USING REMOTE SENSING AND GIS TECHNIQUES IN SPATIAL INFORMATION MONITORING OF COAL REFUSE DISPOSAL PILES

Tang Shilu *

Institute of Land Reclamation & Ecological Restoration, China University of Mining & Technology (Beijing), China – sherrytang00@gmail.com

KEY WORDS: Monitoring; Extraction; Coal Waste Pile; Remote Sensing; GIS

ABSTRACT:

The intention of this paper is to monitor spatial information of coal refuse disposal piles due to long-term mining operation in Wangping Gully, Mentougou District of Beijing. The monitoring techniques in this paper refer to remote sensing and Geographic Information System (GIS), where remote sensing and GIS are highly integrated with a natural and mutually support to each other. Topography map surveyed by Global Positioning System (GPS) and high resolution remote sensing image supported by airborne photogremmetry are the main and basic data resource for this research. Meanwhile, Digital Elevation Model (DEM) derived from topography map is served as the key data for spatial information extraction, while visualization interpretation of remote sensing image is carried. Area of Interest (AOI) of coal refuse disposal piles is derived from remote sensing image, which contains the 2 dimension (2D) information, and therefore the calculation of 2D area of coal refuse disposal piles can be acquired. In addition, on top of DEM and AOI, surface area and volume can also calculated, in accordance with the spatial analysis in GIS platform. Consequently, 2D area, surface area and volume are extracted as three main spatial information factors, which fulfil the spatial information monitoring of coal refuse disposal piles. As a result, the spatial information of coal refuse disposal piles can provide the basic information for future work of environmental evaluation and ecological restoration.

1. INTRODUCTION

1.1 Coal Refuse Disposal Piles

Coal refuse is an incidental production of coal exploitation and processing, which roughly account for 10%-20% of the raw coal production. In China, there is a large amount of coal refuse owing to enormous amount of coal mining operation. In most cases, coal refuse is piled continuously along with the coal exploitation and processing, and consequently into man-made hill, which is called “coal refuse disposal piles” or “coal waste piles”. The problem of coal refuse disposal piles becomes increasing serious recently. Coal refuse is extremely acid, hence runoff and seepage from coal refuse disposal piles add acid and other contaminants to surface water and surrounding land, moreover, fugitive dust and products of spontaneous combustion continue to degrade air quality [2]. Other than water pollution and air pollution, it also causes the problems of land occupation, soil pollution, and vegetation damage [3]. Coal refuse piles not only pollute the nearby environment, where the polluted air also flows further to surrounded residential area about 0.8km. Therefore, the control of coal refuse disposal piles is urgently needed.

1.2 Case Study Site

Wangping Gully locates in the west part of Beijing, with mostly mountain area. The complicated landscape and various climates create the abundant biology resource and geology resource [1]. However, long-term mining operation causes a huge change to ecological system and geological structure. In despite of the close of Mining Corporations, the abandoned mine sites without the coverage of vegetation, seriously damages the general landscape. This paper, particularly, focuses on the monitoring of Coal Refuse Disposal Piles (See Figure 1.1) due to mining operation, which is considered as the most serious damage factors to the local environment problem. The aim of this paper is to monitor coal refuse disposal piles in the respective of spatial information, which serves as the basic information for future environment evaluation and ecological restoration.

Figure 1.1. Coal Refuse Disposal Piles in Wangping Gully

* Corresponding author. D11 Xueyuan Road, Haidian Distirct, Beijing, P.R.C., 100083

1.3 Overviews

Traditionally, extraction of spatial information on remote sensing imagery, such as areas, can be measured using several techniques. At one time, the dot grid was the standard technique for measuring areas. The polar planimeter is a compact instrument with a moveable arm that can be used to trace the outline of an area; a dial at the base of the arm records the area outlined by the perimeter, which can then be converted to ground area. Later, electronic digitizer, which records an electronic version of the outline traced by the analyst, is applied to calculate areas [4].

Today, with the rapid development of both computer hardware and software, advanced technology in remote sensing lead to the integration with GIS, which enable the measurement and calculation of spatial information much time efficient. Gremlica from Czech Republic defined the spatial information of coal waste piles in Kladno region, Czech Repbulic, namely area and volume, with the help of terrain and GIS [5]. Kuang used SPOT satellite image to estimate urban land use floor area in Changchun, China [6]. Working in an integrated GIS/remote sensing environment allows one to take advantage of functionalities of both GIS and remote sensing image analysis techniques [7]. Furthermore, the application of Digital Elevation Model (DEM) and Digital Terrain Model (DTM) provide enormous amount of landscape information to support the extraction of spatial information.

Satellite images (Landsat Thematic Mapper, SPOT, MOMS, ERS-1, ERS-2, RADASAT, etc.) can provide data on the extent and structure of waste disposal sites and characterize the landscape features of a given site. However, the highest resolution and most informative data for waste disposal site investigation are obtained from airborne remote-sensing systems [8]. In Arnstadt, Germany,

Archival Colour Infrared (CIR) Aerial Photographs was applied to evaluate subsurface of waste disposal sites (1999), while in Cripple Creek and Goldfield, U.S.A. Multispectral Remote Sesing Landsat TM and AVIRIS over flight image, and colour-infrared aerial photophgraphs from NAPP (National Aerial Photography Program) of the USGS were used to identify potential wastes and exposed rocks which may be sources of acid drainage contained pyrite (1994). Experience in recent years has shown that the scale of presentation, quality of supporting data and accuracy of restoration influence the validity of interpretation of remote-sensing data [9]. The advantage of a combined application of geo-scientific in coal refuse disposal piles research is obvious, and therefore is widely applied recently.

2. METHDOLOGY

2.1 Data Resource

2.1.1 Topography Map

One of the sources of raw data in this study is topography map of Wangping Town with the scale 1:1000, which is surveyed by GPS in March 2006. The projection of this topography map is a universal project in China, which is Beijing-54 Projection (See Table 2.1).The topography map derived from GPS survey contains dozens of layers with different properties and attributes, where the contour line layer with elevation information is the only one that contributes to this study. The primary goal of the pre-processing of topography map is to obtain contour map of research area (See Figure 2.1), as well as contour editing, for the purpose of establishment of DEM.

Definition of Beijing-54 Projection		
Origin	Longitude	117°00'00" (117.0000)
	Latitude	0°00'00" (0.0000)
False North		0 meter
False East		500,000 meter
Scale Factor		1.0
Projection Type		Transverse Mercator
Projection Datum/Ellipsoid		WGS-84

Table2.1. Definition of Beijing-54 Projection

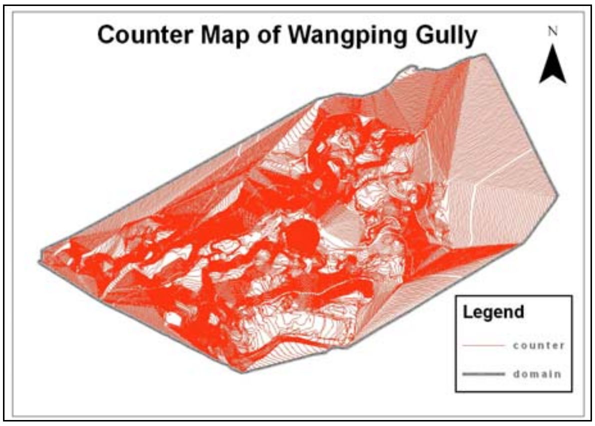

Figure 2.1. Contour Map of Wangping Gully

2.1.2 Remote Sensing Image

Another source of raw data is the remote sensing image in Mentougou District with a high resolution of 0.5m showed in Figure 2.2 below, which is graphed in September 2003 by air-born photogremmetry platform. Furthermore, the projection is an unusual local projection, which is Beijing City Local Projection showed in Table 2.2.

Definition of Beijing Coty Local Projection		
Origin	Longitude	116°51'56.7577" (116.3502518)
	Latitude	39°21'00.9065" (39.86576603)
False North		300,000 meter
False East		500,000 meter
Scale Factor		1.0
Projection Type		Transverse Mercator
Projection Datum/Ellipsoid		WGS-84

Table 2.2. Definition of Beijing-54 Projection

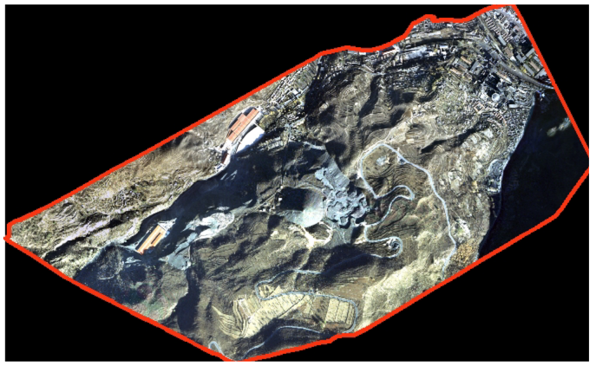

Figure 2.2. Remote Sensing Image of Wangping Gully

2.2 Research Method

Based on remote Sensing and GIS, this paper studies the extraction of major spatial information of coal waste piles that supports the environment evaluation and ecological restoration, which are 2D area, surface area and volume. Meanwhile, DEM is established as the middle process and the bridge for spatial information extraction. Figure 2.3 below describes the basic principle of the research method in this paper.

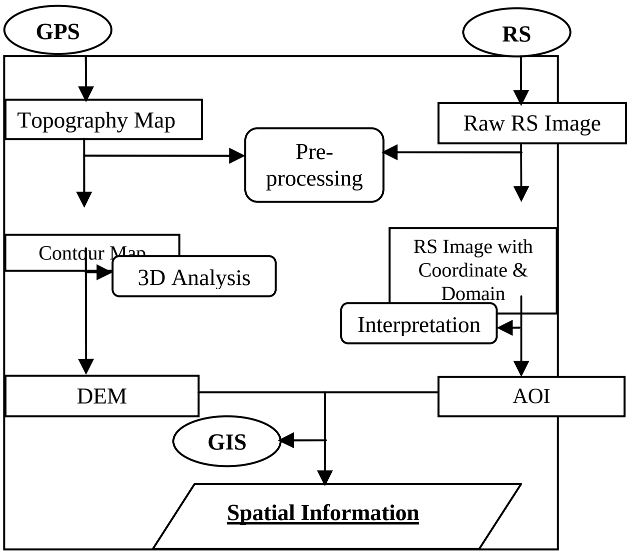

Figure 2.3. Flowchart of the research method

In short, the extraction of spatial information of coal refuse disposal piles is the kernel part of this study. A variety of approaches for spatial information extraction using remote sensing image have been developed and implemented on serial computers [11]. Based on the remote sensing image and contour derived from the previous pre-processing of raw remote sensing image and topography map, image interpretation and three dimension analysis are conducted in order to obtain Area of Interest (AOT) and Digital Elevation Model (DEM). Further calculation of spatial information of coal refuse disposal piles is therefore conducted based on AOI and DEM under GIS operation platform. ArcGIS and ERDAS are selected as the GIS software and RS software, respectively, both from ESRI.

3. EXTRACTION

3.1 Pre-processing

Pre-processing of raw data is equally important as the analysis of processed data. The accuracy and quality of pre-processing data directly impact the final results. As a result, a large amount of pre-processing work is devoted on the accordance with further data analysis.

Basically, the pre-processing of remote sensing image in this study are geometric correction and subset. The purpose of geometric correction is to explicitly determine the mapping polynomials by the use of ground control points (GCPs) and then determine the pixel brightness value in the image [10]. Accuracy of the corrected image, of course, will have direct impact on the results of further analysis and process of remote sensing image. On the contrary, if accurate geometric correction is not achieved, then spurious differences will be detected. That is, instead of comparing properties of the same location at different images, we might mistakenly compare properties of different locations. In geometric correction, main uncertainties affecting the accuracy of remote sensing image include (1) quality of uncorrected image or corrupted image; (2) size and arrangement of GCPs; (3) proficiency of the operator; (4) error from the model of geometric correction and (5) error from GCPs. The effects of all five factors are seriously considered during the geometric correction process, which guarantees the high accuracy of geometric correction of remote sensing image. After adding the coordinate to the original remote sensing image, the subset of the remote sensing image according to the domain of research area is also necessary for the further study. On one side, it confirms the research region of remote sensing image; on the other side, it also composes one important factor of 3D model. Under the platform of ERDAS, Figure 2.2 below shows the remote sensing image of Wangping Gully after the pre-processing of geometric correction and subset.

3.2 Image Interpretation

In general, image interpretation refers to the process of labeling image data, typically in the form of image regions or features, with respect to domain knowledge. This knowledge is either represented explicitly or is encoded implicitly in specific algorithms and constraints used by an interpretation system [12]. In the former, the human interpretation runs as a part of the flow of information from sensor to result; the interpreter uses aerial photographic recordings or digital pre-processed products of originally digital recorded image data. In the latter, the automatic image analysis is conducted by selecting specially designed algorithms software modules and system variables for that very flow, being an interactive processing procedure of the user. Usually it is a process of learning [13]. Image interpretation has been traditionally viewed as an assignment of symbolic labels to image data without explicit reference to the method or algorithm that is used to derive a certain labeling. One may try to recognize spatial patterns by means of segmentation, filtering and texture analysis techniques. In these cases, particular consideration is given to the topological coherence and spatial context in the image. The analysis of pattern of land use, shapes of objects, textures and structures in the image then becomes the aim of the user of image. Naturally, in image analysis the human expertise and skill involved in selection, association and integration are indispensable. Image interpretation centers on the problem of how extracted image features are bound to domain knowledge.

After the pre-processing of raw remote sensing data, it is made suitable for the remote sensing image interpretation, where pixels of remote sensing image are derived from the observed and recorded resolution. Because of the high resolution (0.5m) of remote sensing image, the traditional way of interpretation, which is eye contact interpretation, is adopted in this research. There are seven interpretation signs: shape, size, color, shadow, vein, location and activities, where shape, size, color, and location as the signs of interpretation (See Table 3.1).

Interpretation Sign	Coal Waste Piles Characteristics
Shape	On the remote sensing image, the main shape of coal waste piles is taper. And not far from those taper shape coal waste piles, there are some other small coal waste piles as well
Size	According to local residents, the estimated area of coal waste piles is about 100 mu, which is about 70,000 square meter.
Color	The main color of Coal Waste on RS image is grey.
Location	Coal waste piles located right besides Ping'an Avenue. In addition, there are two brick factories located right besides the coal waste piles.

Table 3.1 Interpretation Sign and Object Characteristic

The result of remote sensing image interpretation is performed by Area of Interest (AOI). AOI is applied on the top of remote sensing data to circle the boundary of coal waste piles according to the interpretation signs and characteristics mentioned in Table 3.1 above. The recognition of the interested area of coal waste pile is performed in accordance with Figure 3.1 below. Particularly, the accuracy of AOI directly affects the accuracy of extraction results.

Figure 3.1. AOI of Coal Waste Piles

Site characterization should begin with interpretation of aerial photographs [8]. However, a map derived from the interpretation of aerial photographs and other remote sensing data is influenced by subjective factors, while maps generated on the basis of automatic classification techniques depend on the quality and appropriateness of the input data and analysis techniques used. Therefore it is particularly important to check interpretations of remote-sensing data in the field.

3.3 DEM

Nowadays, Digital Elevation Model (DEM) has gained popularity in applications of extracting landscape spatial information. DEM is the most advanced methods for automatic extraction of topographic variables and hence geometric routing elements from raster data [14]. Furthermore, DEM are a viable alternative to traditional field surveys and manual evaluation of topographic maps. Landscape features such as slope, aspect, low length, contributing areas, drainage divides and channel network can rapidly and reliably be determined from DEM. The technological advances provided by GIS and the increasing availability and quality of DEM have greatly expanded the application potential of DEM to many environmental computer investigation [15].

DEM generally stored in one of three data structures. These structures are grid structures, Triangulated Irregular Network or TIN structures, and counter-based structures. The data structures used in this research is TIN structures, where a continuous surface is generated from interconnected triangles with known elevation values at the vertices of the triangles. For each triangle the location (x.y) and elevation (z) of the vertices, and topologic information that identify adjacent triangles are stored showed in Figure 3.3. Triangles vary in size, with smaller triangles in areas of rapidly changing topography and larger triangles in areas of relatively smooth topography.

Row	Use	X	Y	Z
1	X	412083.219	4426143.000	216.000
2	X	412082.500	4426143.500	216.000
3	X	412081.875	4426143.500	216.000
4	X	412081.406	4426144.000	216.000
5	X	412081.031	4426144.000	216.000
6	X	412080.750	4426144.000	216.000
7	X	412080.625	4426144.500	216.000
8	X	412080.594	4426144.500	216.000
9	X	412080.688	4426144.500	216.000
10	X	412080.813	4426145.000	216.000
11	X	412080.969	4426145.000	216.000
12	X	412081.156	4426145.000	216.000
13	X	412081.313	4426145.500	216.000
14	X	412081.469	4426145.500	216.000
15	X	412081.656	4426145.500	216.000

Figure 3.2 Restored Data in TIN Database

In addition, the TIN-based DEM is computationally high efficient because of its coordinate random but surface-specific character. In this study, ERDAS is used to obtain TIN data from counter map as well as perform the establishment of DEM. Linear rubber sheeting, a vector data algorithm, is selected as the surfacing method of the DEM (See Figure 3.3) creation in this study. It is defined as a particular technique that can force registration of control points over the vector data with their corresponding points on the image [16].

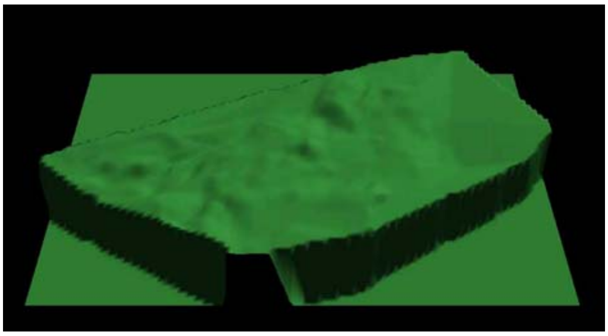

Figure 3.3. TIN-Based DEM of Wangping Gully

3.4 Calculation

After the previous data processing and analysis, the calculation of spatial information of coal waste piles is conducted in the spatial analysis working environment of ArcGIS. The AOI derived from remote sensing image is used to subset of DEM, where all the calculation of spatial information is based on DEM. Plan area, surface area and volume are calculated perceptively. According to field survey and the assessment from local residence, the result of calculation is extensively close to the realistic situation, which definitely meets the requirement in accordance with the environment evaluation and restoration planning.

3.4.1 Plan Area: One of the most useful fundamental GIS operators allows the production of summary area information from thematic layers. With raster data, GIS system obtains the value by counting the number of cells of each value, then multiplying by the area of each unit. In vector systems, the calculation is performed on the basis of the geometry of the polygon [17]. The data provided in this study is raster data, and therefore raster data plan area calculation method is adopted. Raster calculation system is generally faster at area operations than vector calculation system. Nonetheless, it is worth noting that as we are effectively 'counting cells', they do suffer from quantization errors, which will be greater with lower resolutions. Regards to the raster data used in this study, the DEM data is built on the top of counter map with 1m equidistance, which is derived from the topography map with a large scale of 1:1000, while the remote sensing image is photographed on the basis of air-born platform with the resolution of 0.5m. As a result, the low quantization errors problem can be ignored here.

3.4.2 Surface Area: Surface area provides a better estimation of the land area than plan area, and the ratio of this surface area to plan area provides a useful measure of topographic roughness of the landscape. Traditionally, surface area calculations algorithms are developed on the basis of slope, which normally is derived from DEM. Based on slope gradient, the slope area for each pixel is calculated and then the summation of all pixels falling within a parcel constitutes the surface area of the parcel. The slope area for each pixel can be approximately calculated from the plan area of the pixel and the slope value for the pixel [18].

3.4.3 Volume: The volume calculations are based on the geometric volume estimation of solid shapes. This is the product of the shape's base multiplied by its height [19]. Similarly, the calculation of volume also has two methods. It can either be calculated by triangle networks or quadratic networks. New methods of volume calculation were also developed recently. A new algorithm based on the analysis of Voronoi diagram of planar point is applied in the volume calculation in mineral storage [20]. Furthermore, Digital Terrain Model (DTM) is also utilized in the volume estimation of subsidence with the help of digital terrestrial photogrammetry [21].

3.5 Results

The Table 3.2 below show the calculation result of spatial information of coal waste piles based on DEM in ArcGIS software.

Item	Calculation Result
Plan Area (m^2)	70688.20
Surface Area (m^2)	261826.13
Volume (m^3)	5572411.73
Roughness(Surface Area/Plan Area)	3.70

Table 3.2. Calculation result

4. CONCLUSIONS

This paper synthetically adopts remote sensing technique and GIS technique. The two sources of raw data is topography map based on GPS survey and remote sensing image based phtogrammetry. Through a series of data processing based on GIS, remote sensing data and topography map are connected, and then spatial analysis of the integrated data is carried on in GIS platform. On the foundation of such an integrated and coalition platform of remote sensing and GIS, this study eventually extracts the spatial information and simulate 3D model of coal waste piles, which support the further research of environment evaluation and ecological restoration.

GIS has evolved side by side with remote sensing in this study. Firstly, remote sensing contributes data to GIS, where remote sensing data can provide timely information at low cost and in a form that is compatible with the requirement of GIS. Secondly, both remote sensing and GIS use similar equipment and similar computer programs for analysis and display, and therefore the investment of funds tends to cut down compared to traditional survey method. Last but not least, the non-remote sensing data which is counter map from GIS can be used to assist in the analysis of remote sensing images, thus remote sensing and GIS have a supportive relationship to each other. However, the link between remote sensing and GIS in this study is certainly incomplete and imperfectly formed, and much more research in necessary to fully exploit the benefits for their interrelationships.

REFERENCES

[1] Wang Jinrong. Statistic yearbook of Mentougou District, Beijing (2004). Published 2004 Statistic Department of Mentougou District, Beijing.

[2] Barbara Ann G. Lewis, Margaret M. MacDonell, Nirmala Gnanapragasam. Application of Soil Physical, Chemical, and Bioassay Methods to Coal Refuse. Application of Agricultural Analysis in Environmental Studies. ASTM STP 1162, K. B. Hoddinott and T. A. O Shay Eds., American Society for Testing and Materials, Philadelphia, 1993, pp. 5-22.

[3] Hu Zhenqi, Li Pengbo, Zhang Guancan. Coal Waste Pile Reclamation. Published 2005 Chinese Coal Industry. ISBN: 750202834X

[4] James Bachelder Campbell. Introduction to Remote Sensing. Published 2002 Taylor & Francis. ISBN: 0415282942

[5] Tomas Gremlica. Renewal of Ecological and Aesthetic Functions of the Kladno Landscape in Parts Disturbed by the Mining of Black Coal. 11th Conference on Environment and Mineral Processing Part III, 2007. pp.389-394. ISBN: 9788024814315.

[6] Kuang Wenhui, Zhang Shuwen, Zhang Yangzhen. Research on Estimating Urban Land Use Floor Area in Chaungchun Based on High Resolution Satellite Images. Journal of Chongqing Jianzhu University. Feb. 2007, Vol. 29, No. 1.

[7] Rhein, U. Environmental monitoring using an remote sensing and GIS approach. Proceedings of 15th IMACS World Congress on Scientific Computation, Modeling and Applied Mathematics. Vol.6. Application in Modelling and Simulation, 1997, 47-52. ISBN: 3896855565.

[8] Friedrich Kuehn, Trude V.V. King, Bernhard Hoerig, Douglas C. Peters. Remote Sensing for Site Characterization. Published by Springer-Verlag Berlin Heidelberg New York 2000. ISSN 1438-8863, ISBN 3-540-63469-X.

[9] Jean-Yves Scanvic. Aerospatial Remote Sensing in Geology. (1997). Published by Oxford & IBH publishing. ISBN: 81-204-1090-4.

[10] Jensen, J.R., 1996, Introductory digital image processing: a remote sensing perspective, Upper Saddle River, N.J.: Prentice Hall.

[11] Hickman. B.L., Bishop. M.P., Resciqno. M.V. Advanced computational methods for spatial information extraction. Computer & Geosciences, v21, n1, Feb. 1995, 153-73.

[12] Terry. Caelli, Walter F.Bischof. Machine Learning and Image Interpretation. Published 1997 Springer. ISBN: 030645761X.

[13] Henk J. Buiten, J.G. P. W. Clevers. Land Observation by Remote Sensing: Theory and Applications. Published 1993 CRC Press. ISBN: 2881249396.

[14] Vijay P. Singh. Kinematic Wave Modeling in Water Resources. Published 1996 Wiley-IEEE. ISBN: 0471109452.

[15] Paul A. Debarry, Rafael Gonzales Quimpo. GIS model and Distributed Models of Watershed: Report. Published 1999 ASCE Publications. ASCE Task Committe on GIS Modules and Distributed Models of the Watershed. ISBN: 0784404437.

[16] M.S. White and P. Griffin, Piecewise Linear Rubber-Sheet Map Transformation. The American Cartographer, 1985. 12 (2): pp. 123-131.

[17] David Wheatley, Mark Gillings. Spatial Technology and Archaeology: The Archaeological Applications of GIS. Published 2002 CRC Press. ISBN: 0415246393.

[18] Jeff S. Jenness. Calculating landscape surface area from digital elevation models.Wildlife Society Bulletin. Volume 32, Issue 3 (September 2004), pp. 829–839

[19] Peter Van. Oosterom, Siyka. Zlatanova, Elfriede M. Fendel. Geo-information for Disaster Management. Published 2005 Springer. ISBN: 3540249885.

[20] Wu Lixin, Hao Haishen, Yin Zuoru. A New Algorithm for Minieral Storage Calculation Based on Voronoi Diagram of Point-Set of Drill Holes. Geography and Geo-Information Science. January 2004, Vol. 20. No.1.

[21] Sheng Yehua, Yan Zhiguang, Song Jinling. Monitoring Technique for Mining Subsidence with Digital Terrestrial Photogrammetry. Journal of China University of Mining & Technology. Jul. 2003, Vol. 32, No.4,