Journal of Geochemical Exploration 154 (2015) 143–155

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

journal homepage: www.elsevier.com/locate/jgeoexp

# Different spatial methods in regional geochemical mapping at high density sampling: An application on stream sediment of Romagna Apennines, Northern Italy

Valerio Lancianese *, Enrico Dinelli

*I.G.R.G., Università di Bologna, via S. Alberto 163, 48123 Ravenna, Italy*

ARTICLE INFO

*Article history:*
Received 13 January 2014
Revised 14 December 2014
Accepted 20 December 2014
Available online 26 December 2014

*Keywords:*
Geochemical mapping
Stream sediment
Cluster analysis
Exploratory Data Analysis (EDA)
Sample Catchment Basin (SCB) approach
IDW interpolation

ABSTRACT

Geochemical mapping is a fundamental tool for environmental monitoring and land management. For this reason, regional-, national- and global-scale geochemical mapping projects have been carried out in various countries since the late 1960s. A high density regional stream sediment geochemical survey was carried out over an area of 4125 km$^2$ in the Romagna Apennines (Northern Apennines) by collecting 770 samples (1 sample per 5 km$^2$). The <0.180 mm fraction was analysed for 30 elements by means of X-ray fluorescence spectrometry. The area has a complex geology dominated by sedimentary rocks, and characterised by various geological units, which belong to the Ligurian, Tosco-Umbrian and Padano-Adriatic palaeogeographical dominions. In the study area, the industrial sites and the largest towns are located on the plains, the agricultural areas are in the hills, and there is a wooded mountainous area in the upper reaches of the main streams.

Various mapping techniques were used for presenting and interpreting the data: proportionally sized dots, Exploratory Data Analysis (EDA)-based symbols, Inverse Distance Weighted (IDW) interpolation and Sample Catchment Basin (SCB) mapping approach. Proportional dot maps indicate the lithological control of the geological units. EDA maps demonstrate that it might be easier to extract some information with relevant symbols and class divisions; moreover, the subdivision of a whole data set in separate populations, related to a specific grouping variable, highlights anomalous areas, which would not be visible in a general presentation. Finally, the comparison of IDW interpolation and SCB mapping techniques illustrates that significant anomalies related to geological and anthropogenic sources are better modelled when the geochemical landscape is represented as a discrete surface rather than a continuous surface. However, this study shows how the concentration of chemical elements cannot be presented properly with a standardised mapping technique in an area characterised by multiple factors. Indeed, the use of various mapping techniques highlights interesting features for understanding the effects of local geology or human impact.



## 1. Introduction

Over the last sixty years, geochemical mapping projects have been carried out in many parts of the world and have played important roles in both mineral exploration and environmental studies (Andersson et al., 2014; BGS, 1991, 1992, 1993, 1996, 1999, 2000; Birke et al., 2009; Bølviken et al., 1986; Caritat and Cooper, 2011a, 2011b; Cohen et al., 2012; Darnley et al., 1995; De Vos et al., 2006; Fauth et al., 1985; Grunsky et al., 2009; Halamić and Miko, 2009; Halamić et al., 2012; Hawkes and Bloom, 1956; Inácio et al., 2007; Kadûnas et al., 1999; Koljonen, 1992; Licht, 2005; Lis and Pasieczna, 1995; Locutura et al., 2012; Ottesen et al., 2000, 2010; Rawlins et al., 2012; Reimann et al., 1998, 2003, 2014a, 2014b; Salminen et al., 2004, 2005; Smith et al., 2014; Thalmann et al., 1989; Vrana et al., 1997; Webb et al., 1978; Xie and Cheng, 1997, 2001; Xie et al., 2012). The spatial distribution of chemical elements presented as geochemical maps provides a better visualisation of the geochemical processes active in a study area, thus facilitating the decision-making process in land management and assessment (De Vivo et al., 2003, 2004).

When constructing geochemical maps some important criteria should be considered (Sharp, 1987). The presentation scale, sampling density and sampling material should be selected in accordance with the objectives of the project and the ultimate use of the results. In environmental geochemistry, studies at regional and local scale are required for detecting contamination sources or potential risks for human health, whereas in mineral exploration geochemical prospecting requires higher resolution data and regional-scale investigation for tactical studies in order to identify possible targets.

In the latter case, the sampling density increases exponentially with the amount of information required (Chiprés et al., 2008; Demetriades, 2014; Ohta et al., 2011; Xie et al., 2008). Geological and physiographical conditions prevailing in a study area are important criteria for determining the most appropriate sampling material, and other factors, such as logistics and budget, must be considered for the optimisation of the sampling campaign (Demetriades, 2014).

* Corresponding author. Tel.: +39 3202141161.
*E-mail address:* valerio.lancianese2@unibo.it (V. Lancianese).

http://dx.doi.org/10.1016/j.gexplo.2014.12.014
0375-6742/

At regional scale, stream sediment is a widely used sample material in high-density geochemical surveys throughout the world (Salminen et al., 2008) representing a composite sample of rocks and soil that are present in the drainage basin upstream of the sampling site (Darnley et al., 1995; Hawkes and Webb, 1962; Levinson, 1974, 1980; Rose et al., 1979). The stream sediment composition, as well as the soil composition, is closely linked to various factors, such as geological setting, weathering, history, slope, vegetation, pedogenesis and industrial activities (Spadoni et al., 2005). The complex nature of stream sediment can be applied in environmental and exploration geochemistry, and the resulting maps can be useful for defining background values and delineating geochemical anomalies (Spadoni, 2006). Studies carried out at higher sample density can determine the local effects of anthropogenic influences, and the relationships between the chemical composition of stream sediment and bedrock geology (Batista et al., 2006; De Vos et al., 2006; Yamamoto et al., 2007).

The abundance of spatial information in stream sediment data should be appropriately investigated and supported by means of various statistical and cartographical techniques, yet regional-scale sampling generally focuses on a single presentation technique, thus, disregarding the possibilities provided by other elaboration techniques, particularly in areas characterised by complex geology, mineral occurrences and human impact. Nevertheless, some authors (Carranza, 2010; Reimann, 2005) suggest that careful consideration is required concerning the elaboration process, land morphology, sample type and the purpose of statistical treatment and presentation as part of the decision-making process. The main objective is to plot an informative geochemical map, and an accessible data framework in order to achieve the purpose of the study, which is not an easy task, since it is essential to select appropriate statistical graphics, such as histogram, density trace, boxplot and cumulative probability plot, as well as a specific gridding algorithm for interpolation and some artistic aspects, which include effective colour scales, class selection and explicative symbols (Lima et al., 2003; Reimann, 2005).

An example of the various possible elaborations of geochemical data at regional scale could be presented by maps plotted by the inverse distance weighted (IDW) interpolation technique, or the Sample Catchment Basin (SCB) approach (Carranza, 2008, 2010; Carranza and Martin, 1997). A common practice is to use the IDW interpolation technique in environmental geochemistry, geochemical prospecting and geochemical mapping. The efficiency of this technique depends on certain factors, such as a regular sampling grid, and attention should be paid to sampling density, because interpolation of low-density data can lead to unrealistic results. Moreover, this technique does not take into consideration the geomorphological constraints of the watersheds and the functional relationships, in terms of transport and deposition processes, between sampling points along the stream network (Spadoni, 2006).

Although the SCB approach is not a common practice, it can provide useful information whenever sampling density is adequate and it has been used at regional scale for producing geochemical maps since the late 1980s (Bonham-Carter et al., 1987; Carranza and Hale, 1997; Spadoni, 2006; Spadoni et al., 2004, 2005). There are both advantages and disadvantages of using this technique: SCB avoids '*mathematical interference*' between neighbouring samples (Spadoni, 2006), as it accurately establishes the sources of contamination or significant anomalies in individual catchment basins (Carranza, 2010), and it is suitable for defining morphological features in mountainous and hilly regions, but not for large plain areas (Spadoni et al., 2004).

This paper reports the results of a regional-scale stream sediment survey to which various statistical and cartographical techniques have been applied. Maps based on symbols, selected according to different criteria and with secondary subdivisions, have been plotted, and compared with other maps produced by means of an interpolation algorithm and sample catchment basin extrapolation. The aim is to carry out an in-depth investigation on a spatially distributed data set with a 'step by step' approach in order to demonstrate the potential of a reasoned statistical data treatment and visualisation techniques to highlight natural phenomena and possible human impacts.

## 2. Study area

### 2.1. Geological background

The present study was carried out on a surface area of over 4125 km$^2$ covering the entire Romagna Apennine mountain range (northern Italy), which has a NW–SE orientation. The geology (Fig. 1) is mainly composed of sedimentary rocks, and consists of various geological units attributed to different palaeogeographical domains and structural units (Vai, 2001): Ligurian, Tosco-Umbrian and Padano-Adriatic domains. The Ligurian domain, which also includes the sedimentary successions deposited in satellite basins (Epiligurian deposits), occupies the north-western and south-eastern part of the area. There are several types of rock: Chaotic Complex (Pini, 1999), turbiditic units (limestone/clay intercalations) and various types of sandstone. The Tosco-Umbrian domain (more precisely Romagna-Umbria) is situated in the central part of the study area and covers almost half of it. It is composed exclusively of sandstone and marl of the Marnoso-Arenacea Formation, subdivided in several units according to age and sandstone/marl ratio. At the mountain chain border, the Padano-Adriatic domain is parallel to the Tosco-Umbrian domain and includes evaporitic, clastic and clayey sediments and alluvial deposits (AA.VV., 1987; Regione Emilia-Romagna, 1996).

### 2.2. Physiography

The Romagna Apennines are crossed by the catchment basins of eleven rivers: Idice, Sillaro, Santerno, Senio, Lamone, Acerreta-Tramazzo, Montone, Rabbi, Bidente, Savio-Borello and Marecchia (Fig. 2 & Table 1). The hydrographical network follows a SW–NE direction, from the mountains to the plains. Most of the rivers cross the units of the Marnoso-Arenacea Formation, the terrains of the Padano-Adriatic domain and Quaternary alluvial deposits, and follow a regular chronological order with the exception of the Idice, Sillaro and Marecchia rivers that cross the heterogeneous terrains of the Ligurian domain (Mazzanti and Trevisan, 1978).

The elevation of the area ranges from approximately 15 to 1660 m above mean sea level. The rainfall recorded in this region is approximately 800–900 mm per year, and seasonal runoff varies considerably with approximately 70% of the annual runoff occurring between January and April. During this period the average flow of the rivers is approximately 4.8 m$^3$/s, while in summer (June to September) it is 0.5 m$^3$/s (http://www.arpa.emr.it/sim/?idrologia/annali_idrologici).

There are two main fluvial geomorphological forms in the study area: terraces and incised valleys. In the mountainous-hilly section (average slope > 5%), forms of erosion such as deep valleys, gorges and steep valley slopes prevail. Downstream, in the hilly-plain section (average slope < 2%) there are large terraces along the flanks of the valley caused by the recent tectonic evolution of the area (Francavilla and Ricci Lucchi, 1969; Pellegrini and Toni, 1982; Rossetti, 1978; Wegmann and Pazzaglia, 2009).

### 2.3. Land use

The total number of inhabitants in the study area amounts to 1.4 million and more than 60% live in the cities on the plain (Bologna and hinterland, Imola, Faenza, Forlì, Cesena and Rimini), while there are many small towns in the valleys. Most of the area is used for farming (57% covered with arable crops, olive groves, vineyards, orchards) followed by woodland (39%). The industries are located around the main cities, and in several smaller towns in the main valleys where cattle-breeding, aviculture, dairy, ceramic and paint industries are the main activities (Fig. 2).