ground water

Methods Note/

# Reproducing the Piper Trilinear Diagram in Rectangular Coordinates

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## Abstract

Though several alternatives/modifications to the Piper diagram are available, the Piper diagram is still the most common way of representing chemical analyses. The present note shows how to reproduce the Piper trilinear diagram in rectangular coordinates retaining all the essential features of the trilinear diagram. In this form, it can be generated using commonly used graphics packages without requiring specialized software. A sample data set of six samples from Gurur watershed, Chhattisgarh, India, was used to illustrate the method. The patterns of points produced in the trilinear Piper diagram and the reproduced Piper diagram in rectangular coordinates are essentially identical.

## Introduction

There are several graphical methods (Zaporozac 1972; Güler et al. 2002) that are used for visualization and classification of hydrochemical data. The most widely accepted of these is the Piper trilinear diagram (Piper 1944; Hill 1940). This diagram has three parts: a cation triangle, an anion triangle, and a central diamond-shaped field (Figure 1). Similar to the Piper diagram is the diagram proposed by Durov (1948), where the sample points on associated triangles are extended to a central rectangular-shaped field.

Preparation of the previous diagrams is a bit complicated and is facilitated by means of specialized software. As an alternative to the trilinear diagrams, there have been several attempts to plot the relative percentages in rectangular coordinates. Noteworthy are the diagrams proposed by Langelier and Ludwig (1942), Romani (1981), and Chadha (1999). Langelier and Ludwig (1942) proposed a diagram (Figure 2a) using rectangular coordinates in which percent sodium plus potassium is represented on the *Y*-axis and percent carbonate plus bicarbonate on the *X*-axis. This diagram had no cation or anion triangles. In the diagram proposed by Chadha (1999), the difference in mill equivalent percentage between alkaline earths (Ca + Mg) and alkali metals (Na + K), expressed as percentage reacting values, is plotted on the *X*-axis. Similarly, the difference in mill equivalent percentage of weak acidic anions ($CO_3$ + $HCO_3$) and strong acidic anions ($SO_4$ + Cl) is plotted on the *Y*-axis (Figure 2b). Romani (1981) proposed the use of a cation and an anion triangle similar to those in the Piper diagram but used right-angled isosceles triangles instead. The central diamond-shaped field was replaced by a square (Figure 2c). This central square-shaped field in Romani's diagram is the same as the plot devised by Langelier and Ludwig (1942) in terms of combinations of ions and patterns produced.

These diagrams, though essentially variants of Piper trilinear diagram, have their own classification schemes and interpretations, but the Piper diagram still remains the most common diagram for representing hydrochemical analyses. This article shows how to reproduce the Piper diagram in rectangular coordinates retaining its original visual perceptions and interpretations.

## Reproducing the Piper Diagram

The three major components of the Piper diagram are cation triangle, anion triangle, and the central

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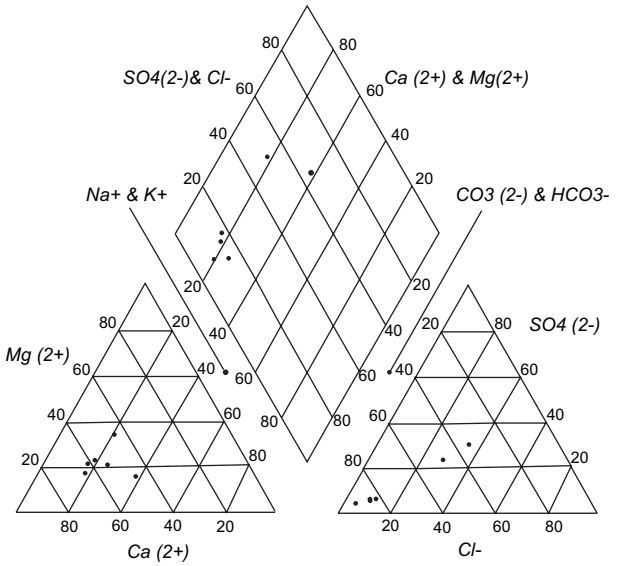


**Figure 1. Piper trilinear diagram. Points plotted on the diagram are given in Table 1. The diagram was prepared using the free applet "triplot" (www.rhyme.com.au).**

diamond-shaped field. Here, we will reconstruct these components individually. The computer-generated Piper diagrams essentially are the plots in rectangular coordinates, transforming the variables and axes to trilinear form (Shikaze and Crowe 2007). We suggest here the combinations of ions that, when plotted on rectangular coordinates, generate patterns similar to the Piper diagram. In this case, no coordinate transformation is needed when plotting in rectangular coordinates, only labeling the regions of interest as shown in Figure 3. Both the cation triangle and the anion triangle can be plotted on rectangular coordinates taking any two of the respective variables. However, to maintain the visual perception of the original diagram, the following combination of variables and procedures is suggested.

The cation triangle can be reproduced by plotting the relative percentages of Ca and Mg on the *X* and the *Y*-axes, respectively (Figure 3a). To maintain the visual perception, the Ca axis has been reversed. It may be noted that since the percentages add to 100, none of the points would plot beyond the dotted line (Figure 3a). Similarly, plotting relative percentages of $SO_4$ on the *Y*-axis and that of Cl on the *X*-axis can reproduce the anion triangle. Here also none of the points would plot beyond the dotted line (Figure 3b). The central diamond-shaped field in the Piper diagram can be reproduced without plotting the associated triangles. $SO_4$ + Cl is to be taken on the *Y*-axis and Na + K is to be plotted on the *X*-axis, and the axes are to be set as shown in Figure 3c.

One of the primary objectives of graphical methods is to group the water samples according to similar chemical composition or classification. The most common classification scheme is that proposed by Back (1966). Back's classification can be defined on these diagrams quite conveniently (Figure 3).

A data set comprising six ground water samples from irrigation wells in Gurur watershed in Durg district, Chhattisgarh, India, was used as an example dataset. The samples were obtained from the Chandarpur Sandstone and Charmuria Limestone belonging to the Chhattisgarh Supergroup (Precambrian) of rocks. All the samples considered here have charge balance errors within ±5% (Table 1).

In both the trilinear Piper diagram (Figure 1) and the reproduced Piper diagram in rectangular coordinates (Figure 3), the samples plot mostly in the field of mixed bicarbonate type of water. The linear trend in the anion

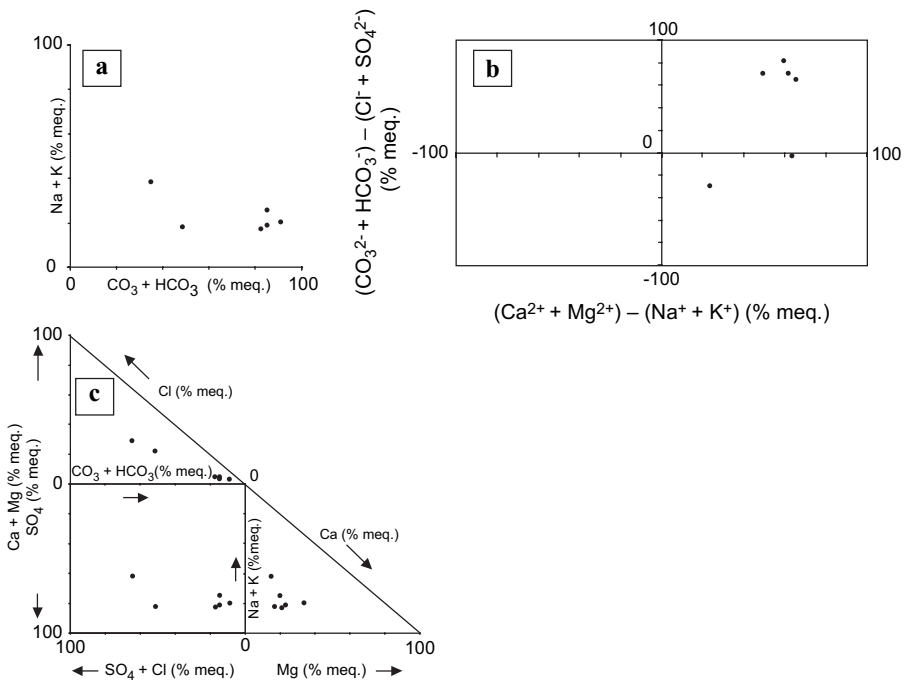


**Figure 2. Plotting of data points (given in Table 1) in the rectangular plots proposed by earlier authors: (a) Langelier and Ludwig (1942), (b) Chadha (1999), and (c) Romani (1981).**

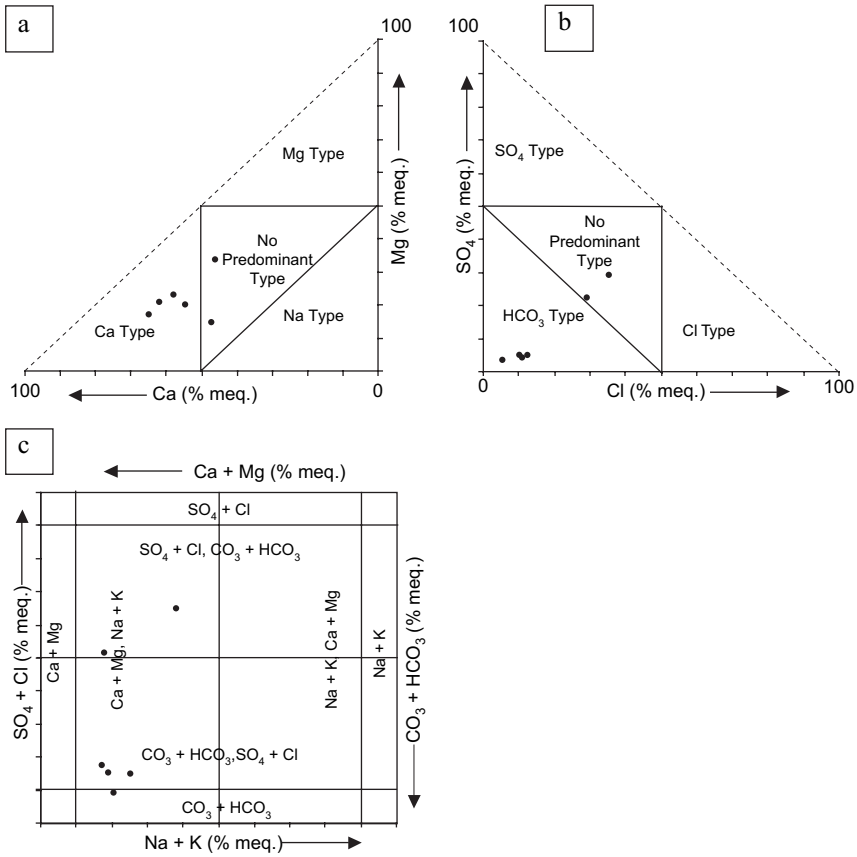


**Figure 3. Piper diagram reproduced in rectangular coordinates: (a) cation triangle, (b) anion triangle, and (c) the reproduced central diamond-shaped field. Water types shown here are as per those given in Back (1966).**

triangle represents the normal evolutionary trend of bicarbonate to mixed type of water in such terrains (Chebotarev 1955a, 1955b, 1955c; Freeze and Cherry 1979).

## Conclusions

Piper diagram can be prepared in rectangular coordinates taking the relative percentages, and the central diamond-shaped part can be reproduced without plotting the cation and anion triangles. The different regions defined in the original diagram are retained in this rectangular plot. The Piper trilinear diagram forms the basis for defining water types (Back 1966), and these areas can easily be defined in the proposed diagram in rectangular coordinates (Figure 3). The proposed diagram can be constructed with the help of commonly used graphical packages like MS Excel. The advantages of plotting on rectangular coordinates are that the presentations become clearer and easier to interpret, because the commonly used graphics applications offer numerous control for editing and annotations. Though the trend lines are not significant in trilinear diagrams, because of closure constraints (Rollinson 1993), if desired, trend lines can be fitted quite conveniently. Since the graphs are on rectangular coordinates, a third axis for electrical conductivity or distance from water divide, for example, can be added to generate a three-dimensional plot. The proposed diagram in rectangular coordinates is a replica of the original trilinear diagram, and thus the visual perceptions as well as the interpretations of the original diagram are retained.

**Table 1**
**Chemical Constituents of Samples Plotted in Figures 1 to 3 and CBE**

| Id | Ca (mg/L) | Mg (mg/L) | Na (mg/L) | K (mg/L) | Cl (mg/L) | $CO_3$ (mg/L) | $HCO_3$ (mg/L) | $SO_4$ (mg/L) | CBE (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 32 | 6 | 28 | 2.8 | 43 | 0 | 73 | 48 | −0.42 |
| 2 | 46 | 11 | 17 | 0.7 | 14 | 0 | 201 | 9 | 1.04 |
| 3 | 54 | 11 | 16 | 2.4 | 18 | 0 | 207 | 10 | 2.93 |
| 4 | 50 | 11 | 25 | 2.8 | 18 | 0 | 244 | 9 | −1.46 |
| 5 | 50 | 22 | 25 | 0.5 | 11 | 0 | 305 | 9 | −0.83 |
| 6 | 134 | 21 | 39 | 6.4 | 96 | 0 | 275 | 100 | 4.99 |

Note: CBE = charge balance error.

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**Editor's note:** This paper is a revised version of an earlier paper that was reviewed by two anonymous reviewers. The current paper was reviewed by the associate editor.