Design and Implementation WebGIS for Improving the Quality of Exploration Decisions at Sin-Quyen Copper Mine, Northern Vietnam

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Abstract. The objective of this study is to design and implement a WebGIS Decision Support System (WDSS) for reducing uncertainty and supporting to improve the quality of exploration decisions in the Sin-Quyen copper mine, northern Vietnam. The main distinctive feature of the Sin-Quyen deposit is an unusual composition of ores. Computer and software applied to the exploration problem have had a significant impact on the exploration process over the past 25 years, but up until now, no online system has been undertaken. The system was completely built on open source technology and the Open Geospatial Consortium Web Services (OWS). The input data includes remote sensing (RS), Geographical Information System (GIS) and data from drillhole explorations, the drillhole exploration data sets were designed as a geodatabase and stored in PostgreSQL. The WDSS must be able to processed exploration data and support users to access 2-dimensional (2D) or 3-dimensional (3D) cross-sections and map of boreholes exploration data and drill holes. The interface was designed in order to interact with based maps (e.g., Digital Elevation Model, Google Map, OpenStreetMap) and thematic maps (e.g., land use and land cover, administrative map, drillholes exploration map), and to provide GIS functions (such as creating a new map, updating an existing map, querying and statistical charts). In addition, the system provides geological cross-sections of ore bodies based on Inverse Distance Weighting (IDW), nearest neighbour interpolation and Kriging methods (e.g., Simple Kriging, Ordinary Kriging, Indicator Kriging and CoKriging). The results based on data available indicate that the best estimation method (of 23 borehole exploration data sets) for estimating geological cross-sections of ore bodies in Sin-Quyen copper mine is Ordinary Kriging. The WDSS could provide useful information to improve drilling efficiency in mineral exploration and for management decision making.

1. Introduction
The study area (Sin Quyen deposit) is in the northern part of Vietnam. It is located in mountain area; it experiences a dry-cold climate from October to March, while the tropical monsoon is rainy season from April to September. The annual average temperature is 23 °C (73 °F), average humidity from 85 - 86%, average annual rainfall 1400 - 1800mm/year. The Sin Quyen copper deposit is localized in the Neoproterozoic metapelite in the Phan Xi Pang zone [1]. Fifteenth ore bodies have been recognized in
the deposit; contains economic concentrations of Cu, Au and LREE, and sub-economic concentration of U-ore (uranium ore). The deposit is currently the largest Cu producer in Vietnam, with annual production of Cu metal is 30,000 Ton.

The Open Geospatial Consortium (OGC), an international voluntary consensus standards organization, it proposed standards for Web Services (OWS) such as Web Map Services (WMS) providing dynamic generation of maps [2], Web Feature Services (WFS) for requesting features of spatial data [3], and Web Processing Services (WPS) is a service designed to standardize the way that Geographic Information System (GIS) calculations are made available to the Internet, WPS provides rule for standardizing input, trigger its execution and output data [4].

Recently, many systems have been successfully developed based on WebGIS technology and OWS such as: A Spatial Data Infrastructures (SDI), an intelligent GeoPortal, and a Decision Systems (DSS). The SDIs for environmental monitoring, natural hazards assessment or disaster risk management were introduced by [5, 6]; an intelligent GeoPortal known as a web portal in order to find and access geographic information associated geographic services were discussed by [7, 8]; a Decision Systems (DSS) have been developed in various study areas such as for earthquake disaster reduction [9], for management of floods [10], for monitoring environmental parameters [11].

GIS software has enable users not only to view spatial data in proper format but also can manipulate advance GIS tools for instance analysis, interpolation, statistics, geostatistical analysis tools. Basically, in the exploration problem, exploration data sets have been processed and visualized with the help of computer software based on one-dimensional, two-dimensional (2D), three-dimensional (3D) methods. Numbers of 2D cross-sections or maps were produced to help determine the location. Three-dimensional can be used for determining orientation and relationship of data. Today, 3D visualization technologies are supported in order to improve the quality of exploration decisions. But until now there is no online system that focuses on this issue. The objective of this study is to design and implement the WebGIS Decision Support System for reducing uncertainty and supporting to improve the quality of exploration decisions in the mineral mines, a case study is Sin-Quyen copper mine (WDSS4M). The system based on set of data including raster, vector data and data from the exploration boreholes data (DFDH). The WDSS4M makes available not only for basic functions of WebGIS for instance display, zoom, pan, edit thematic maps over internet, but also it can present some advanced functionalities: [a] visualization functionality shows how underground of exploration drill hole looks like in 2D or 3D; [b] statistical functionality presents data analysis of DFDH; [c] interpolation tool for predicting ore-body volume; and [d] add a new DFDH to Geodatabase in DBMS (database management system).

2. Study area and data used

2.1. Study area

The Sin Quyen deposit is located between the longitude 103°48'28.05"E and 103°49'9.271"E, and between the latitude 22°37'0.6"N and 22°37'40"N (Figure 1). Gold and silver in the deposit are distributed unevenly in the ores: Their contents vary from hundreds and tenths ppm to 1.8 ppm. High contents have also been established for Pr, Nd, Sm, Eu, Gd, and Tb [1]. Recent drillings down to -400 m depth have discovered extra 100 Mt of ore with an average grade of 0.95 wt.% Cu [12]. The analysis results of ore-body in spatial structure of Sin Quyen has showed that Cu content has non-uniform change, regional anisotropic and the direction is north-south (0±22.5°). In this study, Cu content will be concentrated because only copper samples are sufficient for study.

2.2. Data used

The data used in this study can be divided into two groups, the first group is remote sensing (RS) and Geographic Information System (GIS) data and the second group is DFDH data.
The RS and GIS data includes:

- The Land used and land cover map (LULC) was extracted from High-Resolution Land Use and Land Cover Map Products (HRLULC) of the Advanced Land Observing Satellite ALOS-2 [13] with a resolution is approximate 15m×15m. The Digital Elevation Model (DEM) from ASTER image with a spatial resolution of 30x30 m, DEM can generate map of three geomorphometric factors (slope; aspect and relief amplitude).

- The GIS data such as administrative boundary maps, drainage system, and vegetation cover were extracted from database of Vietnam atlas 2009.

![Figure 1. Study area and the map of 23 drill holes encounter copper ore](image)

The second group (DFDH data) was collected from exploration drill holes (Figure 1). It was collected from document of [12]. Two characteristic ore bodies have been selected in this study, because only two datasets are available. The number of boreholes encountered ore and the number of samples shown in (Table 1).

| Element/Orebody (B) | Number of holes and sample | Min | Max | Average | Skewness | Kurtosis | Variance |
|---------------------|-----------------------------|-----|-----|---------|----------|----------|----------|
| Cu/B3               | 26/940                      | 0.1 | 3.2 | 1.154   | 0.818    | -0.513   | 0.841    |
| Cu/B7               | 26/372                      | 0.1 | 3.2 | 0.912   | 1.176    | 0.976    | 0.512    |
3. System architecture
3.1 Selection of WebGIS Platform
WebGIS known as the World Wide Web GIS, it is also a type of distributed information system, comprising at least a server and a client. In the WDSS4M system, the server-side was deployed under GeoServer and PostgreSQL/PostGIS. On opposite side, OpenLayers and GeoExt frameworks were used to develop the client-side.

3.1.1. The Server-side. GeoServer is an open source server written in Java that allows users to share process and edit geospatial data using OGC standard. GeoServer in the WDSS4M was applied to support the OGC Web Map Service and Web Feature Service. The raster dataset such as DEM, LULC were imported to GeoServer using Pyramid plugin to builds multiple mosaics of images; and the vector dataset, such as administrative boundary maps, drainage system combined with their styling contents were also stored in GeoServer.

The PostgreSQL is a powerful, open source object-relational database system. PostGIS is a spatial database extender for PostgreSQL, stores the DFDH data of 23 drill holes as a geodatabase. At each exploration drill hole (DFDH), samples were collected at various points underground, all points were converted to latitude and longitude based on the function of {depth, height, azimuth angle}, this step can be understood as pre-processing data, then those were imported to PostgreSQL/PostGIS. Moreover, Geoserver can also connect to the PostGIS and makes geodatabase available as a WMS layer.

3.1.2. The Client-side. The raster and vector datasets are served in GeoServer as WMS layers. OpenLayers is a client-side software which is widely combined with GeoServer. OpenLayers is a map viewing library in JavaScript, it can support WMS, WFS and other different standards. GeoExt (http://www.geoext.org/) is a JavaScript toolkits and specific components combining the GIS functionality of OpenLayers.

3.2. OGC Web Processing Service
For OGC Web Processing Service, we used ZOO-Project framework (http://www.zoo-project.org/) as a WPS server. ZOO-Project is a Web Processing Service implementation written in C, Python and JavaScript. It is an open source platform which implements the WPS 1.0.0 and WPS 2.0.0 standards edited by the Open Geospatial Consortium (OGC). It also offers efficient tools for creating new innovative web services and applications [14].

3.3. Interpolation and visualization implementation.
3.3.1 Kringing Interpolation. Comparison of Kriging with inverse-distance method and Nearest-neighbor interpolation, both inverse-distance and nearest neighbor can give very inaccurate predictions. Kriging interpolation is the most popular and widely used at present in geostatistics. There are many Kriging methods that are used nowadays. However, because of limitation of samples, the Ordinary-Kriging will be selected. Basically, Ordinary-Kriging predicts the value $Z^{*}(x_0)$ by following equation:

$$Z^{*}(x_0)=\sum_{\alpha=1}^{N} \lambda_{\alpha} Z(x_{\alpha})$$ (1)

$\lambda_{\alpha}$ are the weights that indicate the influence of variables $Z(x_{\alpha})$, $Z$ defined at each point on a region, $N$ data location $(x_i, i = 1 \ldots N)$ and a value $Z$ at $x_\alpha$ location. The equation (1) is determined by the Kriging in equation (2).
\[
\begin{align*}
\left\{ \sum_{\beta=1}^{n} \lambda_{\beta} y(x_{\alpha} - x_{\beta}) + \mu = \bar{y}(x_{\alpha}, V_0) \right. \\
\left. \sum_{\beta=1}^{n} \lambda_{\beta} = 1 \right\}
\end{align*}
\]

(2)

Where \( y(x_{\alpha} - x_{\beta}) \) is the theoretical variogram [15], \( \bar{y}(x_{\alpha}, V_0) \) is a mean variogram of local neighborhoods \( x_{\alpha} \) with sub-block \( V_0 \), \( \mu \) is Lagrange parameter.

3.3.2 HUMGeostat. For implementing the Kriging interpolation and analysis tools we implement the HUMGeostat tool. The tool was created based on the Stanford Geostatistical Modeling Software (SGeMS) platform [16]. The SGeMS is an open-source computer package for solving problems involving spatially related variables. Four commonly used Kriging methods Ordinary-Kriging, Simple-Kriging, Indicator-Kriging, CoKriging were developed and tested in the HUMGeostat. The strength of a HUMGeostat is 3D graphics display, processing capabilities and data analysis. The program is compiled on Microsoft Visual Studio 2010 IDE and C++, the interface was designed on Qt 4.7 integrated the Visualization Toolkit (VTK). It is an open source program, freely available software system for computer graphics, image processing, and visualization (http://www.vtk.org/).

The WDSS4M makes user possible to request WPS based on HTTP Get or Post in order to trigger HUMGeostat to process data, then execute Kriging interpolation tools. A client calls the WPS server for interpolating; the server read the information, executes and returns the results to the client. The HUMGeostat requires two set of parameters (Variogram and Kriging) from the HTTP Post. The parameters of the WPS Post are provided as an XML string, the (Figure 2) is an example of parameters to run the Kriging tool.

![Figure 2. XML string of WPS base on HTML Post for calculating Kriging interpolation](image-url)
3.3.3 Statistical analysis. This implementation was also using statistical tool in HUMGeostat. A client can select a statistical function and send WPS request to server for executing calculation. At first, WPS invokes DFDH data by connecting to PostGIS and then WPS send those data to HUMGeostat, data will be processed and responded to client, the return values can be chart, table or image. (Figure 4) shows the histogram of 940 samples from 23 drill holes, Cu content is from 0% - 3.19%.

3.4. DFDH database design
In this study, spatial data includes two tables (DrillHole and DrillHoles_Details); they respectively store points. Among them, point data can be the input data for presenting a map of drill holes and visualizing map of samples underground (Figure 5). In addition, the values of samples are the main input for executing Kriging interpolation and statistical analysis. The DrillHole table contains names and coordinate of the drill holes, date/time, name of drilling company and geometry at coordinate system for Vietnam with EPSG: 4756 (VN-2000). The Drillholes_Details table includes samples information such as geometry, porosity, thickness. Otherwise, the other three attribute tables were used. The table TypeOre contains the ID and name of a minerals and a porosity standard (for example Copper is 0.5%). The table BodyOre: contains the IDs and name of a body ore. Finally, the ExplorationLine table stores definition of the exploration line, coordinate of a starting point and its azimuth.

![Figure 3. Spatial and attribute database of DFDH in WDSS4M system](image)

3.5. Design of system
The system architecture of WDSS4M is showed in (Figure 6), the system was created based on WMS, WFS and WPS. The WMS1 and WFS2, from client-side user can directly request maps (WMSs) or search/query (WFSs) features of the maps. The WPS3 is visualization service, in which user can request DFDH data into PostgreSQL and then invoke HUMGeostat to execute spatial analysis for DFDH data. The WPS4, user can get data from PostGIS and then generate 2D or 3D visualization results of the underground exploration drill holes in the client-side based on three.js. Three.js is a
cross-browser JavaScript library/API used to create and display animated 3D computer graphics in a web browser (https://threejs.org/). Otherwise, at the WPS5, client can request prediction values of ore body volume in 2D, 3D based on Kriging interpolation. The final, the WPS6 plays the role as a tool for inserting new DFDH data into PostgreSQL.

![Figure 4. Histogram of 940 samples at 23 drill holes, copper content from 0%-3.2%](image)

![Figure 5. 3D visualization of the underground exploration drill hole](image)
4. Results and discussions
The WDSS4M is completely used Free and Open Source Software (FOSS). For testing and validating the system, we used 23 boreholes with their 940 samples; the copper content in Sin Quyen mine was from 0% to 3.19%. The calculation time in test machine for 200*200*200 sub-blocks (one sub-block equivalent to 5m x 5m x 5m) is about 5 minutes for the laptop with an i7-4500U GPU: GeForce840M, and has 8GB of RAM.
The system makes available not only swap off-line tools to online tools but also satisfies some expectations such as: a global access, large number of user, low-cost system and supports real-time spatial analysis, visualization and interpolation. The system helps the decision makers to take appropriate decisions in order to reducing uncertainty and supporting to improve the quality of exploration tasks in the Sin-Quyen copper mine. From client interface, client can get images which are used to display drill holes, surface, 2D cross-section, 3D cross-section and distribution of copper mineralization (Figure 7). The ore body volume was generated from 940 sub-block, the color of sub-block displayed Cu content which is from 0% to 3.2%. Moreover, server can also return interpolation result in csv text file (Figure 8) including xyz-coordinate axis system and copper content.

However, the system has difficulty to validate Co-Kriging method cause of limitation of sample. The method for displaying interpolation result needs to be improved. The operational system has only ability to display interpolation results using images and csv text file, feature work needs to use three.js for displaying interpolation results.

![Figure 8. 3D of Ore body (B3) in csv format](image_url)

### 5. Conclusions

The WG4SQD based on OWS has been successfully implemented and developed in test server at the Hanoi University of Mining and Geology. In addition, HUMGeostat can be a good platform for WebGIS based Decision Support for improving the quality of exploration decisions at Sin-Quyen copper mine (northern Vietnam) or other mines. For validate the system, 23 boreholes and 940 samples were used, the number of sub-block for calculating Kriging interpolation is 800000 sub-blocks. The run-time is fast; the system is low-cost, user-friendly and no software/plug-in requirement on client-side. The result from this study may be useful for decision making and policy planning in Sin-Quyen mine or other mines in future.

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