

MULTIVARIATE HYDROGEOCHEMICAL INVESTIGATION IN THE VAIPPAR BASIN, SOUTH INDIA

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ABSTRACT : Multivariate techniques are applied to study the chemical characteristics of the groundwaters in the Vaippar Basin, south India. Factor analysis is used to analyse the interrelationships among a large number of variables and to explain these variables in terms of their common underlying dimensions. Multiple regression analysis is used to identify the variables as dependent and independent ones. Eighty two groundwater samples are collected from the representative wells in the Vaippar basin for pre-monsoon and post-monsoon seasons. The factor models are derived independently for pre-monsoon and post-monsoon periods. The hydrogeochemical behaviour of vaippar basin is very well established by these models.

INTRODUCTION

The multivariate techniques, developed to examine the relationships between or among more than two variables, are applied in the present study of the chemical characteristics the groundwater of Vaippar basin, South India. Among the multivariate techniques, the factor and multiple regression analysis are used in the present paper to bring out the chemical behavior of the aquifers in a more refined manner.

The factor analysis falls in the group of interdependence techniques and this technique can be used to analyse the inter relationships among a large number of variables and to explain these variables in terms of their common underlying dimensions (factors) i.e. the information contained in a number of original variables into a smaller set of dimensions (factors) with a minimum loss of information. The application of this technique

in groundwater chemistry is very well demonstrated by various workers (Lawrence and Upchurch 1976 & 1982, Balasubramanian et. al 1990, Razak and Dazy 1990, Reiz et. al 1990, Jayakumar 1993).

The multiple regression analysis, grouped under the dependence techniques, is used to identify the variables as dependent and independent ones. The objective of multiple regression analysis is to predict the changes in dependent variables in response to the changes in several independent variables and the predictions are achieved by least square estimation. In the present study reverse calculations are attempted to calculate the chemical constitution of ground water by using the measured value of total dissolved solids (TDS). This technique has already been successfully utilized to evolve the chemical composition by the Electrical conductivity (EC) value (Balasubramanian et. al 1990 and Jayakumar 1993).

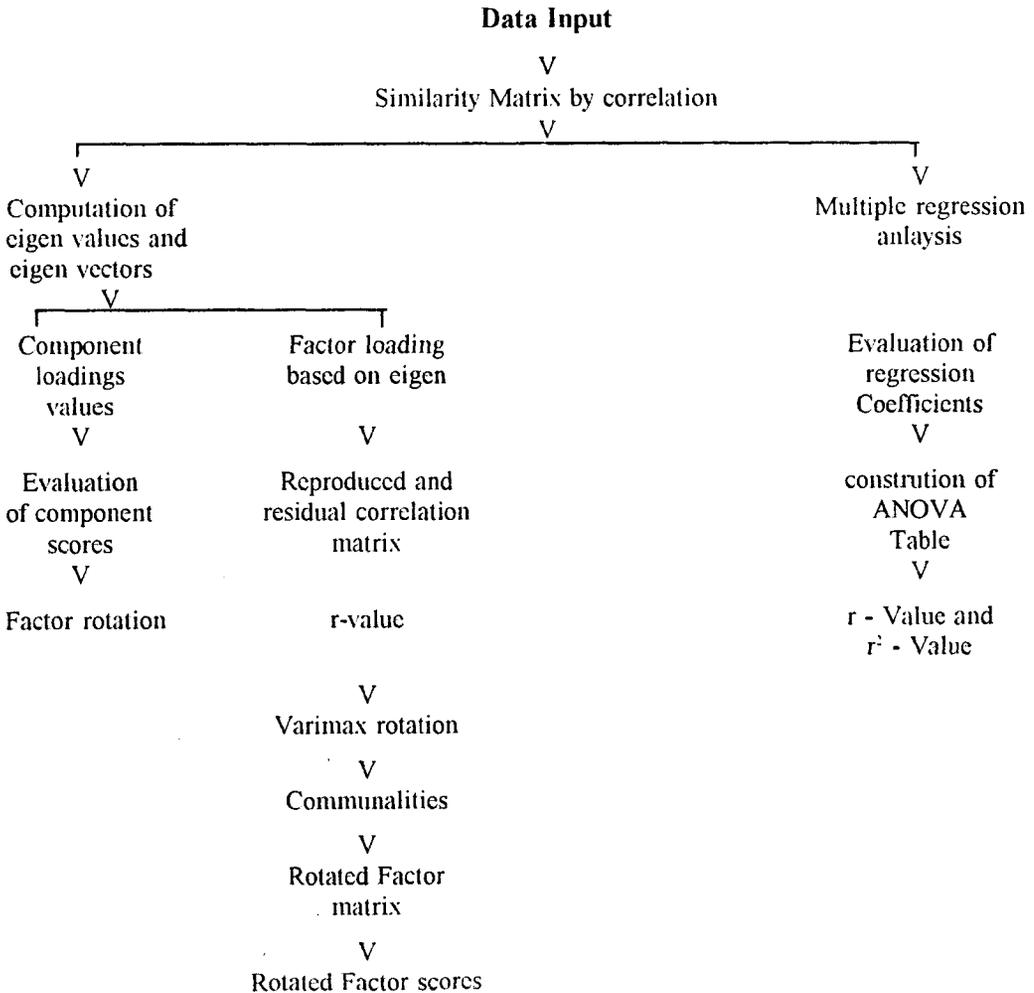
THE STUDY AREA

The Vaippar basin is one of the 17 major river basins of Tamil Nadu and it is located in the rain shadow tract of the Western Ghats between 8° 58' to 9°45' N latitudes and 77°10' to 78° 15'E longitudes with a total area of 5356 Sq. km. The basin can be broadly classified as the hills of Western Ghats (extreme west) and plains, while the latter covers more than 80% of the basin area. The unclassified gneisses and charnockites are the major rock types of the basin and the basin is covered mostly by thick black cotton soil. The average annual

rainfall of the basin is 780 mm.

THE DATA

In the present study 82 groundwater samples are collected from the representative wells in the Vaippar basin for two seasons viz., pre - monsoon (July) and post-monsoon (January) and analyzes following the standard procedures (APHA 1975). The major anions and cations viz., Ca⁺, Mg⁺, Na⁺ + K⁺, HCO⁻₃ +Co⁻₃, So⁻₄, Cl⁻ and TDS in ppm are taken into consideration for constructing the multivariate models.



THE METHODS

The factor analysis and multiple regression analysis are performed by following the procedure explained by Davis (1973). The flow chart explains the general outline of the data processing operation performed during this study.

FACTOR ANALYSIS

In the factor analysis the correlation between variables are taken as similarity measures. The correlation matrices are computed separately for two seasons followed by eigen values and percentage of trace or the .p166 amount of vaiance. The eigen vectors are calculated to bring out the principal axis matrix where the variables loaded in the components are brought out. Then the factors are introduced to the

analysis. For this analysis three factors in pre-monsoon and post-monsoon are selected with a minimum acceptable eigen value at 1.0 as explained by Harman (1976) and Kaiser (1958). As such, the variance explained by the pre monsoon 83.65% by first three factors and in post monsoon 87.19% variance is explained by the selected first three factors. The factor scores are derived for these three factors respectively. After this, the reproduced and residual correlation matrix is computed for the new set of data arrived from the factor analysis. The varimax rotation is performed for maximizing the variance. By this process, it is possible to achieve a single and pragmatically more meaningful factor solution. Then the communalities are inserted in the diagonal of the correlation

Table 1

Rotated factor loading Matrix - Pre Mansoon

Sl. No.	Variables	R.F.I.	R.F.II.	R.F.III	Communality
1	Ca	-	- 0.8587	-	0.82801
2	Mg	-	- 0.7047	-	0.51963
3	Na+k	0.8707	-	-	0.92763
4	HCO ₃ +CO ₃	-	-	0.9638	0.94356
5	SO ₄	0/8166	-	-	0.76465
6	Cl	0.5769	- 0.7559	-	0.70502
7	Eingn Value	5.81	1.51	1.03	-
8	% Trace	58.14%	15.15%	10.36%	-

Table 2

Roated Factor Loading Matrix - Post Mansoon

Sl. No.	Variables	R.F.I.	R.F.II.	R.F.III	Communality
1	Ca	-	- 0.8587	-	0.82801
2	Mg	-	- 0.7047	-	0.51963
3	Na+k	0.8707	-	-	0.92763
4	HCO ₃ +CO ₃	-	-	0.9638	0.94356
5	SO ₄	0/8166	-	-	0.76465
6	Cl	0.5769	- 0.7559	-	0.70502
7	Eingn Value	5.81	1.51	1.03	-
8	% Trace	58.14%	15.15%	10.36%	-

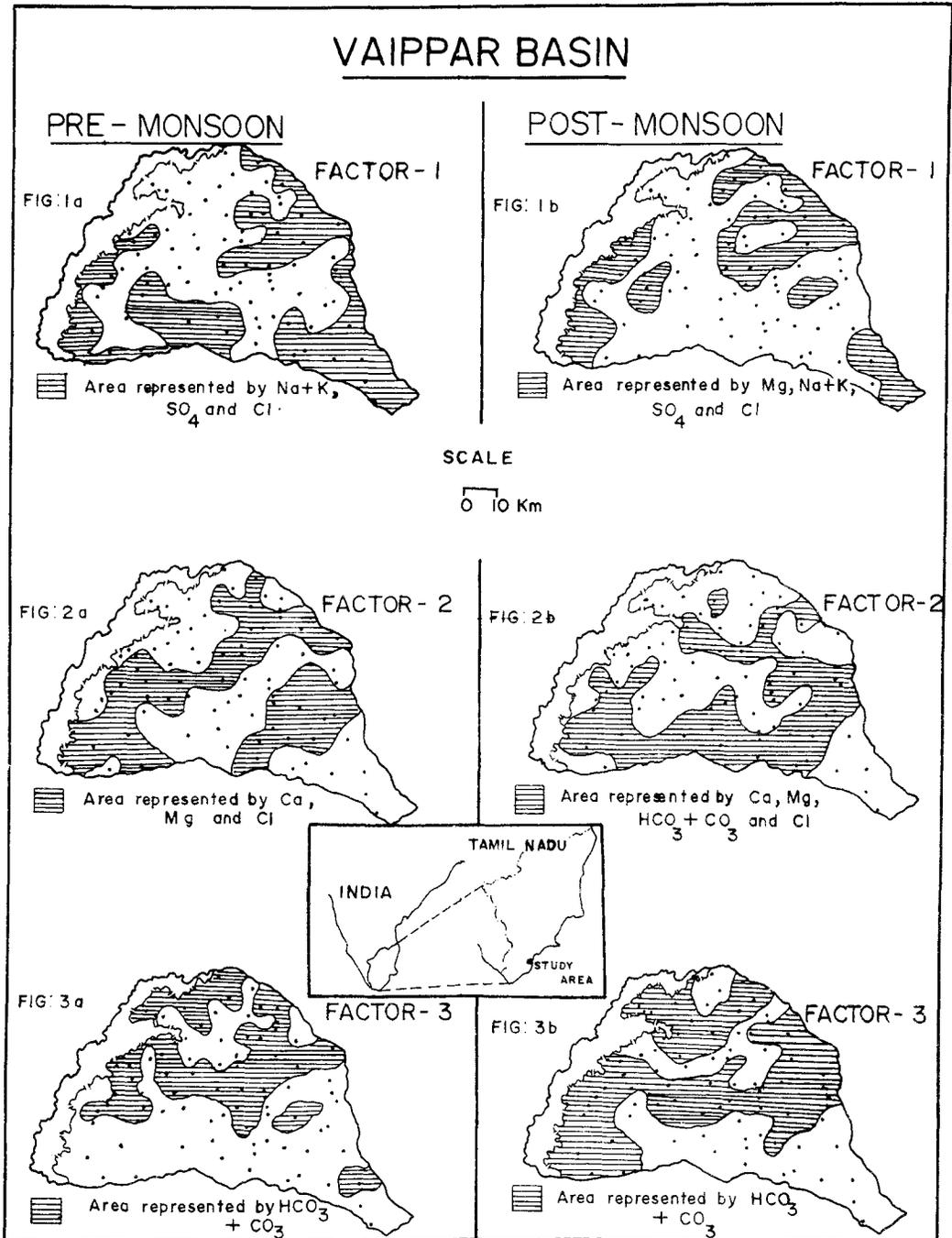


Fig. : Vaippar Basin

matrix and the extracted factors are based only on the common variance as original variables which share with all the other variables. Finally the interpretable rotated factor matrix and rotated factor scores (varimax) are computed. The rotated factor matrix of pre-monsoon (Table-1) and post-monsoon (Table 2) are presented accordingly.

Multiple Linear Regression Analysis :

In the multiple regression, any observed variable can be considered as a function of any other variable measured on the same samples. The regression model of an independent variable upon a dependent variable can be expressed as

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \dots + b_n x_n$$

In the groundwater chemical analysis data TDS value is the main dependent variable which depends on the concentration of major cations and anions.

THE RESULTS

The derived results from factor analysis and multiple linear regression analysis models were developed. With the help of factor models of two seasons the chemical behavior and its major ions evolution can be determined in a spatial manner. From the regression equation it is possible to determine the specific chemical composition of the water with the help of measured E.C. values through inverse calculations.

FACTOR MODELS :

Factor 1 of pre monsoon

The factor 1 of pre monsoon is loaded heavily by Na+k, SO_4 and Cl which contributes 58.14% of the variance of samples.

The presence of sodium and potassium in the pre monsoon water is attributed to the primary

source of weathering of feldspathic minerals. Also the high proportion of sodium and potassium with sulfate shows that the rocks must have abundant plagioclase than of mafic minerals (Garrels and Mackenzie 1967). The presence of chloride is influenced by surface run-off and represents a path way/ origin process involving recharging of water. The factor scores indicate the zone of high weathering and the presence of feldspathic Gneiss complex in the positive score area (Fig - 1a) The attribution of sodium and potassium in the pre-monsoon water denotes the following (i) when the water exchange is slow, the positive ions strengthen the sodium in groundwater and replaces calcium (ii) The concentration of sodium increases with increasing depth, (iii) cation exchange reaction removes calcium and magnesium ions from solution and replaces them with sodium (Hem 1970).

Factor 1 of post-monsoon :

The factor 1 of post monsoon period represented by magnesium sodium and potassium, sulfate and chloride contributes 61.44% of the variance of sample. The source of magnesium is generally from the dissolution of minerals of silicate and feldspathic rocks (Hem 1970). The magnesium dissolution is much slower and it takes a longer time of contact between water and rock.

Therefore the factor 1 of post monsoon is a lithologically controlled factor reflecting dissolution activity of carbonate and feldspathic rocks (Lawrence and Up church 1982). The distributions of chloride ion concentration indirectly reflects the water interaction with rocks, permeability variations of aquifer and inter transmissivity of rocks (Hum 1970). Though the chloride ion is a useful normalizing factor, it is also useful in explaining the groundwater chemistry (Garrels and Christ 1965). The water mass of the post monsoon

period represents the Mg-Ca-Cl facies water type and the distribution of the same is explained spatially by Fig 1. b.

Factor 2 of pre-monsoon :

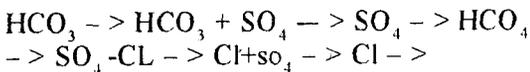
Factor 2 of pre monsoon is represented by the chemical ions of calcium, magnesium and chloride, with the variance of 15.15%

The origin of magnesium and processes related to chloride are explained in detail in the preceding section. The addition of calcium ions also confirms the lithological control over the groundwater in the area. The source of calcium is attributed to dissolution of carbonate minerals in the aquifer. The areas of negative loadings in Fig 2 a. reflect dissolution of carbonate and magnesium minerals in the Vaippar aquifer.

Factor 2 of post-monsoon

The groundwater of post monsoon in factor 2 is represented by calcium, magnesium, chloride and bicarbonate and carbonate with variance of 15.79%.

The presence of calcium, magnesium and chloride are explained in detail in the former paragraphs and the same co-ordinates in this factor also. In addition to this, the loading of bicarbonate and carbonate explains the groundwaters flow path is very sluggish. Further, the dominance of bicarbonate, carbonate and chloride ions explains the nature and age of the waters Chebotarev (1955) has demonstrated the major ion evolution sequence as travel along the flow path as increasing age.



These changes are expected when the water moves from shallow zones of active flushing, through intermediate zones, where the flow path is very sluggish and the water is old (Freeze and cherry 1979). The same is explained spatially through the Fig 2 b.

Factor 3 of pre and post-monsoon :

The factor 3 of pre and post monsoon are represented by bicarbonate and carbonate ions with the variance of 10.36% and 9.96% respectively. The source of bicarbonate and carbonate is mostly from decayed organic matter and sulphate reducing bacteria. The source from weathering of silicate minerals is also demonstrated by Kumaraswamy (1985). It is used as a measure of eviction of ground water flow and transmissivity gradient. Similarly, it serves as a good measure of geochemical evaluation or reaction progress in groundwater system with carbonate quantity (Nesbit and yung 1984). The area of influence of these factors are explained in Fig 3. a. and 3. b.

MULTIPLE REGRESSION MODELS:

Pre monsoon:

The regression coefficients are substituted in the following equation

$$Y (\text{TDS}) = 29.03640 + 0.45131 (\text{Ca}) + \\ 0.57357 (\text{Mg}) + 1.08867 (\text{Na+k}) \\ + 0.55622 (\text{HCO}_3^- + \text{CO}_3^{2-}) \\ + 1.04105 (\text{SO}_4^{2-}) + 1.26933 (\text{Cl}) \\ \text{with goodness of fit } (r^2) \text{ of } \\ 0.9879).$$

Considering a known value of TDS (and its components, concentrations of inverse computation should be made to) it is possible to find out the percentage contribution of each ions by substituting the sample ionic values (Balasubramanian et. al 1989 and Jayakumar 1993).

$$1563 \text{ TDS} = 96 (\text{Ca}) + 90.3 (\text{Mg}) + 271 \\ (\text{Na+k}) + 586 (\text{HCO}_3^- + \text{CO}_3^{2-}) + \\ 86 (\text{SO}_4^{2-}) + 440 (\text{Cl})$$

The percentage of ions in contributing total dissolved solids are -

- (1) Ca = 6.1% ;
 (2) Mg = 5.8%;
 (3) Na+k = 17.3%
 (4) $\text{HCO}_3 + \text{CO}_3 = 37.5\%$;
 (5) $\text{SO}_4 = 5.5\%$
 (6) Cl = 28.2%.

Post monsoon :

By substituting the coefficients in the following equation arrived

$$Y (\text{TDS}) = 30.00894 + 2.86908 (\text{Ca}) + 5.44464 (\text{Mg}) + 2.3803 (\text{Na+k}) + 1.10736(\text{HCO}_3 + \text{CO}_3) + 0.17061 (\text{SO}_4) + 0.088 (\text{Cl})$$

with goodness of fit (r^2) of 0.9877.

The inverse computations were adopted again as carried out in the case of pre monsoon and percentage of ionic contributions are arrived as

$$723 (\text{TDS}) = 74 (\text{Ca}) + 57.2(\text{Mg}) + 92 (\text{Na+k}) + 262 (\text{HCO}_3 + \text{CO}_3) + 43.2 (\text{SO}_4) + 217 (\text{Cl})$$

- (1) Ca = 10.2% (2) Mg = 7.9%;

- (3) Na+k = 12.7% (4) $\text{HCO}_3 + \text{CO}_3 = 36.2\%$;
 (5) $\text{SO}_4 = 6.0\%$; (6) Cl = 30.0%

Using these percentages, the ionic concentrations of any ground-water samples in any location in the basin which the TDS is measured could be determined with 98% accuracy.

CONCLUSIONS

The factor models were derived independently for pre monsoon post monsoon periods. The hydrogeochemical behavior of the Vaippar basin is very well established by these models. These models could be used as a forerunner before making any water based activities. Also, the agricultural development could be carried out with reference to the hydrochemistry of groundwater in different zones and also in the post monsoon and pre-monsoon periods. The multiple regression models are further used to find out the ionic concentration of the groundwater samples in this basin if the dependent variable TDS is measured for different locations, by inverse calculations as explained earlier.

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OBITUARY

PROFESSOR KHANDERAO PRALHAD KSHIRSAGAR

(1926-96)



One of the early teachers of Geography in Maharashtra, who initiated the teaching of Geography at the college and University level in the State, Prof. Kshirsagar died on 15th May 1996 at Pune after

a short illness of about a week. His death is attributed to the agony he could not bear following the deteriorating condition of his terminally ill younger son, a brilliant physicist, who died a week later true to the Hindu tradition, the father departed before the son. Prof. Kshirsagar is survived by his wife, his elder son a professor at M.I.T. Pune, & other members of the family.

Prof. Kshirsagar was born on 4th Feb. 1926 at Nasik in a Brahmin family, from where he moved with the family, when he was only seven, to Gwalior where his father had taken an assignment as a tutor in some princely family. Highly inspired by the family tradition, Prof. Kshirsagar pursued his studies seriously and obtained the B. Sc. degree with physics, Chemistry and Maths from Agra University at the age of nineteen. After that he joined immediately the Central Technical Institute at Gwalior as a lecturer and its Vice-Principal. After a gap of five years, while still working, he obtained his master's degree in Geography in 1951.

This was the beginning and the foundation of a long and successful career in geography teaching and research. In the same year as he got his master's degree, Prof. Kshirsagar joined the reputed S. P. College at Pune, as a lecturer in geography laying the foundation of geography teaching at the collegiate level in the University of Pune. This was the time when geography did not form part of the graduate courses of the Universities in Western India, and geographers were rare. Young and enthusiastic Prof. Kshirsagar not only made the subject popular at the degree level but even convinced to the University, the importance of the discipline as a science of space organization. After the establishment of the post graduate department in the University of Pune, he joined the University in 1953 as a lecturer and continued working in the same department with unwavering loyalty to the discipline till he retired from the service of the University as a Reader in Feb. 1986.

At the University of Pune, he worked with dedication, and with Prof. V. S. Ganaganathan, who was then the Head of the department, contributed greatly to the teaching of geography and the growth of the discipline at the university level. The geography department of the University of Pune was the only university department in Western India in the early fifties. With his power of persuasion and genial temperament, Prof. Kshirsagar was able to induce many colleges in Western India

to introduce geography at the-degree level and can be credited with the foundation of geography teaching in Western India. He was a key person in the core-group that developed the courses of studies at the degree and post-graduate level in geography at the University of Pune.

Prof. Kshirsagar taught physical geography but the main area of his interest was climatology. He successfully guided a number of Ph. D. and M. Phil students in Climatology, particularly its applied aspects. A novel feature of his climatological research, related to the prediction of the monsoons or weather conditions, was his division of the year into 'Nakshatras', known to Indian astronomers for over 2500 years, instead of using the Gregorian calendar months and the widely used division of the year into pentads. This was an effort to make the results of climatological research understandable to the farming community in India who are familiar with the concept of 'Nakshatras' for centuries. One may say with justification that he with another of his colleagues Prof. K. Ramamurthy-though both worked independently - pioneered research in geographical climatology in Western India. He was, undoubtedly, the spirit behind introducing specialization in climatology in the University of Pune and has left behind a tradition of climatological research which his students are continuing.

Another area where Professor Kshirsagar's contribution is well known is the field of 'Geography-education'. He was associated with the NCERT and developed, in association with some other geographers, a model syllabus for

high schools, besides the methods of geography teaching. At the state level, he was associated with the SSC Board as a chief moderator in geography. Besides teaching and research, Prof. Kshirsagar took interest in promoting geography through organizational media. He was the founder President of the Pune Geography Teacher's Association and the founder Vice-President of the Institute of Indian Geographers and promoted these two academic bodies with his active participation in their activities.

He was an excellent teacher and had a good rapport with his students endearing himself by his sincere advice, genuine encouragement and a fatherly attitude. The doctoral students working with him were treated like his family members and enjoyed the warm hospitality of Ms Kshirsagar at their residence on the University campus. His students were always welcome at his home from where they always returned wiser and happier.

Having worked for an uninterrupted period of over three decades in the department of geography of Pune University, Prof. Kshirsagar has carved a niche for himself in the history of the department and its growth. His contribution to the discipline and the institution he worked in, will be ever remembered by the successive generations of students and teachers.

The Institute of Indian Geographers, of which he was the founder Vice-President, deeply mourns his death.

-K. R. Dikshit