Representation of Geochemical Data in Geospatial Domain

Ashok Kumar Joshi¹ and Sisodiya D.S.²

¹Regional Remote Sensing Centre, NRSC, Dept. of Space, ISRO, Nagpur, Maharashtra, India
²Geological Survey of India, Central Region, Nagpur, Maharashtra, India

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Abstract

Geochemical surveys are integral part of systematic geological survey to cover mineral provinces and geological basin. These surveys have indicated new mineral occurrences in different geological terrains. Large amount of data collected in the field is finally submitted as report in the hard copy format as part of the annual field survey plan. It takes many years to complete the geochemical survey of a geological basin by several parties working on different aspects. Geographical Information System (GIS) facilitates input, editing and display of spatial data collected in various forms (location, traverses, and boundaries) and analyse in most efficient way. However, large amount of geochemical data collected from various sources poses several challenges to represent and analyse the data in a meaningful way. This paper addresses all such difficulties in handling unformatted inputs and most optimal method for display, analysis and integration of geological data from various sources.

Keywords

Geochemical Exploration; GIS; Remote Sensing; Sakoli Basin

1. Introduction

Geological mapping of mineral belts is carried out to suggest potential zones for further detailed exploration using geophysical and geochemical methods. Systematic geochemical sampling is carried out depending upon the type of mineralization and its extent. Organizations world over are also involved in collection of rocks samples for geochemical assessments at regional scale. Geochemical mapping has been successfully used as a tool to target mineral deposits in geologically diverse environments.

Geochemical data collected in the field is contoured and geochemical patterns are compared with geological map to locate probable anomalies. With increasing data volume and parameters being collected, representation of the datasets has been attempted in different ways (Bjorklund and Gustavsson, 1987). Innovative techniques of computer database structure and analysis termed as ‘Data Mining’ has been employed by Grunsky, 2007, emphasizing the role of multi-variate geo-statistical techniques in identification of geochemical anomalies. These techniques have been successfully employed in different parts of the world (Sisodiya, 1993; Sisodiya & Joshi, 2002; Samal et al., 2011; El-Makky and Sediek, 2012; Yilmaz et al., 2015). New techniques of data processing such as fractal analysis and fry analysis have been tested over known mineral deposits (Carranza, 2009).
Under various programmes of the government institutions in the world a repository of geochemical data has been created for geo-environmental studies to advice local governments over anomalous metal concentrations in some areas (Darnley et al., 1985; Timo, 1996).

Initially most of the surveys were carried out to detect a metal anomaly over a potential target; however, today most of the geochemical surveys are done to identify multi-metal anomalies over the large mineral provinces. Few geochemical surveys are also carried out to delineate the source of environmental degradation due to natural or man-made features.

Data collected through geochemical surveys over the years are sometime too voluminous to be analysed using simple tools. Visualization of these data to derive any inference becomes a challenge at times while studying geological basins on 1:50,000 scale. Multi-metal/temporal data collected from different sources presents many challenges in analyses of these data. Traditional way of representing these data is by graphs and grids which results in loss of spatial information and its comparison with other available maps.

With the availability of Geographic Information System (GIS) it is now possible to preserve the spatial relationship of the geochemical data collected over the years and with different parameters, however optimally representing the data and modeling is still a challenge to the geologists. A large amount of spatial maps/data are available from various sources which needs integration in a GIS. Several demonstrative studies have been carried out in a limited way over small regions however studies covering geological/mineral basin/province are rare.

Importing large amount of geochemical data into a GIS poses several challenges in terms of their positional accuracy, calibration, formatting and validation which takes away most of the project time. Today with much awareness about geomatic tools and techniques the data can be collected and imported into a GIS using defined templates very easily and analysed in a shorter time.

A demonstrative study has been carried out for Sakoli Basin in Central India involving large amount of geochemical data collected through stream sediments and bedrock samples during several field seasons toposheets-wise by various teams of Geological Survey of India. Chemical analyses data later has been appended for each sample analysed for Cu, Pb, Zn, Ni & Co; and analysed. An approach for representation of complex geochemical data along with other thematic maps has been demonstrated for deriving the inference on geochemical anomalies in a given geological basin/province.

2. Study Area

The area of study includes rocks of Sakoli Fold Belt (SFB) and adjacent gneisses of Nagpur, Bhandara and Gadchiroli districts of Maharashtra, in Central India (Figure 1). The area is bounded between latitude 20°25' N and 21°33' N and longitude 79°20'E and 80°10'E. Geographically the area spreads in a total of 13 Survey of India toposheets (55 O/8, 12, 15 & 16; 55P/5, 9, 13 & 14; 64C/3 & 4; 64D/1, 2 & 3.) on 1:50,000 scale.

3. Database

The core of the spatial database is geochemical data. Systematic geochemical surveys in the Sakoli Basin by stream sediment and bed rock sampling over 4060 sq km resulted in collection of a total of 11,491 samples (7815 Nos. of stream sediment and 3676 Nos. of bed rock) which have been analysed by Atomic Absorption Spectrometer for Cu, Pb, Zn, Ni & Co generating about 57,455 items of analytical data. Other spatial database includes lithology, structure, mineral map, gravity, geomorphology, drainage, slope, elevations, roads & settlements. IRS LISS-III satellite data was used
as image base to correct, update and refine vectorized thematic maps such as drainage, water body, roads, settlements etc.

Since most of the thematic database was in hard copy maps, all the maps were converted into softcopy, digitized and coded in a GIS database depending upon point, line and polygon features. In case of geochemical maps, the sample locations were digitized from the toposheets and were numbered using a standardised procedure maintaining the unique number for each location throughout the basin. Accordingly these unique numbers were also generated in the analytical attribute database. Unique number assigned was used to retrieve the geochemical value of respective metal for each sample location. Data for sample locations with metal values are treated separately for stream sediments and bedrock and GIS database was generated for further analysis.

3.1. Creation of Attribute Database

The availability of enormous amount of geochemical data collected over the Sakoli Basin has been compiled as analytical attribute database in commercially available GIS SW. The database contained field sample number, field season, toposheet number, rock description (in case of bedrock), metal content in ppm, and block name. This data was available in different files with inconsistencies in format. As a first step to rectify all the errors, all the database files are imported into common tabular format and corrected. A unique new code was given to each sample location for stream sediment and bedrock. The cartographic coordinates of each sample location with unique number were extracted from the point coverages (geospatial thematic database) of stream sediment and bedrock files. Using unique number the analytical data from the tabular sheet were appended with x, y locations derived from the coverage. Thus an analytical attribute database was generated with 11,491 records with 57,455 items of analytical data with geographic coordinates.

To ensure correctness of point data with geological and drainage map a proximity analysis was run and marginal errors in point location corrected. Also an error check was run on the values of various elements to ensure that the data falls in defined data bounds.

3.2. Representation of Geochemical Data

Geochemical Maps

The geochemical maps show distinct chemical concentration pattern that can be correlated with geological features, and the zones with higher metal abundance can be targeted for probable mineral deposit.

The geochemical map in this project has been prepared based on the dispersion of various metals in the stream sediments collected from first and second order drainage and also from bedrock samples. Separate point coverages have been prepared for each metal in stream sediments and bedrock samples. For better representation of geochemical data different methods have been adopted. Maps have been generated for stream sediments and bedrock separately to represent one or more metals at a time. A brief description of the methodology adopted is given in the following text.

Stream Sediments

As a first step the analytical data of stream sediments has been subjected to statistical analysis and based on standard deviation of the metal content in ppm a threshold has been calculated for each of the metal. The results of statistical analysis are given below:
The number of stream sediment samples is very high and due to this high density of points they could not be represented with appropriate markers in the map. For better representation the metal values in ppm stream sediment data were contoured. For contouring the data, various methods of interpolation have been used and spatial maps generated.

The first procedure involved contouring the points using TIN (Triangular Irregular Network) module with various options and then smoothening the output. Such outputs have very angular contour lines and large number of contour lines around a high or low value.

Another procedure involved converting the TIN output to lattice and then applying low-pass filters to the grid. This resulted in smoother contour lines and were also matching with the point data.

The last procedure involved contouring using TOPOGRID (ARC/Info) module which generated an output matching the real world situation using drainage maps and watersheds. This method can be employed with different options and constraints; and that is why a better contour map could be produced. Care shall be exercised while contouring the stream sediment sample data across the ridge line/watershed divide. A high value on the other side of the ridge can greatly influence the contour value and will depict a misplaced/displaced anomaly. Many other statistical techniques can also be employed for contour interpolation, however care shall be exercised that most of the input values are justified in the interpolated surface.

The contours from the interpolated surface have been calculated for an interval of 20 ppm for all the metal maps. However, for an effective presentation of these contours thresholds were selected for creating the Isogrades of different metals. The thresholds adopted are given in respective outputs.

**Bedrock**

The analytical data of the bedrock samples for each metal has been subjected to the statistical treatment. The various parameters arrived at are as follows:

**Table 2: (n=3676, metal values in ppm)**

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Element</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Threshold Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Copper</td>
<td>5</td>
<td>1000</td>
<td>77.12</td>
<td>159</td>
<td>395.12</td>
</tr>
<tr>
<td>2</td>
<td>Lead</td>
<td>5</td>
<td>1000</td>
<td>28.45</td>
<td>89.42</td>
<td>207.29</td>
</tr>
<tr>
<td>3</td>
<td>Zinc</td>
<td>5</td>
<td>1000</td>
<td>52.55</td>
<td>92.96</td>
<td>238.47</td>
</tr>
<tr>
<td>4</td>
<td>Nickel</td>
<td>5</td>
<td>1000</td>
<td>36.79</td>
<td>52.85</td>
<td>142.49</td>
</tr>
<tr>
<td>5</td>
<td>Cobalt</td>
<td>5</td>
<td>1000</td>
<td>21.90</td>
<td>56.61</td>
<td>135.12</td>
</tr>
</tbody>
</table>

(Stray high values of the metals have been excluded from the statistical analysis)

Since bedrock samples represent the value at the sampling location within a particular litho-unit, this data cannot be contoured to delineate anomalous zones. The representation in such cases can be
limited only to point markers. Various methods of representation of these point markers have been carried out to optimally bring out the anomalies from the background for one or more metals at a time.

After extensive tests of alternative techniques of representation of the contents at sampling sites, technique based on the use of continuously increasing dot size with increasing contents was found to give satisfactory results in representation on the map (Bjorklund et al., 1987). An exponentially increase in diameter of the dots with exponentially increasing in metal content has been found to be better for visualisation of the pattern of metal content variation.

The above representation has been again modified since the larger dots mask the smaller dots thus hindering the true depiction. The open circles with increasing diameter proportional to the metal content were found more useful than dots and in this case all the circle sizes were distinct and could display the pattern in a more effective way. Such representations also hold good when overlayed on the geological map of the area.

The above type of representations are good for one metal, however in this case since at each location five metals are to be represented another approach has been adopted. The whole range of the metal content of all the sample points cannot be represented, which makes the output very clumsy. To avoid this problem the metal contents have been grouped in to four ranges (<50 ppm, 50 to 200 ppm, 200 to 400 ppm and >400 ppm), and the diameter of the circles (or patterns such as triangle, square etc.) has been decided accordingly. This helps correlating the size of the symbol directly with the range of the metal content. Such maps when overlaid on other themes clearly bring out the relationships. For multi metal representation different marker symbols have been assigned to each metal with range categories plotted in different sizes.

An effort was made to draw the isogrades of various metals as primary dispersion within a lithologic unit. However, in the small and narrow units the representation was not adequate. Also due to large discontinuity in terms of metal concentration across two litho-units the outputs were difficult to understand. Several modifications of this approach were experimented but did not yield good results. This was also due to the erratic distribution of metals (especially base metals) which are often structurally controlled.

Few software provides provision for softlines or hardlines (faults etc.) while interpolating the data but contoured outputs do not match the geological environment or human logic.

Figure 2, 3 & 4 show the distribution of copper, lead and zinc metals in stream sediments (contours) and bedrock samples (markers) over geology of the Sakoli basin.
Figure 1: Geological Map of Sakoli Basin (After GSI). Survey of India 1:50,000 grid is overlaid on the map along with major towns.
Figure 2: Map showing the dispersion of copper metal in Sakoli Basin area over geological map. Circles of different colour represent Cu concentration in ppm in bedrock. The dashed line with contour value shows distribution of Cu in stream sediments. Interesting Areas A and B marked on map are shown in detail in insets.
Figure 3: Map showing the dispersion of lead metal in Sakoli Basin area over geological map. Squares of different colour represent Pb concentration in ppm in bedrock. The dashed line with contour value shows distribution of Pb in stream sediments. Interesting Areas A and B marked on map are shown in detail in insets.
Figure 4: Map showing the dispersion of zinc metal in Sakoli Basin area over geological map. Triangles of different colour represent Zn concentration in ppm in bedrock. The dashed line with contour value shows distribution of Zn in stream sediments. Interesting Areas A and B marked on map are shown in detail in insets.
Figure 5: Dispersion of Copper, Lead & Zinc in bedrock shown as continuous surface (DEM) in RGB combination. White areas depict high concentration of all the three metals. Other colors are combination of two or three metal high anomalies. Geological map has been overlaid as line feature in yellow. Interesting Areas A and B marked on map are shown in detail in insets.
**Figure 6**: Metal concentration above the threshold has been shown as circles for bedrocks and contours as stream sediments. Red color of copper, green for lead, blue for zinc, yellow for nickel and magenta for cobalt has been used to depict bedrock and stream sediments anomalies. Geological map displayed in background to correlate geochemical anomalies to draw inferences.

### 4. Integration and Modelling

The geographical information system is a powerful tool for integrating information (coverages) on points, lines and polygons for a digital cartographic database. The thematic maps can be overlayed, combined and intersected in any way one desires (such as points with line, points with polygon, line with polygon, polygon with polygon etc). The integration of several layers results in creation of n-dimensional database which can be used to derive the maps based on decision rules to arrive at the final map for a particular application. Modelling helps in performing the tasks in a systematic way to achieve the final results. Due to these important capabilities GIS plays a significant role in integrating data such as geological, geophysical, geochemical, geomorphological, slope, drainage, watershed etc. for mineral prognostics.

After extensive analysis of these datasets in a GIS using overlaying, unioning, buffering, proximity analysis, 3-D modelling etc., good correlation has been observed between primary and secondary dispersion patterns in certain areas leading to delineation of potential mineralized zones (Figure 2, 3, & 4).
Contours above the threshold values in stream sediment samples for each metal were extracted and correlated with bedrock values above the threshold in the Sakoli Basin in conjunction with geological map and gravity map (Figure 5 & 6).

The above exercise of extracting only anomalies in stream sediments and bedrock samples was done for all the five metals at a time and visualized with geological map in the background to ascertain the important (real) anomalies due to multmetal mineral occurrences. These anomalies were also checked with drainage and watershed map to differentiate correlated primary and secondary dispersion patterns.

Following conclusions have been drawn after analysis of results:

- An attempt has been made to represent various metals with varying ranges in two different sample media viz. Stream sediments and bedrock on a single map maintaining clarity and proper representation of the data using dots and symbols of different sizes (Figure 2, 3 & 4).

- The multi-metal anomaly zone thus brought out by superposition reflects the general dispersion of metal ions of higher order in meta-sediments as compared to gneisses. In gneisses the higher metal content is noted along shear and silicified zones due to remobilization (Figure 6).

- The anomaly between Sakoli and Tirka is significant, overlying the meta-basic + phyllitic rock with several primary spots of high values in the bedrock (Figure 6). Although prominent gossanisation is not seen the reported slag dumps and clay retorts indicate mineralized zone in the area. This anomaly is also substantiated by pitting and trenching near Tirka wherein the metal content (Pb +Zn) increases with depth (Sisodiya, 1993). Incidence of gold values with this anomaly further enhances the potentiality of this mineralisation.

- The Kitari Anomaly supported by gravity interpretation is important with prospecting point of view for gold, tungsten as base metal sulphides have good correlation with gold and tungsten as supported by the mineral map (Figure 5).

- The digital cartographic database thus created following extensive standardization procedure and integrated in a GIS environment provides wider scope for interpretation, integration and modelling of various thematic maps and forms a base for future scientific use related to Sakoli Basin or another such area.

5. Future Work

With the advancement in technology the geochemical sampling locations can be captured through mobile and field data can be directly integrated in a GIS along with photographs. While capturing the location of bedrock, input geological map can be used as background to precisely know the geological environment. Associated structures can also be recorded and sent to the Server through mobile application.

To optimize the sampling geomorphological maps can be used depicting degree of weathering which controls the movement of metals from the bedrock into stream sediments. Therefore, it is important to realize that lithology, structure, geomorphology, drainage, slope and watershed form a system which needs to be analysed in details before proceeding for a geochemical survey. Also the traditional concept of grid sampling needs modification to optimally sample the area in less number of samples.
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