2	1.6

Table 2. Linear regression equation for TDS as a function of EC

Study area	Linear regression equation	r^2	Standard error of estimate
Post-monsoon season			
Upper Gunjanaeru River basin	TDS = 4.35 + 0.58 EC	0.997	12.30
Pre-monsoon season			
Upper Gunjanaeru River basin	TDS = 12.95 + 0.65 EC	0.998	8.83

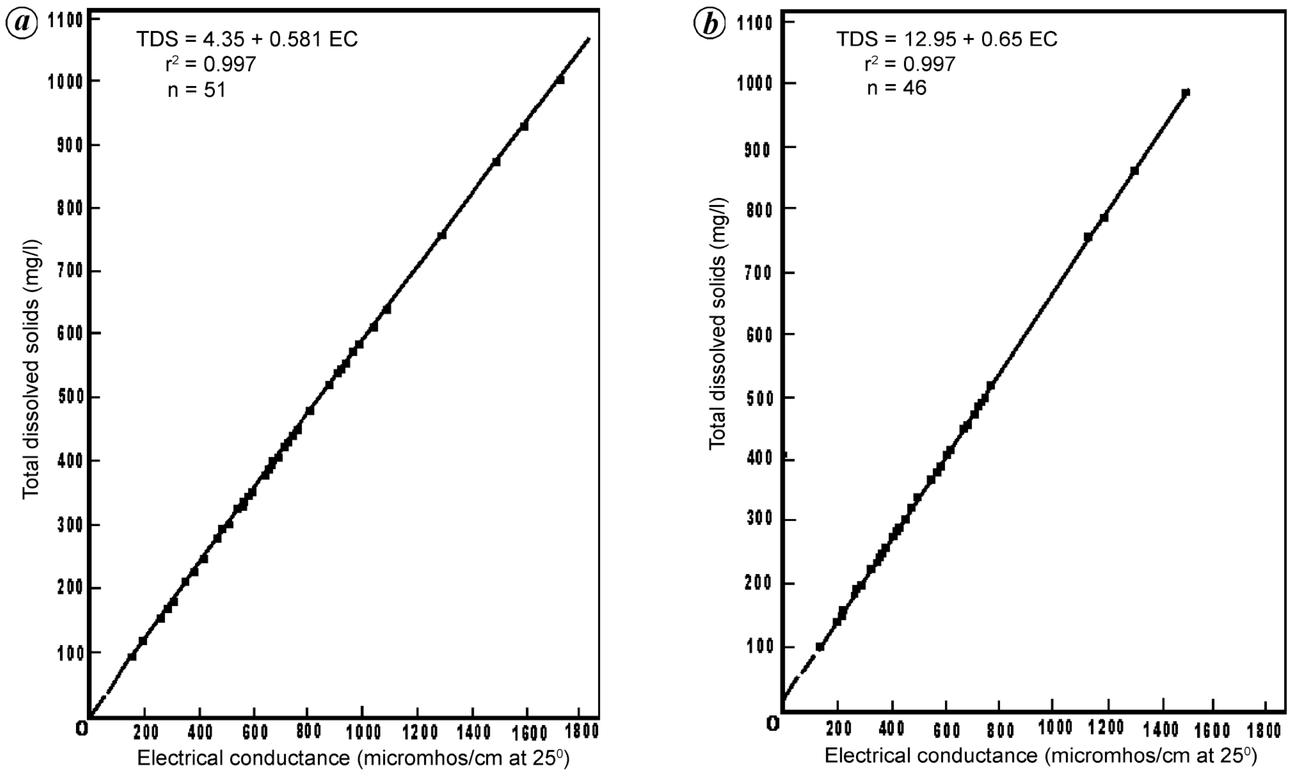

Figure 3. TDS as a function of EC for the upper Gunjanaeru River basin for (*a*) post-monsoon and (*b*) pre-monsoon seasons.

large database for post-monsoon and pre-monsoon seasons of the study area. For these samples, TDS was estimated by simple regression models (Table 2) and multiple regression models (Table 3) and compared with measured TDS for post-monsoon and pre-monsoon season. Inclusion of SiO_2 concentration in the regression models produces, for individual samples, a lower per cent difference (Table 4) between measured and estimated TDS for both seasons. However, on the average, inclusion of SiO_2 in regression models reduced the mean difference from 2.12

Table 3. Multiple regression equation for TDS as a function of EC and SiO_2

Study area	Multiple regression equation	r^2	Standard error of estimate
Post-monsoon season			
Upper Gunjanaeru River basin	TDS = 3.95 + 0.58 EC + 1.40 SiO_2	0.997	12.08
Pre-monsoon season			
Upper Gunjanaeru River basin	TDS = 9.39 + 0.65 EC + 1.25 SiO_2	0.998	8.74

Table 4. Comparison of estimated TDS from regression models with measured values of upper Gunjanaeru River basin for post and pre-monsoon season

	Measured values			TDS estimated by regression using		Per cent difference with respect to measured	
Sample number	SiO_2 (mg/l)	EC (μS/cm)	TDS (mg/l)	EC	EC + SiO_2	TDS estimated by EC	TDS estimated by EC+ SiO_2
Post-monsoon season (n = 51)							
3	5.0	748	416	438	437	+ 5.28	+ 5.05
8	5.0	1850	1126	1079	1078	– 4.17	– 4.26
12	5.0	580	335	341	340	+ 1.79	+ 1.49
17	5.0	670	404	393	392	– 2.72	– 2.97
21	7.5	350	208	207	209	– 0.48	+ 0.48
26	7.5	1000	579	585	587	+ 1.03	+ 1.38
30	7.5	640	383	376	377	– 1.83	– 1.56
38	7.5	730	436	428	430	– 1.83	– 1.37
45	10.0	950	560	556	561	– 0.71	+ 0.17
51	5.0	890	528	521	520	– 1.33	– 1.52
Mean						2.12	2.03
Pre-monsoon season (n = 46)							
3	2.5	613	417	412	411	– 1.19	– 1.43
8	10.0	1515	1009	999	1006	– 0.99	– 0.29
12	5.0	412	282	281	284	– 0.35	+ 0.71
17	5.0	420	290	286	288	– 1.37	– 0.68
21	2.5	265	178	184	186	+ 3.37	+ 4.49
26	5.0	680	470	456	458	– 2.97	– 2.55
30	5.0	450	310	306	309	– 1.29	– 0.32
38	10.0	585	400	393	403	– 1.75	+ 0.75
45	5.0	650	440	436	439	– 0.91	– 0.23
51	5.0	370	250	253	257	+ 1.20	+ 2.80
Mean						1.54	1.43

to 2.03% for post-monsoon season and 1.54 to 1.43% for pre-monsoon season. Even for those constituents with large relative percentage differences between the measured and estimated loads, estimation of constituent concentrations with regression analysis and real-time water-quality monitoring has numerous advantages over periodic manual sampling.

Regression equations for TDS as a function of EC and for TDS as a function of EC and SiO_2 were determined for the study area. In the present study the multiple regressions analysis model did not improve the predictability of TDS values compared with the linear regression model. Hence, TDS can be estimated from EC or both EC and SiO_2 using these regression models with acceptable error for post-monsoon and pre-monsoon season. From these studies it is concluded that the need for determining TDS using the time-consuming standard procedure can be reduced. The models used in this study can be used in other groundwater quality studies where TDS values are desired for the upper Gunjaneru River basin, once a regression model has been made for the functional relationship between TDS and EC or TDS and EC plus SiO_2. The models developed can be used conveniently as an alternate to the conventional tedious gravimetric dry residue method for the estimation of TDS quickly within acceptable limits of error, once EC measurements are made with portable instrument and SiO_2 in the laboratory using the calorimetric method. EC can be monitored instead of TDS if a valid relationship between the two can be established, thereby reducing analytical costs.

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ACKNOWLEDGEMENTS. I am grateful to Prof. T. V. Krishna Reddy, Sri Venkateswara University, Tirupati, for constant encouragement and guidance. I also thank the anonymous reviewer and reviewing editor whose thoughtful comments and constructive suggestions have improved the quality of the manuscript.

Received 4 February 2006; revised accepted 1 September 2006

Role of glaciers and snow cover on headwater river hydrology in monsoon regime – Micro-scale study of Din Gad catchment, Garhwal Himalaya, India

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The role of glaciers and snow cover in controlling the headwater river run-off variability of areas under the influence of monsoon is discussed here. This work is based on the studies carried out in a micro-scale catchment in the Garhwal Himalaya, covering an area of 77.8 sq. km. Run-off data of summer ablation period of 1998, 1999 and 2000 were collected from three hydrometric stations established at different altitudes in the Din Gad catchment. These data have been analysed along with the winter/summer precipitation, temperature and mass balance variations of the Dokriani glacier. The study shows that the hydrometric station at 2360 m asl (Tela) experienced 45% reduction in summer discharge from 1998 to 2000, which translated into a two-fold increase in the percentage glacier contribution. This paradox resulted from variations in the winter precipitation characteristics masking the run-off variations of the glacial regime. Glacier degraded run-off volume varied from 3.5% of the bulk glacier discharge in 1994 to 7.5% in 1999. This study suggests that the uncertainties in the precipitation characteristics in a changing climate, especially the winter snowfall have pronounced effect on the headwater river run-off variability rather than the run-off variations from a receding glacier. On the other hand, glaciers play an important role in sustaining the river flows during the years of low summer run-off.

Keywords: Dokriani glacier, Garhwal Himalaya, headwater hydrology, monsoon.

GLACIOLOGICAL studies in the Himalaya are essentially aimed at managing the large frozen water reserves of the glaciers, especially to study the response of glaciers and snow cover to the changing climate of the region, as one of its long-term objectives. Himalayan glaciers are situated above 3500 m asl, and these regions are away from human settlements. Hence water derived from snow and glaciers is being used for drinking, agriculture and power generation only at lower altitudes of the mountain. This peculiar situation, specific to the Himalayan region, de-

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